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Terrestrial Trunked Radio (TETRA);
Voice plus Data (V+D);
Designers' guide;
Part 2: Radio channels, network protocols and service performance

Reference

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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Terrestrial Trunked Radio (TETRA).

The present document is part 6 of a multi-part deliverable covering Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Designers' guide, as identified below:

ETR 300-1: "Overview, technical description and radio aspects";

TR 102 300-2: "Radio channels, network protocols and service performance";

TR 102 300-3: "Direct Mode Operation (DMO)";

ETR 300-4: "Network management";

TR 102 300-5: "Guidance on numbering and addressing";

TR 102 300-6: "Air-Ground-Air".

This version of the present document adds results of the new simulations done in setting performance requirements for TETRA equipment working at frequency range 138 MHz to 300 MHz.

The original document (ETR 300-2 ed.1) is kept without modifications and the new result as presented in annexes F and G.

NOTE: Clauses 4 to 5.6.5 and annexes A to E contain historical information and that may have been modified in the actual protocol definitions in EN 300 392-2 [i.2].

Annex A provides details of the traffic scenarios for TETRA V+D systems.

Annex B provides Message Sequence Charts (MSCs) of all the simulated procedures.

Annexes C, D and E provide Service Diagrams (SDs) related to the various models.

Introduction

The design of a mobile radio network is a complex process where many parameters play an important role.

The starting point of this process is the estimate of the traffic that is offered to the network. For a single mobile subscriber, the type of required services, the frequency of requests, the duration and the minimum performance are the common variables that are considered in the estimate. Moreover the number of subscribers and their distribution inside the network allow the estimation of the total amount of traffic.

A parallel operation is the investigation of the propagation environment in the region where the network will be placed.

The cell positioning and dimensioning is a crucial step in the design process. More than the amount of the offered traffic and of the propagation environment, an important role is played by the knowledge of how the design choices affect the performance for the offered services. This information is strongly related to the particular radio interface of the mobile radio system.

The positioning and dimensioning of network switches and databases close the overall process. As in the case of radio interface, this operation requires the knowledge about the influence of the design choices on the overall performance.

The design process is usually iterative. A final analysis on the whole network allows to check the validity of the process. In case of inadequate result, the process is repeated.

The evaluation of effects of the design choices on the overall network performance is usually performed by simulation (nevertheless, when some network have been deployed, it can be done also through real experiment).

This evaluation should allow the designer to determine the radio coverage and the resource allocation just starting from the target performance for the provided services. Due to the complex structure of a mobile network this operation is usually made by iterations. Starting from the network configuration, the overall performance are evaluated, then the comparison with the target performance can lead to accept or to repeat the evaluation with different parameters.

1 Scope

The scope of the present document is to be a useful, but not exhaustive, basis to a network designer for the cell planning and radio resource allocation during the design process. The present document reports the performance of a TErrestrial Trunked RAdio (TETRA) Voice plus Data (V+D) network in some different scenarios.

All the presented results have been evaluated through computer simulations by some companies taking part in the TETRA standardization bodies. The network users involved in the development of the TETRA standard provided some realistic and significant network scenarios, giving information about the offered traffic.

The characterization of radio channels is the first step for the evaluation of performance of both network protocols and quality of provided services. The present document starts with the description and the illustration of performance of TETRA V+D radio channels, in terms of Bit Error Ratio (BER) and Message Erasure Rate (MER) as function of the Signal-to-Noise Ratio (SNR) and Carrier on co-channel Interference ratio (C/I).

The present document also deals with the performance of network protocols (in terms of delay and throughput) and of provided services (BER for circuit switched services and delay plus throughput for packet switched services). A consequence of the analysis of access protocols is the evaluation of traffic capacity of control and traffic channels.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI EN 300 392-1: "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 1: General network design".

[i.2] ETSI EN 300 392-2 / ETSI TS 100 392-2: "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)".

NOTE: The references EN 300 392-2 and TS 100 392-2 are two instances of the same document. For a shorter presentation only EN 300 392-2 [i.2] is used as the reference in the present document.

[i.3] CEC Report COST 207: "Digital Land Mobile Communications".

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AACH	Access Assign CHannel
BER	Bit Error Rate
BNCH	Broadcast Network CHannel
BS	Base Station
BSCH	Broadcast Synchronization CHannel
BUx	Bad Urban at x km/h
C/I_c	Carrier on co-channel Interference ratio
CC	Call Control
CONP	Connection Oriented Network Protocol
DMO	Direct Mode Operation
E_s/N_0	Signal on Noise ratio
HTx	Hilly Terrain at x km/h
ISDN	Intergrated Services Digital Network
LLC	Logical Link Control
MAC	Medium Access Control
MCCH	Main Control CHannel
MER	Message Erasure Rate
MLE	Mobile Link Entity
MMI	Man Machine Interface
MS	Mobile Station
MSC	Message Sequence Chart
NFD	Net Filter Discrimination
PAMR	Public Access Mobile Radio
PDU	Protocol Data Unit
PMR	Private Mobile Radio
PSTN	Public Services Telephone Network
PUEM	Probability of Undetected Erroneous Messages
RAx	Rural Area at x km/h
RCPC	Rate Compatible Punctured Convolutional
REF	REFerence
RF	Radio Frequency
RM	Reed-Müller
SCH	Signalling CHannel
SCH/F	Signalling CHannel / Full slot
SCH/F	Signalling CHannel, Full size
SCH/HD	Signalling CHannel / Half slot Downlink
SCH/HD	Signalling CHannel, Half size Downlink
SCH/HU	Signalling CHannel / Half slot Uplink
SCH/HU	Signalling CHannel, Half size Uplink
SCLNP	Special Connection Less Network Protocol
SDL	Specification and Description Language
SDS	Short Data Service
SNR	Signal to Noise Ratio
STCH	STealing CHannel
SwMI	Switching and Mobility Infrastructure
TCH	Traffic CHannel
TCH/S	Traffic CHannel / Speech
TCH/x N=y	Traffic CHannel for x kbit/s and interleaving depth N=y
TDMA	Time Division Multiple Access
TETRA	TErrestrial Trunked RAdio
trasm/h	Transmissions per hour
TUx	Typical Urban at x km/h
UNIF	UNIForm
V+D	Voice plus Data
$\pi/4$-DQPSK	$\pi/4$-shifted Differential Quaternary Phase Shift Keying

NOTE: Instead of HTx and Tux also HT-x and TU-x are used in the present document.

4 Radio channels performance

4.1 Introduction

Performance of TETRA V+D logical radio channels are reported in this clause. They have been evaluated through computer simulations for all the propagation environments that are modelled in EN 300 392-2 [i.2], clause 6. Moreover, performance are also reported for some values of the Mobile Station (MS) speed in each propagation environment.

Radio channel figures are preceded by the description of the model of radio channels and of the assumptions that have been considered for simulations. Then, for each channel, performance figures are grouped and showed in the following order:

- comparison among different propagation environments with one value of MS speed per environment;
- performance sensitivity to the MS speed in TU propagation environment;
- performance sensitivity to the MS speed in BU propagation environment;
- performance sensitivity to the MS speed in RA propagation environment;
- performance sensitivity to the MS speed in HT propagation environment.

Due to the different possibilities in the model of the radio receiver, two groups of simulations have been carried out:

1) the first with ideal synchronization technique; and
2) the second with a particular implementation of the synchronization block.

In the present document performance figures are distinguished in two clauses for each channel and scenario.

Figures that are reported in this clause will be considered as the basis for the evaluation of network protocol and traffic performance, presented in the following clauses.

4.2 Radio channels simulation description

Each of the TETRA V+D logical channels has been defined in order to exploit particular data transmissions (protocol messages or user data) over the radio interface. In order to match the requirements related to throughput and error rate, each channel has been designed with a suitable coding scheme. The complete description of logical channels is found in EN 300 392-2 [i.2], clause 8.

On the basis of their usage in the system, the logical channels can be divided in two main groups:

- Signalling channels:

  All signalling messages and packet switched user data are carried on these channels. Error detection and error correction coding schemes are applied on transmitted messages. Moreover for these applications it is required that corrupted messages are discarded in order to not cause erroneous state transitions. The coding schemes of TETRA V+D channels have been designed in order to minimize the probability that an erroneous message is not detected (PUEM). According to EN 300 392-2 [i.2], PUEM < 0,001 % is obtained for all signalling channels with the exception of AACH (PUEM < 0,01 %). Due to the usage of these channels, the measured performance is the MER.

- Traffic channels:

  Speech frames and circuit switched user data are carried on traffic channels. Error detection and error correction coding schemes are applied on transmitted data. No discarding mechanism is performed on traffic channels with the exception of the TCH/S. Before entering the speech decoder, the speech frame is discarded if corrupted. For all the other traffic channels received data are presented to the user application even if corrupted. In general, it is significant that the measured performance for traffic channels is the BER. Due to the particular design of the TCH/S channel, its performance is measured in terms of both MER and residual BER (that is the BER detected on speech frames that are not discarded).

Table 1 summarizes the main characteristics of TETRA V+D logical channels and indicates the evaluated performance.

Table 1: Summary of logical channels characteristics.

Logical Channel	Direction	Physical resource	Category	Evaluated performance
AACH	Downlink	30 initial bits of downlink timeslot	Signalling	MER
SCH/HD, BNCH and STCH	Downlink	Half slot	Signalling	MER
SCH/HU	Uplink	Half slot	Signalling	MER
BSCH	Downlink	Full slot	Signalling	MER
SCH/F	Uplink / Downlink	Full slot	Signalling	MER
TCH/S	Uplink / Downlink	Full slot	Traffic (Speech)	MER, residual BER
TCH/7,2	Uplink / Downlink	Full slot	Traffic (Data)	BER
TCH/4,8 (N=1, 4, 8)	Uplink / Downlink	Full slot	Traffic (Data)	BER
TCH/2,4 (N=1, 4, 8)	Uplink / Downlink	Full slot	Traffic (Data)	BER

A further element of distinction is the transmission mode of a channel: uplink, discontinuous downlink and continuous downlink. Traffic channels and the SCH/F allow all these modes. The difference is the type and the number of training sequences inserted in the transmitted radio bursts.

Radio receiver simulations have been performed according to the model represented in figure 1.

The transmitter has been modelled according to the standard scheme given in EN 300 392-2 [i.2], clause 4.3.

The structure of the radio receiver is not covered by the standard. The model given in figure 1 is a general scheme that is commonly accepted. Some of the receiver blocks are the mirror counterpart of others on the transmitter (root raised cosine filter, demodulator, differential decoder, burst splitter, de-scrambler and de-interleaver). Nevertheless the structure of the other blocks is dependent from the implementation; it is the case for synchronization and timing recovery block and for the decoder.

The decoder block has been realized according to the "soft" decision Viterbi algorithm, with path length = message length.

The synchronization and timing recovery block can be realized according to different schemes. For this reason simulations have been performed according to the two following synchronization techniques:

- ideal technique:
- the local timing system of the receiver is perfectly aligned to the received TDMA frames;
- realistic implementation of the synchronization technique:
    - one realization of synchronization technique has been implemented; this technique exploits correlation properties of the training sequences defined in the standard in order to evaluate burst and symbol synchronization.

The physical radio channels have been modelled according to EN 300 392-2 [i.2], clause 6.

At the top of figure 1 two blocks have been introduced in order to evaluate the radio channel characteristics.

In the case of signalling channels and TCH/S simulations, accepted and discarded Medium Access Control (MAC) blocks are counted. The evaluated MER is given by the ratio between discarded MAC blocks and the total of transmitted blocks.

In the case of traffic channels a comparison between transmitted and correspondent received bits allows the evaluation of the total amount of erroneous received bits. The evaluated BER is given by the ratio between the number of erroneous bits and the total number of transmitted bits.

The number of training sequences that is transmitted inside radio bursts may influence the behaviour of the synchronization and timing recovery block, depending on its particular implementation. In the case of ideal synchronization technique there is no influence. In the case of realistic synchronization algorithms implementations without equalizer, the impact of the number of training sequences on radio performance is negligible if compared to the case of receiver with equalizer.

The radio receiver that has been simulated does not make use of equalisers. As a consequence, in the case of traffic channels and SCH/F, performance related to uplink, discontinuous downlink and continuous downlink transmission modes will be considered without distinction.

Radio channel performance have been evaluated as functions of E_s/N_0 or C/I_c at the antenna connector of the receiver. E_s is the energy associated to a modulation symbol, N_0 (one-sided noise power spectral density) is the energy of electric noise related to the modulation symbol period and due to other phenomena than TETRA transmissions; in actual simulations it will be only related to thermal noise; C is the transmitted power associated to the modulation symbol; I_c is the power associated to a pseudo-random continuous TETRA modulated signal that takes place on the same frequency (co-channel interference) of the useful signal. The figures of the channels show that the influence of E_s/N_0 on channel performance is similar to the influence of C/I_c. Differences between curves are less than 1 dB for the same performance level.

Due to the differences in the synchronization technique, two groups of results are presented for each logical channel. Performance of each synchronization technique is evaluated for different propagation scenarios (TU, BU, RA, HT) and considering different values of the mobile terminal speed.

The two groups of results in this ETR have to be considered as a sort of performance boundaries. For each simulation scenario real receivers are reasonably expected to have performance within the range limited by the evaluated curves for the two synchronization techniques.

Results of simulations obtained from different companies show a good agreement. Radio channel performance in this ETR have been evaluated as an average of available homogeneous simulation results from different companies.

Making reference to figure 1, and according to the previous assumptions, simulations have been performed according to the following assumptions:

- ideal transmitter:
    - all blocks in the transmitter have an ideal behaviour as described in EN 300 392-2 [i.2];
- ideal RF receiver:
    - the RF to baseband signal conversion is considered ideal;
- 400 MHz carrier frequency;
- analysis of performance versus E_s/N_0 and C/I_c;
- class B receiver:
    - radio channel simulations in this clause are performed to meet class B receiver requirements as defined in EN 300 392-2 [i.2]:
        - better performance is expected to be given by a receiver with an equalizer block;
- 10 000 MAC blocks per simulation point:
    - each simulated point has been evaluated on a set of 10 000 MAC blocks;
- ideal and realistic synchronization technique:
    - when available two groups of performance are reported for each logical channel, one for ideal synchronization technique, the other for realistic technique;
- soft decision Viterbi decoder with path length = message length.

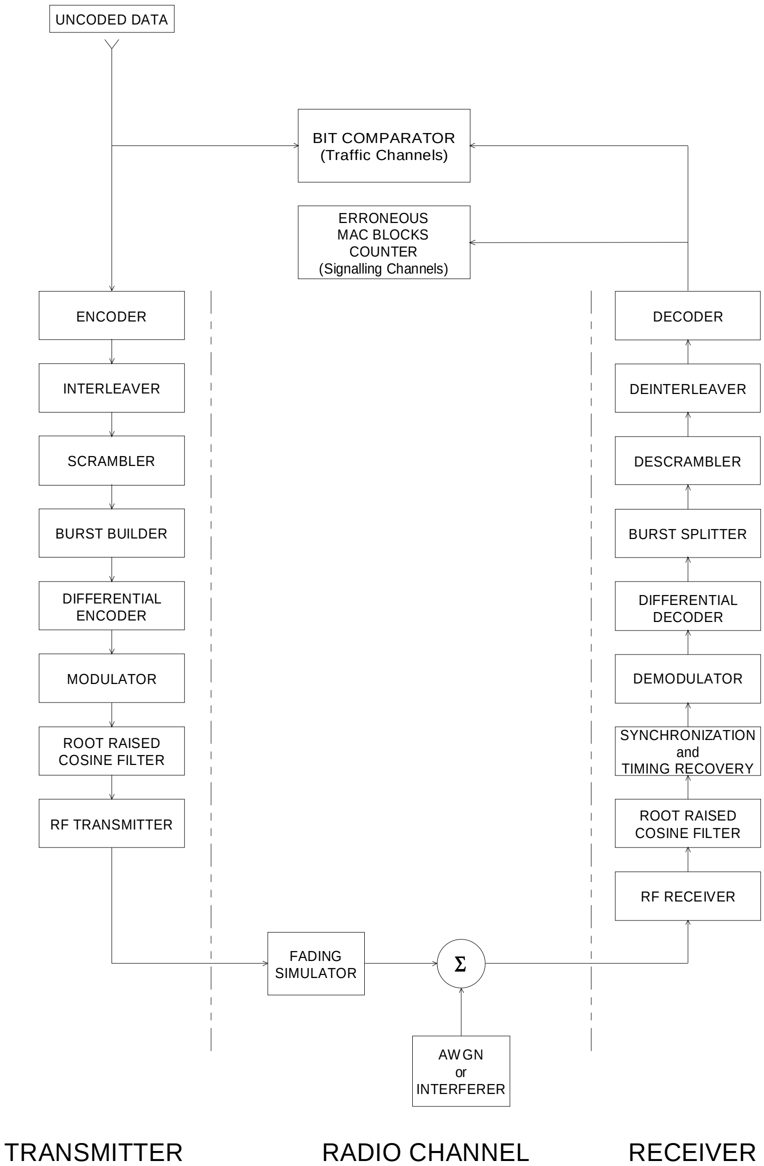

Figure 1: Schematic diagram of the model for the simulation of a generic TETRA V+D logical channel

4.3 Performance of signalling channels

Signalling channels are devoted to the transmission of signalling and packet data messages on the air interface. For this kind of applications it is important that each received burst is decoded without errors or discarded.

For these channels the simulations evaluate the probability for the received message to be discarded, the MER. Simulations have been performed for different combinations of propagation environments and MS speed.

Table 2 summarizes the performance that has been evaluated for all channels and associates them to the figures in the present document.

Table 2: Summary of document figures that report signalling channel performance

Logical channel	Figure numbers	Description
AACH	Figure 2 (Ideal synch)	MER of AACH as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 3 (Ideal synch)	MER of AACH as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 4 (Ideal synch)	MER of AACH as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 5 (Ideal synch)	MER of AACH as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 6 (Ideal synch)	MER of AACH as function of E_s/N_0 in HT50, HT100,HT200 propagation environments with ideal synchronization technique
	Figure 7 (Realistic synch)	MER of AACH as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique
SCH/HU	Figure 8 (Ideal synch)	MER of SCH/HU as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 9 (Ideal synch)	MER of SCH/HU as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 10 (Ideal synch)	MER of SCH/HU as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 11 (Ideal synch)	MER of SCH/HU as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 12 (Ideal synch)	MER of SCH/HU as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 13 (Realistic synch)	MER of SCH/HU as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique
SCH/HD BNCH STCH	Refer SCH/HU (Figure 8 to Figure 13)	Performance for these channels (all of them present the same coding scheme) is the same of the channel SCH/HU
SCH/F	Figure 14 (Ideal synch)	MER of SCH/F as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 15 (Ideal synch)	MER of SCH/F as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 16 (Ideal synch)	MER of SCH/F as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 17 (Ideal synch)	MER of SCH/F as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 18 (Ideal synch)	MER of SCH/F as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 19 (Realistic synch)	MER of SCH/F as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique
BSCH	Figure 20 (Ideal synch)	MER of BSCH as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 21 (Ideal synch)	MER of BSCH as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 22 (Ideal synch)	MER of BSCH as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 23 (Ideal synch)	MER of BSCH as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 24 (Ideal synch)	MER of BSCH as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique

4.3.1 AACH

4.3.1.1 Ideal synchronization technique

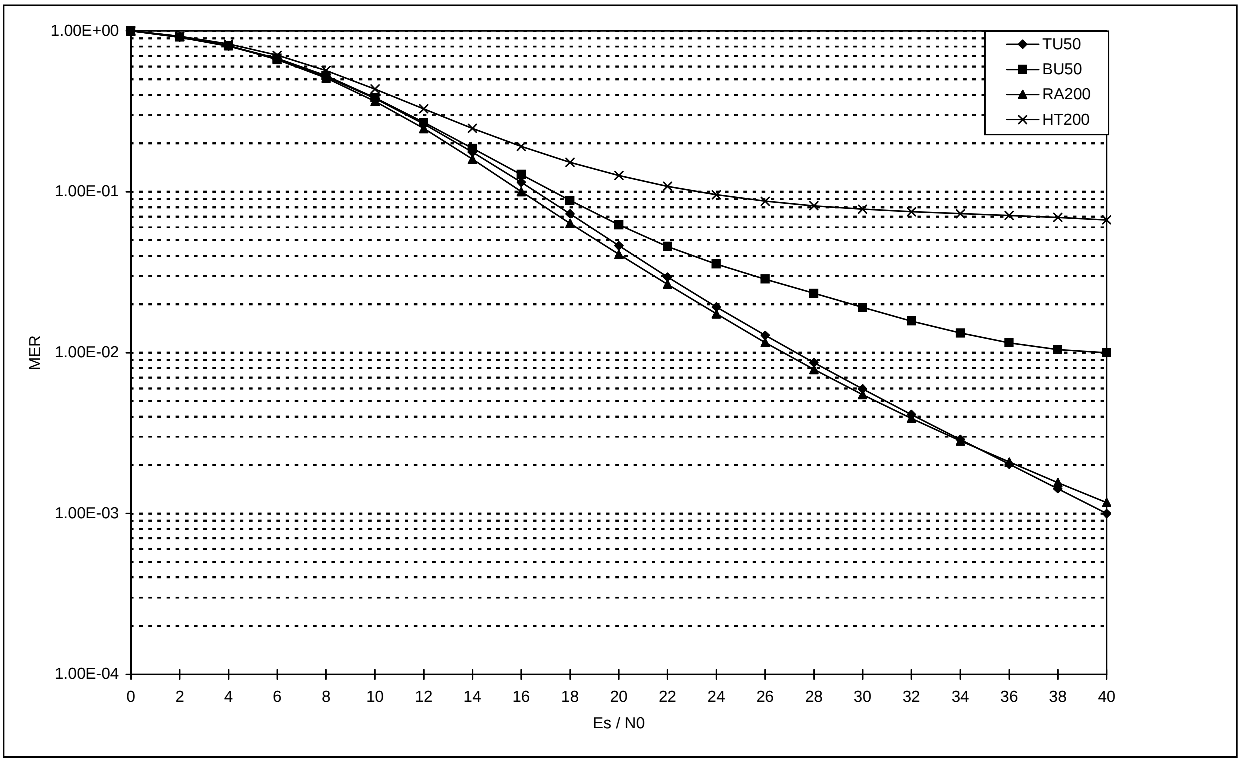

Figure 2: AACH performance in different propagation scenarios

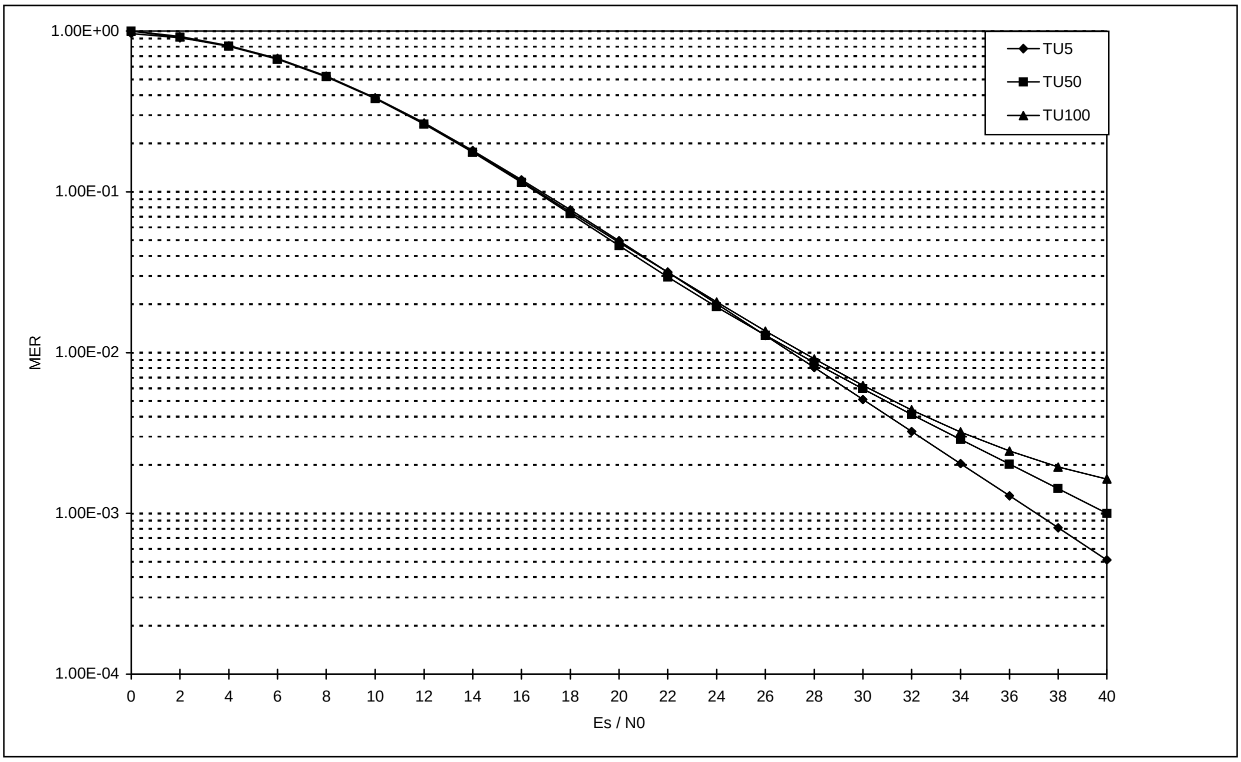

Figure 3: Influence of MS speed on AACH in TU propagation environment

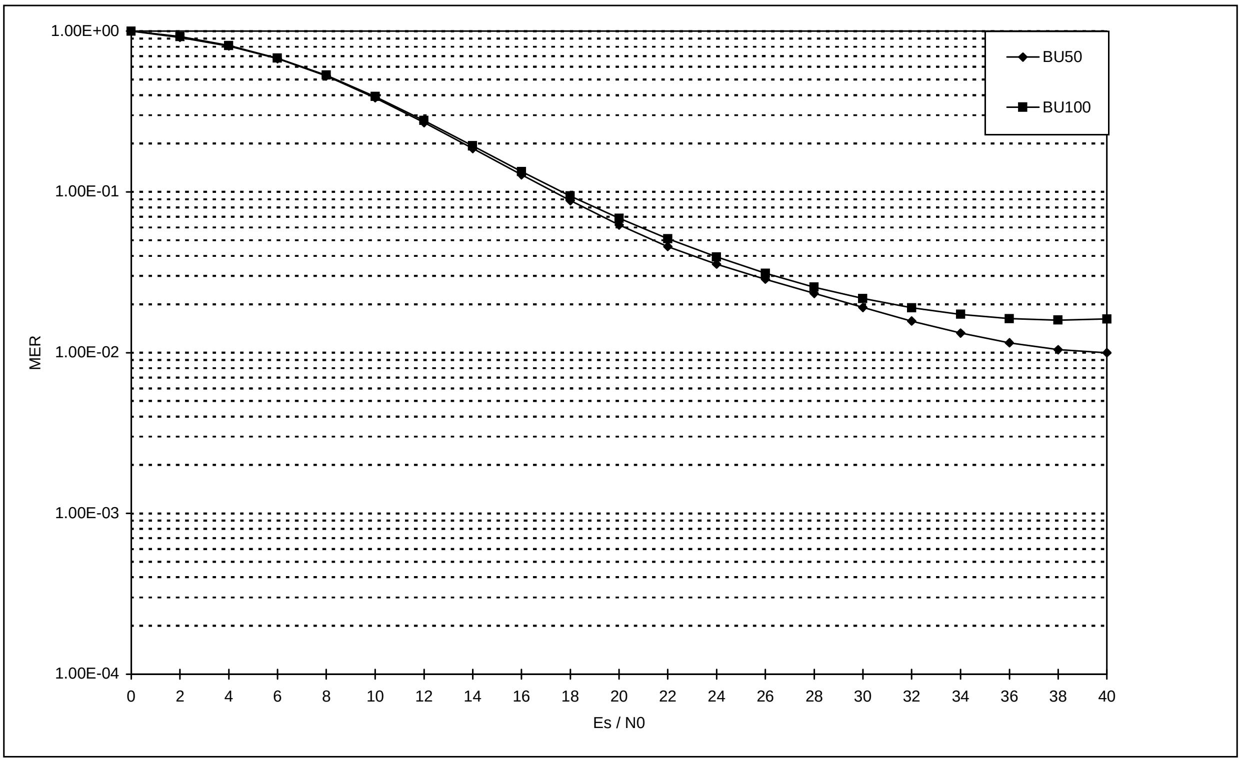

Figure 4: Influence of MS speed on AACH in BU propagation environment

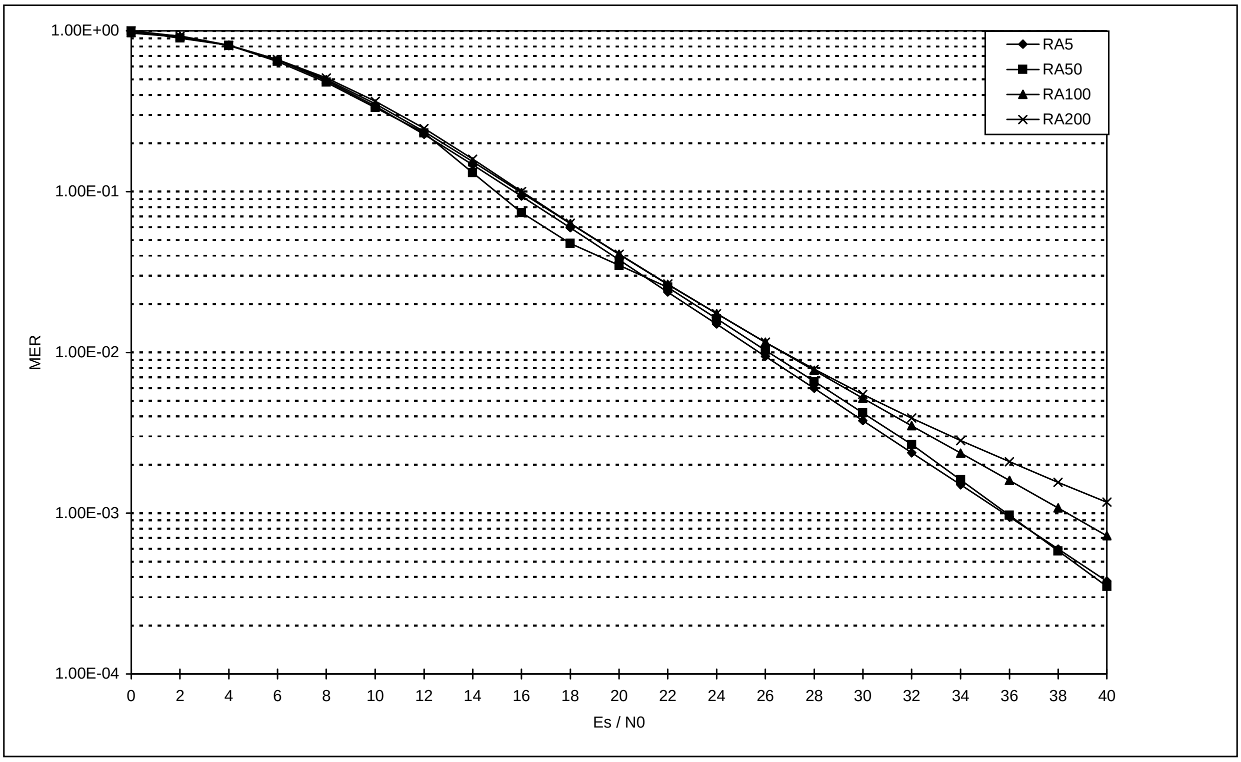

Figure 5: Influence of MS speed on AACH in RA propagation environment

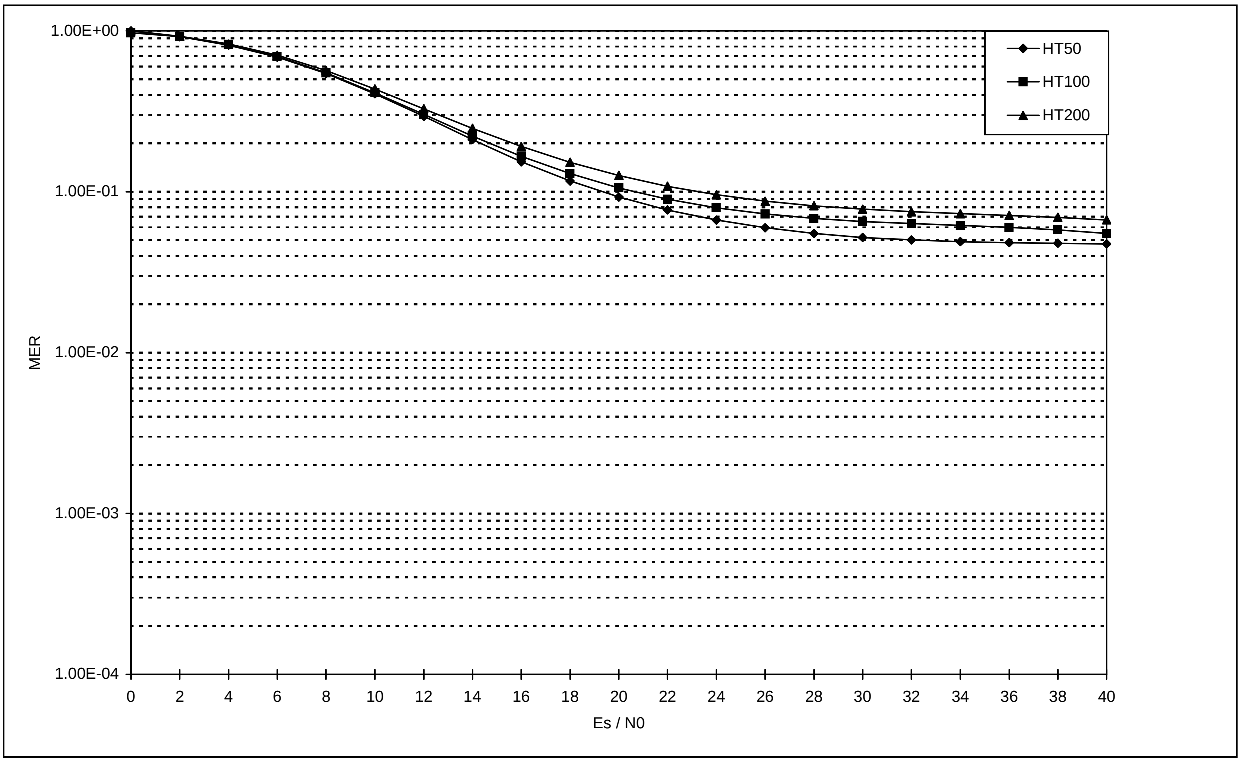

Figure 6: Influence of MS speed on AACH in HT propagation environment

4.3.1.2 Realistic synchronization technique

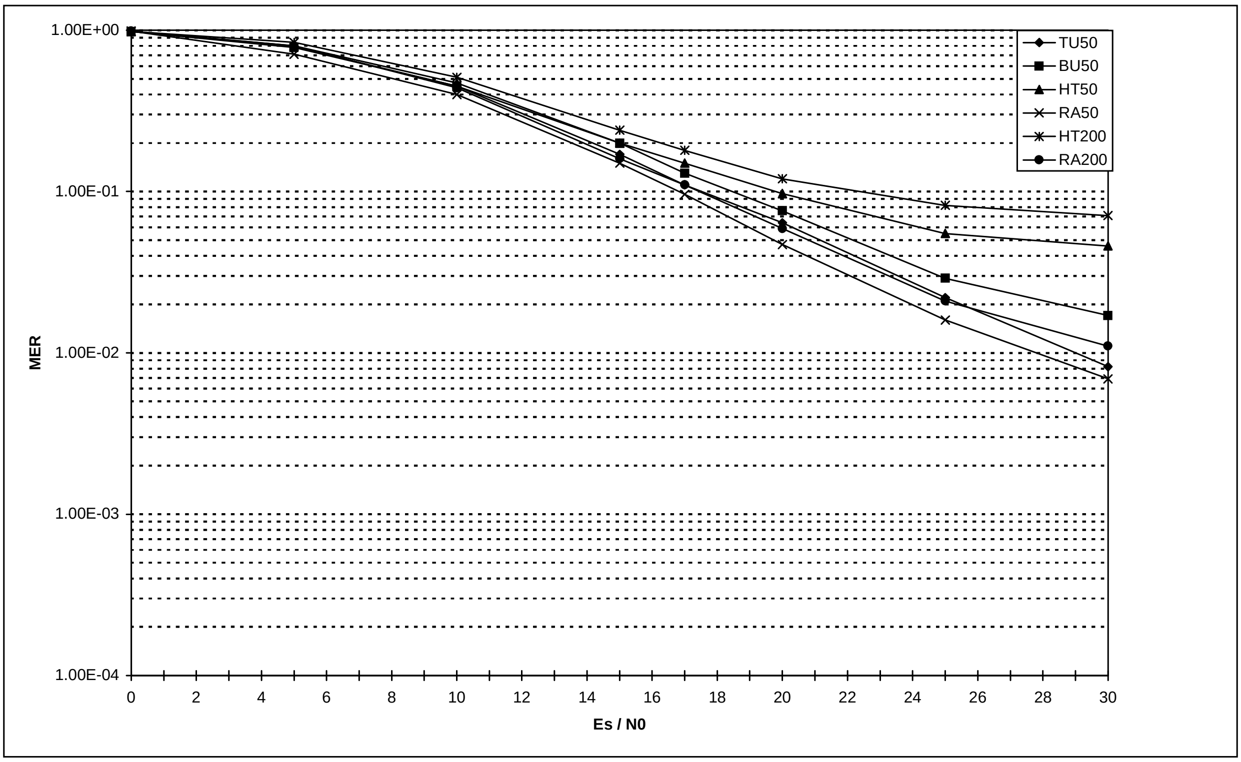

Figure 7: AACH performance in different propagation scenarios

4.3.2 SCH/HU

4.3.2.1 Ideal synchronization technique

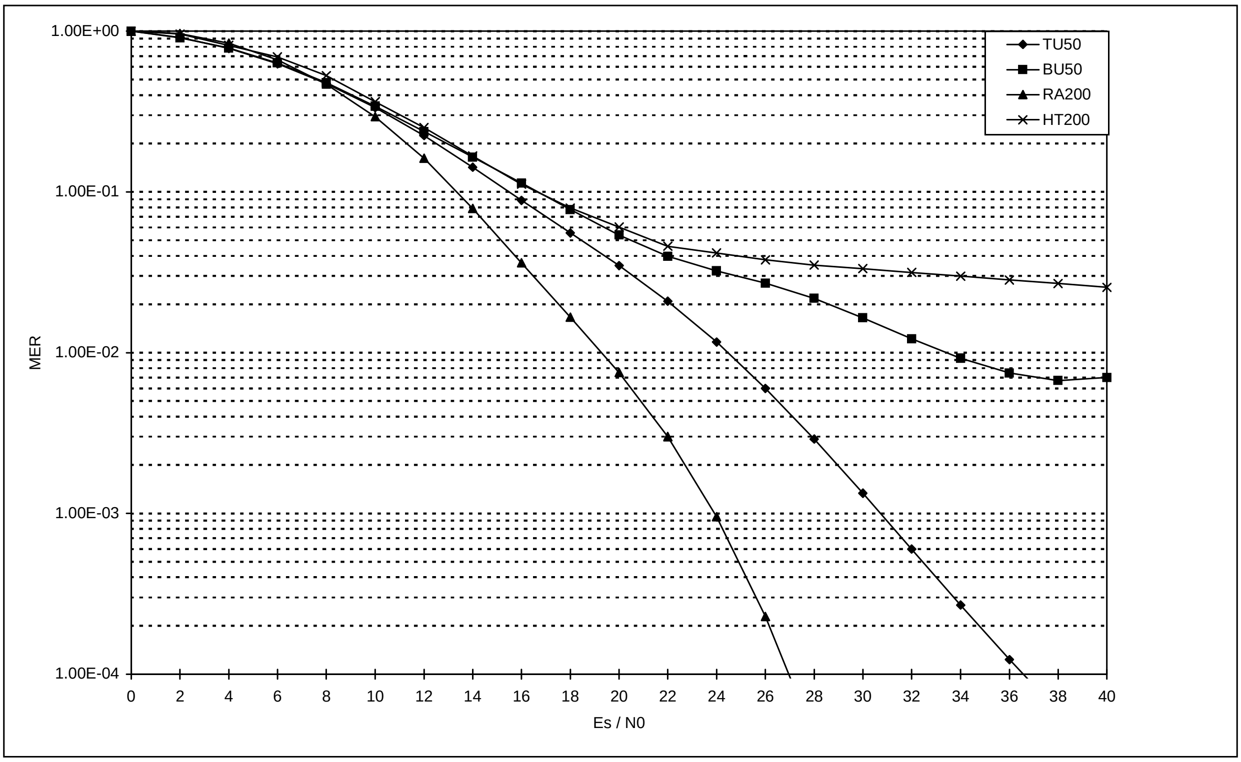

Figure 8: SCH/HU performance in different propagation scenarios

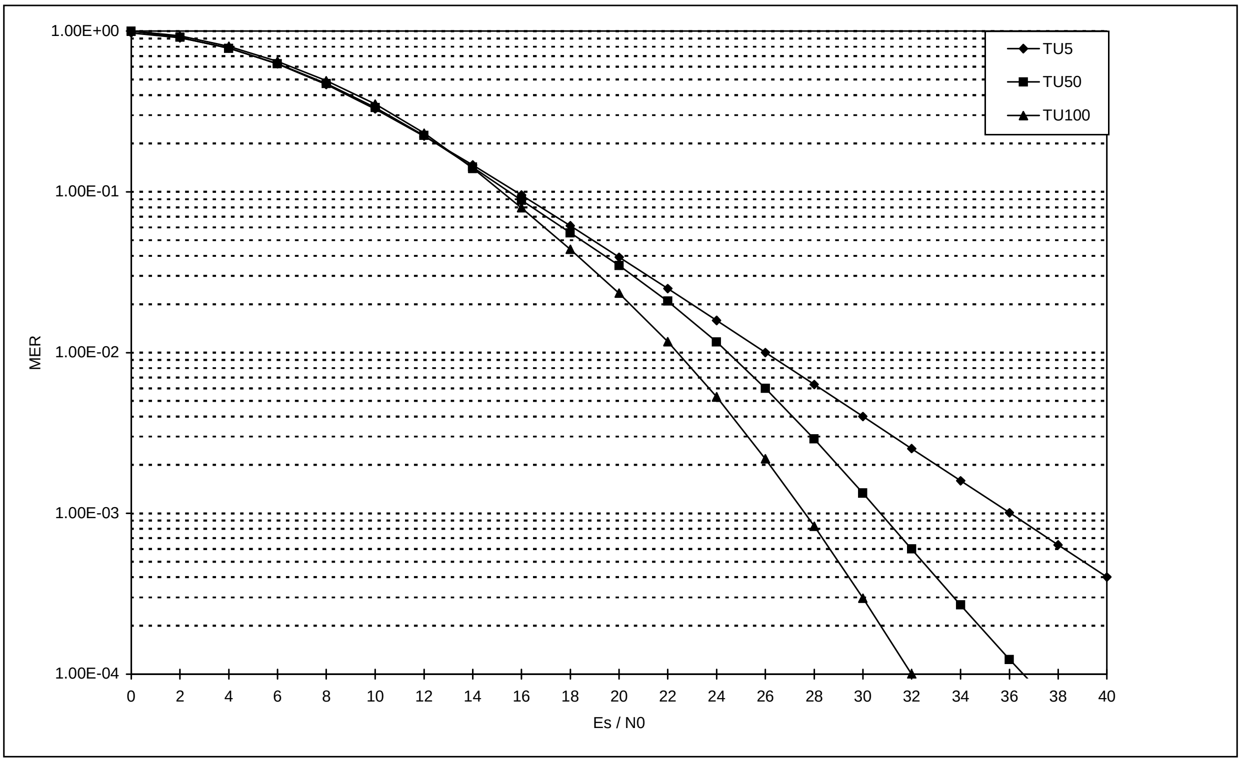

Figure 9: Influence of MS speed on SCH/HU in TU propagation environment

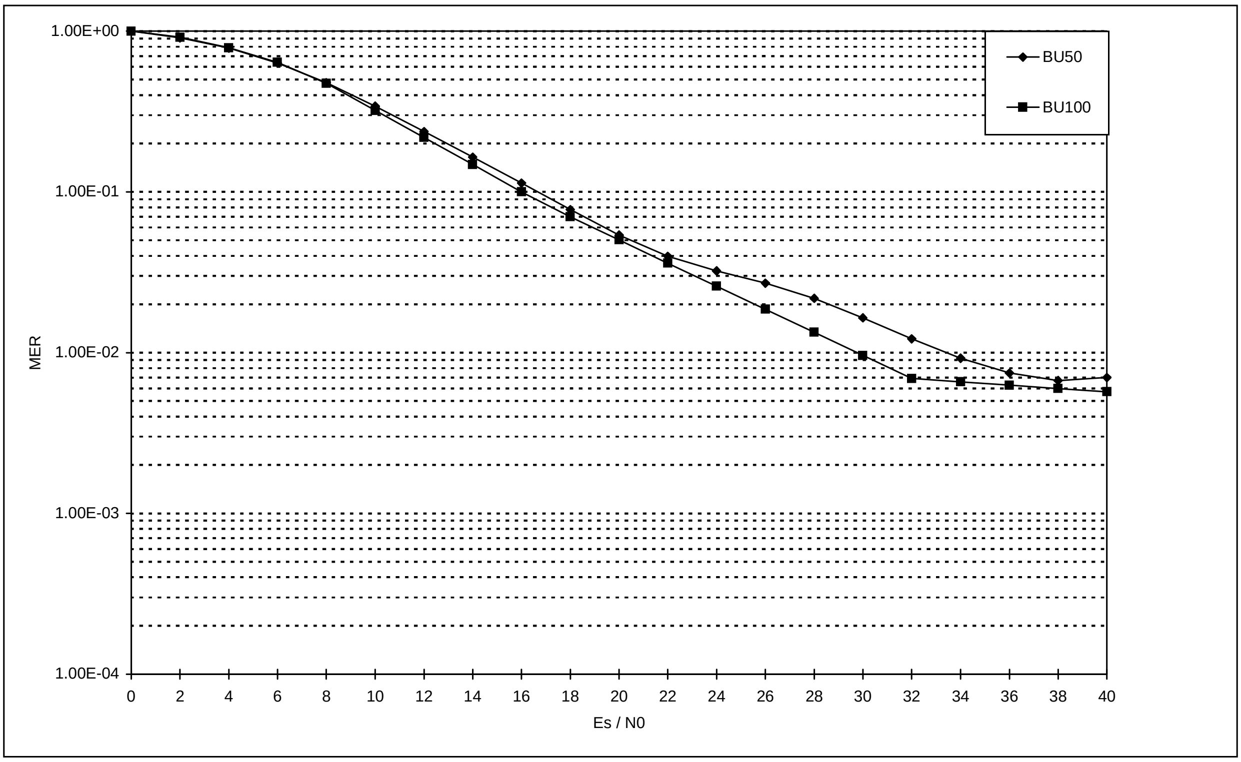

Figure 10: Influence of MS speed on SCH/HU in BU propagation environment

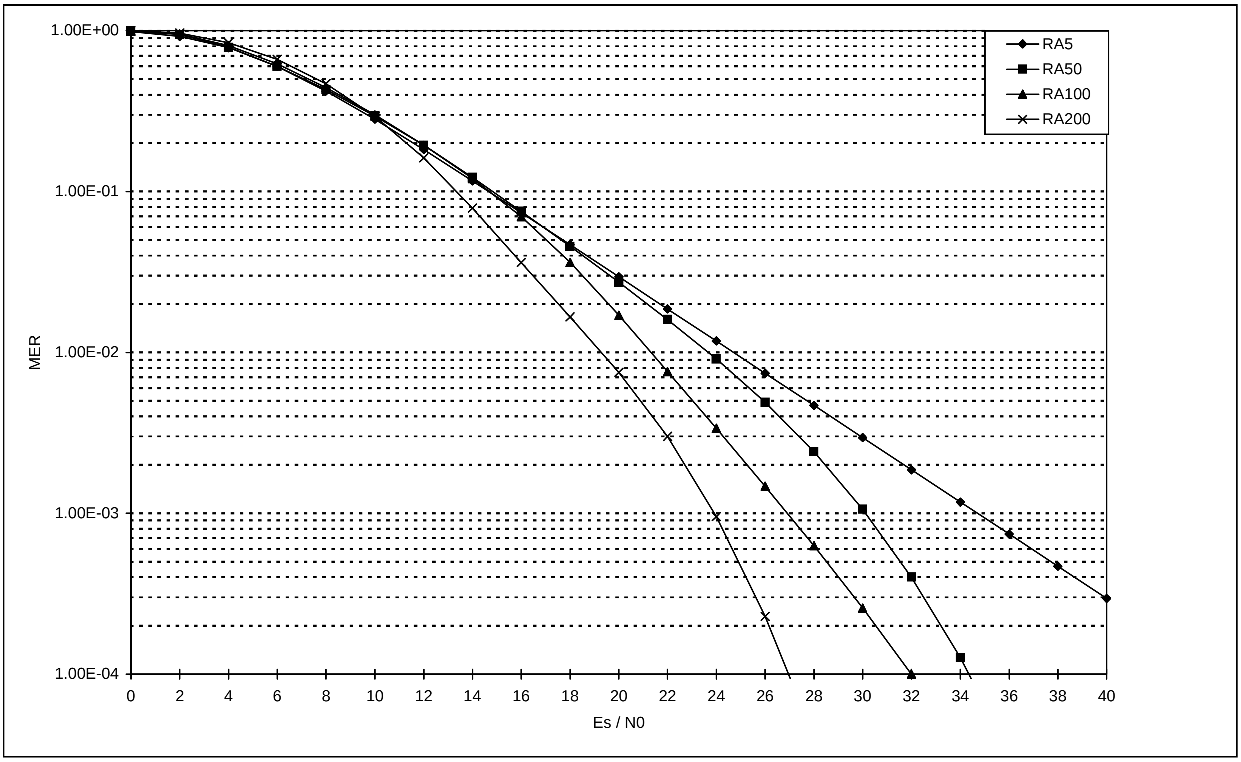

Figure 11: Influence of MS speed on SCH/HU in RA propagation environment

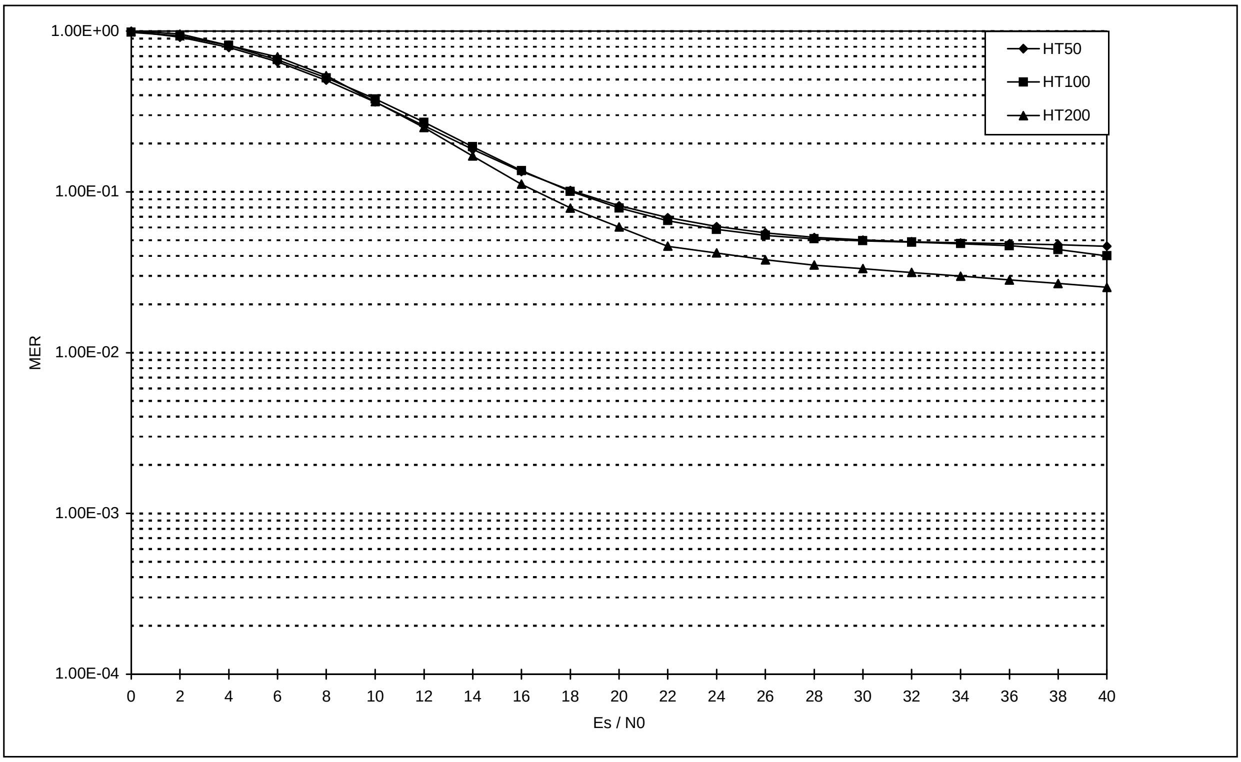

Figure 12: Influence of MS speed on SCH/HU in HT propagation environment

4.3.2.2 Realistic synchronization technique

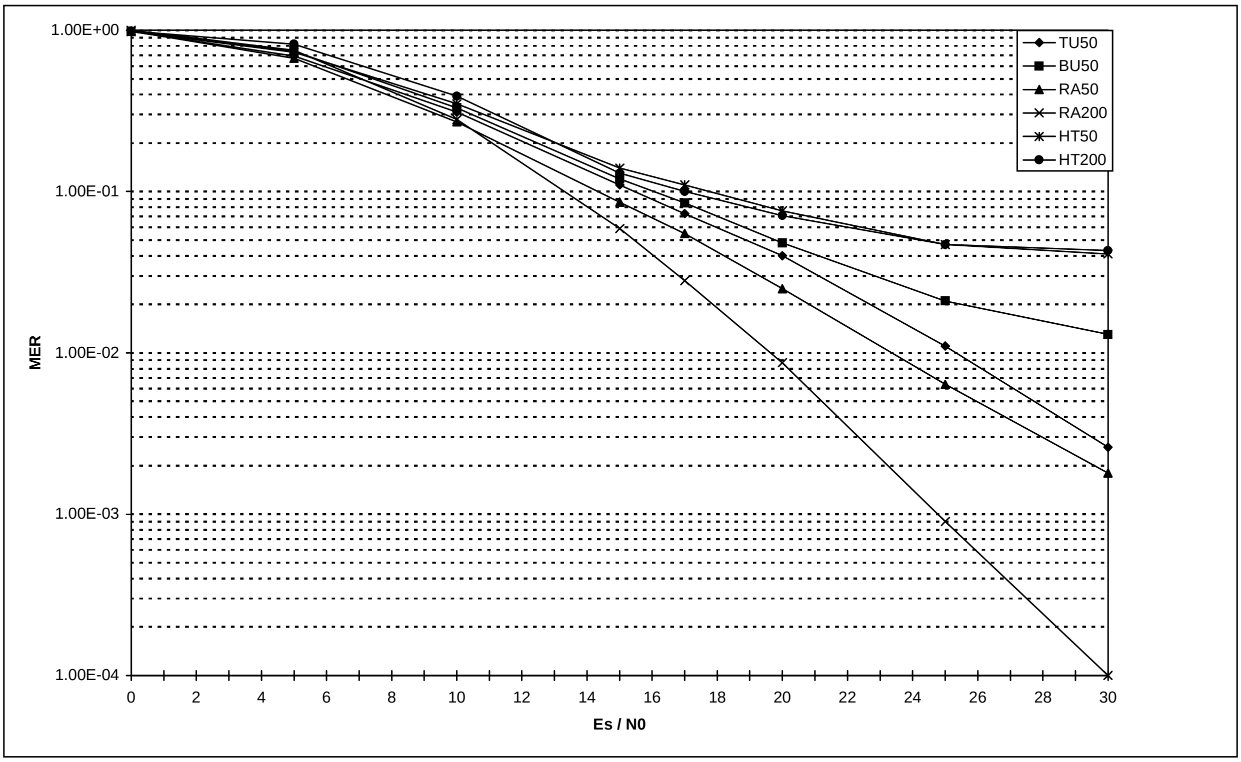

Figure 13: SCH/HU performance in different propagation scenarios

4.3.3 SCH/HD, BNCH and STCH

4.3.3.1 Ideal synchronization technique

Simulation results for this channel show that performance figures are similar to the SCH/HU channel (see clause 4.3.2.1).

4.3.3.2 Realistic synchronization technique

Simulation results for this channel show that performance figures are similar to the SCH/HU channel (see clause 4.3.2.2).

4.3.4 SCH/F

4.3.4.1 Ideal synchronization technique

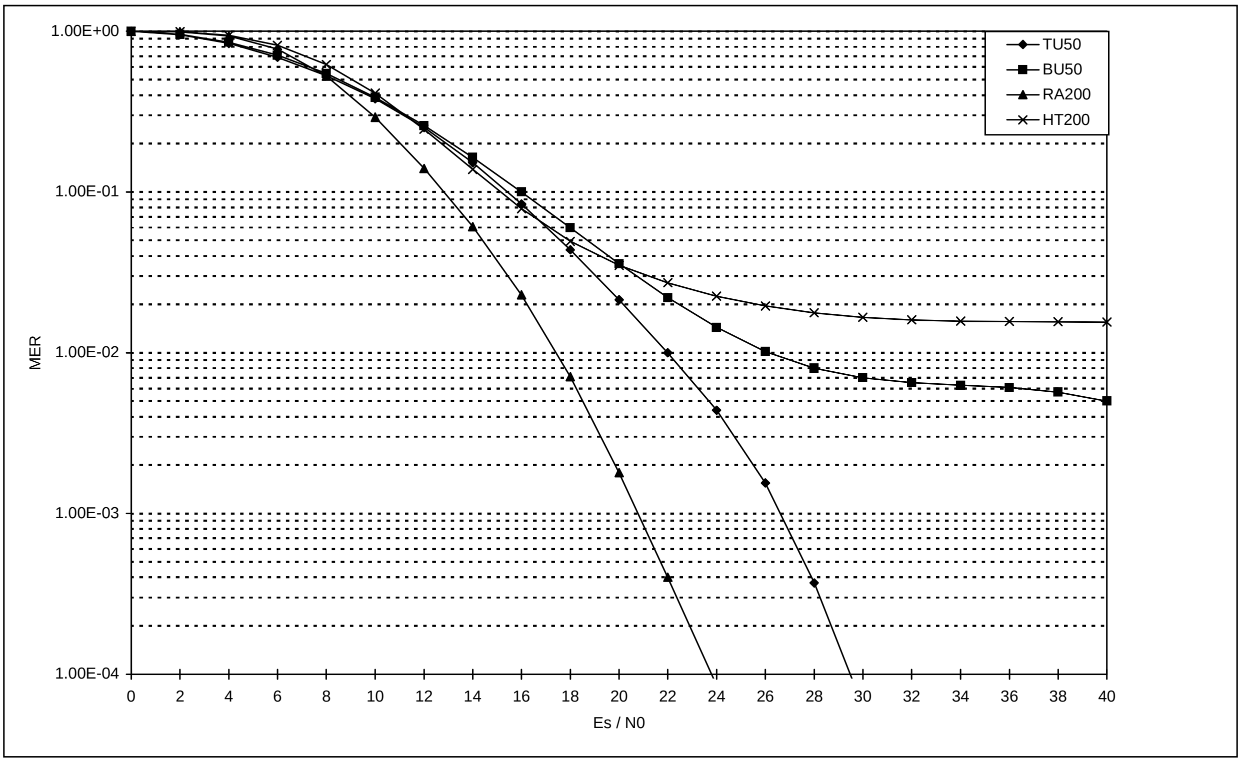

Figure 14: SCH/F performance in different propagation scenarios

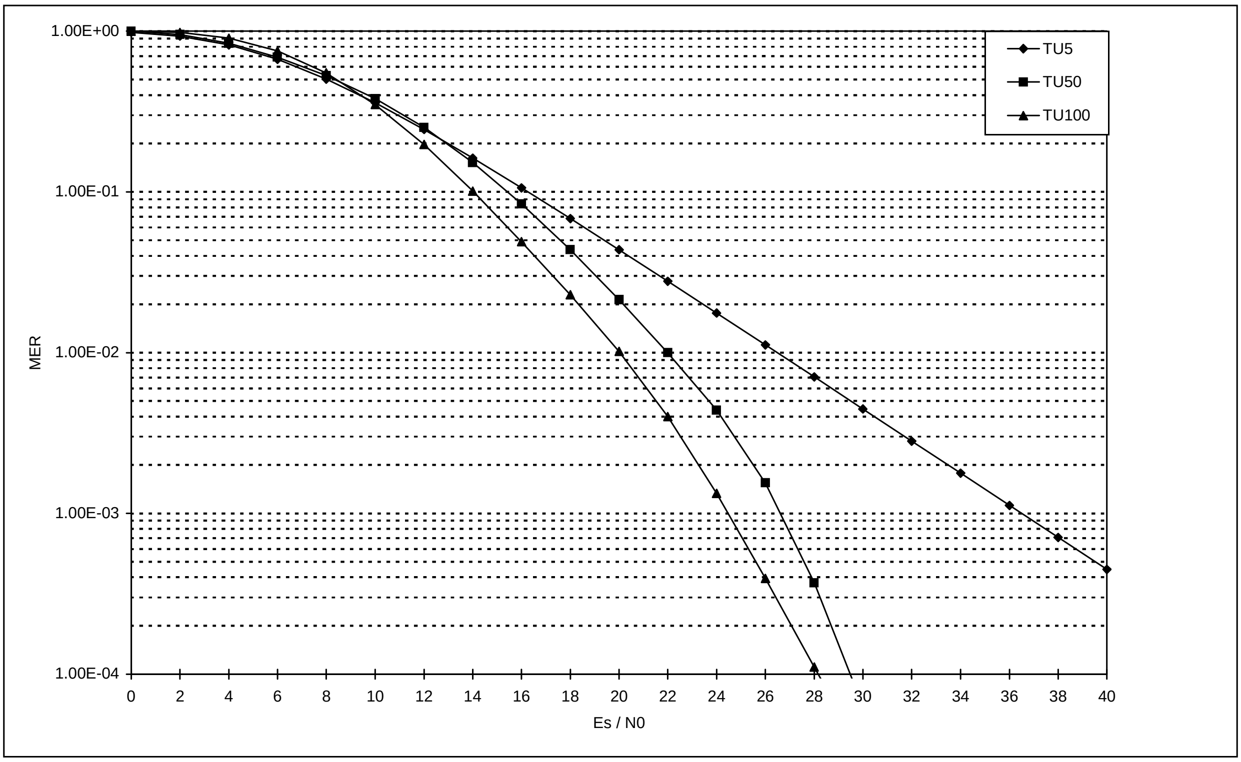

Figure 15: Influence of MS speed on SCH/F in TU propagation environment

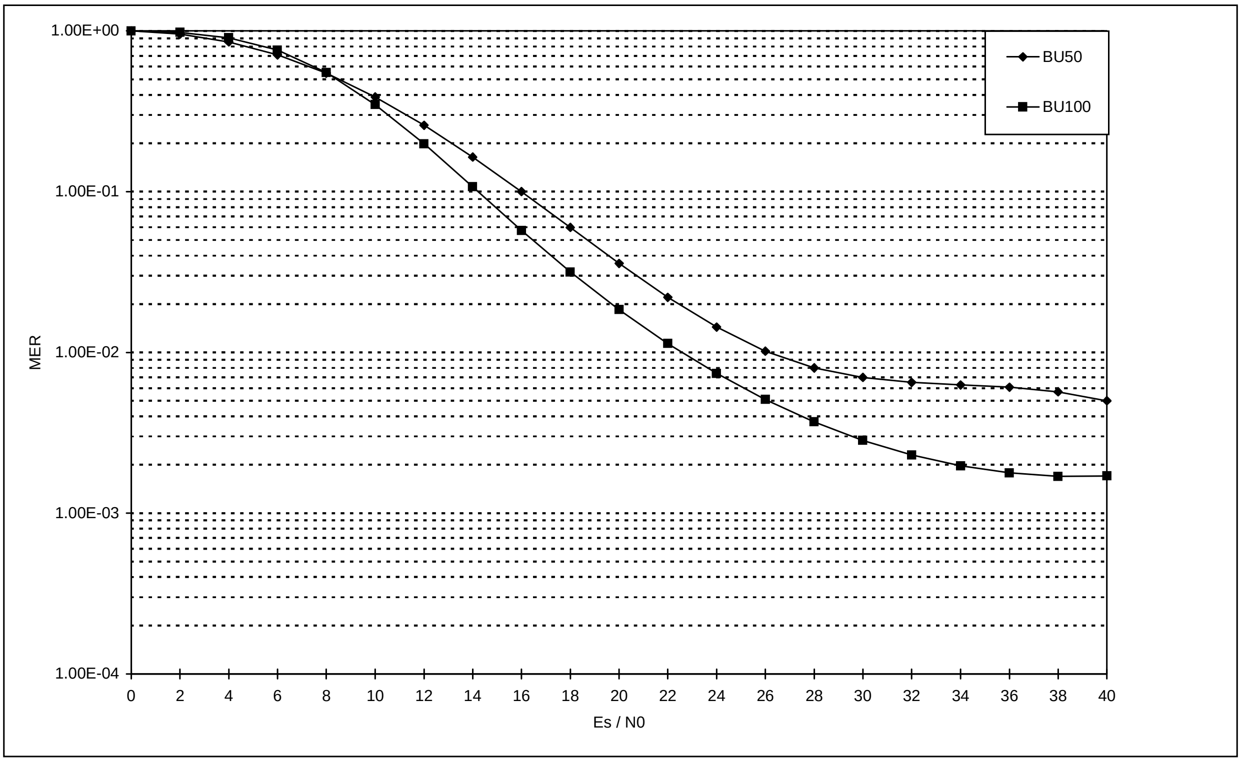

Figure 16: Influence of MS speed on SCH/F in BU propagation environment

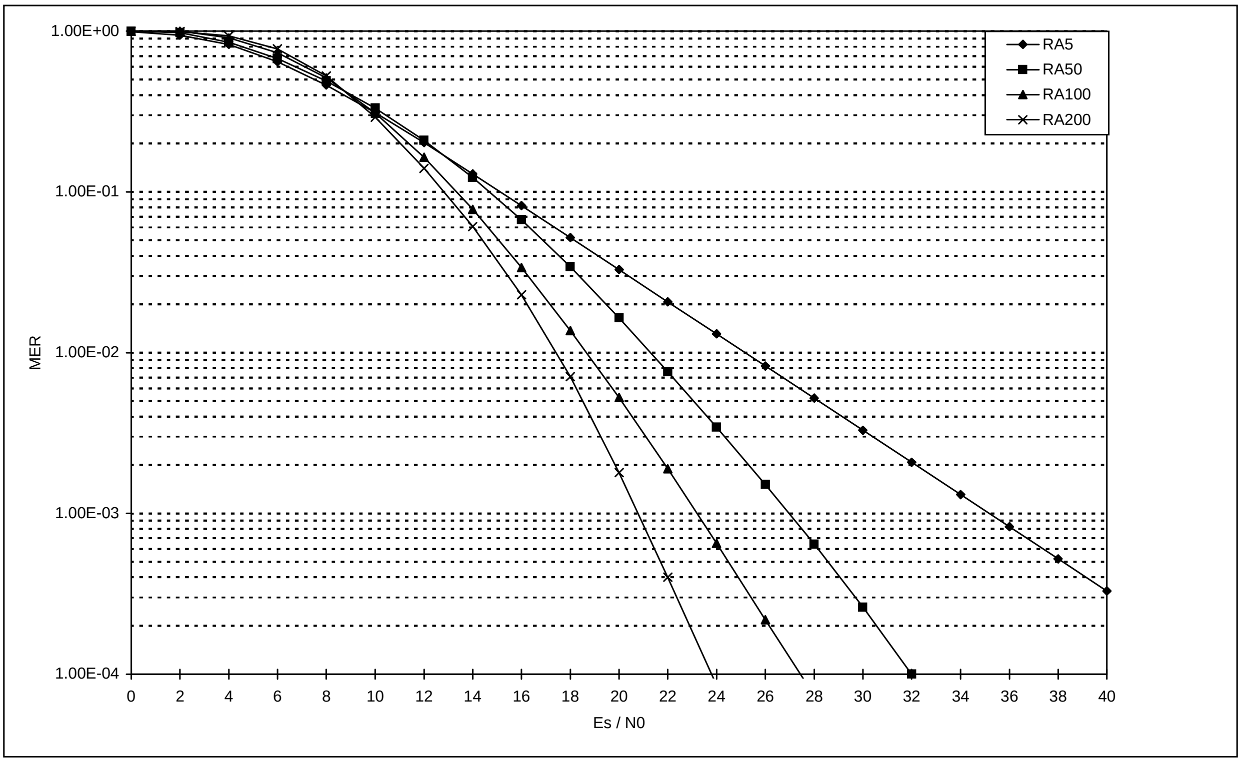

Figure 17: Influence of MS speed on SCH/F in RA propagation environment

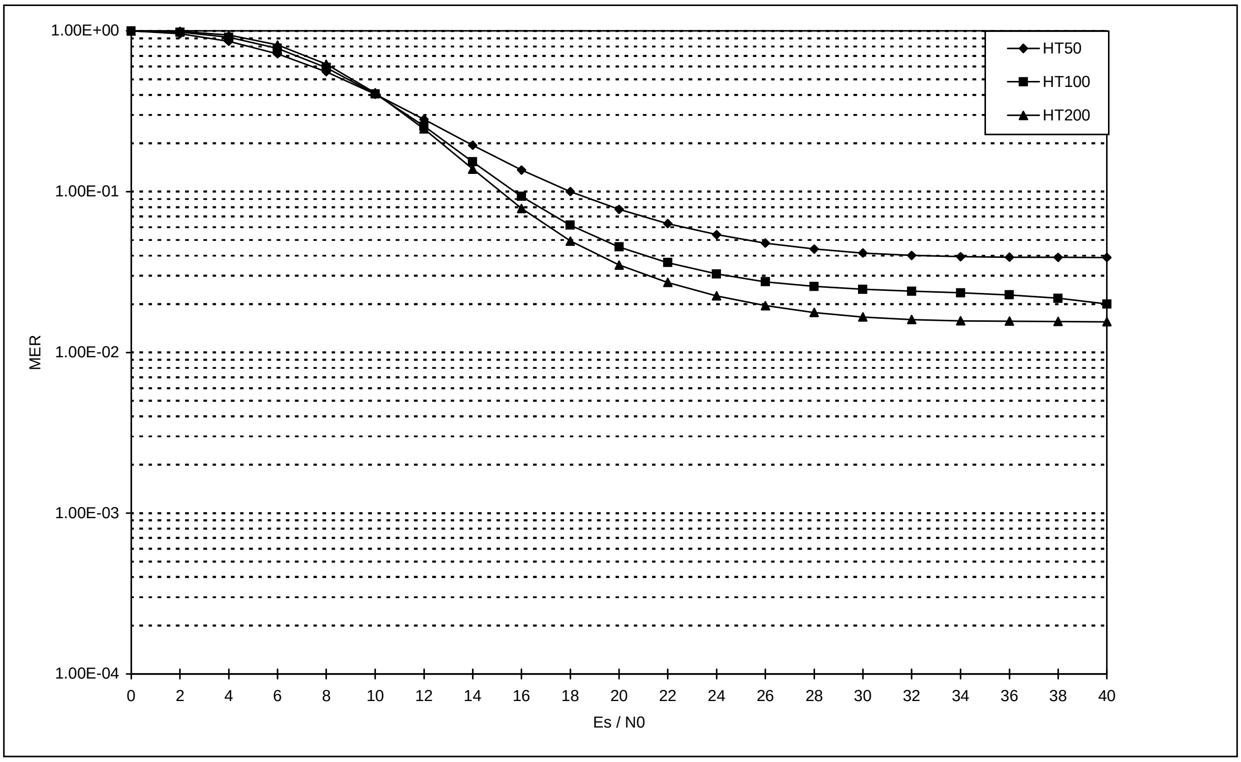

Figure 18: Influence of MS speed on SCH/F in HT propagation environment

4.3.4.2 Realistic synchronization technique

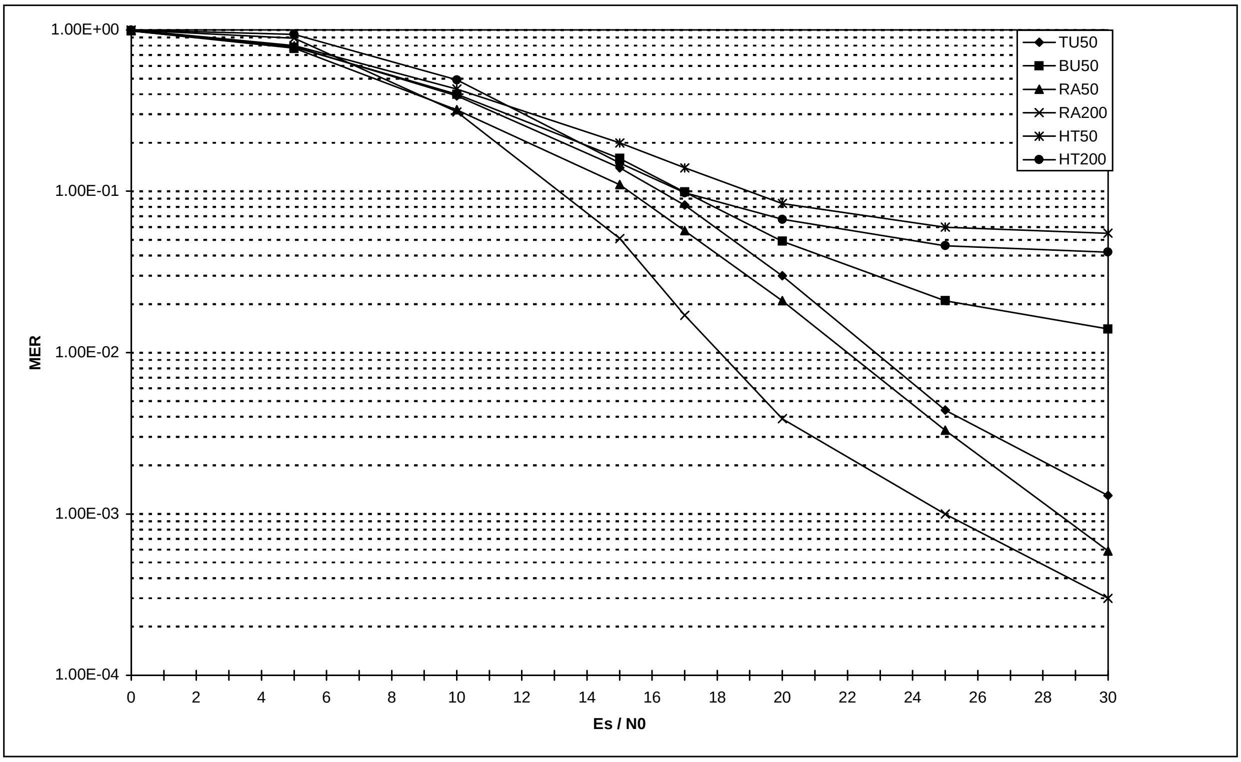

Figure 19: SCH/F performance in different propagation scenarios

4.3.5 BSCH

4.3.5.1 Ideal synchronization technique

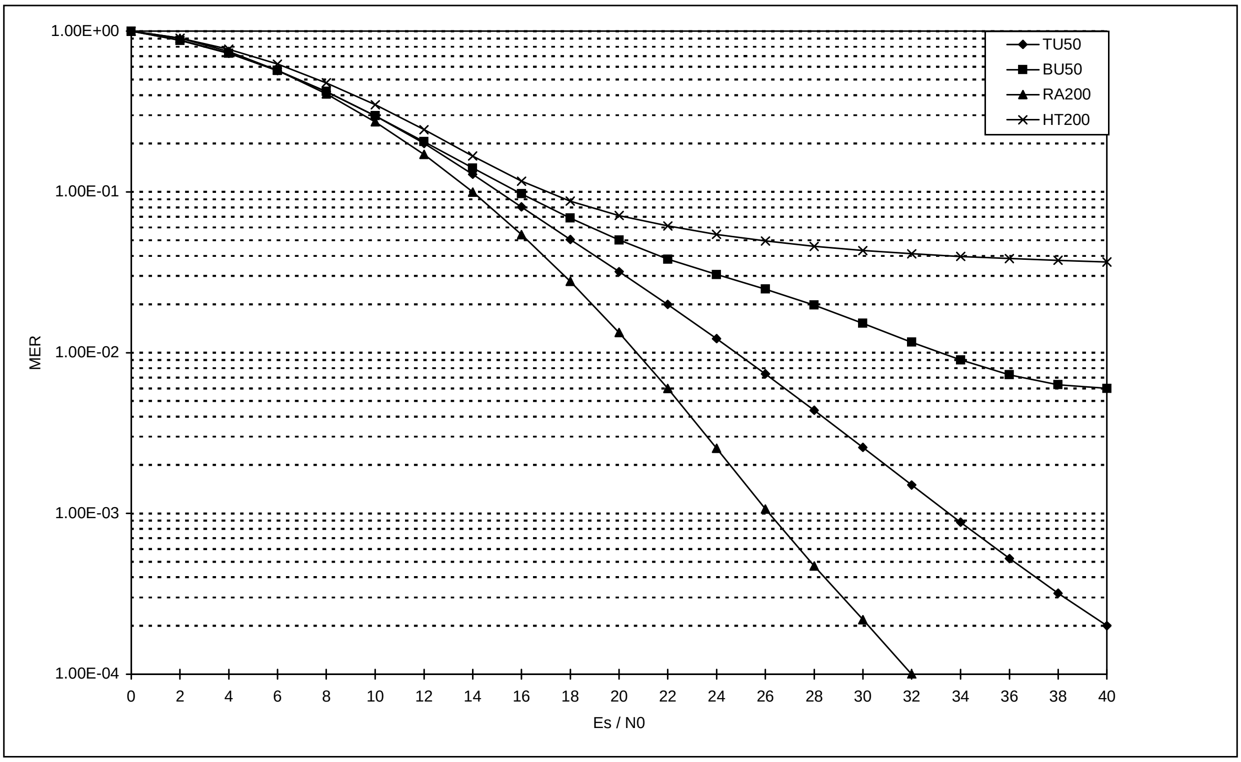

Figure 20: BSCH performance in different propagation scenarios

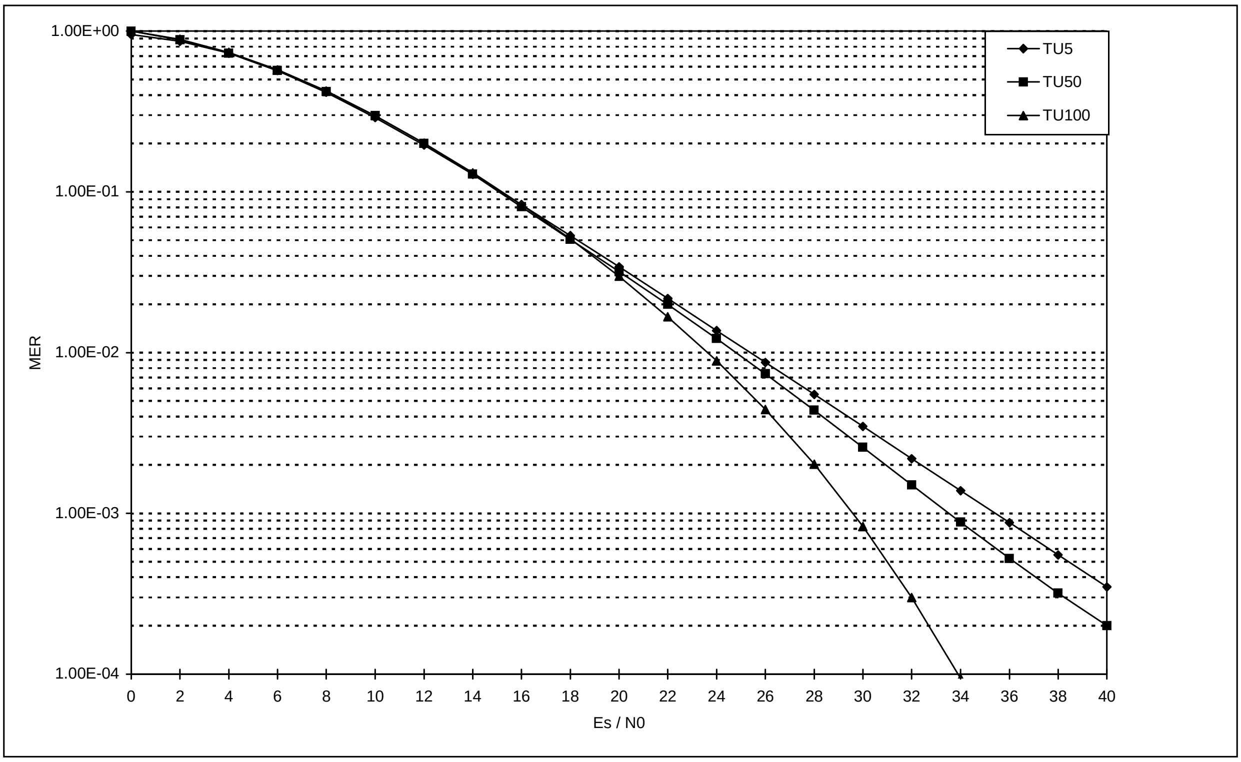

Figure 21: Influence of MS speed on BSCH in TU propagation environment

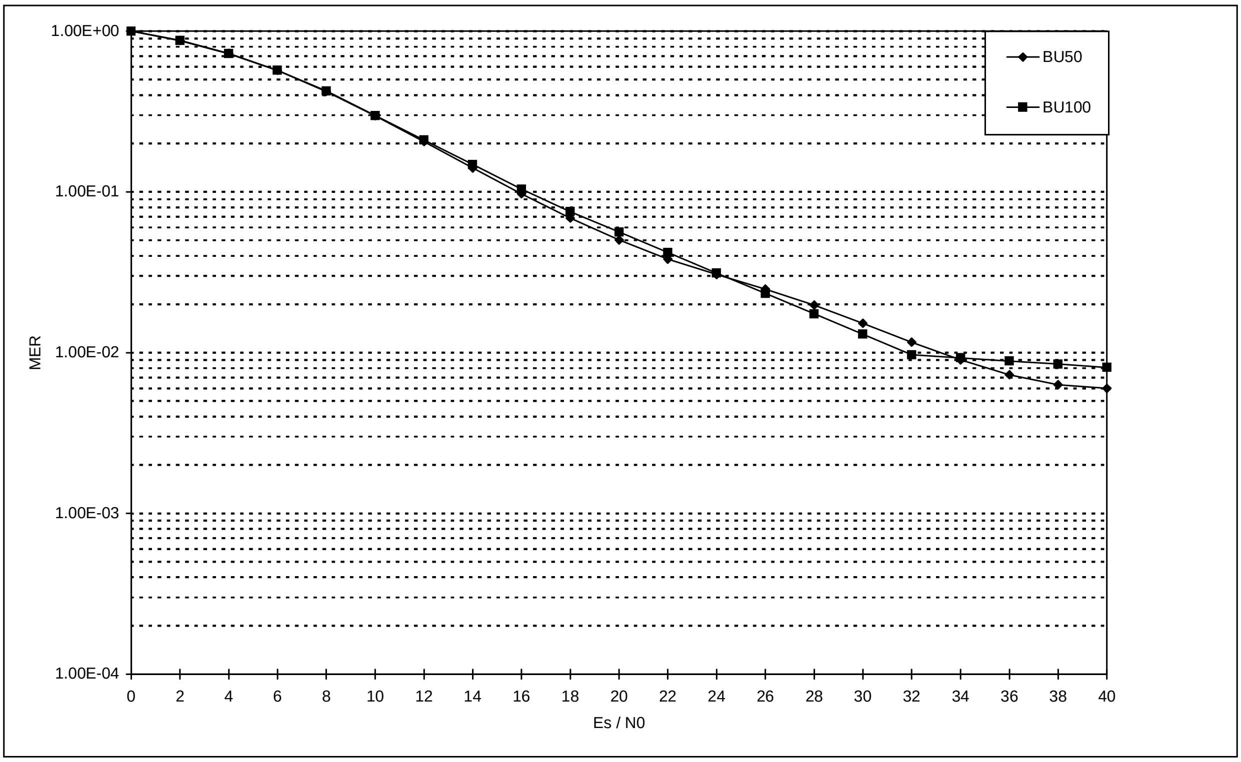

Figure 22: Influence of MS speed on BSCH in BU propagation environment

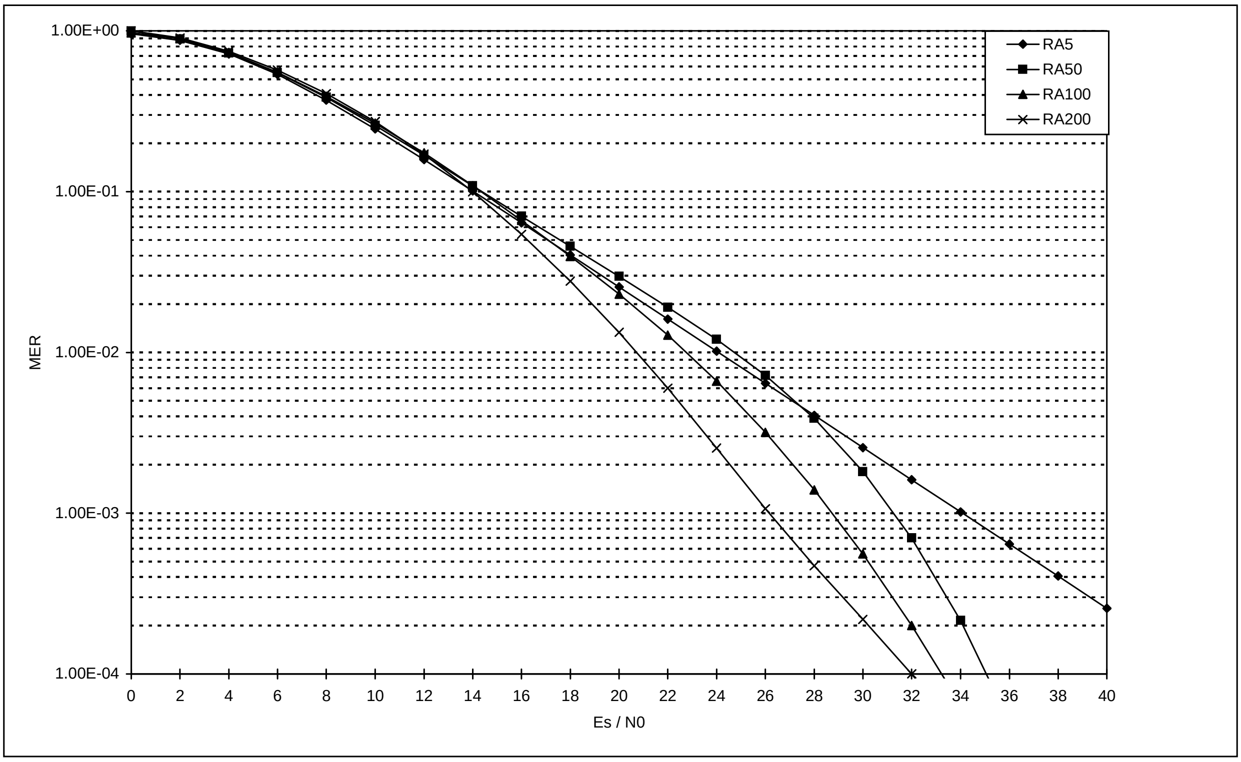

Figure 23: Influence of MS speed on BSCH in RA propagation environment

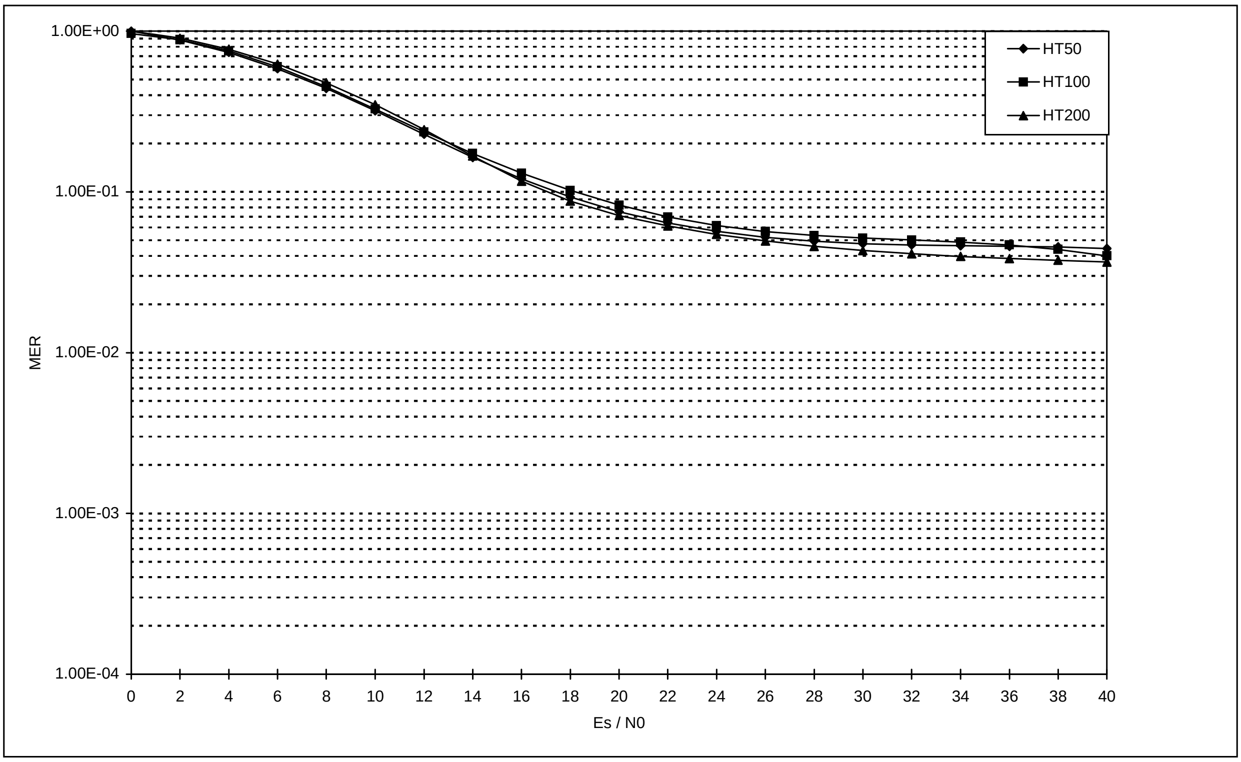

Figure 24: Influence of MS speed on BSCH in HT propagation environment

4.4 Performance of traffic channels

Traffic channels are devoted to the transport of user information on the air interface when a short and constant delay is required by the service in action. Channels have been designed for three values of capacity:

- 7,2 kbit/s (TCH/7,2);
- 4,8 kbit/s (TCH/4,8); and
- 2,4 kbit/s (TCH/2,4).

Moreover, TCH/2,4 and TCH/4,8 present three different interleaving depths in order to improve their performance, N=1, 4, 8.

The logical channel TCH/7,2 has been designed for the transport of the coded speech. Nevertheless the channel to be analysed for speech presents a different error coding scheme and it is properly called TCH/S (S = Speech). No performance is available for TCH/S, then the only estimate of the speech transmission quality will be made making reference on TCH/7,2. It is important to underline that performance of TCH/7,2 is not linearly related to those of the speech transmission.

Table 3: Summary of figures that report traffic channel performance

Logical channel	Figure numbers	Description
TCH/7,2	Figure 25 (Ideal synch)	BER of TCH/7,2 as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 26 (Ideal synch)	BER of TCH/7,2 as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 27 (Ideal synch)	BER of TCH/7,2 as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 28 (Ideal synch)	BER of TCH/7,2 as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 29 (Ideal synch)	BER of TCH/7,2 as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 30 (Realistic synch)	BER of TCH/7,2 as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique
TCH/4,8 N = 1	Figure 31 (Ideal synch)	BER of TCH/4,8 (N=1) as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 32 (Ideal synch)	BER of TCH/4,8 (N=1) as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 33 (Ideal synch)	BER of TCH/4,8 (N=1) as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 34 (Ideal synch)	BER of TCH/4,8 (N=1) as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 35 (Ideal synch)	BER of TCH/4,8 (N=1) as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 36 (Realistic synch)	BER of TCH/4,8 (N=1) as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique
TCH/4,8 N = 4	Figure 37 (Ideal synch)	BER of TCH/4,8 (N=4) as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 38 (Ideal synch)	BER of TCH/4,8 (N=4) as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 39 (Ideal synch)	BER of TCH/4,8 (N=4) as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 40 (Ideal synch)	BER of TCH/4,8 (N=4) as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 41 (Ideal synch)	BER of TCH/4,8 (N=4) as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 42 (Realistic synch)	BER of TCH/4,8 (N=4) as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique
TCH/4,8 N = 8	Figure 43 (Ideal synch)	BER of TCH/4,8 (N=8) as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 44 (Ideal synch)	BER of TCH/4,8 (N=8) as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 45 (Ideal synch)	BER of TCH/4,8 (N=8) as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 46 (Ideal synch)	BER of TCH/4,8 (N=8) as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 47 (Ideal synch)	BER of TCH/4,8 (N=8) as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 48 (Realistic synch)	BER of TCH/4,8 (N=8) as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique
TCH/2,4 N = 1	Figure 49 (Ideal synch)	BER of TCH/2,4 (N=1) as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 50 (Ideal synch)	BER of TCH/2,4 (N=1) as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 51 (Ideal synch)	BER of TCH/2,4 (N=1) as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 52 (Ideal synch)	BER of TCH/2,4 (N=1) as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 53 (Ideal synch)	BER of TCH/2,4 (N=1) as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 54 (Realistic synch)	BER of TCH/2,4 (N=1) as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique

Logical channel	Figure numbers	Description
TCH/2,4 N = 4	Figure 55 (Ideal synch)	BER of TCH/2,4 (N=4) as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 56 (Ideal synch)	BER of TCH/2,4 (N=4) as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 57 (Ideal synch)	BER of TCH/2,4 (N=4) as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 58 (Ideal synch)	BER of TCH/2,4 (N=4) as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 59 (Ideal synch)	BER of TCH/2,4 (N=4)as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 60 (Realistic synch)	BER of TCH/2,4 (N=4) as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique
TCH/2,4 N = 8	Figure 61 (Ideal synch)	BER of TCH/2,4 (N=8) as function of E_s/N_0 in TU50, BU50, RA200, HT200 propagation environments with ideal synchronization technique
	Figure 62 (Ideal synch)	BER of TCH/2,4 (N=8) as function of E_s/N_0 in TU5, TU50, TU100 propagation environments with ideal synchronization technique
	Figure 63 (Ideal synch)	BER of TCH/2,4 (N=8) as function of E_s/N_0 in BU50, BU100 propagation environments with ideal synchronization technique
	Figure 64 (Ideal synch)	BER of TCH/2,4 (N=8) as function of E_s/N_0 in RA5, RA50, RA100, RA200 propagation environments with ideal synchronization technique
	Figure 65 (Ideal synch)	BER of TCH/2,4 (N=8) as function of E_s/N_0 in HT50, HT100, HT200 propagation environments with ideal synchronization technique
	Figure 66 (Realistic synch)	BER of TCH/2,4 (N=8) as function of E_s/N_0 in TU50, BU50, RA50, RA200, HT50, HT200 propagation environments with realistic synchronization technique

4.4.1 TCH/7,2

4.4.1.1 Ideal synchronization technique

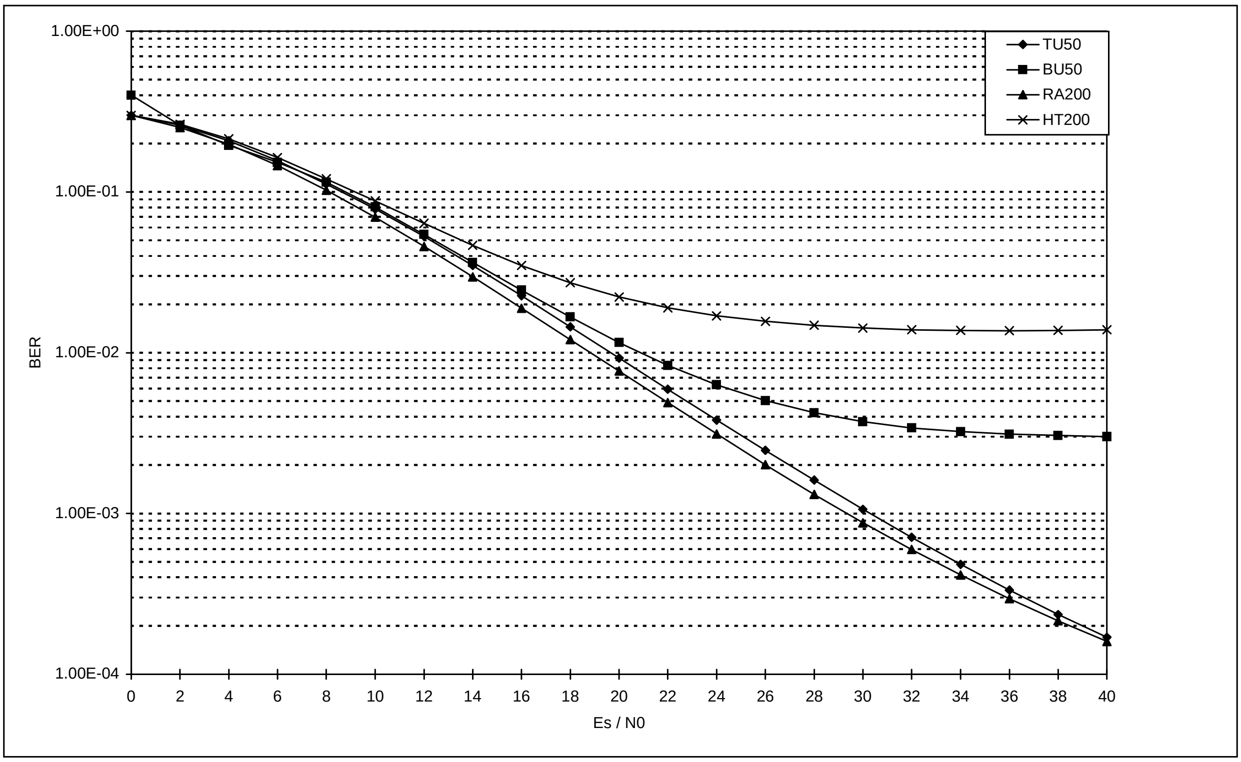

Figure 25: TCH/7,2 performance in different propagation scenarios

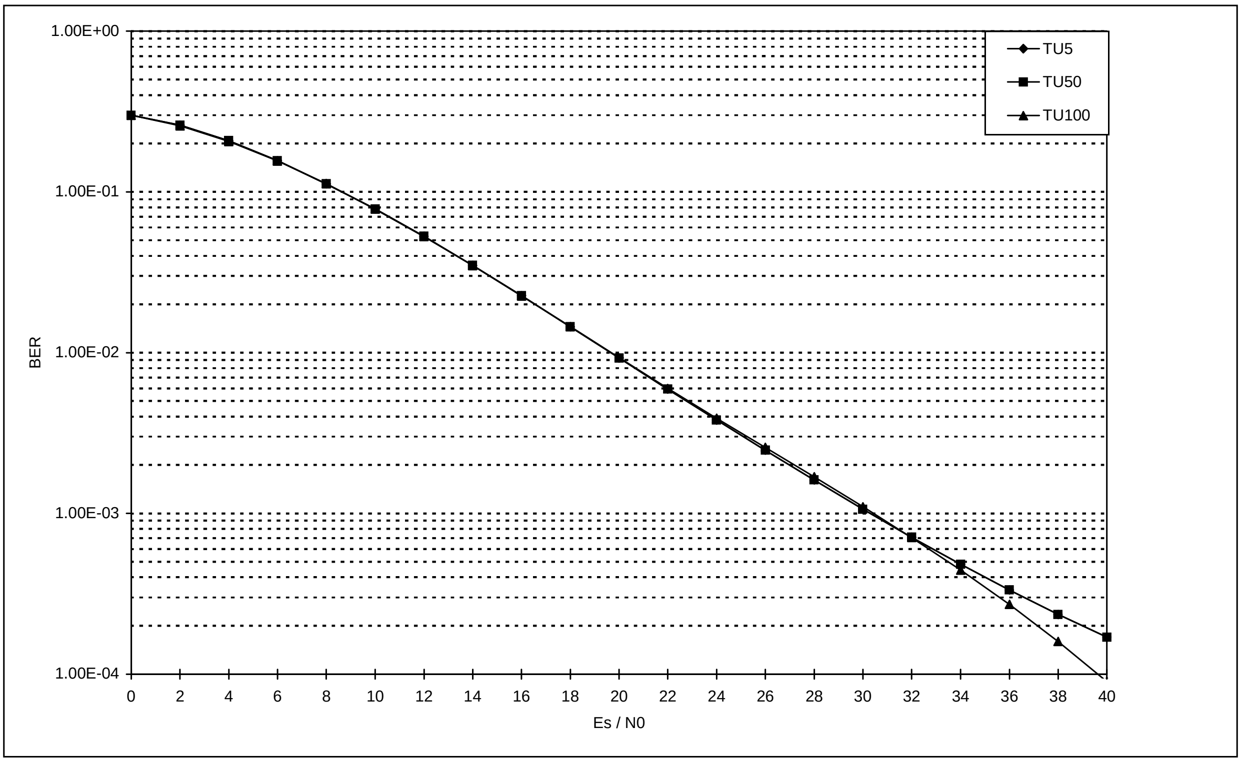

Figure 26: Influence of MS speed on TCH/7,2 in TU propagation environment

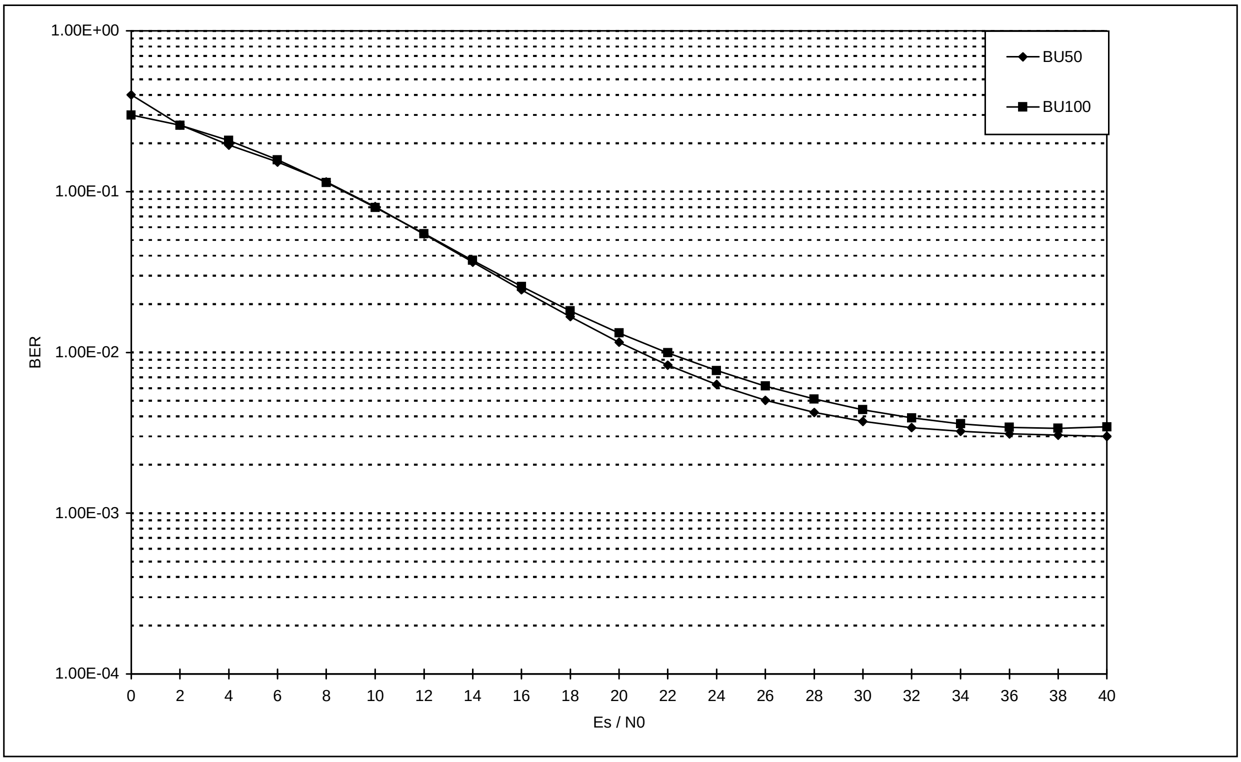

Figure 27: Influence of MS speed on TCH/7,2 in BU propagation environment

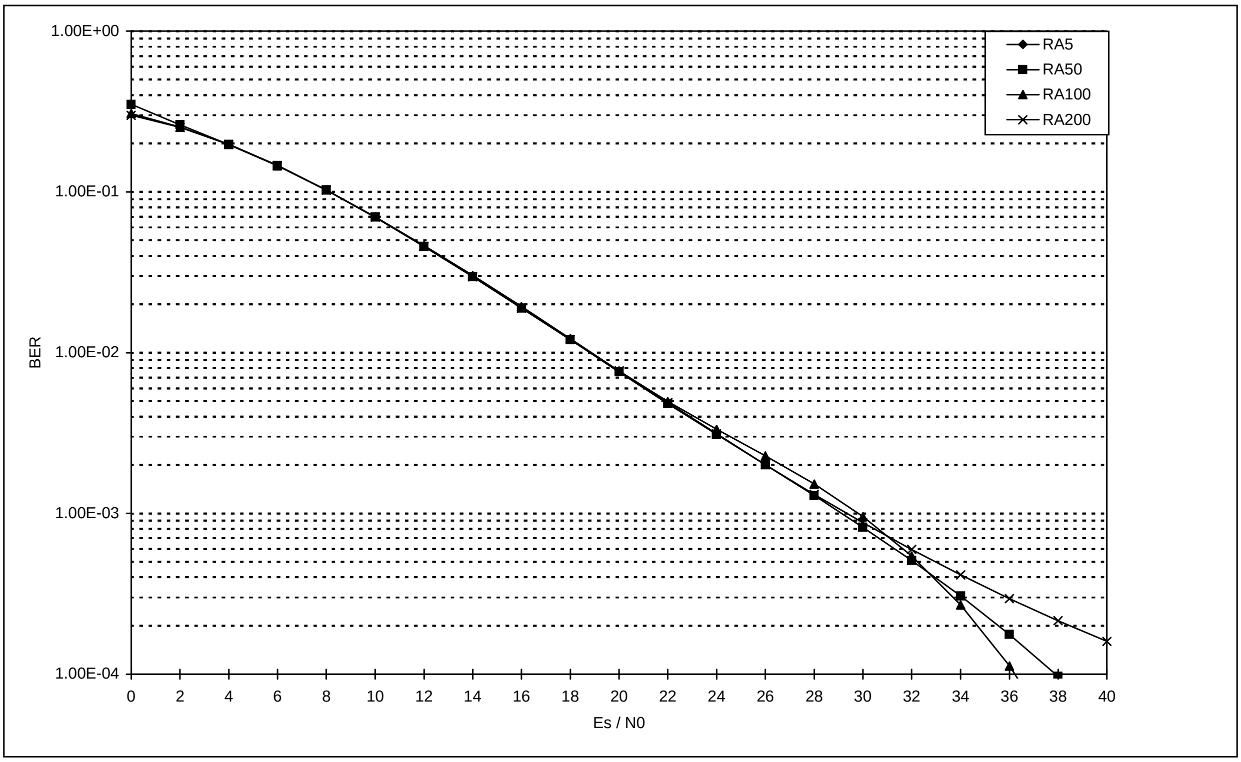

Figure 28: Influence of MS speed on TCH/7,2 in RA propagation environment

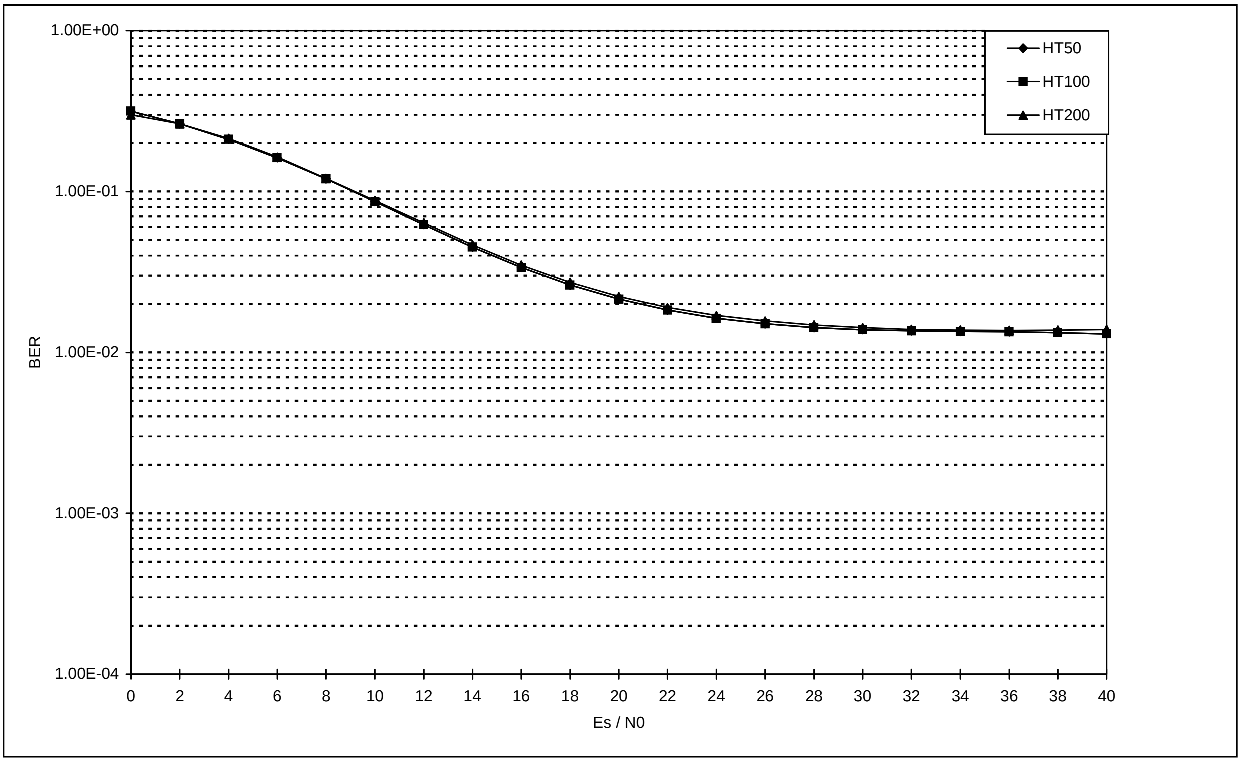

Figure 29: Influence of MS speed on TCH/7,2 in HT propagation environment

4.4.1.2 Realistic synchronization technique

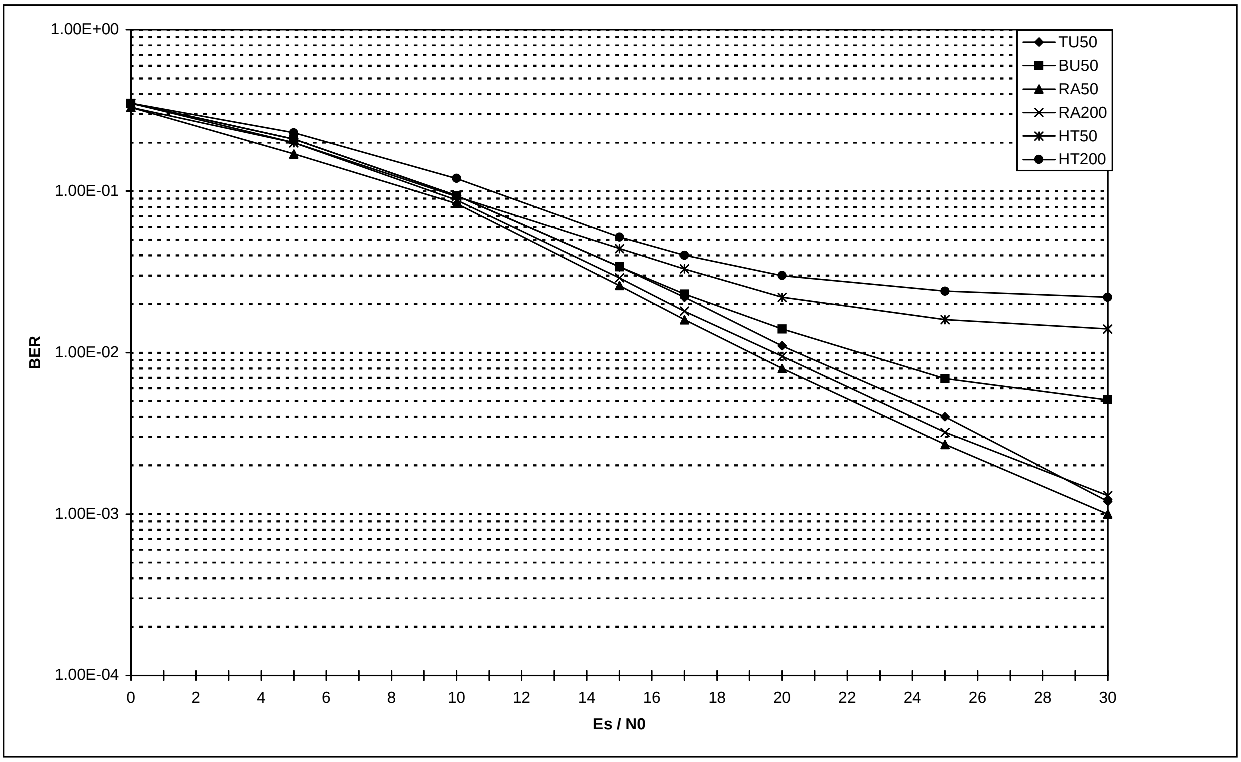

Figure 30: TCH/7,2 performance in different propagation scenarios

4.4.2 TCH/4,8 N = 1

4.4.2.1 Ideal synchronization technique

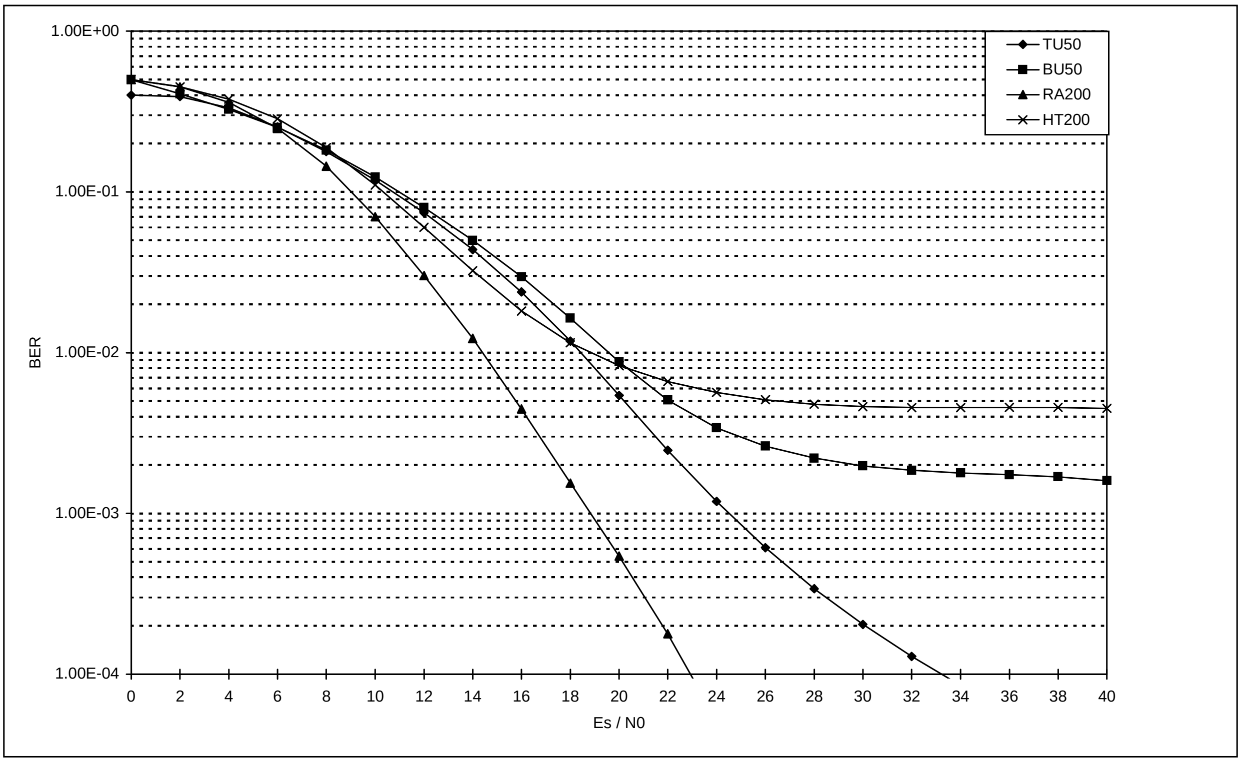

Figure 31: TCH/4,8 N=1 performance in different propagation scenarios

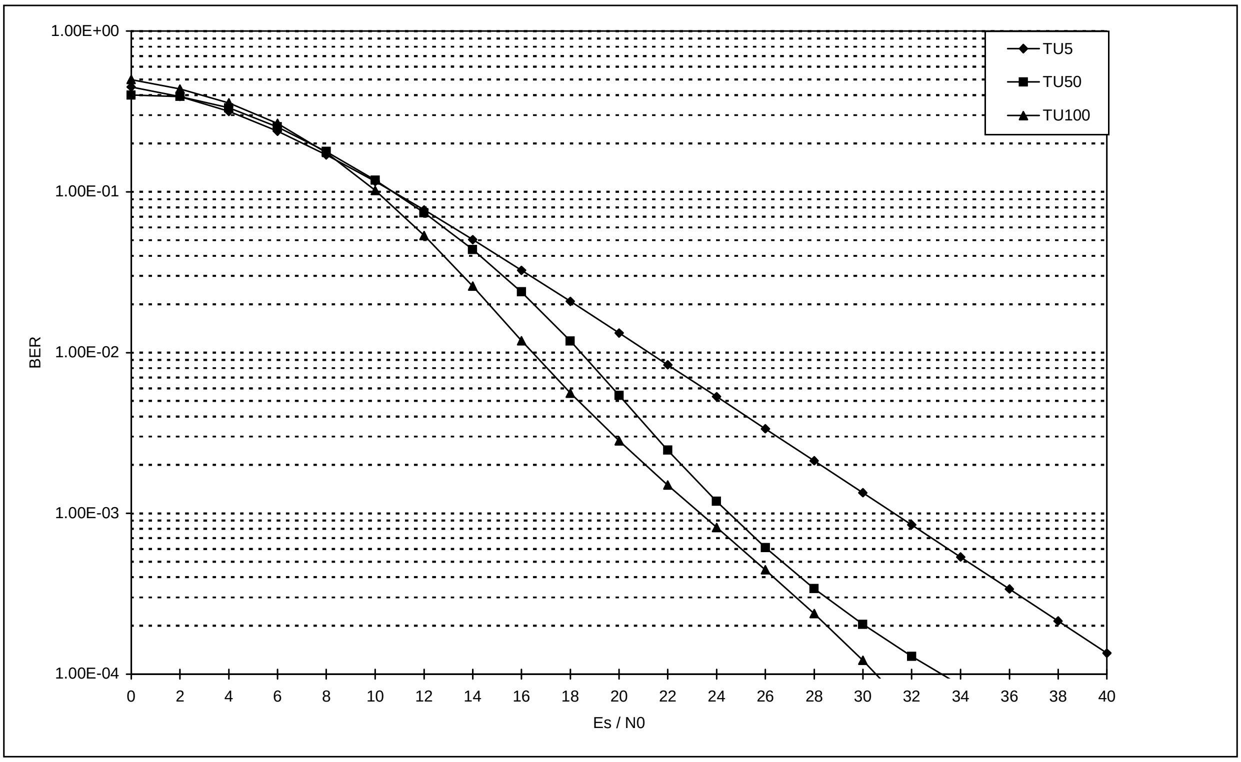

Figure 32: Influence of MS speed on TCH/4,8 N=1 in TU propagation environment

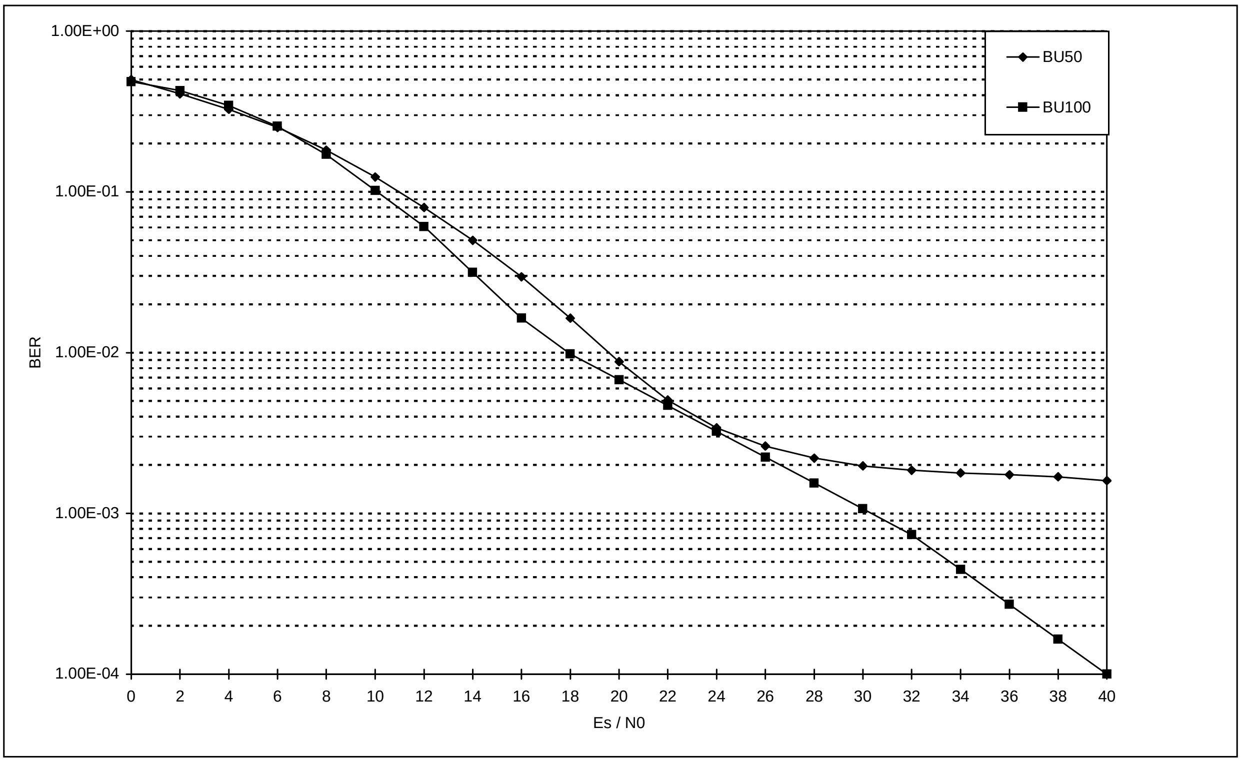

Figure 33: Influence of MS speed on TCH/4,8 N=1 in BU propagation environment

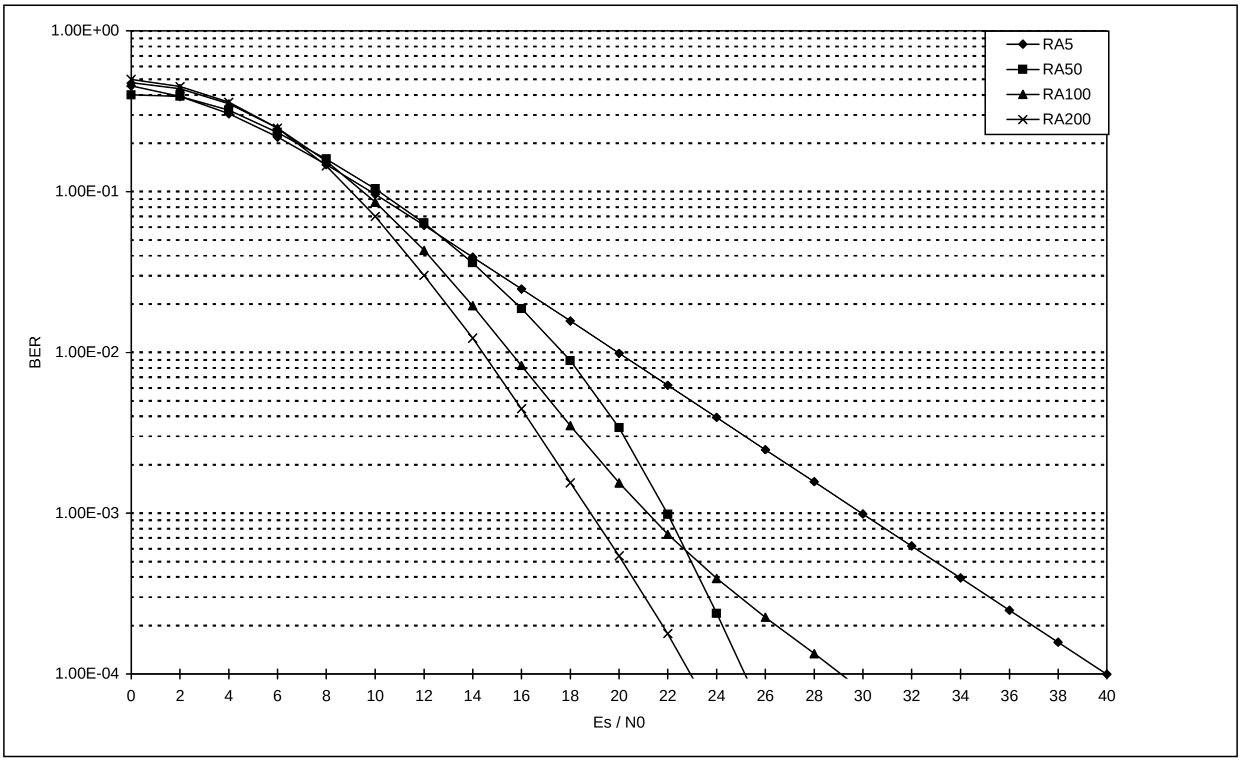

Figure 34: Influence of MS speed on TCH/4,8 N=1 in RA propagation environment

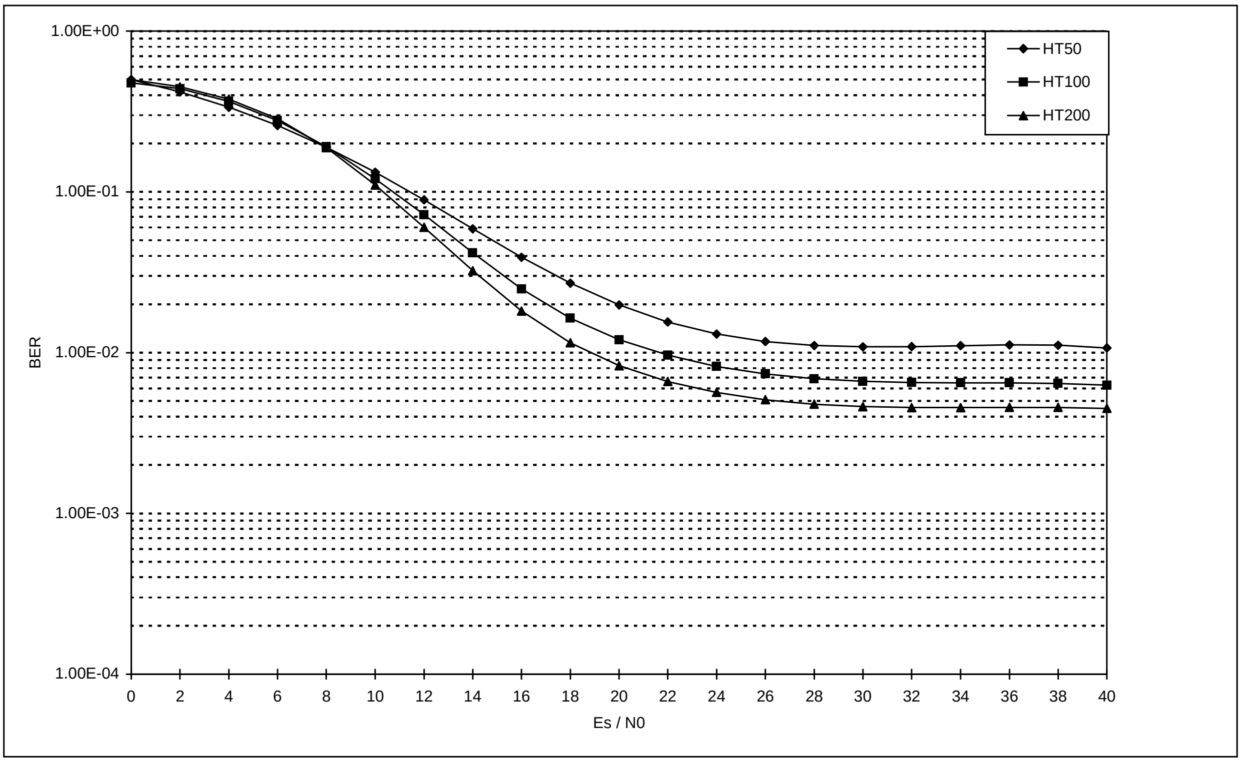

Figure 35: Influence of MS speed on TCH/4,8 N=1 in HT propagation environment

4.4.2.2 Realistic synchronization technique

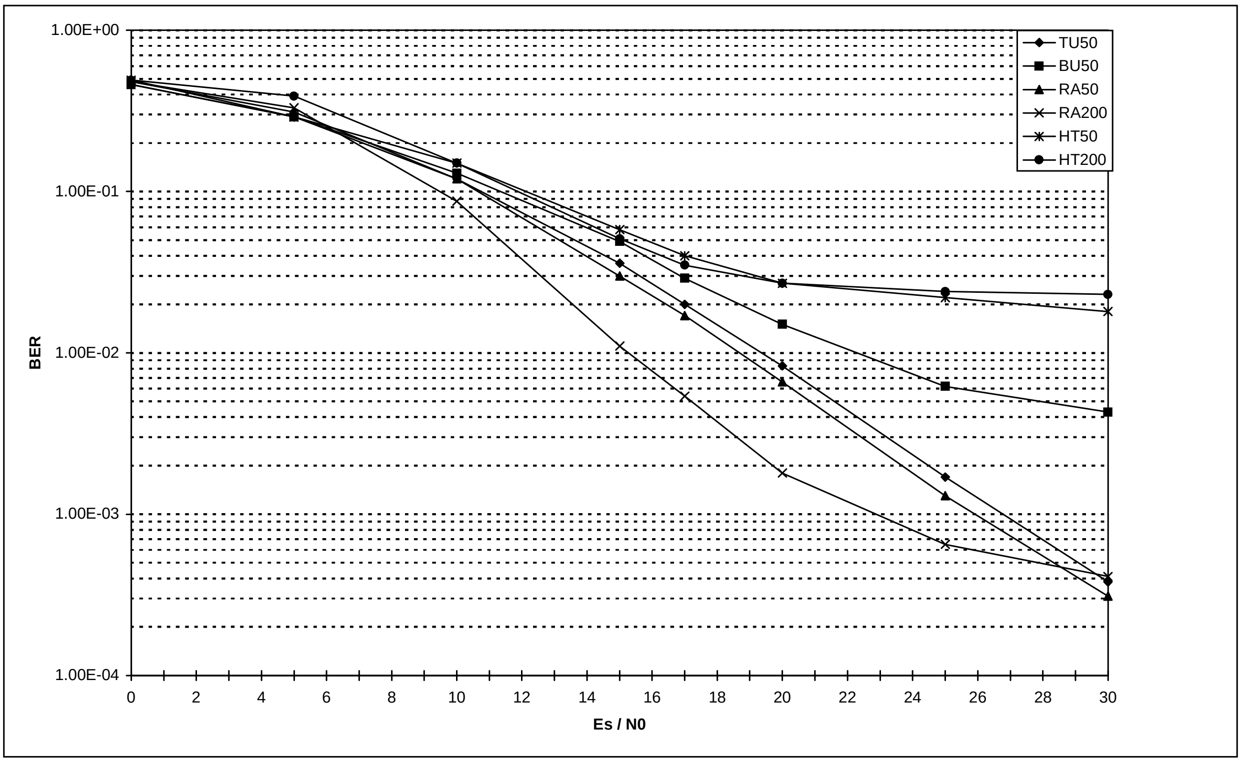

Figure 36: TCH/4,8 N=1 performance in different propagation scenarios

4.4.3 TCH/4,8 N = 4

4.4.3.1 Ideal synchronization technique

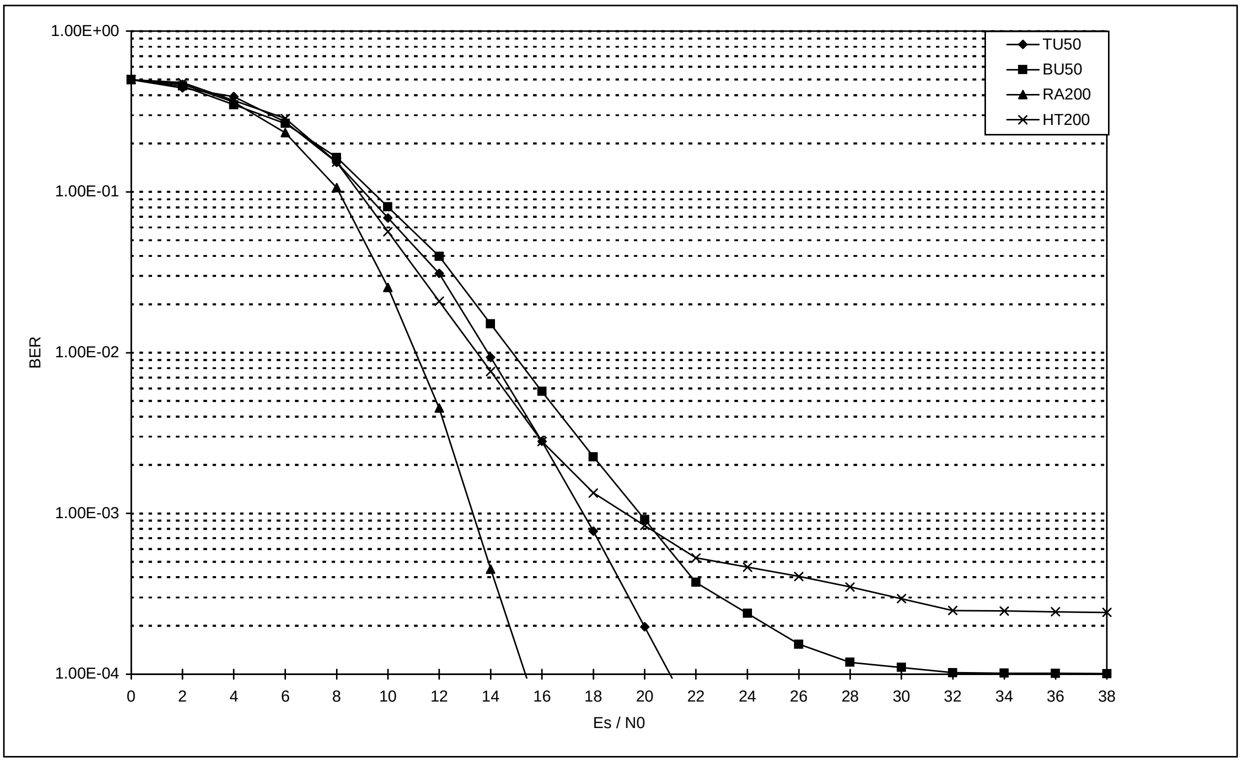

Figure 37: TCH/4,8 N=4 performance in different propagation scenarios

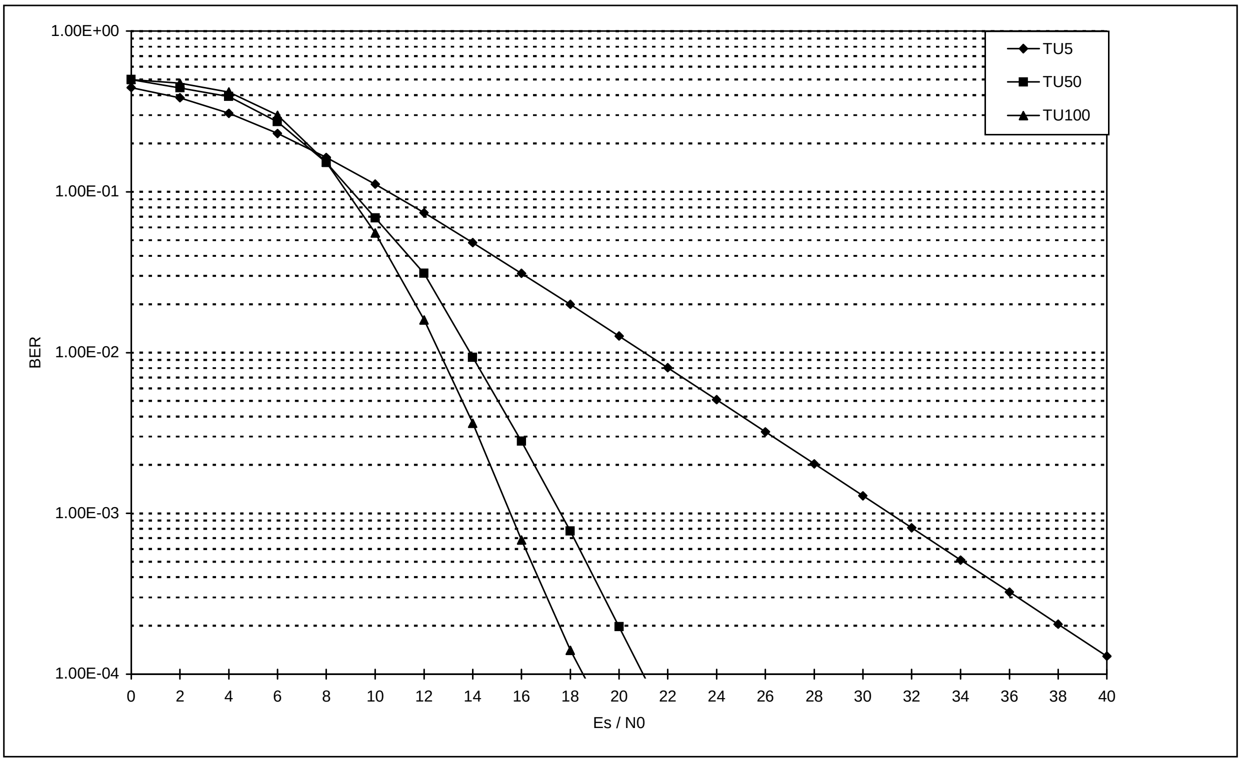

Figure 38: Influence of MS speed on TCH/4,8 N=4 in TU propagation environment

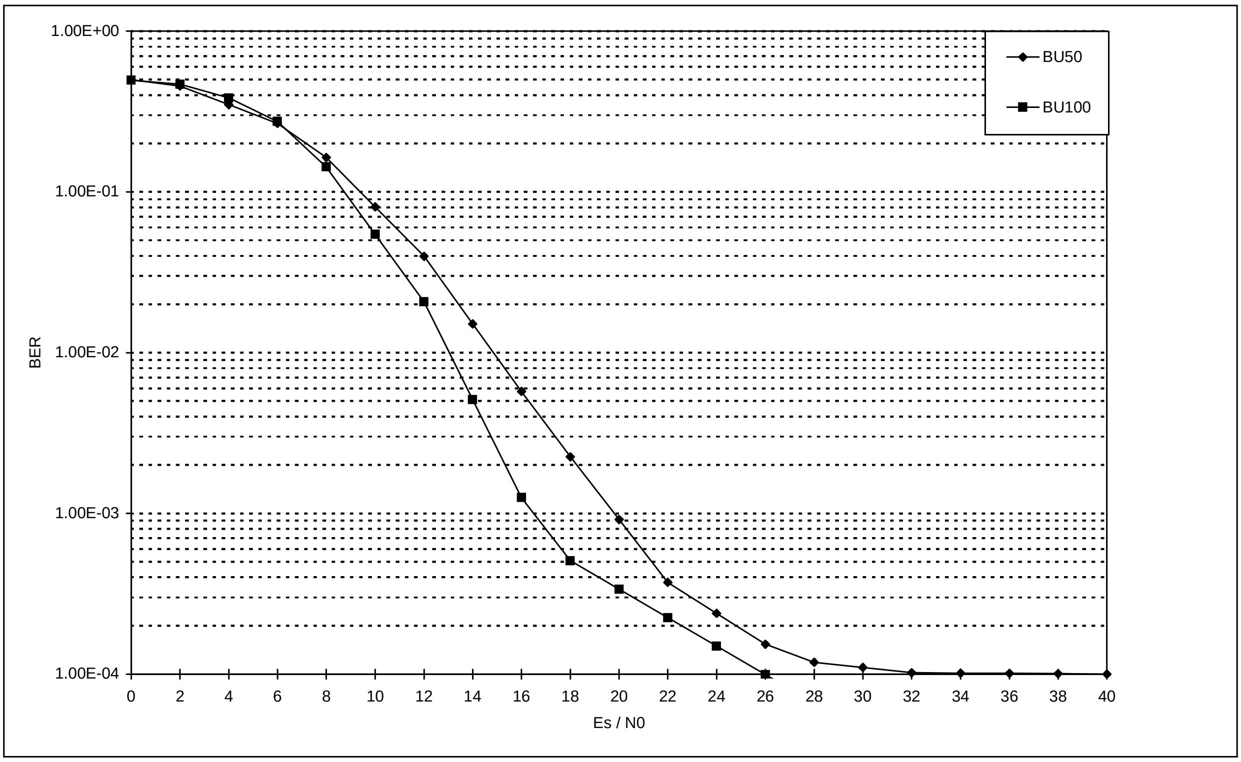

Figure 39: Influence of MS speed on TCH/4,8 N=4 in BU propagation environment

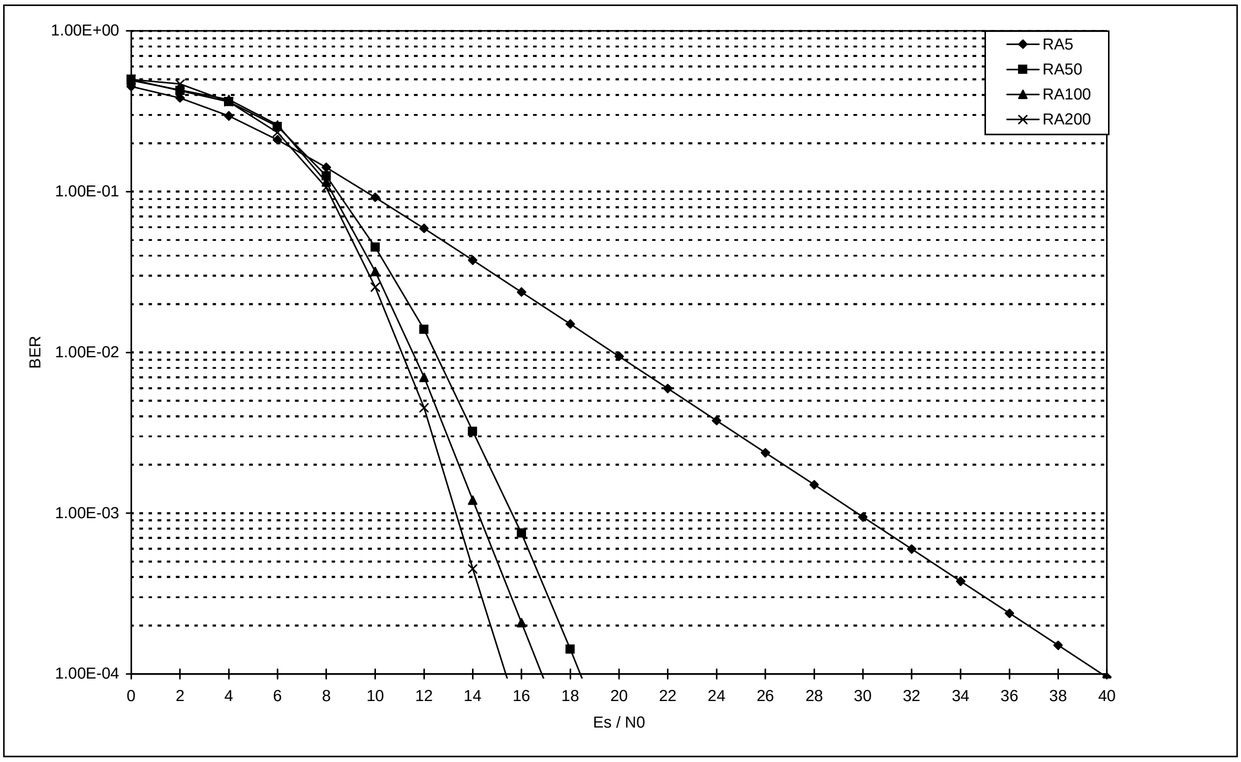

Figure 40: Influence of MS speed on TCH/4,8 N=4 in RA propagation environment

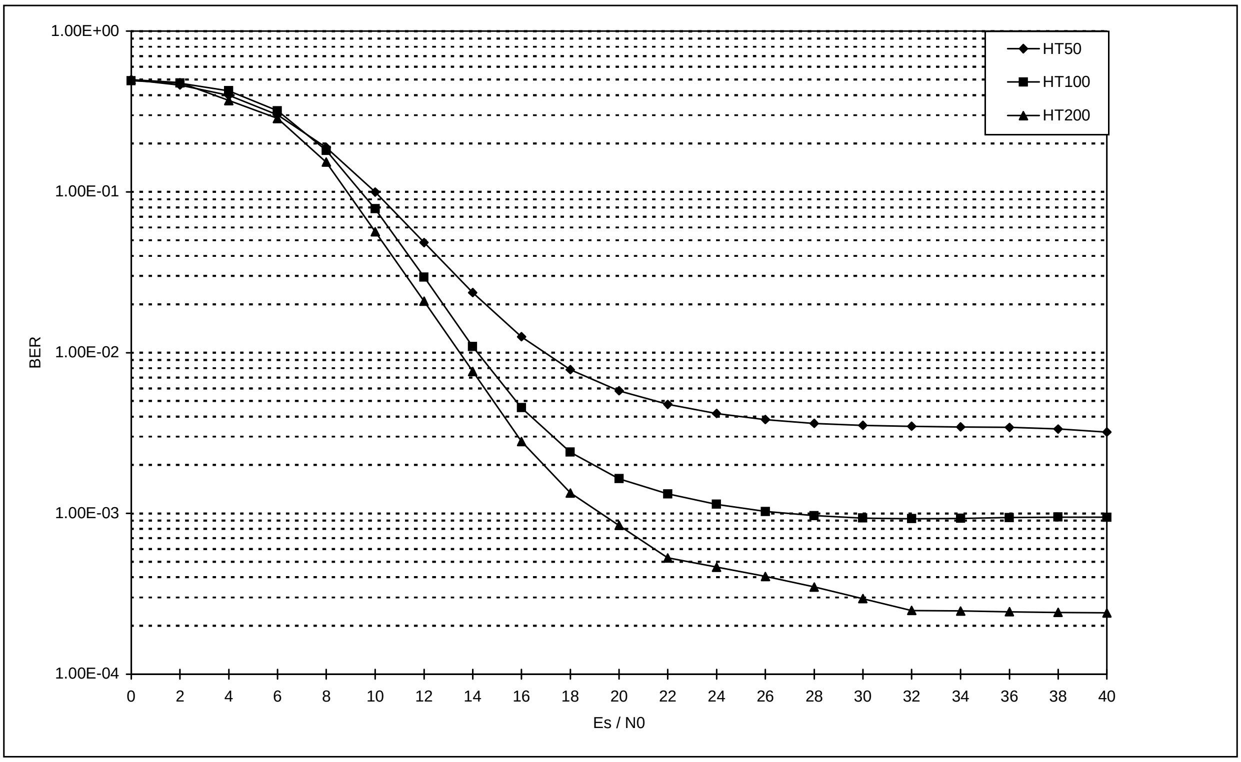

Figure 41: Influence of MS speed on TCH/4,8 N=4 in HT propagation environment

4.4.3.2 Realistic synchronization technique

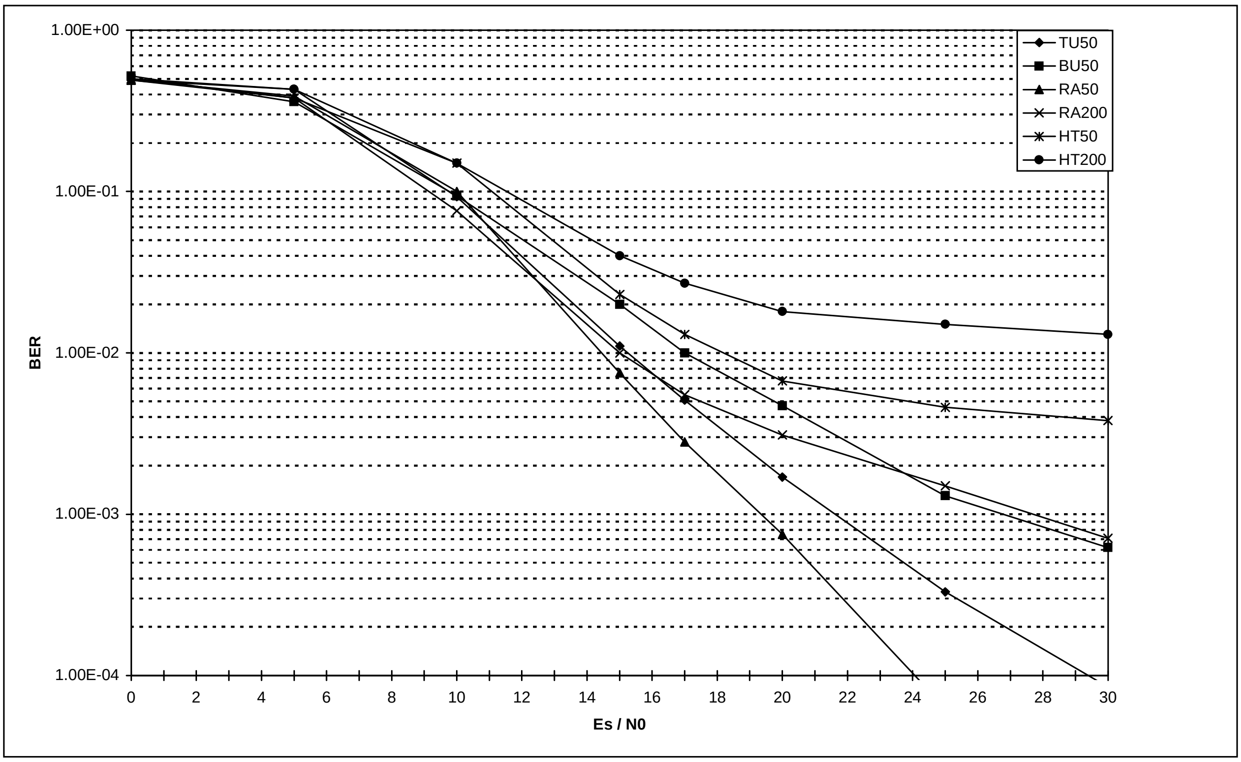

Figure 42: TCH/4,8 N=4 performance in different propagation scenarios

4.4.4 TCH/4,8 N = 8

4.4.4.1 Ideal synchronization technique

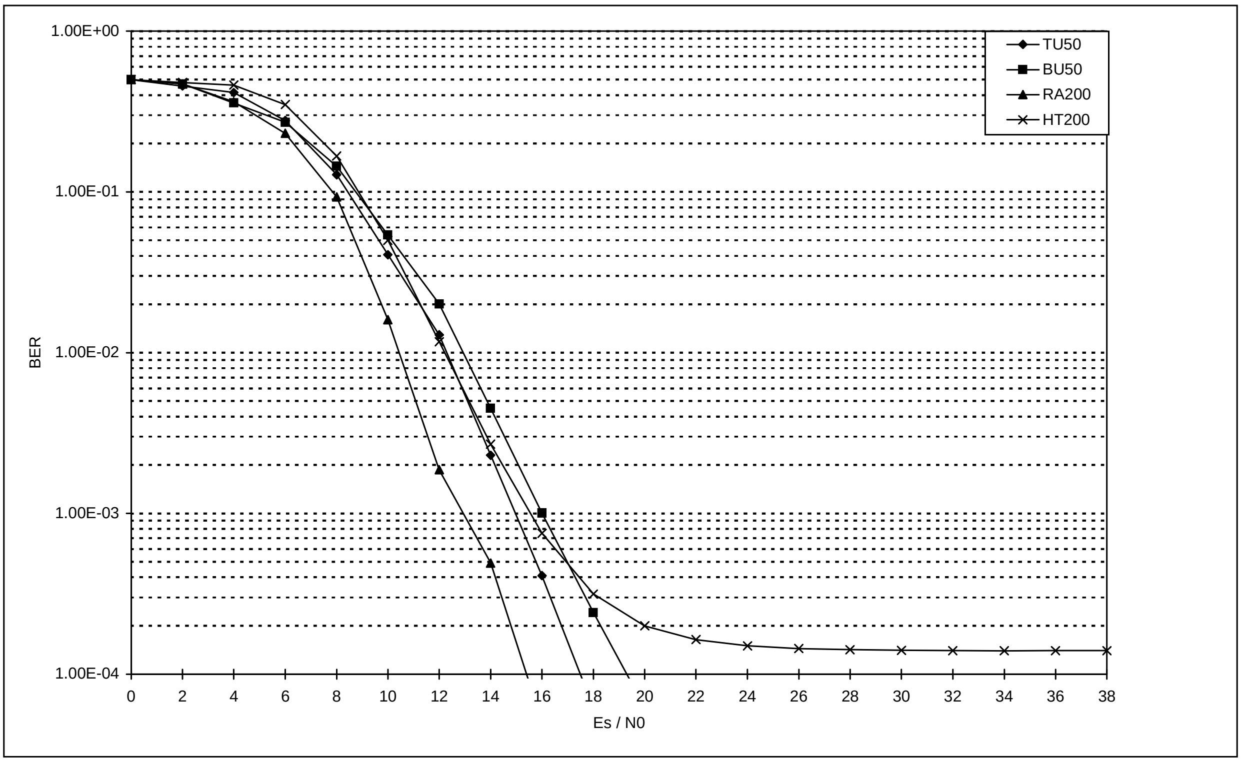

Figure 43: TCH/4,8 N=8 performance in different propagation scenarios

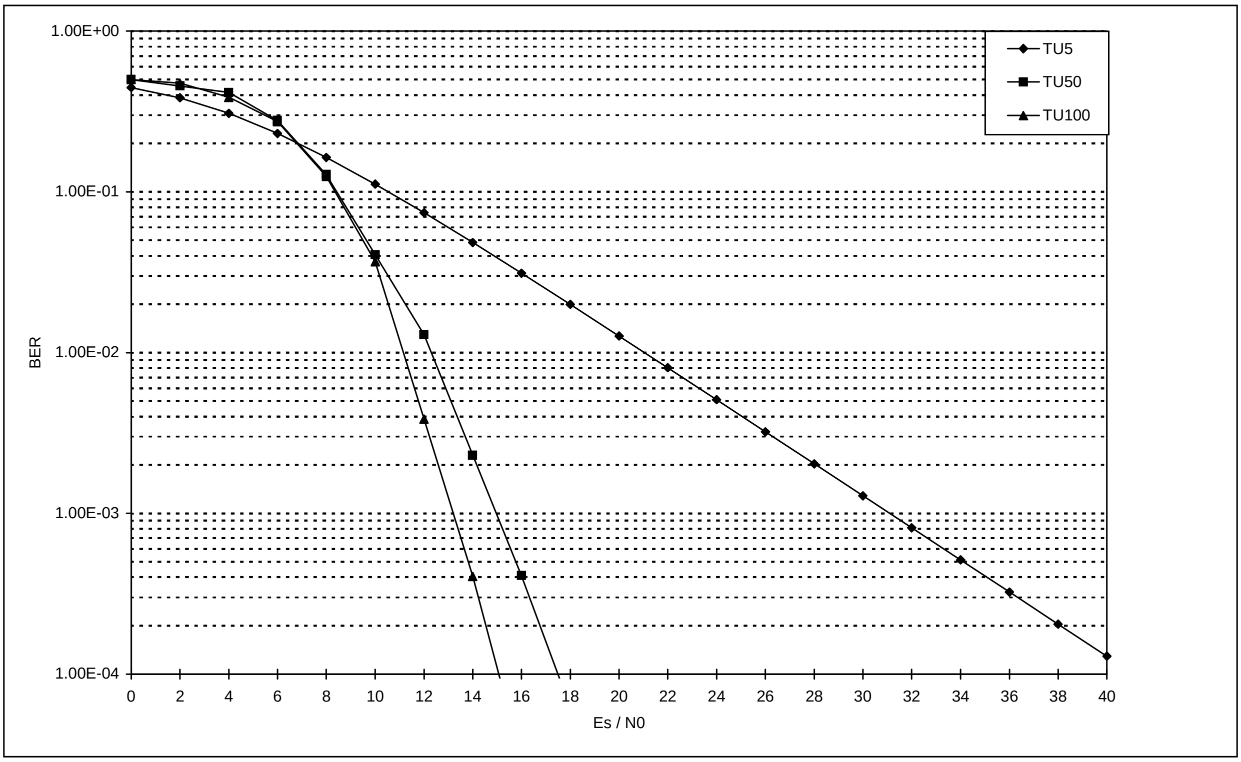

Figure 44: Influence of MS speed on TCH/4,8 N=8 in TU propagation environment

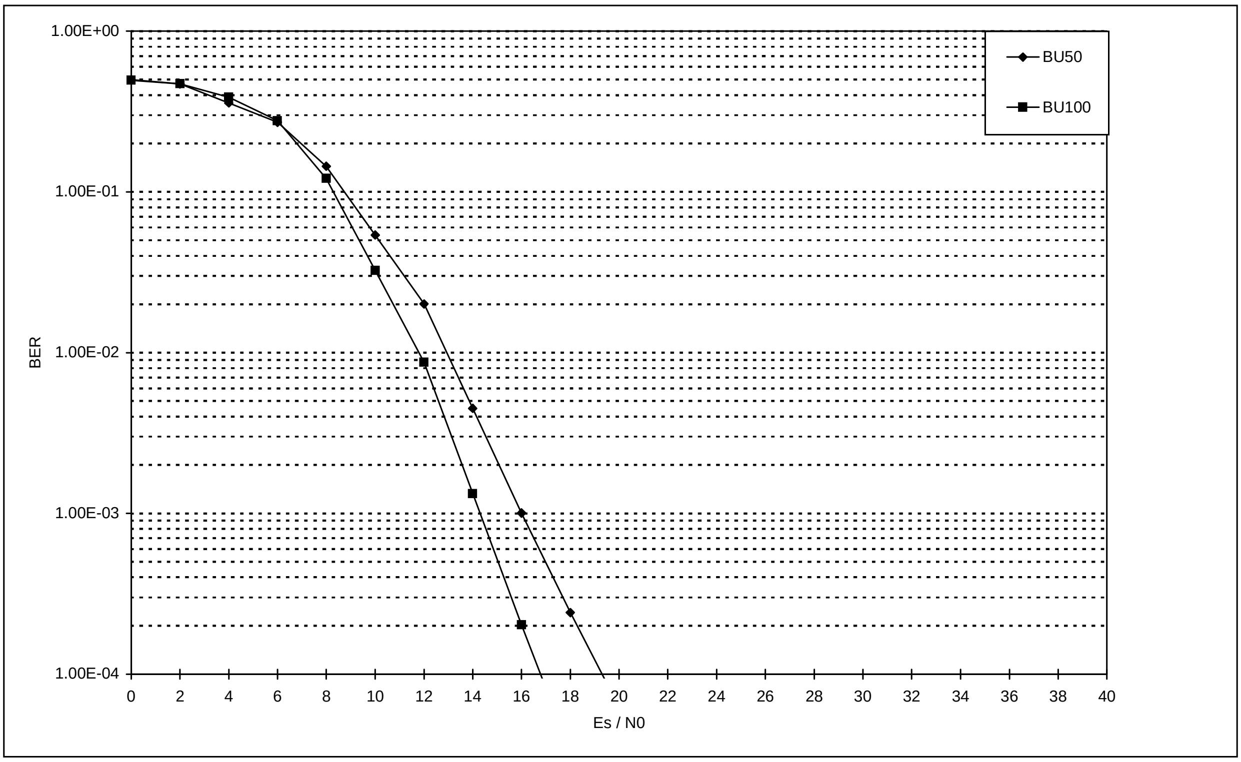

Figure 45: Influence of MS speed on TCH/4,8 N=8 in BU propagation environment

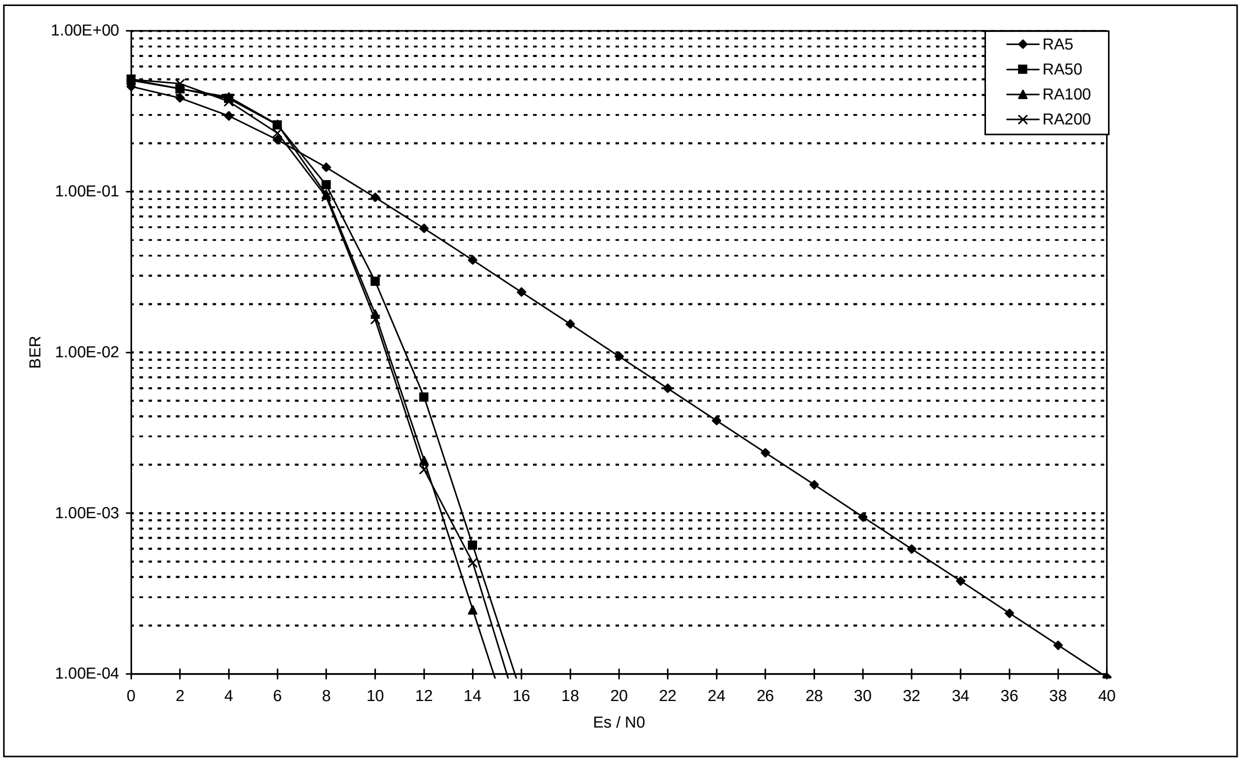

Figure 46: Influence of MS speed on TCH/4,8 N=8 in RA propagation environment

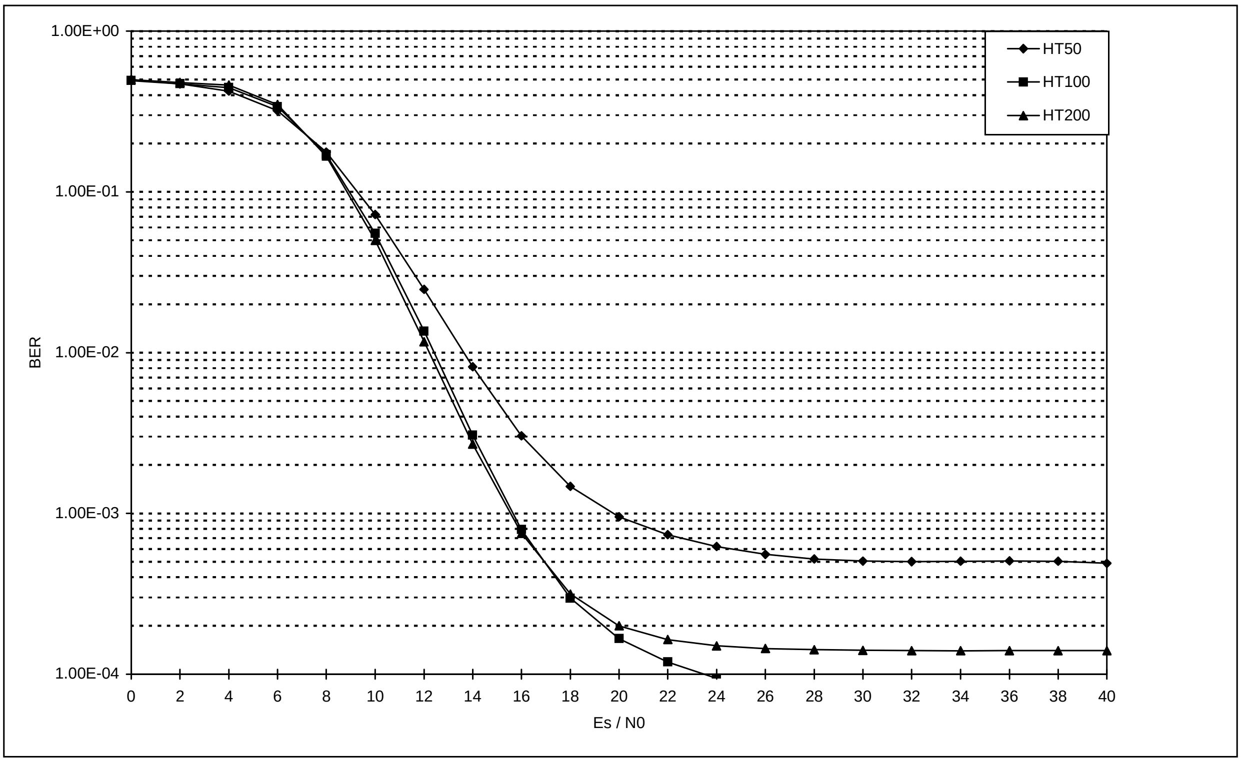

Figure 47: Influence of MS speed on TCH/4,8 N=8 in HT propagation environment

4.4.4.2 Realistic synchronization technique

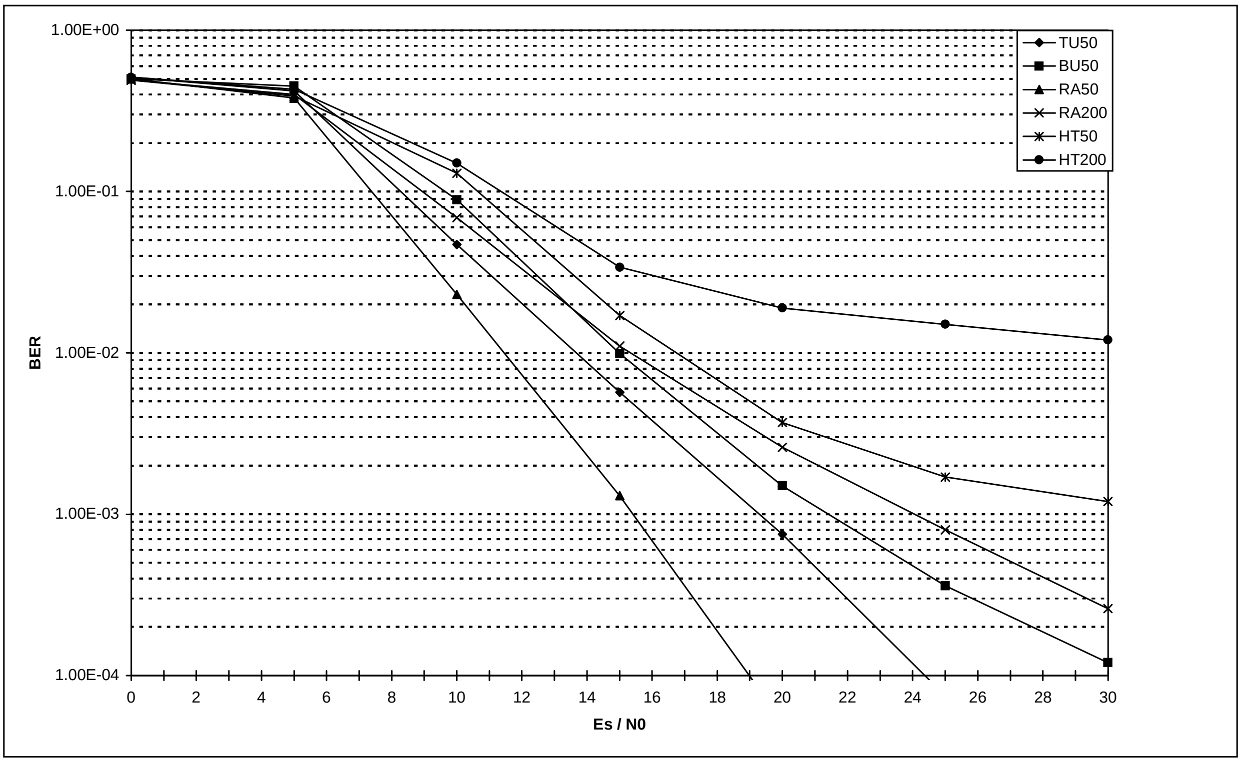

Figure 48: TCH/4,8 N=8 performance in different propagation scenarios

4.4.5 TCH/2,4 N = 1

4.4.5.1 Ideal synchronization technique

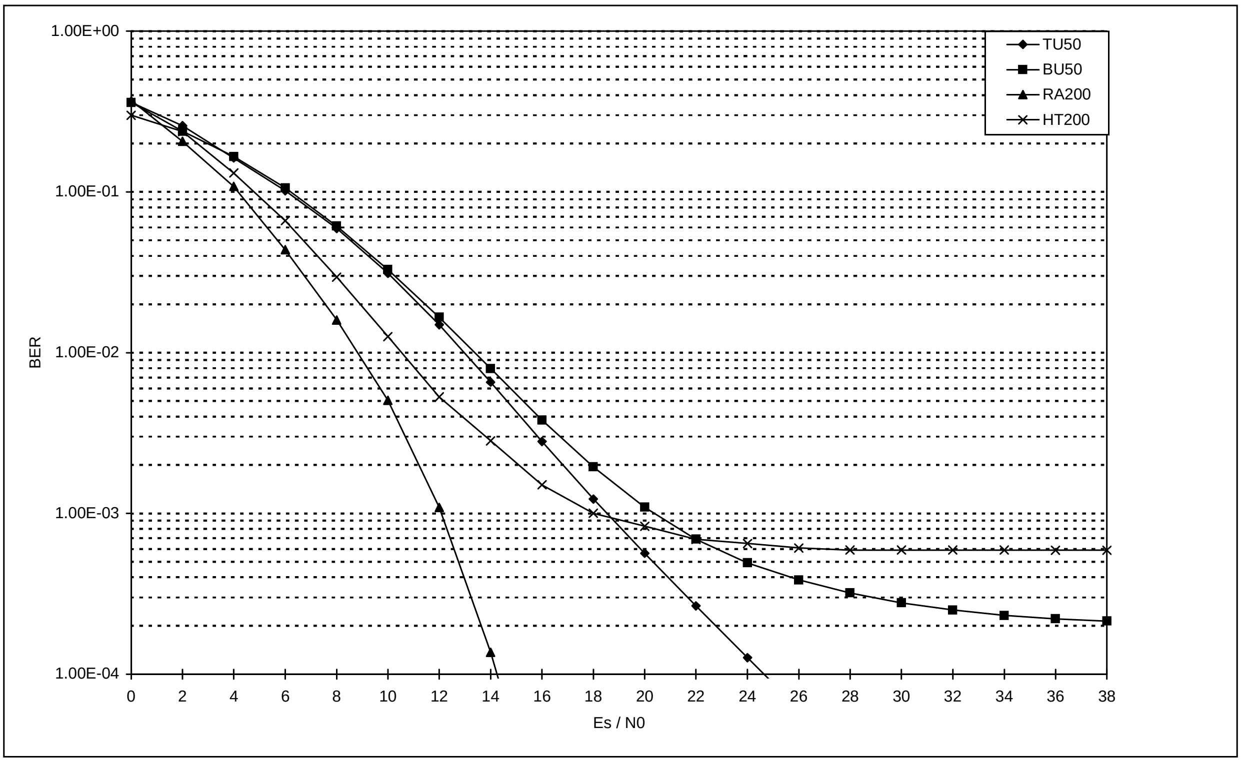

Figure 49: TCH/2,4 N=1 performance in different propagation scenarios

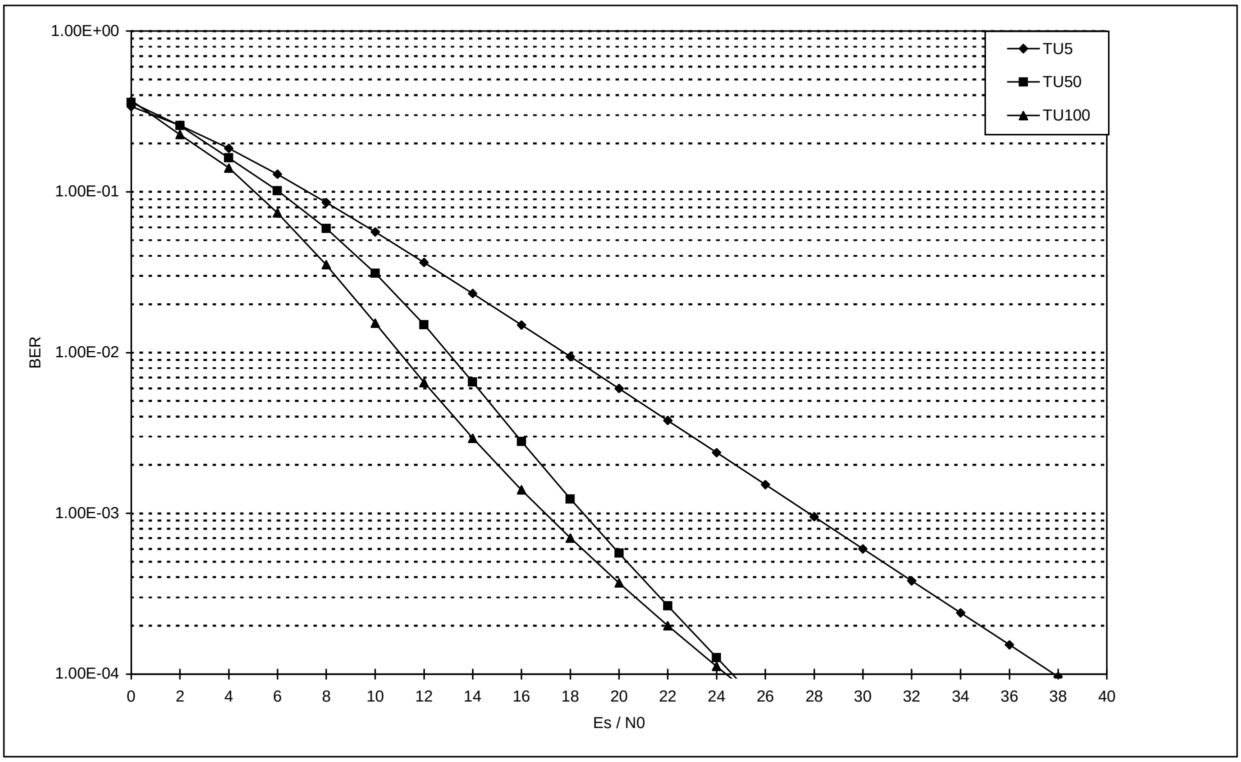

Figure 50: Influence of MS speed on TCH/2,4 N=1 in TU propagation environment

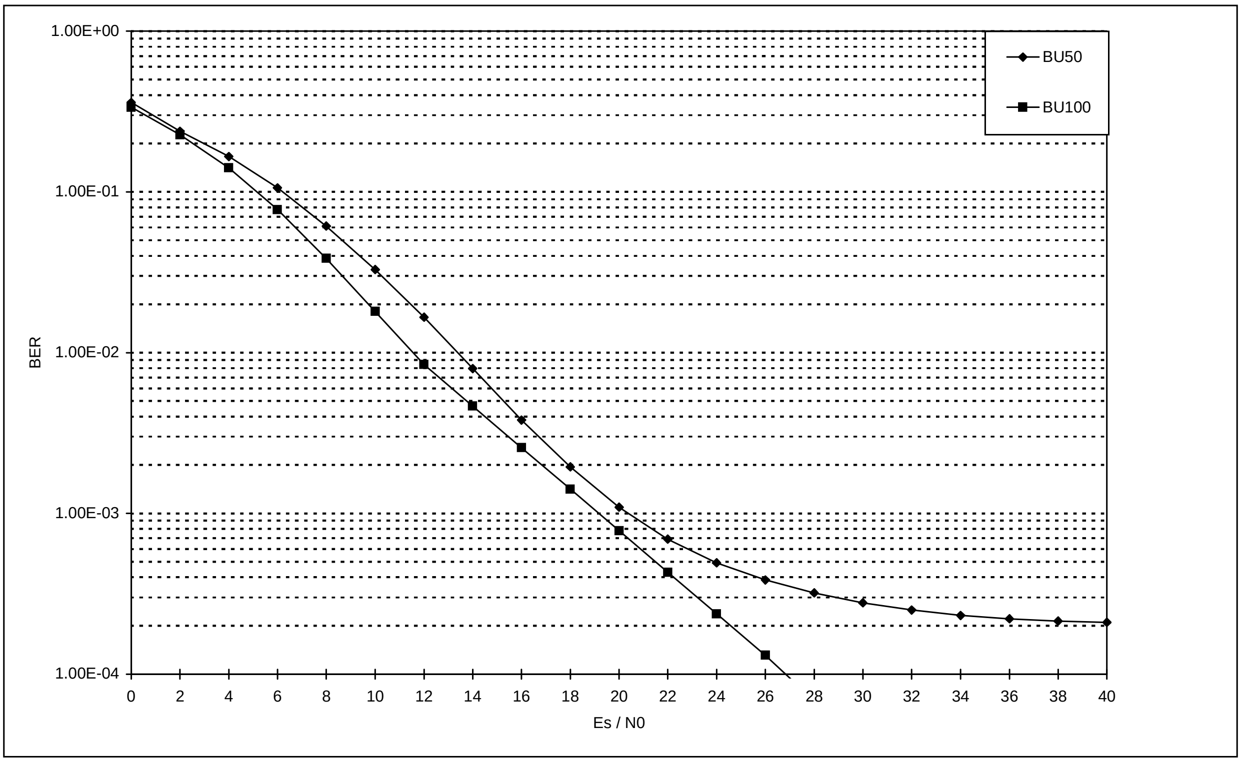

Figure 51: Influence of MS speed on TCH/2,4 N=1 in BU propagation environment

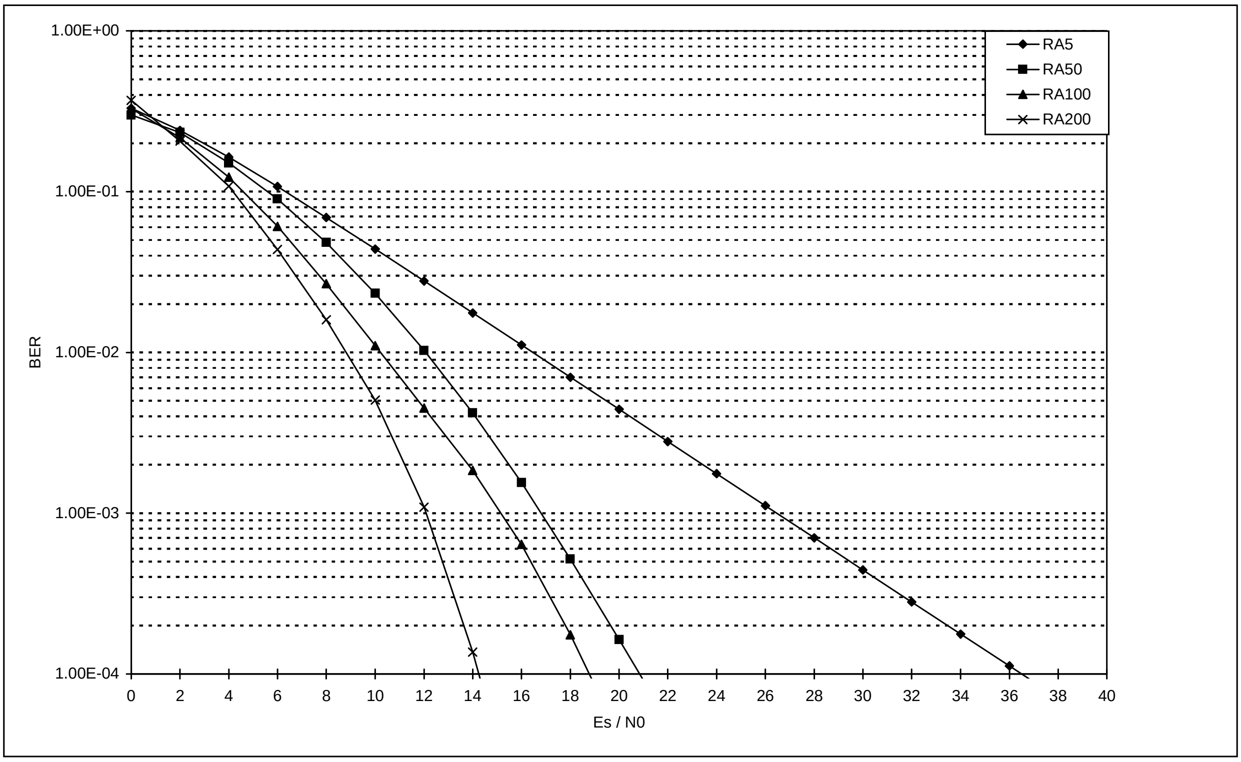

Figure 52: Influence of MS speed on TCH/2,4 N=1 in RA propagation environment

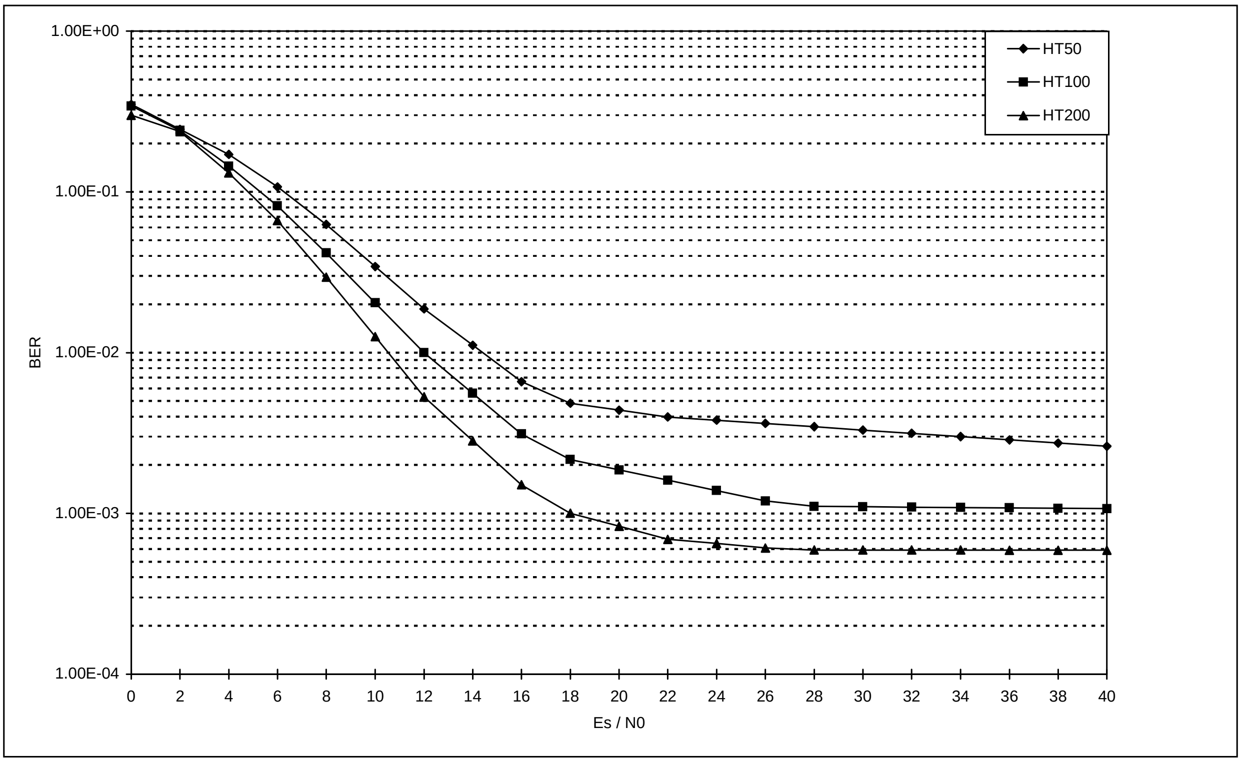

Figure 53: Influence of MS speed on TCH/2,4 N=1 in HT propagation environment

4.4.5.2 Realistic synchronization technique

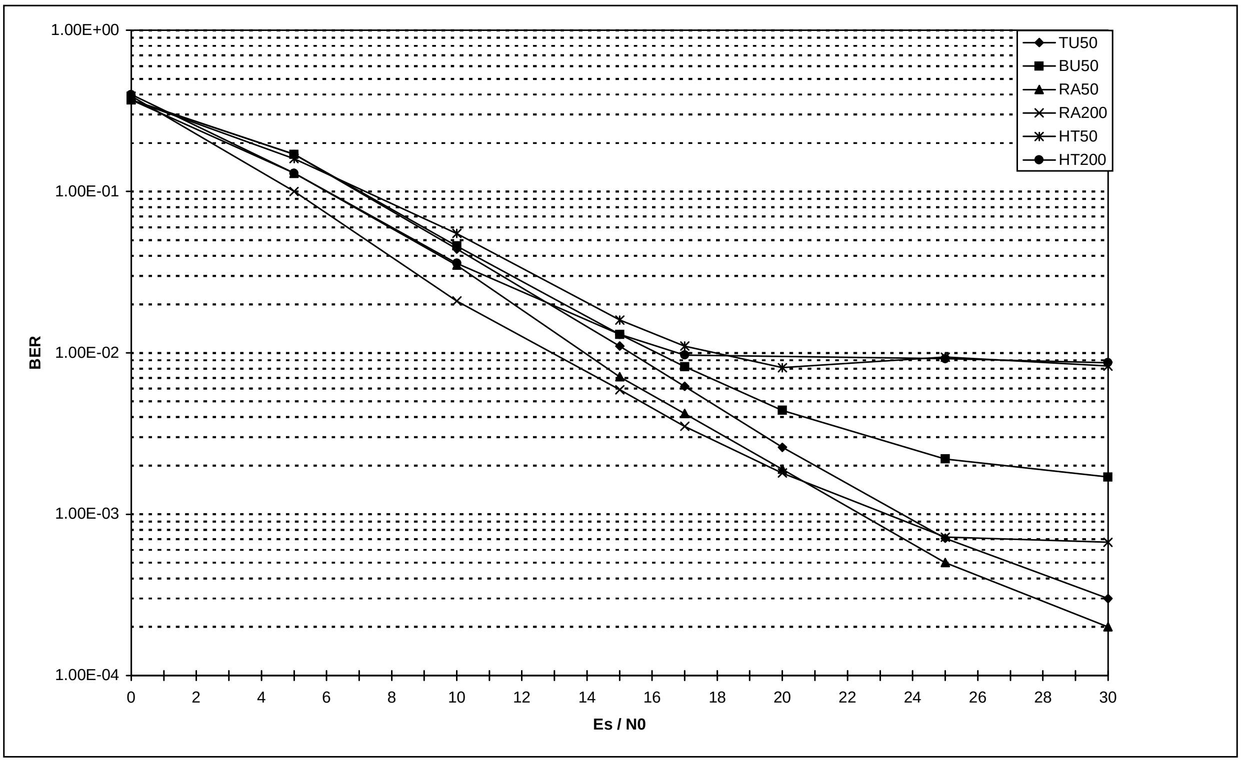

Figure 54: TCH/2,4 N=1 performance in different propagation scenarios

4.4.6 TCH/2,4 N = 4

4.4.6.1 Ideal synchronization technique

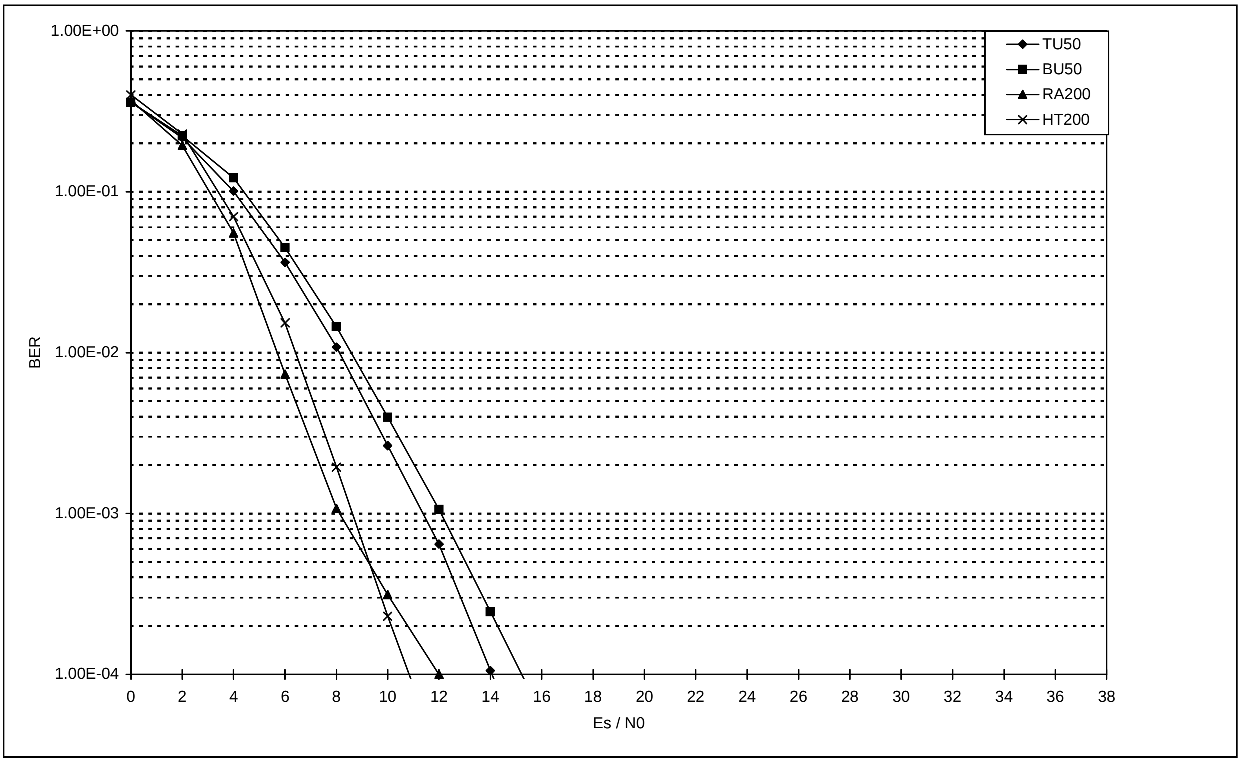

Figure 55: TCH/2,4 N=4 performance in different propagation scenarios

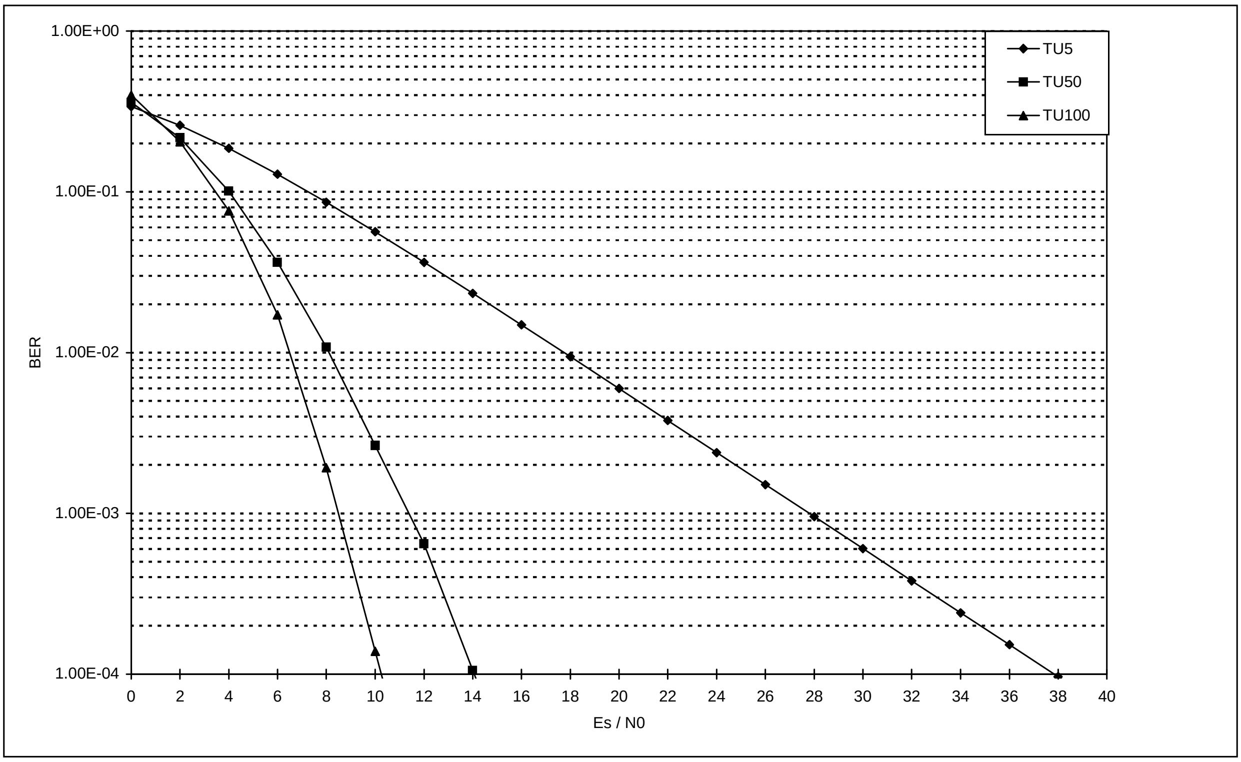

Figure 56: Influence of MS speed on TCH/2,4 N=4 in TU propagation environment

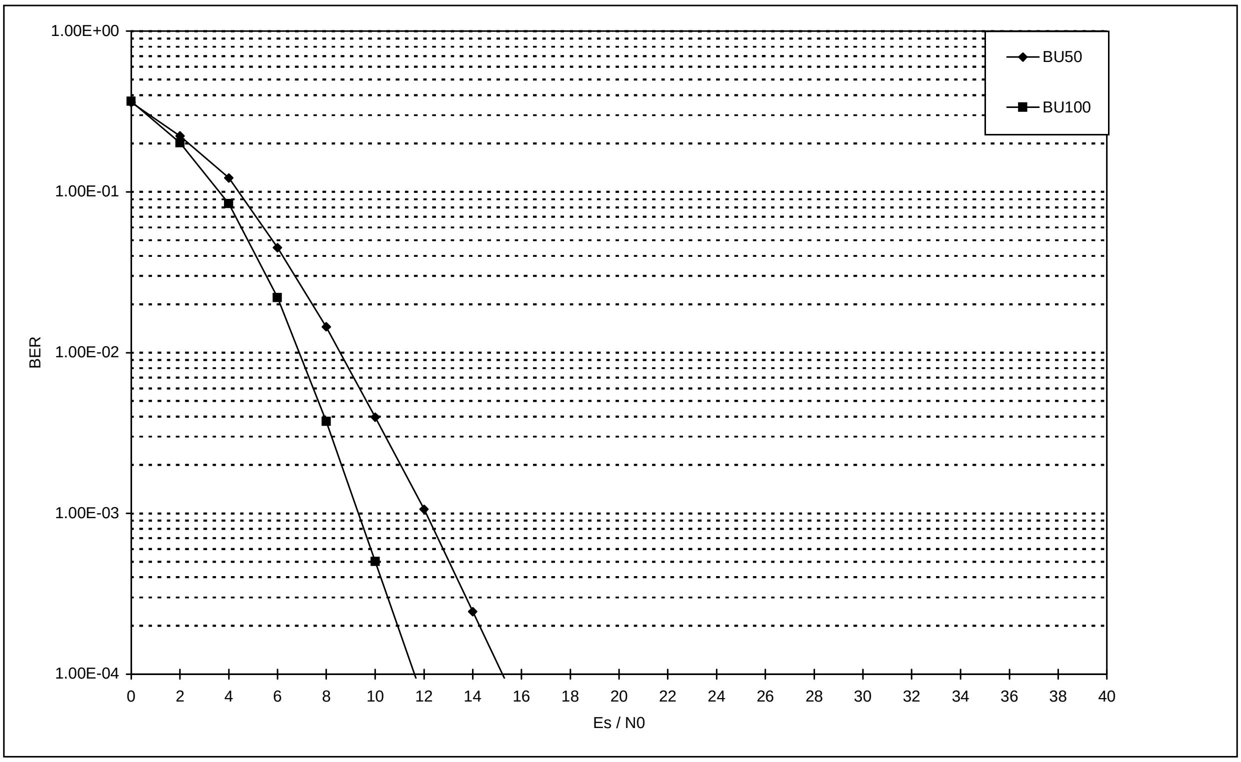

Figure 57: Influence of MS speed on TCH/2,4 N=4 in BU propagation environment

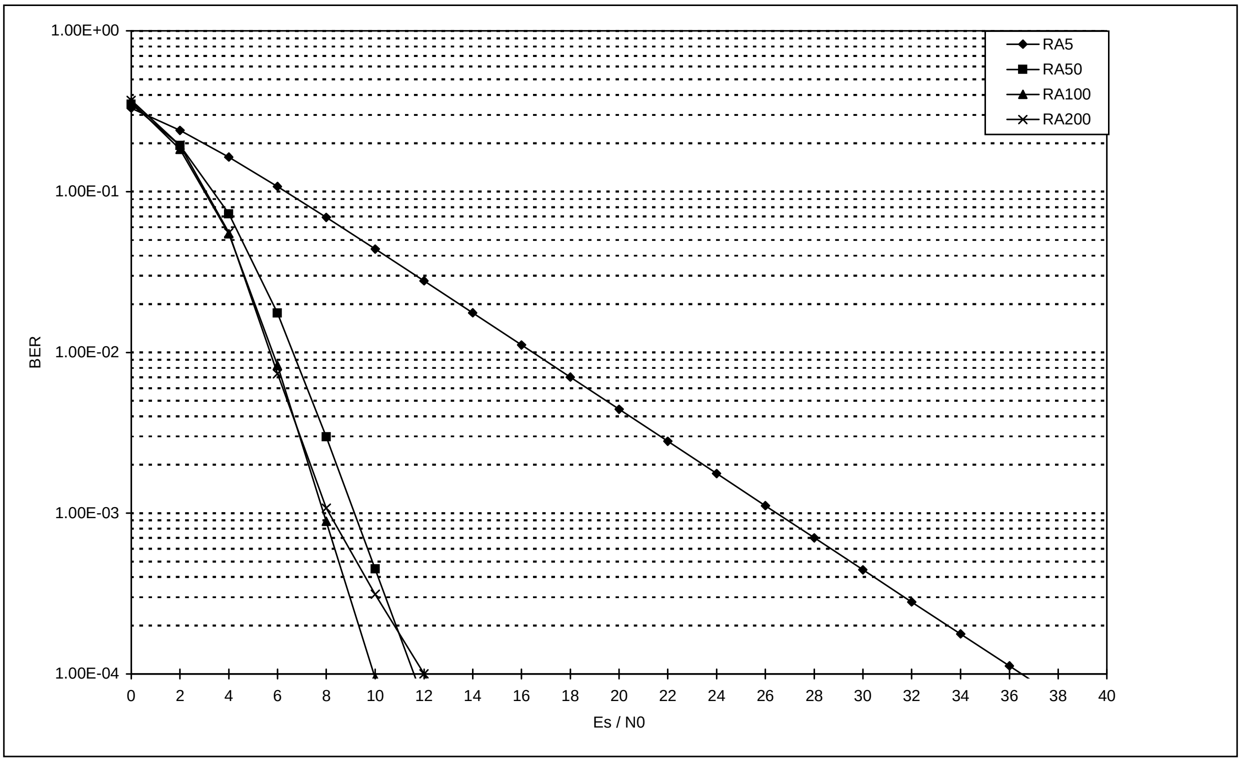

Figure 58: Influence of MS speed on TCH/2,4 N=4 in RA propagation environment

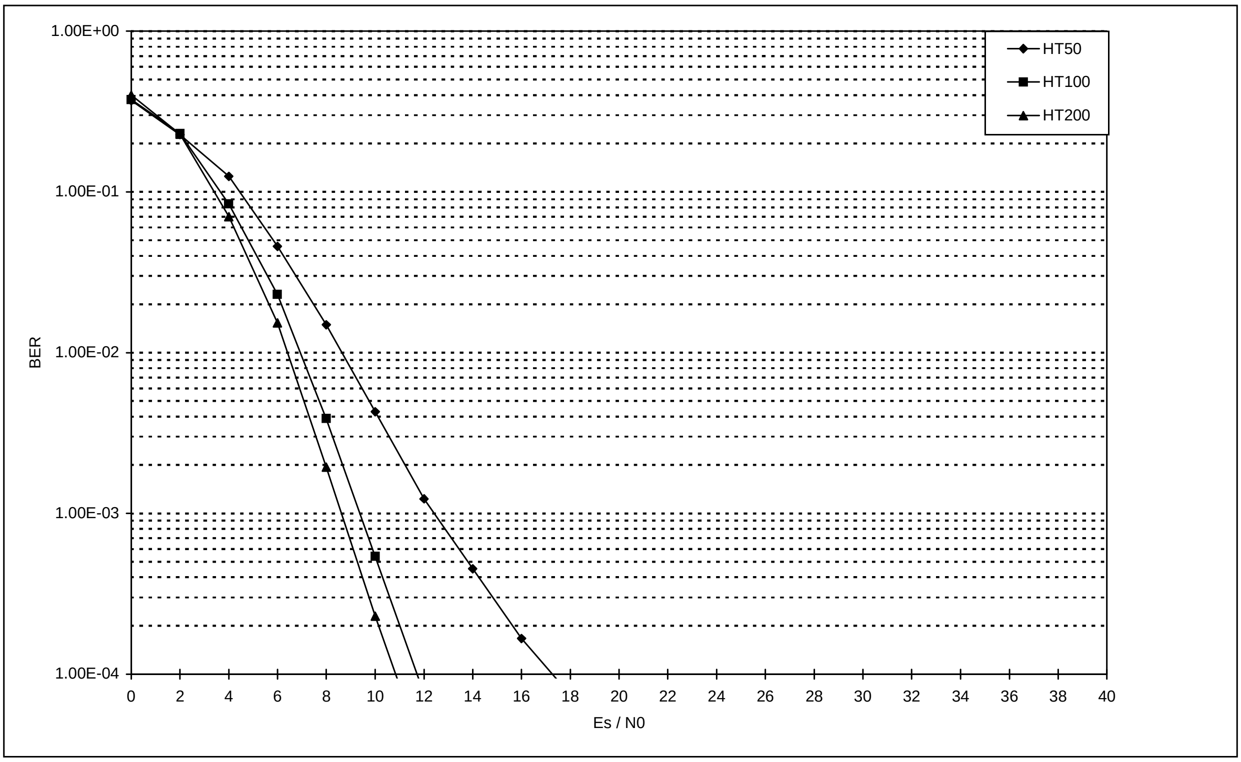

Figure 59: Influence of MS speed on TCH/2,4 N=4 in HT propagation environment

4.4.6.2 Realistic synchronization technique

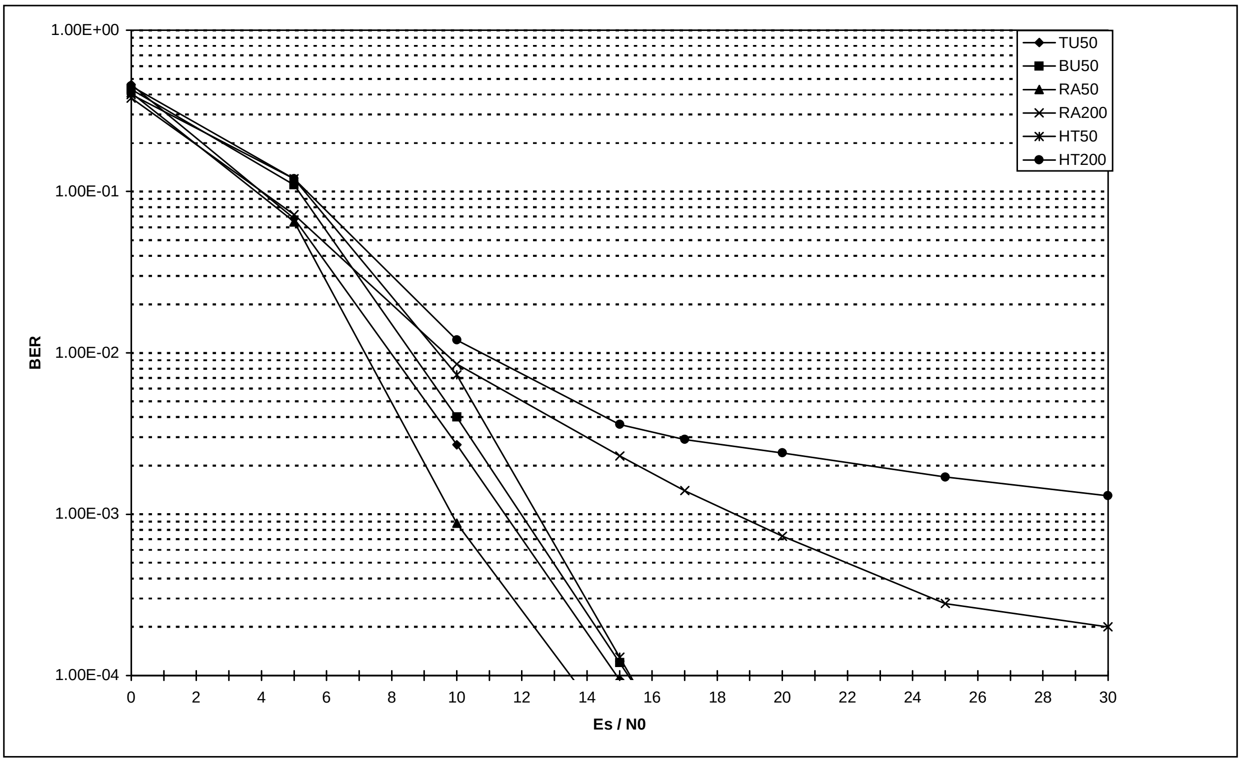

Figure 60: TCH/2,4 N=4 performance in different propagation scenarios

4.4.7 TCH/2,4 N = 8

4.4.7.1 Ideal synchronization technique

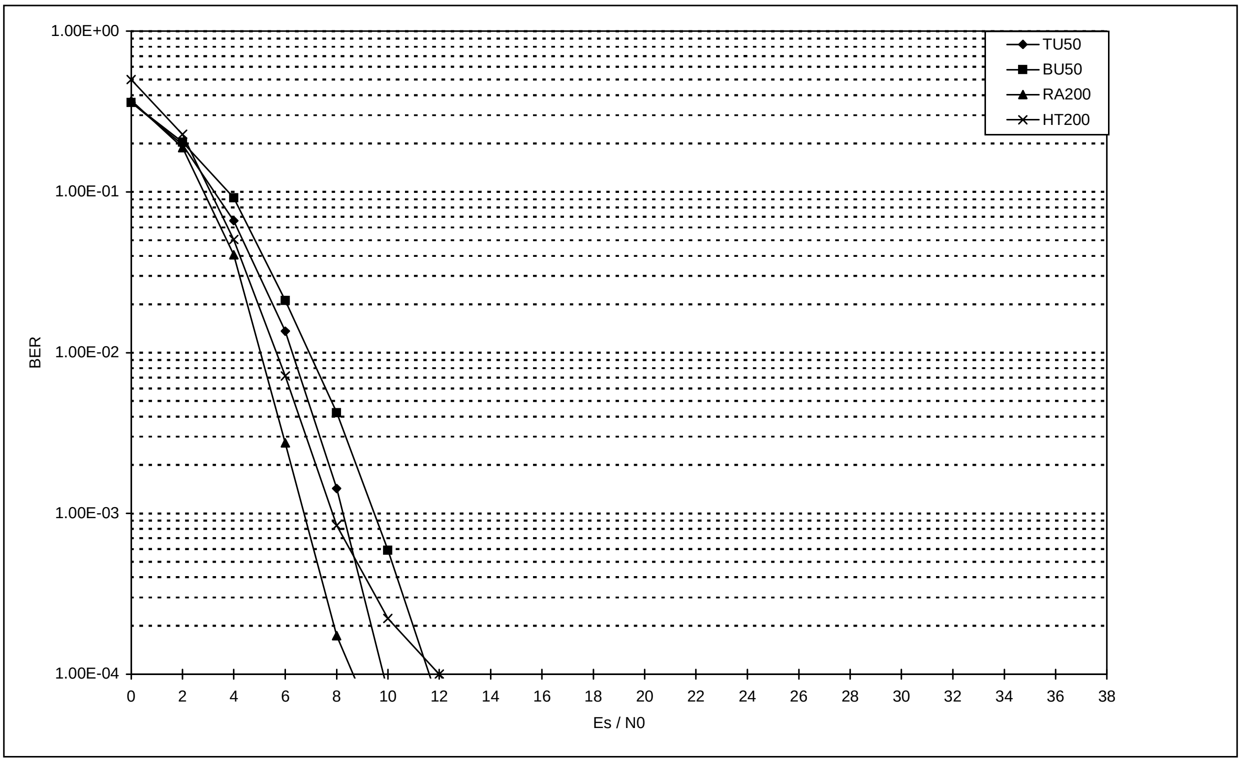

Figure 61: TCH/2,4 N=8 performance in different propagation scenarios

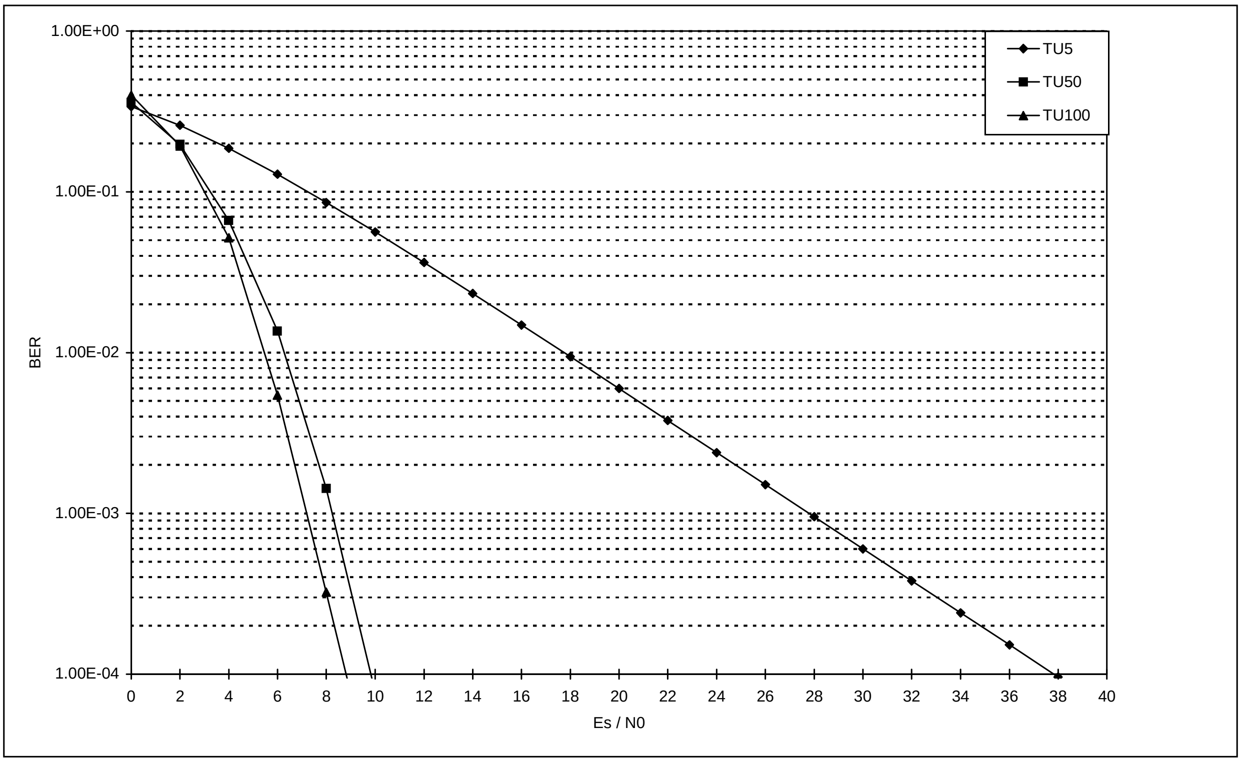

Figure 62: Influence of MS speed on TCH/2,4 N=8 in TU propagation environment

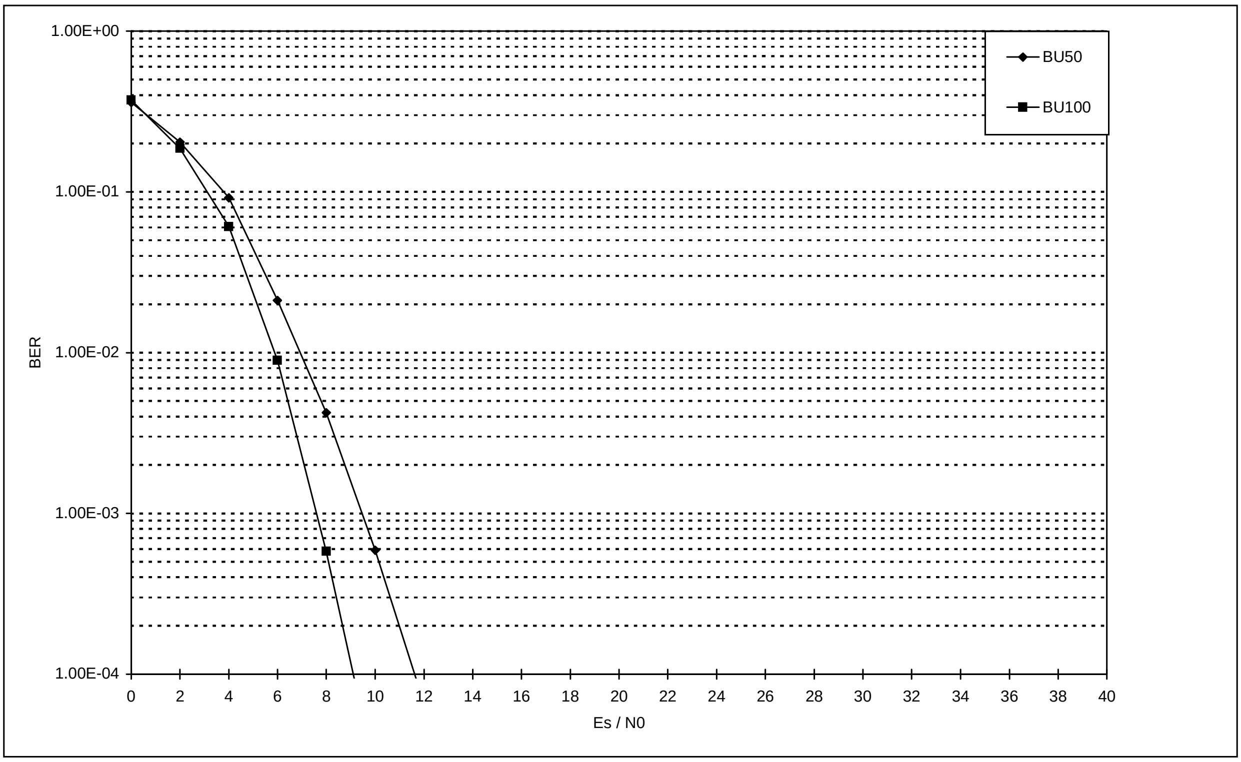

Figure 63: Influence of MS speed on TCH/2,4 N=8 in BU propagation environment

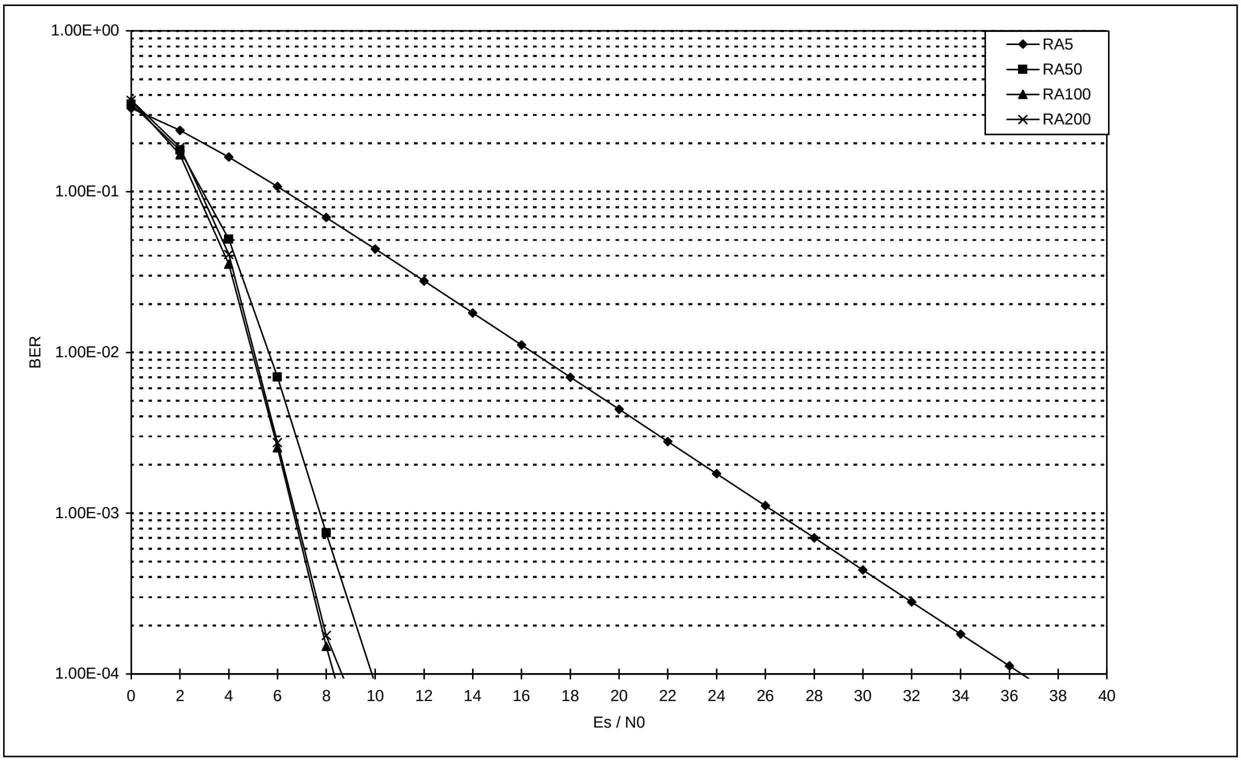

Figure 64: Influence of MS speed on TCH/2,4 N=8 in RA propagation environment

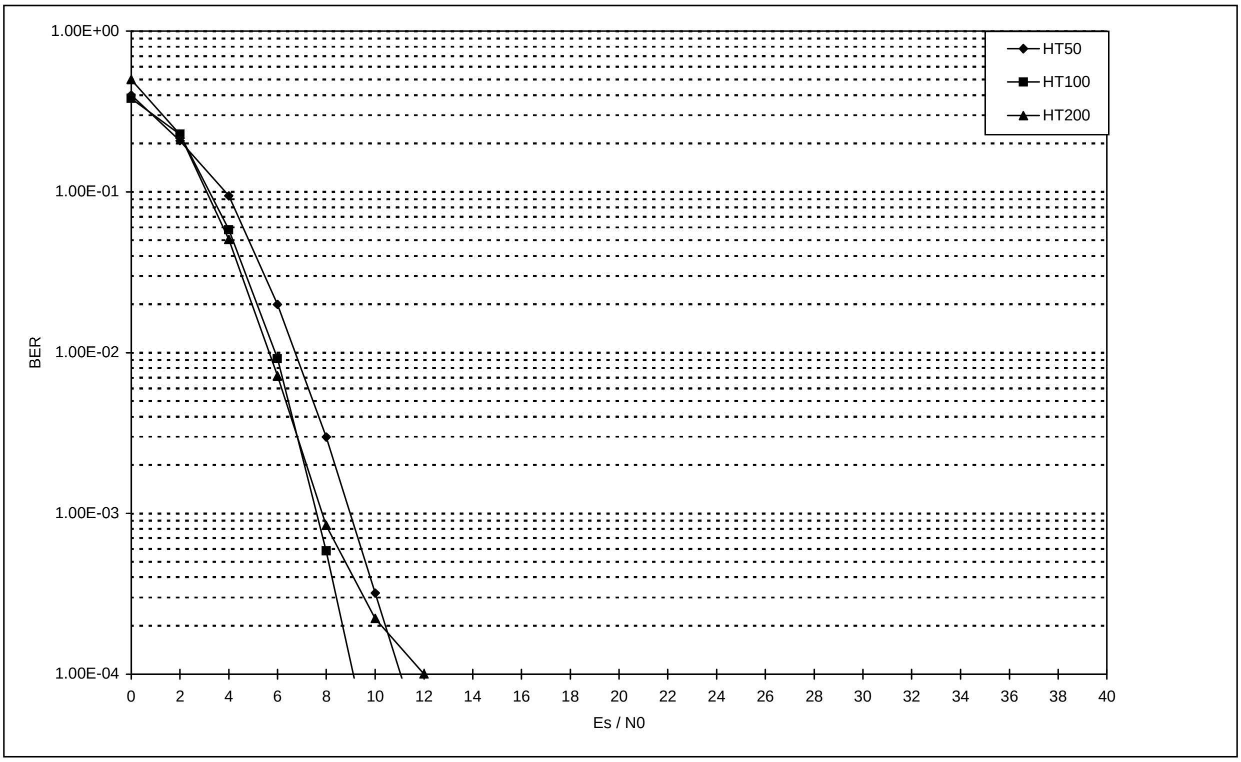

Figure 65: Influence of MS speed on TCH/2,4 N=8 in HT propagation environment

4.4.7.2 Realistic synchronization technique

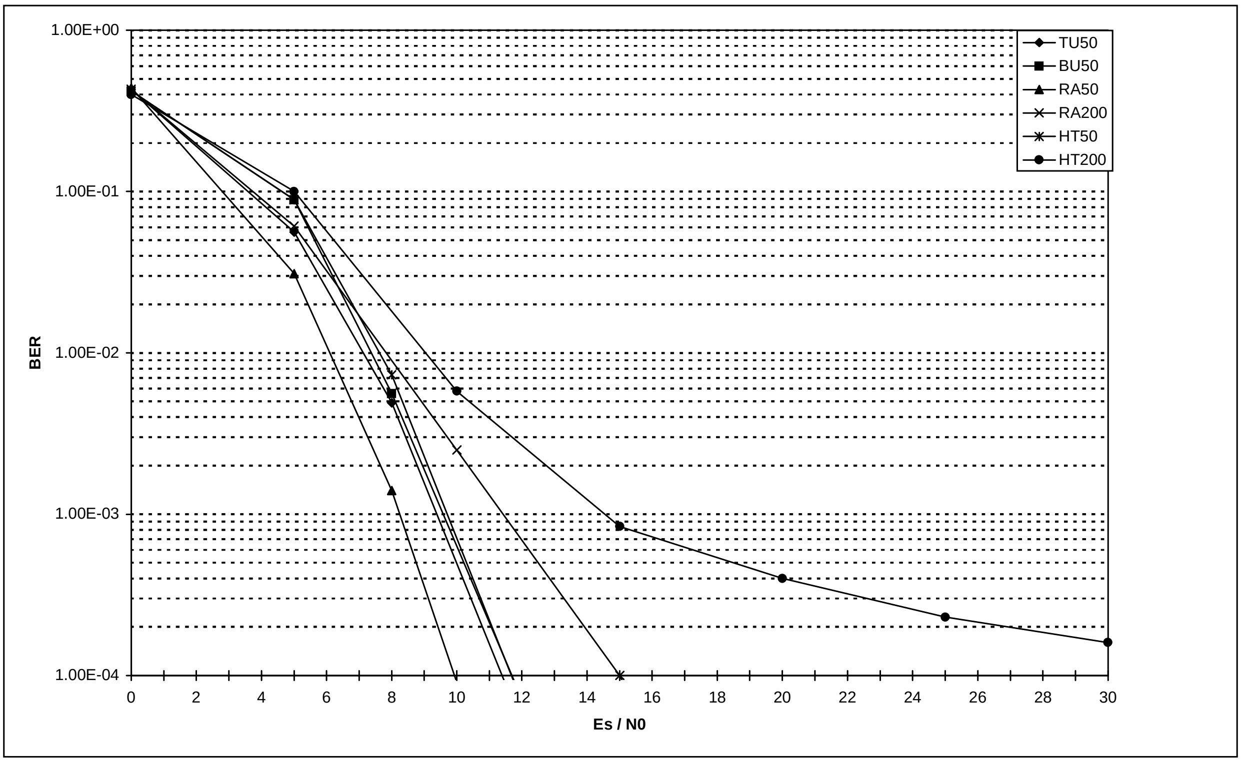

Figure 66: TCH/2,4 N=8 performance in different propagation scenarios

5 Access protocols and service performance of TETRA V+D network

5.1 Introduction

This clause aims to illustrate the performance of a TETRA V+D network when it operates in realistic traffic scenarios. The evaluation of this performance has been carried out through computer simulations.

A detailed description of the simulated system and of TETRA traffic scenarios is reported first; then, TETRA performance is shown for a significant subset of the previously defined network scenarios.

5.2 General description of traffic scenarios

5.2.1 Introduction

A traffic scenario is the description of the traffic offered to the network by all the subscribers.

The building block for the evaluation of a traffic scenario is the single user traffic profile; it consists of the set of requested services, the frequency of the requests, the service duration and some individual user parameters, like the travel speed. Starting from this profile, the number of subscribers in the system and their spatial distribution allow a complete description of the traffic scenario.

5.2.2 Reference traffic scenarios

A detailed description of some significant traffic scenarios is reported in annex A.

In general, two kind of users can be identified for a TETRA network: public (PAMR) and private (PMR) network users. Tables 4 and 5, and making reference to annex A, summarize the traffic profiles for a single user respectively of a PMR network and of a PAMR network. The user spatial distribution is commonly considered uniform or Gaussian (this last case when a town or people concentration is included in the area covered by the network).

The detailed description of the traffic profiles that have been simulated is reported in the clause where results are illustrated.

Table 4: PMR subscriber traffic profile

Service	Individual voice	Group voice (only to MSs)	Individual short data (to Fixed)	Individual long data	Group long data (only to Mobiles)
Mean offered traffic	3 mE	3 mE	5 trasm/h to 10 trasm/h	70 % of 0,5 trasm/h	30 % of 0,5 trasm/h
Service access distribution	Poisson (30 % M-M, 70 % M-F)	Poisson	Poisson	Poisson (28,6 % M-M, 71,4 % M-F)	Poisson
Size of the group	------	10 or 20	------	------	10 or 20
Number of "overs" in a group call	------	5 "overs" (the first on the calling user)	------	------	1 (calling user sends and other listen)
Average duration of service	30 s	30 s	100 bytes	8 Kbytes	8 Kbytes
Distribution of service duration	UNIFORM [20 to 40]	UNIFORM [20 to 40]	Fixed	Fixed	Fixed
Subscriber speed	3 km/h to 80 km/h				

Table 5: PAMR subscriber traffic profile

Service	Individual voice	Group voice	Individual short data (to Fixed)	Individual long data (only to Fixed)	Group long data (only to Mobiles)
Mean offered traffic	10 mE	2,5 mE	20 trasm/h	80 % of 0,5 trasm/h	20 % of 0,5 trasm/h
Offered traffic distribution	Poisson (25 % M-M, 75 % M-F)	Poisson	Poisson	Poisson	Poisson
Size of the group	------	10 or 20	------	------	10 or 20
Number of "overs" in a group call	------	5 "overs" (the first on the calling user)	------	------	1 (calling user sends and other listen)
Average duration of service	20 s	20 s	100 bytes	10 Kbytes	10 Kbytes
Distribution of service duration	UNIFORM [10 to 30]	UNIFORM [10 to 30]	Fixed	Fixed	Fixed
Subscriber speed	3 km/h to 80 km/h				

5.3 General description of network model

5.3.1 Introduction

Figure 67 reports a general TETRA network scheme. It is related to the TETRA V+D standard documents (e.g. a detailed SwMI internal architecture is not reported because it is not a standard feature).

The whole description has been made for a single network. Standard functionality are modelled according to standard documents; nevertheless, when non-standard features have to be taken into account, their model is described in detail, also providing information on the possible implementations.

Referring to figure 67, three entities can be distinguished in a TETRA network:

1) Mobile Subscriber:
   - it is the set of the single subscriber and his available user applications;
2) Mobile Station:
   - it is the equipment used by the subscriber to make access to the network services;
3) SwMI (Switching and Management Infrastructure):
   - it is the whole fixed infrastructure in the network; it embraces radio transceivers, switching and signalling equipment, network data base.

Each of these objects communicate with others through appropriate interfaces:

1) User - MS:
   - it is the MMI (Man Machine Interface) between the subscriber with its user applications and the MS; it can be modelled as an ideal link with negligible transmission delays and error rates;
2) MS - SwMI:
   - each MS is synchronized to only one radio transceiver at time. The radio link consists of one to four physical channels (i.e. frequency carrier and TDMA timeslot number) at time. Signalling and user data between the transceiver and the MS fit on physical channels according to the rules of TETRA standard;

3) SwMI inner interfaces:

- they are not described in the TETRA standard; in the figure the internal splitting of network entities is only devoted to better describe the network. They can be considered as ideal interfaces, with negligible delays and error rates;

4) SwMI - External systems:

- it is related to inter-working between TETRA and other telephone systems (PSTN, ISDN etc.) through gateways, or to the connection of SwMI and TETRA LSs and Dispatcher.

In this clause, after a preliminary description of the assumptions that are related to the communication layers, the entities of a generic TETRA V+D network (making reference to the scheme illustrated in figure 67) are described in detail as functional elements.

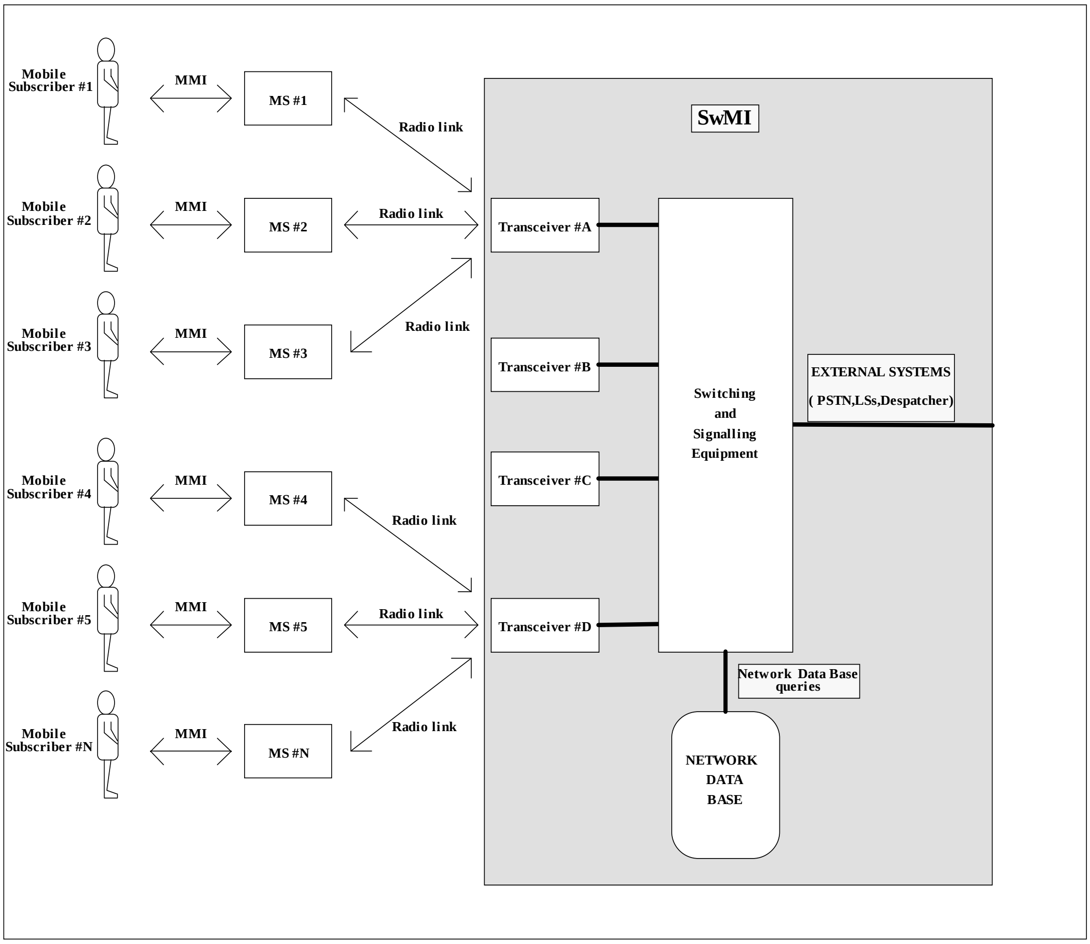

Figure 67: General scheme for TETRA network simulations

5.3.2 General assumptions on communication layers

In this clause the assumptions related to the communication layers are described.

According to the standard documents, some optimization options can be employed for LLC and MAC layers:

- LLC can put layer 3 messages for the same subscriber on a single LLC PDU (BL-DATA and BL-ACK) until the reception of a MAC_READY signal from the MAC layer;
- MAC layer can know when data are ready to be transmitted by the LLC through the DATA IN BUFFER PDU from LLC;
- MAC layer can fit more than one LLC messages on a single timeslot.

Figures 68 and 69 show the time diagrams related to a basic link transmission (receiving part); making use of the described options. In figure 68 the layer 3 is able to send back the response in a very short time, then LLC is able to fit it in its response BL-ACK. In figure 69, the response time is longer, then separate transmissions are needed for BL-ACK and layer 3 response.

In more detail, looking to those figures, time delays can be distinguished in two groups:

- fixed delays related to layer 2 procedures:
  - BL-ACK and BL_DATA PDUs preparation (no time interval associated in figures 68 and 69);
  - embedding of layer 3 messages in BL-DATA or BL-ACK (Δt4);
  - transfer times between layers (Δt1, Δt2);
  - fragmentation (Δt5);
- variable delays:
  - call processing in the layer 3 (Δt3).

If fixed delays are known, a boundary for variable delays can be evaluated:

$T_{thresh} = \Delta_{t3} - (\Delta_{t1} + \Delta_{t2} + \Delta_{t4} + \Delta_{t5})$

If $\Delta_{t3} > T_{thresh}$ the time diagram of figure 69 applies. Otherwise layer 2 is able to embed layer 3 and layer 2 responses on the same timeslot.

NOTE: The TETRA simulation results reported in this ETR are not affected by fixed delays (as they have been defined) because they are considered negligible with respect to timeslot duration. Moreover, the previous optimization options are implemented in simulations.

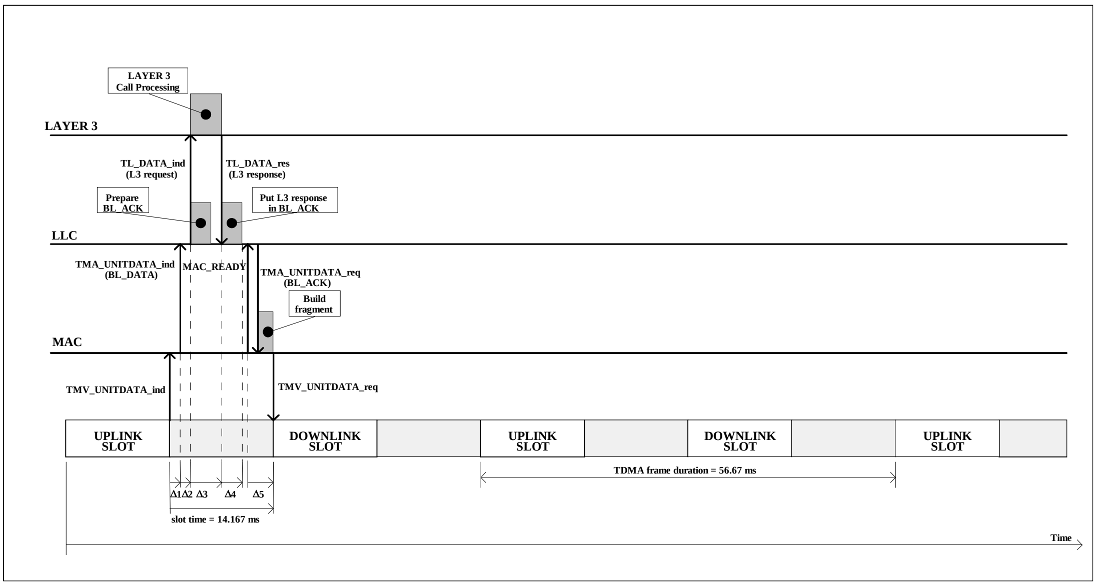

Figure 68: Time diagram related to message exchange in MAC, LLC and layer 3 with short response times

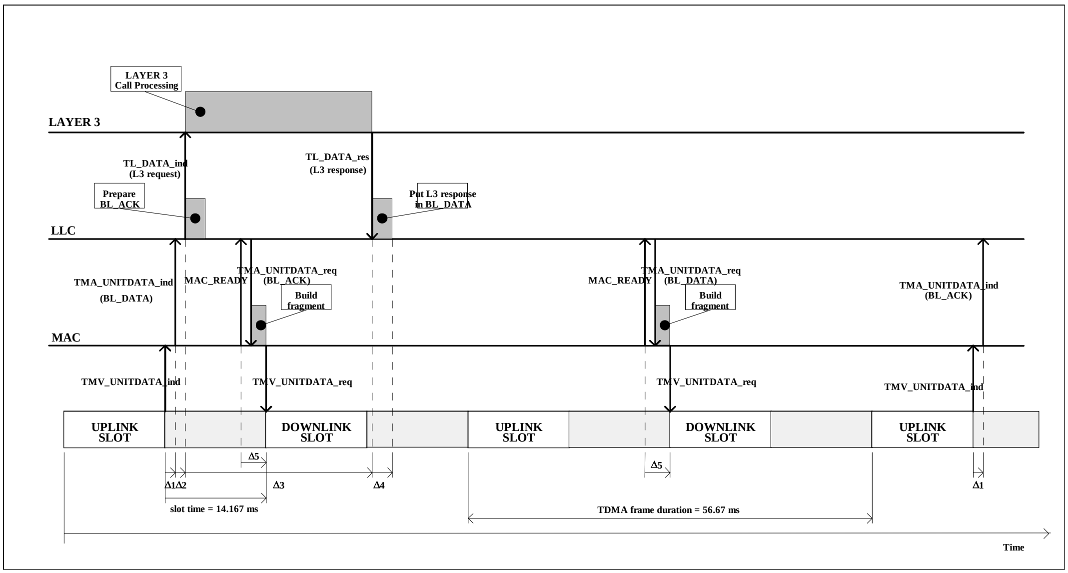

Figure 69: Time diagram related to message exchange in MAC, LLC and layer 3 with long response times

5.3.3 Mobile user

The mobile user consists of the single subscriber and his available user applications (e.g. file transfer applications, vocoder). The subscriber may be the origin and the destination of any service procedure.

Each service transaction is triggered by one signal primitive sent through the MMI. It carries information about the required service, the priority of the originating subscriber, the address of the called party (single subscriber or group). For packet data calls this primitive contains also the message to be transmitted. In case of circuit switched services (voice or data) a continuous stream of user data frames is sent to the MS at the end of the service access procedure.

The model of the single subscriber is a set of parallel and statistically independent random processes, each representing a particular service. Each service process can be identified by two parameters:

- Generation time:
  - it is the starting time of the transaction. The distribution of generation times on a time axis can be described through a stochastic (usually a Poisson process) or a deterministic (periodic generation times) process;
- Duration:
  - in the case of voice services it represents the time duration of a call; for data services it is usually the size of the message to be transmitted. Generally it is a random variable whose distribution is related to a stochastic process.

The detailed model of the process (reported in SDL notation) related to each service in the mobile user is illustrated in annex B. In figure C.1, timers T_SERVICE_request and T_SERVICE_duration are related to the generation time and the duration of the service.

Real values of these timers are obtained by drawing random variables that depend on the particular required service. The timer T_U_plane_trasm is constant for circuit switched services. In short data transmissions the message is included in the requesting primitive.

The following list shows the assumptions made on the random processes related to the generation of service transactions and to their duration:

- Individual Voice Call:

  It is a telephone conversation between two subscribers. One of them can be a fixed network subscriber. This service can be modelled as a full duplex or half duplex communication. The call generation process related to a single subscriber is modelled with a Poisson process of frequency $\lambda_{(ind.v.)}$. The duration of a call is modelled with a uniform random variable distributed in the interval $[a_{(ind.v.)}, b_{(ind.v.)}]$. In presence of on/off hook signalling procedures, the called subscriber could be alerted by the MS: in this case the call set up procedure is suspended until the subscriber hooks off. The probability of unanswered calls is indicated by $P_{nothook}$. Finally the answering time of a Mobile User is modelled with a random variable with uniform distribution.

- Group Voice Call:

  It is a telephone conversation among the members of a group of subscribers. In any time only one subscriber speaks, while the other members of the group listen. The model of this service is similar to the individual call with a Poisson process describing the calls generated by one member of the group and a uniform distribution for the call duration. Only half duplex mode is supported for voice group calls. Parameters that identify the particular distribution are $\lambda_{(gro.v.)}$ and $[a_{(gro.v.)}, b_{(gro.v.)}]1/\mu_{(gro.v.)}$. Several members of the group gain the control of conversation in different times during a call. Each conversation period is considered an "over".

- Individual Circuit Data Call:

  This service is modelled as a data transmission between two subscribers (one of them can be linked directly to the fixed network). Requirements on transmission delays are very tight (low and constant) even if error rates are high. Examples of this service are fax and real time image transmission. The model for this service consists of a Poisson call generation process with frequency $\lambda_{(ind.c.d.)}$ and a fixed length for the call duration $1/\mu_{(ind.c.d.)}$.

- Group Circuit Data Call:

  It is a data transmission among the members of a group of subscribers. Generation of calls in a single subscriber and duration of service transaction are modelled by Poisson process (frequency $\lambda_{(gro.c.d.)}$) and fixed length $1/\mu_{(gro.c.d.)}$ respectively. In these simulations, for circuit data group call, the call originator sends his message to other members. The call ends with the message.

- Individual Packet Data Call:

  It is a data transmission between two subscribers (one of them can be linked directly to the fixed network). Requirements on error rates are more tight than for circuit data services; the service transaction generation process can be modelled by a Poisson process with frequency $\lambda_{(ind.p.d.)}$. For this service the duration of the single transaction is the size (in bytes) of the message to be transmitted. The model of message size can be either a random variable uniformly distributed between two bounds or a fixed value or a negative exponential random variable; in these simulations a fixed length $1/\mu_{(ind.p.d.)}$ is considered.

Due to the statistical independence between generation processes related to different services, the single subscriber could generate overlapping transactions. This is a realistic scenario, then it is a task of the MSs to serve parallel transactions or to queue them.

5.3.4 MS

It is used by subscribers to get services from the network. Its main task is to guarantee the best possible service performance to the user. When the MS is switched on, cell selection and re-selection processes allow it to be camped on the cell with the highest received power level.

NOTE 1: In the simulated system no cell selection and re-selection procedures are performed: during a service transaction, the position of a single user does not change. As a consequence, the MLE layer is considered as a transparent entity devoted to route primitives between layers 2 and 3.

Service requests from the subscriber or from the network (by mean of radio channels) are processed by the MS according to signalling procedures dependent on the type of service.

- Circuit services:

  A set-up procedure is performed between the calling party and the called party/parties before the call is active. After the set-up phase a dedicated channel is connected through the network. Depending on the amount of circuits required by the service, full duplex or half duplex communications can be set-up.

- Packet data services:

  Two ways of transmitting data in packet mode are possible in a TETRA network:

  1) Connection less. The packet to be transmitted is sent to the network without any negotiation with the called party. Each network node routes the packet to adjacent nodes up to the called party making use of the complete called party address.

  2) Connection oriented. A virtual connection with the called party has to be set up before the first packet transmission; subsequent transmissions make use of the same call identifier. Each packet is sent to the network and routed to the called party through the connection identifier, that is shorter than the complete address.

In accordance with TETRA standard documents, message transmission in packet mode and signalling transmissions make use of LLC and MAC procedures. LLC offers two types of links: Basic link and Advanced link. Basic link is always available in the LLC, Advanced link requires a set up phase (the lifetime of this virtual connection is negotiated).

In annex C the service diagrams related to the MS for circuit services set-up (direct set-up) and for packet data transmission are reported. If the "on/off hook signalling" flag is set, the call set-up procedure requires an immediate U_ALERT message (instead of U_CONNECT) from the called MS. The procedure ends when the called user hooks off and a U_CONNECT message is sent to SwMI through random access (no radio resource can be allocated before the subscriber answer). If the "on/off hook signalling" flag is not set, the U_CONNECT message is immediately sent back to the network (before the user hooks off).

In voice group calls the "on/off hook signalling" option is not supported (see EN 300 392-1 [i.1] and EN 300 392-2 [i.2]), then only direct set-up procedure is performed. In the area selected by the call originator ("area selection" field in U_SETUP message) the network broadcasts D_SETUP messages with information on the channel reserved to the call. The called user has to synchronize to the new channel and enter the call. In each cell of the selected area one traffic channel per group call has to be allocated. In message trunking systems, the traffic channels are allocated for the lifetime of the call. In transmission trunking systems the allocation of channels is limited to an "over", after which the call has to obtain again the radio resource.

NOTE 2: In the performed simulations the following assumptions are considered:

- signalling procedures are carried on basic link;
- packet data transmissions are carried on basic link. This model can represent a connection-less data transmission (e.g. SDS);
- no data transmission is performed on signalling channels associated to traffic channels;
- the MS answers to paging (with U_CONNECT in direct set up, with U_ALERT when "on/off hook signalling" applies) in the first uplink timeslot that follows the D_SETUP message;
- in group calls no presence checking is performed, then no answers are required from the called user;
- signalling transmissions on traffic channels are considered ideal (e.g. the acknowledgement of CONNECT and CONNECT_ACK PDUs, the call release procedure and closed loop power control).

5.3.5 Switching and Management Infrastructure (SwMI)

It embraces all the fixed infrastructure in a TETRA network. In order to make an easier logical description of SwMI some inner sub-entities are described in the following clauses.

5.3.5.1 Switching infrastructure

It can be logically described as a set of two network entities:

- Transceiver:

  It is the part of SwMI completely related to a single cell. is devoted to the management of radio resources allocated to the cell and to the timing inside it. It is responsible of the access opportunity allocation on its random access channels and of access contention resolutions.

- Switching and Signalling Equipment:

  It contains the higher hierarchical layers in the network (for a TETRA system, layers CC, CONP, SCLNP are allocated to this part of the network). It is devoted to the management of the overall network resources and to the system synchronization. Through transceivers it communicates with the higher layers in the MS.

Depending on network characteristics and user requirements, several strategies can be employed by the Switching and Signalling Equipment for network resource management. Standard documents do not recommend or prevent any particular strategy, nevertheless it affects the overall network performance.

The resource management function operates in order to allocate network resources to the services. TETRA standard allows to have a priority level associated with a call (there are up to 8 priority levels and the possibility of pre-emptive priority). There is no mention about the usage and the implementation of priorities in a TETRA network, nevertheless these features allow some different strategies for the management function.

In general, two kind of strategies are commonly employed for the resource management function:

Blocking:

Blocking consists of releasing the call request when no resources are available. No priorities can be employed for this strategy with the exception of pre-emptive priority (in this case the eldest active call is disconnected in order to give the resources to the new call). The blocking strategy is usually employed in public access networks, in general when a short set-up time is required and a high amount of resources is available.

Queuing:

When no resources are available, the call request is queued with the exception of pre-emptive priority call (this type of call is always processed with the same technique as described in the blocking strategy). When radio channels become available, a call is extracted from the queue and served. Making use of priority levels related to calls, different queue service strategies can be realized. Moreover a maximum holding timer can be introduced in the management function; when the timer elapses, the queued call is interrupted.

This strategy is commonly used in private networks, in general when a limited amount of resources are allocated to the network and a short set-up time is not required.

Individual voice and circuit data calls are simulated as full duplex communications. When a call is set-up between two users in the cell, two channels are allocated to the call. When only one of the users is in the cell, one channel is allocated.

In group calls the SwMI allocates one traffic channel per cell in the area selected by the call originator (see EN 300 392-2 [i.2], clause 14.8.1).

NOTE: The protocol stack of the radio interface on the SwMI side is the symmetric counterpart of the MS. All assumptions on MAC and LLC layers apply.

Because of the ideal behaviour of the fixed network interfaces (infinite resources), the overall resource management function is only related to radio channels.

5.3.5.2 Network data base

The network data base is devoted to contain the information of all network subscribers. Each user has his own record with some related parameters like address, position (location area), cipher keys, priority level, subscribed services, etc.

The data base is queried by the switching and signalling equipment when a call set-up is required. Referring to figures 68 and 69, call processing time in layer 3 includes data base information retrieval. Time delays related to this procedure can be very different depending on the real implementation of switching equipment and of data base itself.

NOTE: In the performed simulations for TETRA network, data base is modelled as a delay block. Characteristic parameters for the data base description are the following:

- minimum value of the delay for information retrieval is 500 ms;
- Maximum value of the delay for information retrieval is 2 s;
- Statistical distribution of delays between the two boundaries is Uniform.

5.3.6 External network

The external network consists of the set of fixed users connected to a TETRA system, i.e. PSTN users, ISDN users, TETRA Line Stations and Dispatchers.

Dispatcher represents a special type of user found in the Private Mobile Radio (PMR) business. Their main task is to co-ordinate activities of one or more of PMR users, or user groups. Typical dispatcher applications include co-ordinating an incident, like a road traffic accident, or despatching resources, such as in parcel delivery or a taxi service. Consequently, a dispatcher generates a level of traffic which is considerably higher than that of a typical mobile user.

Despatches usually operate from a fixed location, such as a police control room, and since they need priority access and full control of the infrastructure they are commonly wire-connected. It is, however also possible to have the radio-despatches. These access the infrastructure in the same way as a mobile user, and, as a result, generate extra traffic load on the air interface.

The TETRA standard does not describe the Dispatcher applications or operations.

The interface to the external world is modelled as ideal (i.e. signalling message transmissions are always correctly performed). For voice services, calls to external systems will alert the called part, then a delay element can be considered as a suitable model for the external network behaviour. The probability of unanswered calls is indicated with $P_{not\ hook}$.

NOTE: In the performed simulations the Dispatcher is modelled as a fixed user that generates a large amount of voice and circuit data group calls. All other fixed terminals generate a traffic level that is symmetric to the received traffic (in agreement with traffic profiles in annex A).

5.3.7 Radio channels

Transmission impairments are taken into account in order to have information about network and service performance in some relevant propagation scenarios for different user speeds and positions.

Performance of a particular logical channel (as they are reported in clause 4) is given as MER or BER in relationship with either E_s/N_0 or C/I_c.

Starting from the radio simulation figures, it is possible to model the transmission of one burst on a radio channel making the assumption that propagation conditions(environment, speed, position) are not modified during the burst time. The propagation model can be described making reference to the following parameters:

- Distance between transmitter and receiver ρ;
- Propagation environment;
- Transmitter antenna height H;
- Receiver antenna height h;
- Antennas gain;
- Transmitter power P_{tr}.

Figure 70 shows the reference scheme for the radio propagation.

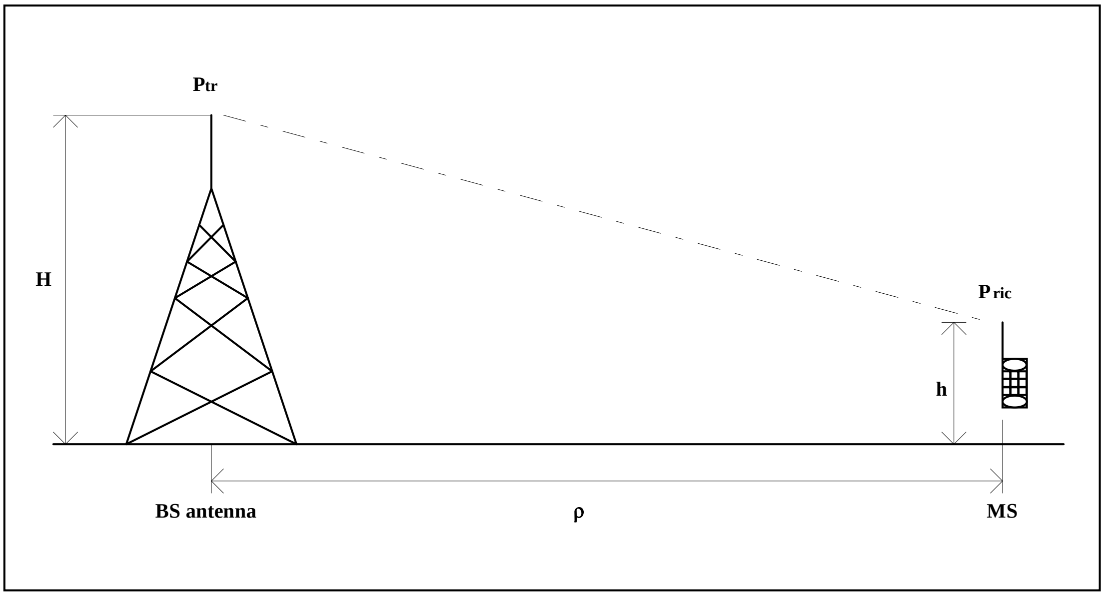

Figure 70: Radio propagation example with parameters for the description of the model

The model evaluates the power level of wanted signal, the thermal noise and the interference at the input of the receiver.

5.3.7.1 Power level of wanted signal

The attenuation of the transmitted signal on a radio channel can be represented as a deterministic term depending on transmitter-receiver distance **r** and propagation environment (represented by the parameter γ), associated to a stochastic shadowing process A_{shad} with log-normal distribution.

Making reference to the radio propagation model proposed by COST 207 [i.3] for frequencies in 400 MHz band (Hata model), the value of $\boldsymbol{\gamma}$ can be considered as a constant that depends on some physical parameters like BS height, MS height and frequency.

Suitable values for standard deviation of A_{shad} are shown in table 6.

Table 6: Standard deviation of the power level due to shadowing in different propagation environments

Propagation scenario	Standard deviation of A_{shad}
RA	3
TU	4
BU	5
HT	7

The path loss formula has a validity range for distances between antennas from some tenth of meters up to 20 km. In this condition (the "near field" attenuation is represented by A_{nf} and A_{rec}, respectively for transmitter and receiver part, and depend on the frequency in use, the heights (H and h) and the shape of antennas), the received power level P_{rec} can be evaluated as function of the transmitted power level P_{tr}:

$$P_{rec} = P_{tr} \cdot A_{nf}(H) \cdot A_{rec}(h) \cdot \rho^{-\gamma} \cdot A_{shad}$$

In dBm we obtain:

$$P_{rec}[dBm] = P_{tr}[dBm] + A_{nf}(H)[dB] + A_{rec}(h)[dB] - \gamma \cdot 10 Log\rho + A_{shad}[dB]$$

The performed simulations consider radio receivers that do not exploit antenna diversity. Moreover, considered antennas have the same gain figures in transmission and reception.

Previous formulas are valid for the description of the propagation on both uplink and downlink.

In this last formula, A_{shad} [dB] is a Gaussian stochastic process.

The energy of a single modulation symbol can be represented as $E_s = P_{rec} * T_{symbol}$.

Assuming a particular value P_1 for the deterministic part of P_{rec} at distance r_1, if far field conditions are satisfied at a distance r_2, the related power value P_2 can be obtained with the same formula, where A_{nf}, A_{rec} and P_{tr} are the same values as for r_1 .The comparison between the two formulas allows the evaluation of P_2 starting from P_1 and the ratio between r_1 and r_2; the following expression applies:

$$P_2[dBm] = P_1[dBm] - 10 \cdot \gamma \cdot Log_{10}\left(\frac{\rho_2}{\rho_1}\right)$$

This expression shows that the wanted signal level is no more dependent on terms due to "near field" effects and on the absolute distance between MS and BS. The complete expression for the received power level can be obtained simply adding (in dBs) the shadowing term to P_2.

Starting from the previous assumptions, the cell radius can be determined as the maximum distance between MS and BS where the power received by the mobile is equal to the reference sensitivity level plus a margin which takes into account shadowing and fading processes. The width of this margin determines the probability for the received signal power level to be above the reference sensitivity level. It is called "Location probability". In this condition, and making reference to the previous equations, the cell radius for the simulations is considered normalized to 1. The actual value of cell radius can be determined taking into account the conditions needed to obtain the Location probability in the appropriate propagation environment.

The static E_s/N_0 (without taking into account fading and shadowing processes) is assumed equal on both MS and BS sides during a MAC block transmission. The power control, when active, modifies the E_s/N_0 uplink value compared to the correspondent downlink value.

The open loop power control process on the MS operates as a function of the received radio signal from the BS. Measured power level is an average of different signal samples taken over a time period; fading effects are filtered by this averaging process; it is assumed that the measured power level is the static E_s/N_0 (without taking into account fading and shadowing processes). A power control threshold is fixed in order to reduce the transmitted power level in the MS when the estimated signal received by the BS exceeds that threshold. In actual simulations a threshold of 22 dBs has been considered. It is a reasonable value corresponding to a 5 dB margin over the reference sensitivity.

5.3.7.2 Noise power

It is the radio power in the same band of the wanted transmitted signal due to events that are independent from TETRA world. The stochastic process related to this kind of events is considered as a white Gaussian noise with power N (the noise energy related to a single symbol transmission will be $N_0 = N \times T_{symbol}$). Due to the independence of the process from TETRA transmissions, it can be assumed that the value of N is the same in any area covered by a TETRA system.

5.3.7.3 Interference power

It is the radio power, I, in the same band of the useful transmitted signal caused by another TETRA transmission. Due to the independence between the two transmissions, the interfering signal is modelled as a pseudo random continuous TETRA modulated signal.

The interfering signal can be split into two contributions:

- Co-channel interference I_c: it is due to transmissions carried on the same frequency and on the same timeslot of wanted signal. There are some cases of co-channel interference:

    1) signals coming from external cells when frequency reuse algorithms are adopted;

    2) simultaneous random access attempts.

    If position and speed of interference generators are known, I_c could be evaluated as the sum of power levels received from each generator; the formula for the evaluation of the wanted signal power can be applied.

- Adjacent channel interference I_{ad}: it is due to transmissions carried on adjacent frequencies and on the same timeslot of wanted signal. The TETRA standard fixes an upper boundary on this kind of interference. Input filters in the receiver will reduce the interference power before signal entrance in the receiver. The portion of the signal power of adjacent channel transmissions is given as a function of the Net Filter Discrimination (NFD); for TETRA system (see EN 300 392-2 [i.2], clause 6.6.2.3) it is more or equal to 64 dB. Therefore, in the propagation model, the amount of interference power coming from adjacent channels will be at most 64 dB less than the total amount of adjacent channel power. In the performed simulations the contribution of adjacent channel is then considered negligible in respect of Co-channel interference.

5.3.7.4 Global evaluation

In clause 4 it has been stated that radio channel performance as a function of thermal noise is similar to those related to co-channel interference. Starting from this assumption and relating to the previous clauses, the signal-to-overall-noise ratio can take the following shape:

$$\frac{P_{rec}}{D} = \frac{P_{rec}}{N + I} = \frac{\frac{P_{rec}}{N} \cdot \frac{P_{rec}}{I}}{\frac{P_{rec}}{N} + \frac{P_{rec}}{I}}$$

Suitable values for channel performance in this case can be obtained just matching the evaluated ratio with channel figures as functions of E_s/N_0.

5.3.7.5 Transmission on a dedicated timeslot

According to the previous descriptions, the result of the transmission simulation is a BER or MER value obtained from radio channel performance as the correspondent value of the evaluated signal and noise power level.

The final step of the radio transmission simulation is the decision about the correctness of the received signal. MER is the probability to receive a not correct message; a random variable x (uniformly distributed between 0 and 1) can be drawn and then a decision can be taken as follows:

- x > MER: correct reception;
- x < MER: discarded message.

5.3.7.6 Simultaneous transmissions for random access

The description of simultaneous transmissions on the random access channel requires a particular remark. There are cases where one colliding signal is correctly decoded by the BS, otherwise the collision is totally destructive. After the evaluation at the receiver site of power levels related to each colliding signal, one of them has to be elected as the possible correctly decoded signal. Then, all other signals are considered as interference power and are included in the I_c term. The evaluation of the transmission performance will then be carried out as for a normal signal. If the interference power is high there is a low probability to have a successful transmission, otherwise it is possible to have a correct access.

5.4 Description of evaluated parameters

Simulations of each network configuration to be studied are performed in order to give performance figures as functions of the offered traffic; each user is considered as the minimum amount of traffic that is offered to the network. Performance is then provided as a function of the number of subscribers inside the network cell.

In order to clarify the meaning of throughput parameters, figures 72 to 74 show the scheme of the simulated calls (individual circuit call, group circuit call, individual packet data call), with the detail of the counters employed for the evaluation. In case of circuit data calls (figures 72 and 73) the operation of checking system resources covers also the possibility of queuing calls in the system due to the lack of resources.

Starting from this assumption and relating to the previous paragraphs, the signal-to-overall-noise ratio can take the following shape:

The following parameters are analysed independently by the service:

- Average random access time:
    - from the user request of a service to the successful reception of the MAC_RESOURCE PDU with the flag set to random access response. In case of circuit switched calls (voice and circuit data) this event corresponds to D_CALL_PROCEEDING or D_CONNECT correct receipt by the accessing mobile. In case of short data transmission the MAC_RESOURCE confirms also the reserved slots for the further transmission.
- Random access procedure throughput:
    - it is defined as the probability of successful random access (see figures 72 to 74 for detailed description).

For voice and circuit data calls the following parameters are reported:

- average service access time from the request of calling subscriber to the correct reception of D_CONNECT and D_CONNECT_ACK messages for individual calls and from the request of calling subscriber to the correct reception of the last transmitted D_CONNECT for group calls;
- GoS at x % of service access time which for the service access time it is the upper limit for the 100 - x % of successful access procedures. Figure 71 illustrates the relationship between $\tau_{x\,\%}$ and GoS;
- radio interface throughput of the service access procedure: it is the probability of having a successful signalling procedure during call set-up, either successful connection or successful release; This parameter gives a measure of the radio link and random access quality during a signalling procedure, independently on the resource allocation in the system;
- system throughput of the service access procedure: it is the probability of having a successful call connection. In this case all released calls (because called user is busy or because of lack of radio resources) are considered as failed. It is a measure of the ability of the overall system (radio interface and resource allocation) to set-up a call;
- average BER on the communication after evaluating the BER for each fragment transmitted, the parameter is the time average related to the whole duration of a transaction. For group calls the average will regard the uplink channel of the speaker and the downlink channel of all listeners;
- percentage of reached called users in a group call;
- blocking probability: when the call management strategy can block a call due to the lack of radio resources (blocking policy or queuing policy with time-out), it is the probability for a circuit call to be blocked after system resources are checked for availability (see figures 72 and 73 for details). The blocking probability value is dependent on the amount of resources required by the particular service transaction. In case of full duplex calls in the same cell site, two traffic channels are employed for each call, then the blocking probability is higher than the case of half duplex calls;
- average queue time: when the call management strategy puts calls in a queue when resources are not available, the call set-up procedure is delayed by the hold time in the queue. This parameter gives a measure of this delay.

For packet data calls the following parameters are considered:

- average service duration time: it is related to the time interval from the call request to the successful reception of the last fragment;
- GoS at $x_{\%}$ of service duration time: it is defined as in the previous paragraphs and it is related to the complete transmission time;
- throughput of the service procedure: it is the probability of successful data transmission. Referring to figure 74, this parameter represents both system throughput and radio interface throughput.

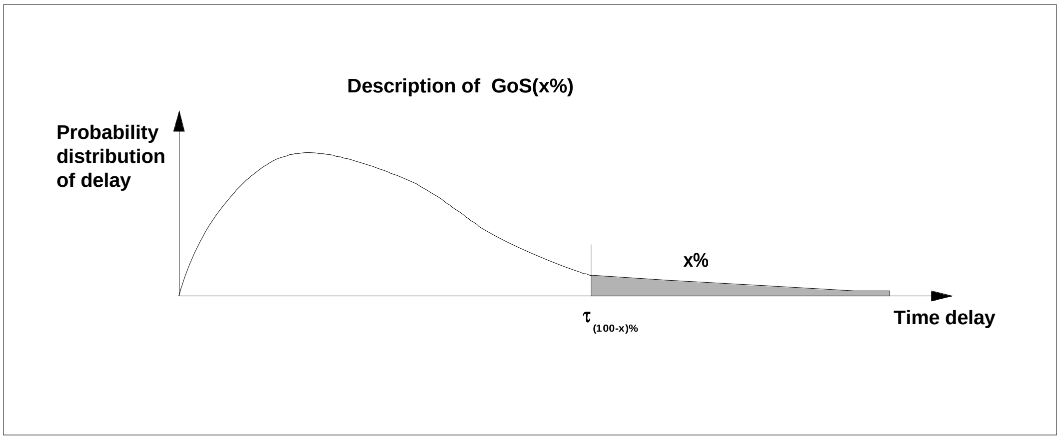

Figure 71: Definition of GoS parameter

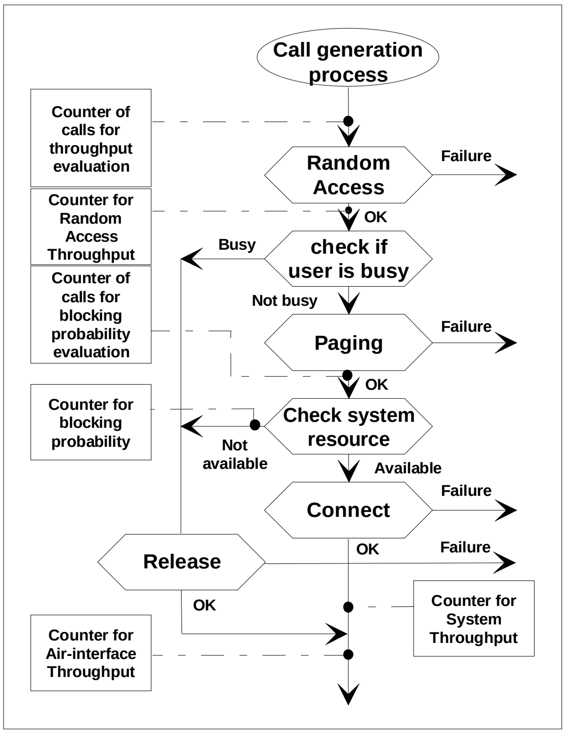

Figure 72: Individual circuit call procedure scheme with counters for the evaluation of throughput parameters

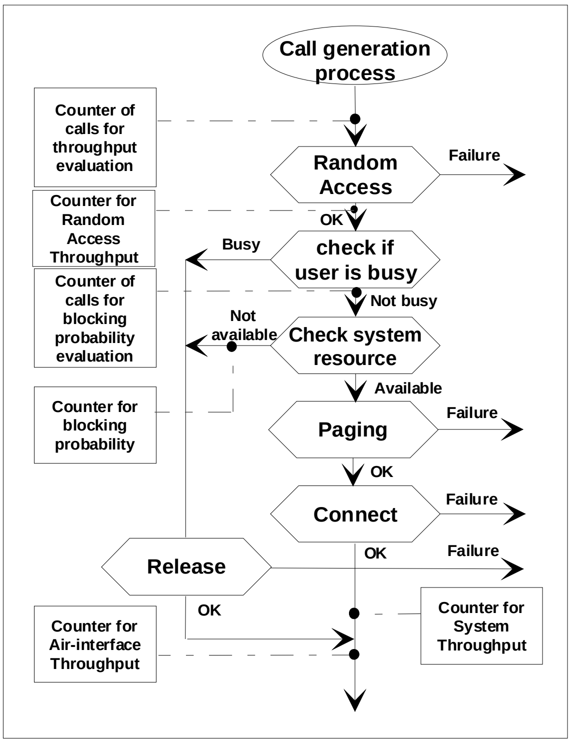

Figure 73: Group circuit call procedure scheme with counters for the evaluation of throughput parameters

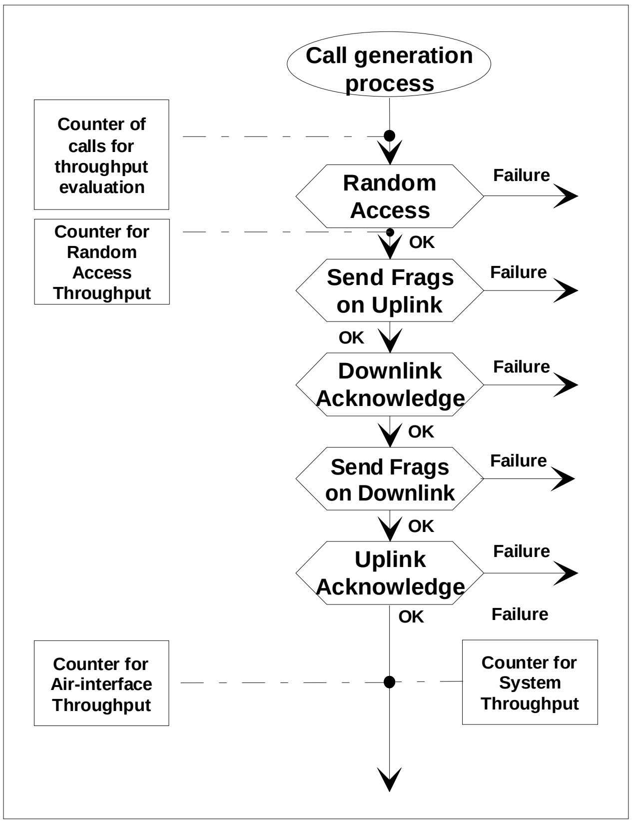

Figure 74: Packet data call procedure scheme with counters for the evaluation of throughput parameters

5.5 Access protocols and packet data performance

5.5.1 Introduction

This clause collects the results of simulations for the performance analysis of a TETRA V+D network. The evaluated performance has been described in clause 5.4.

After a short description of the particular assumptions that have been adopted for each scenario simulation, access procedures for all supported services and short data transmission, that employ Control Channel, are analysed in different system configurations.

Finally, the analysis of circuit service quality is presented. The transmission on all the traffic channels is studied in different propagation scenarios. Statistic distribution of BER are given in order to highlight the probability of having BER below a fixed maximum value. This information is presented for each kind of Traffic Channel and interleaving depth for some significant propagation environment.

5.5.2 Scenario 1: Urban and sub-urban PAMR network

5.5.2.1 Introduction

This clause reports the performance and some sensitivity analysis of a significant number of network configurations, all making reference to scenario 1 (see annex A). As a general criterion, all analysis start from a reference configuration, changing one parameter each time.

Clause 5.5.2.2 collects all the particular assumptions that have been done for the implementation of simulations for scenario 1. The general assumptions on the simulations (as illustrated in clause 5.3) apply.

The first analysed configuration investigates the influence of the system data base on the network performance. Different values and statistic distribution of data base delay are considered and compared.

The second investigation regards the influence of MCCH structure (control channels allocated) on circuit service signalling procedures and short data transmission.

In general, when the total amount of traffic is low, a single control channel can be employed as MCCH.

In case of high loads, the MCCH can be supplemented by an additional control channel. The two control channels can be designed in two ways:

- the second channel as a repetition of the first one, each channel supports all kind of traffic;
- the second channel that supports a different kind of traffic from the first one. Traffic related to Circuit Services signalling can be divided from the short data transmission and carried by a different channel.

The two solutions are analysed below in order to provide an estimate of the number of users with a particular traffic profile that can be served by the network cell.

The final analysis regards the influence of access control parameters (random access and basic link parameters) on system performance. Starting from the reference network configuration and traffic profiles, the influence of access control parameters and some network parameters on the system performance is carried out.

NOTE 1: Due to the high amount of radio resources available in the system, the call set-up delay is only due to the radio transmission impairments and to the random access collisions. Call failures are then mainly due to the same cause, with the exception of blocked calls. For this reason, the throughput performance is reported through both the blocking probability and the radio interface throughput.

NOTE 2: In general, as a result of simulations, the paging procedure for group calls (Unacknowledged Downlink transmission) is able to reach more than 99 % of group members in all the simulated scenarios. For this reason this output parameter is not presented.

5.5.2.2 Simulation assumptions for Scenario 1

5.5.2.2.1 Simulated traffic scenario

Annex A reports a detailed description of different traffic profiles. The results reported in this clause are based on scenario 1, that is a public urban network. User spatial distribution has been considered uniform in the observed network. Table 7 reports the detailed single user traffic profile for scenario 1.

Table 7: Reference traffic profile for Scenario 1

Service	Parameter	Reference Scenario 1
M-M individual voice call	Frequency of requests	0,3 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
M-F individual voice call	Frequency of requests	0,9 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
F-M individual voice call	Frequency of requests	0,9 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
M-M group #1 voice call	Frequency of requests	0,045 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
	Group size	10
M-M group #2 voice call	Frequency of requests	0,045 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
	Group size	20
M-M group #3 voice call	Frequency of requests	0,21 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
	Group size	20
M-F individual circuit data call	Frequency of requests	0,4 calls/h (POISSON)
	Call duration	10 Kbytes (FIXED)
F-M individual circuit data call	Frequency of requests	0,4 calls/h (POISSON)
	Call duration	10 Kbytes (FIXED)
M-M group circuit data call	Frequency of requests	0,1 calls/h (POISSON)
	Call duration	10 Kbytes
	Group size	20
M-F Short Data transmission	Frequency of requests	20 trasm/h
	Call duration	100 bytes

5.5.2.2.2 Simulated network procedures and reference access parameters

Annex B collects the Message Sequence Charts (MSC) of these procedures in case of positive radio transmissions. SDL diagrams related to the single network entities are the reference for negative and erroneous cases. Annex C, D and E report the detailed behaviour of all the network entities in SDL notation.

The simulated procedures in scenario 1 are the following:

- individual voice call from TETRA MS to TETRA MS (Full duplex);
- individual voice call from TETRA MS to external fixed terminal (Full duplex);
- individual voice call from external fixed terminal to TETRA MS (Full duplex);
- group voice call from TETRA MS to a group of TETRA MSs (Half duplex);
- individual circuit data call from TETRA MS to external fixed terminal (Full duplex);
- individual circuit data call from external fixed terminal to TETRA MS (Full duplex);
- group circuit data call from TETRA MS to a group of TETRA MS (Half duplex);
- individual packet data call from a TETRA MS to TETRA SwMI.

It is supposed that network cells are not affected by Co-channel interference and are covered through omni-directional antennas.

NOTE 1: Scenario 1 represents a public network; a suitable strategy for the call management in case of lack of resources is to block the call. No pre-emption mechanisms have been considered in these simulations. The adopted strategy consists of immediately releasing (see annex C, D, E for the call release procedure) the call request when no resources are available.

NOTE 2: Simulated MSs are not able to support parallel transactions. When a new call is generated by the user and the MS is busy, in case of data services (circuit and packet calls) the MS puts this parallel transaction in a local queue; in case of voice calls it is released. When the present transaction is finished the local queue is checked in order to give service to the queued transactions.

NOTE 3: During the call set-up procedure, the TCH assignment policy in the SwMI is an implementation option; in the standard document two possibilities are given: early assignment and late assignment. In scenario 1 simulations late assignment has been adopted.

All network and access control parameters in the reference situation for the simulations are summarized in table 8. The results have been evaluated for a suitable set of network scenarios that have been derived by this reference, changing one parameter each time.

The definition of the evaluated performance given in clause 5.4 applies. In the following clauses they are presented for each network configuration. The number of allocated traffic channels has been evaluated in order to have a low blocking probability (< 5 %) for all the services. Before showing the overall performance, a table reports the number of allocated channels with the associated blocking probability of different kind of services:

- full duplex calls in the same cell site, requiring 2 TCHs per call;
- half duplex calls or full duplex calls in different cell sites, requiring 1 TCH per call.

Table 8: Summary of network parameters of the reference scenario 1

Parameter	Reference value
Random access: value of the timer regulating the first access attempt (IMM)	15
Random access: maximum number of access attempts (Nu)	5
Random access: Back off time (WT)	5 TDMA frames
Random access: Access frame length	10 access opportunities
Basic link: Maximum number of re-transmissions (N.252)	3
Basic link: Sender retry timer (T.251)	4 TDMA frames
Propagation scenario	TU50
Power gap between signals received on the mobile and on the BS	0 dB;
MS antenna height	1,5 m
User distribution on the cell	uniform (flat) distribution
BS antenna height	50 m
Type of cell antenna	Omni directional
Reuse factor	∞
Location probability	90 %
Call management policy in case of lack of network resources	BLOCKING
Number of Control Channels allocated on the cell	1
Number of Traffic Channels allocated on the cell	Dependent on the target blocking probability
Number of User Access Sets that are in the coverage area of the cell	1
Traffic channel used for circuit data transmission	TCH/4,8 with interleaving depth 1
Access Codes allocation on the Control Channels	A=100 %, B=0 %, C=0 %, D=0 %

5.5.2.2.3 Confidence analysis for scenario 1 results

All reported results have been evaluated through computer simulations. The obtained results have been filtered making use of confidence region analysis. After a transitorial time (duration dependent on the traffic load), each simulation has been analysed in time blocks. The end of simulation is given when all evaluated results are affected by an error below a suitable threshold. The used thresholds for the final results are the following:

- Delay values:
    - relative error < 5 % of the delay value with probability 99 %;
- throughput and probability values:
    - absolute error < 0,01 with probability 99 %.

5.5.2.3 Influence of network data base delays

In the simulated network, a system data base is accessed at the end of the random access and before the paging procedure in order to obtain the position of the called party or of the called group. It has been modelled as a delay block, in accordance with clause 5.3.4.2.

The presence of this delay in the call set-up procedures of circuit switched services (voice and circuit data) affects the overall delay.

An investigation has been made with two systems, the first with data base, the second without data base.

In this clause the influence of the characteristics of the data base on the overall performance has been studied taking into account a third system whose data base is faster than in the first system.

The sum of two random variables is still a random variable whose statistic distribution is the convolution of the distributions of the original variables; the mean value of the new variable is the sum of the mean values of the original variables.

In order to study the influence of this block on the call set-up delays, some simulations have been performed with different kind of data base characteristics. The following situations have been analysed:

- zero response time;
- response time with uniform distribution between 0,1 s and 1,6 s;
- response time with uniform distribution between 0,5 s and 2 s.

The examined scenarios have the same user traffic profile and access control parameters. They have been set in accordance with reference parameters (see clause 5.4).

In order to illustrate the influence on the statistic distribution of time delays, probability function and distributions for each type of data base are reported. A population of 250 subscribers in the cell has been considered; only the individual circuit switched call set-up delay has been illustrated in these figures, nevertheless all services have been simulated according to the reference traffic profile. Due to particular techniques employed for the collection of the distribution data, the abscissa of the distributions is in logarithmic scale.

Figure 75 reports the probability function and the cumulative distribution of individual circuit call set-up time in case of zero delay data base.

Figure 76 represents the function and the cumulative distribution of individual circuit call set-up time with the data base characterized by a uniform delay between 0,1 s and 1,6 s.

Figure 77 illustrates the function and the cumulative distribution of individual circuit call set-up time with the data base characterized by a uniform delay between 0,5 s and 2 s.

Observing the three figures, the distribution reported in figure 75 is shifted and distorted when data base delay is considered, as shown in figures 76 and 77.

In figures 76 and 77 it is important to see that the distributions are very similar in shape. This confirms the theoretical analysis, that in fact the delays introduced by the data base have the same distribution centred on different means. The overall call set-up delay in the second case is seen to be a delayed copy of the first.

NOTE: Distributions are given in logarithmic scale.

In the set of performance that is considered, $\tau_{90\,\%}$, $\tau_{95\,\%}$ and $\tau_{97\,\%}$ there is a direct expression of the shape of the statistical distribution of call set-up delay; due to the non-linearity of the convolution, evaluated values for these parameters are typical for their own particular data base delays.

In order to investigate the distortion of performance curves due to the presence of system data base, further figures are given. Each of them reports one performance parameter evaluated as a function of cell population for the different data base characteristics.

Figure 78 reports the random access mean values as a function of cell population and for different data base characteristics. The influence is negligible because the data base is accessed after random access and the overall simulated process is stationary.

Figure 79 reports the mean value of call set-up time as a function of the number of users and for different data base characteristics. In order to make easier comparisons, the call set-up time mean values are decrement by the mean value of the data base delay. The slight differences between these curves confirm that the overall mean value is the sum of call set-up and of data base mean delays.

Figures 80 to 82 report respectively the call set-up boundaries $\tau_{90\,\%}$, $\tau_{95\,\%}$ and $\tau_{97\,\%}$ as a function of cell population for different data base characteristics. In all cases reported values have been decrement by the mean value of data base delay in order to make easy comparisons. The effect of data base is a distortion of the curves: for low levels of offered traffic the differences between the curves reach the maximum values. For high traffic the differences are less appreciable.

Figures 83 and 84 report respectively the random access throughput and the call set-up throughput. The effect of the data base characteristic is not significant, nevertheless it is visible. These differences can be explained by some difference in the behaviour of signalling procedures. For long data base delays, the random access procedure is only concluded by the D_CALL_PROCEEEDING message from the network. When this delay becomes short, this procedure can also be concluded by a D_CONNECT message. For this reason in case of very fast data base, throughput for both random access and call set-up is better than for slow systems.

Table 9 reports the number of TCHs allocated to the simulated cell in order to give a low blocking probability for all services. Two categories of services are reported depending on the number of channels required. The reported values are valid for each data base performance figure.

Table 9: Blocking probability for the simulated configurations

Number of users	Number of allocated TCHs (Frequency Carriers)	Blocking probability of services requesting two TCHs	Blocking probability of services requesting one TCH
100	7 (2)	2 %	0,5 %
250	11 (3)	4 %	1,5 %
500	19 (5)	2 %	1 %
750	23 (6)	2,5 %	1 %
1 000	23 (6)	5 %	2 %

In the following clauses performance of network protocols and services is evaluated. In all cases the reported call set-up delay values have been decrement by the mean value of the data base delay. Nevertheless the results in this clause show that if a different kind of data base is introduced in the network, only mean values can be linearly obtained; the delay boundaries for call set-up time have to be evaluated more carefully due to the non linear consequence of convolution on the statistical distributions.

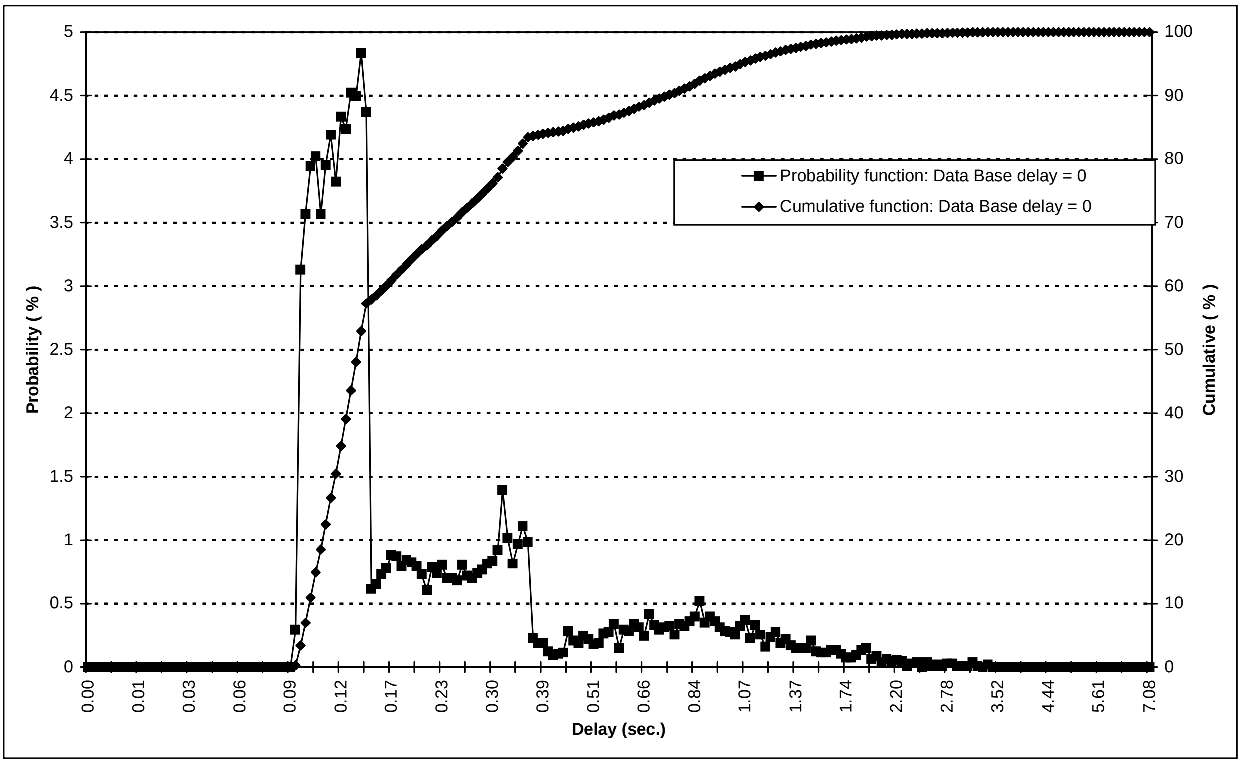

Figure 75: Probability function and cumulative distribution of call set-up time with zero delay data base

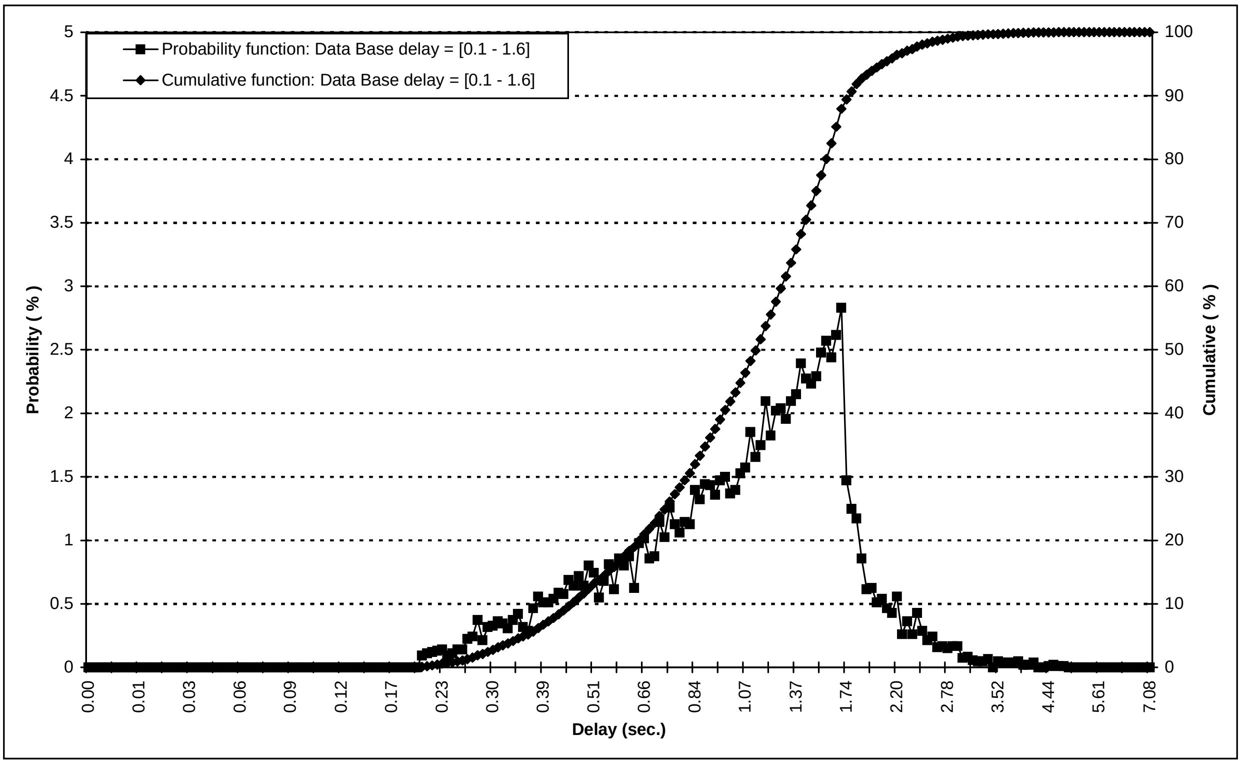

Figure 76: Probability function and cumulative distribution of call set-up time with data base delay uniformly distributed between 0,1 s and 1,6 s

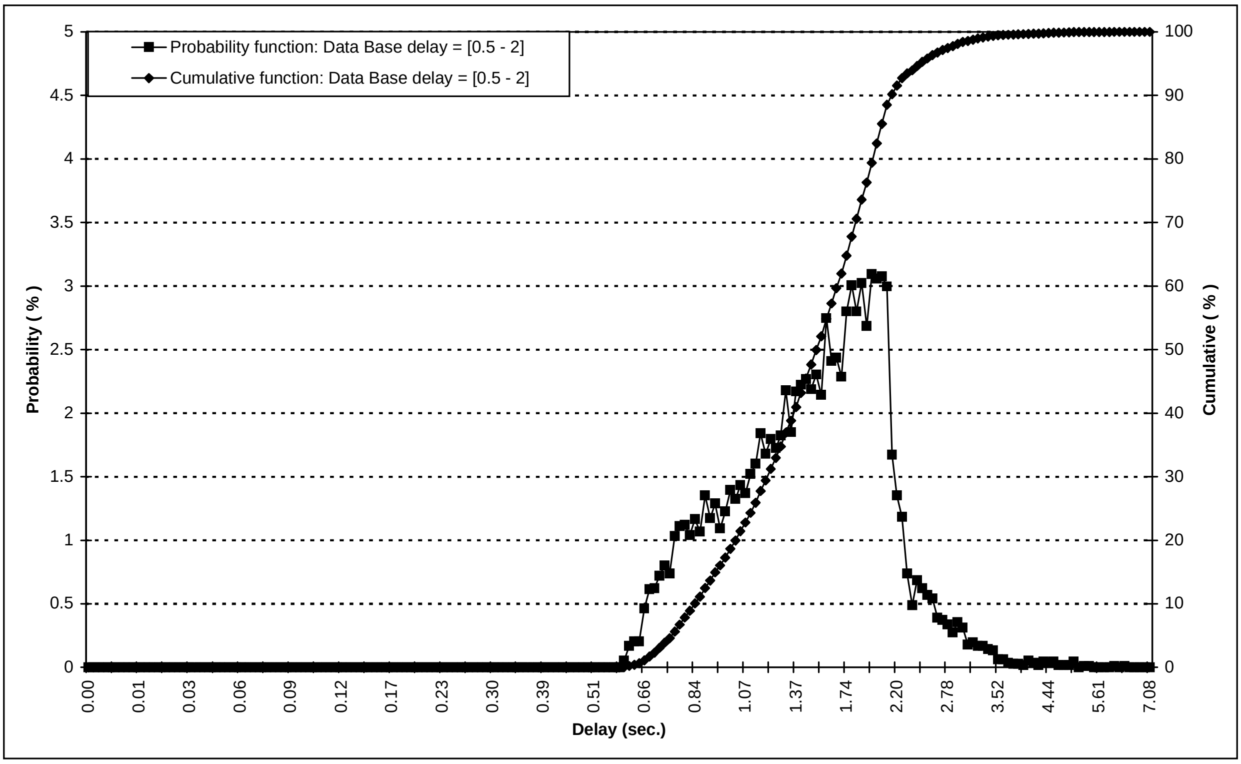

Figure 77: Probability function and cumulative distribution of call set-up time with data base delay uniformly distributed between 0,5 s and 2 s

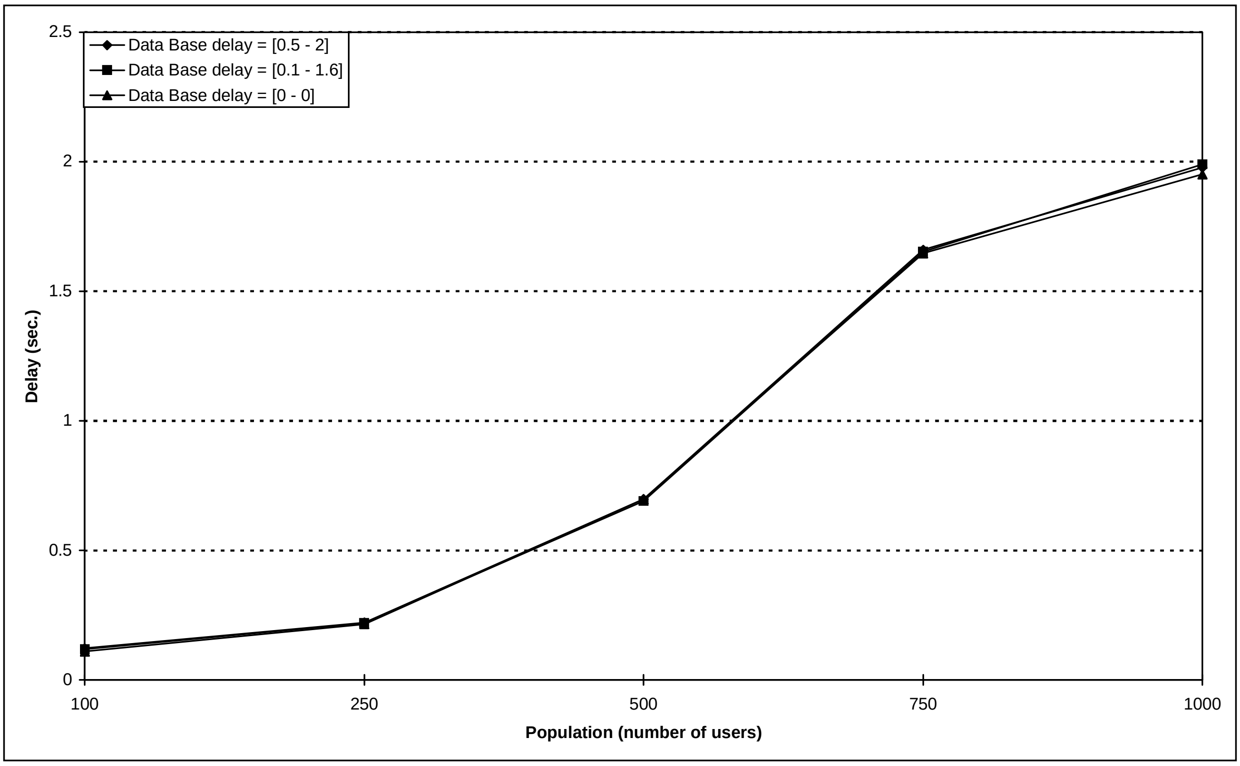

Figure 78: Comparison of random access mean value for different characteristics of system data base (all curves overlap)

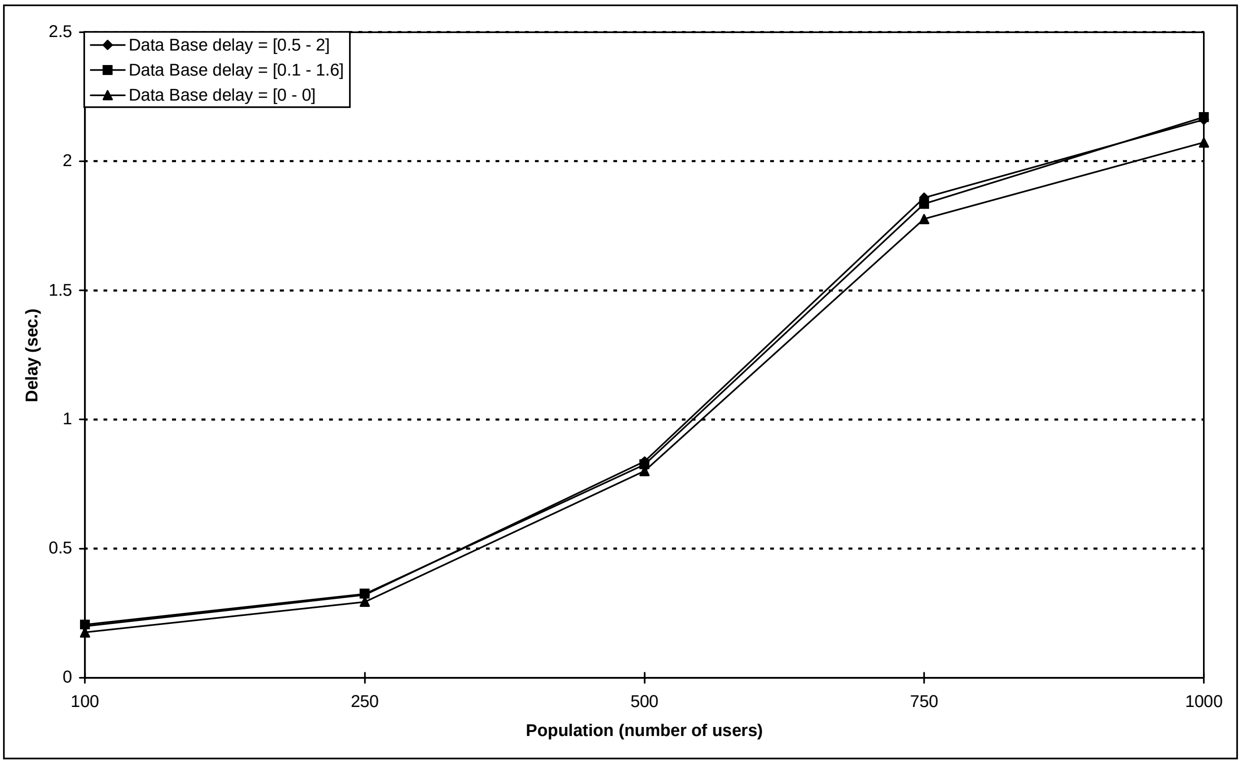

Figure 79: Comparison of call set-up mean value for different characteristics of system data base (curves for delay in 0,5 s to 2 s and in 0,1 s to 1,6 s overlap)

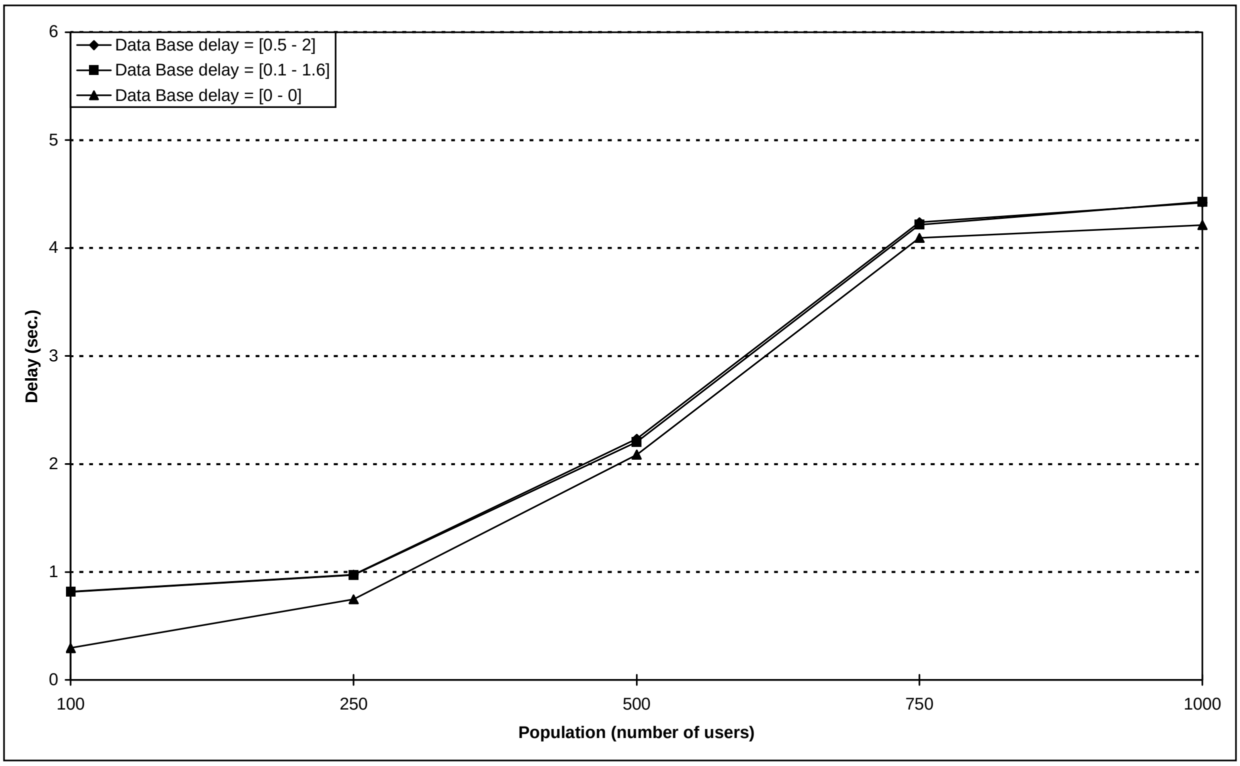

Figure 80: Comparison of call set-up $\tau_{90\ \%}$ for different characteristics of system data base (curves for delay in 0,5 s to 2 s and in 0,1 s to 1,6 s overlap)

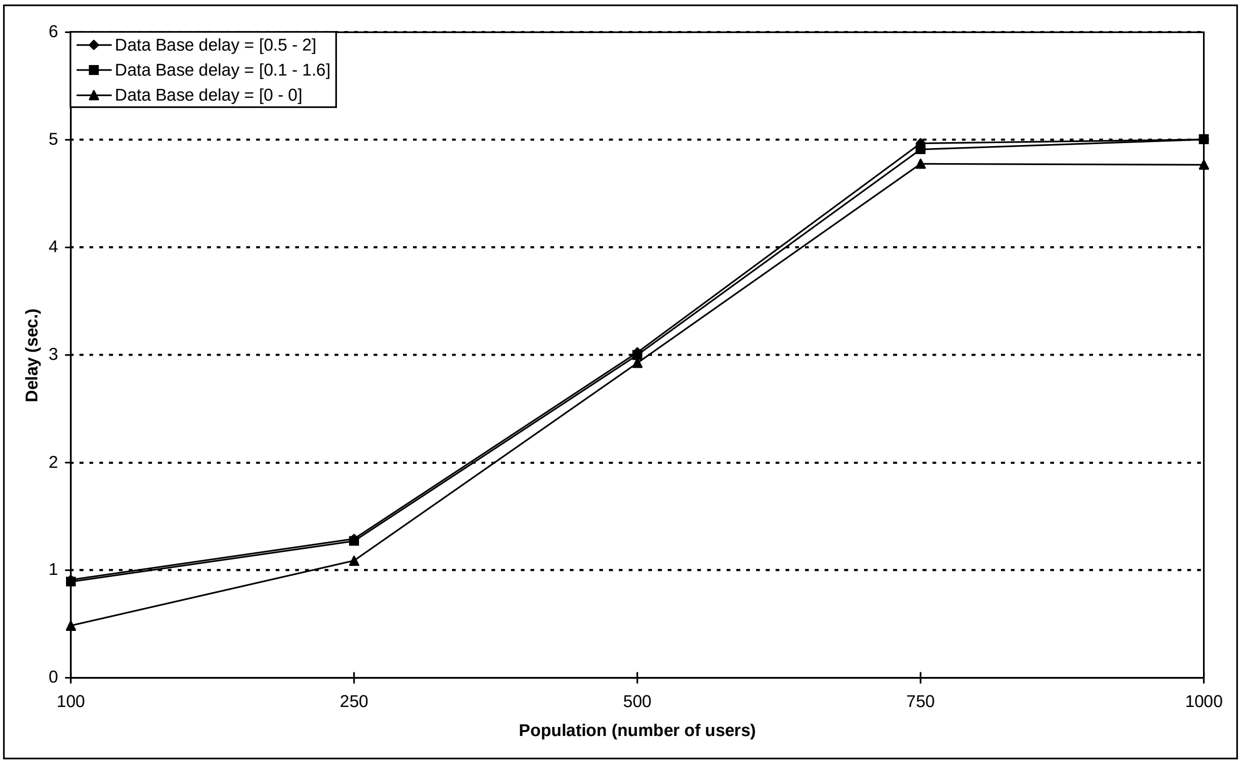

Figure 81: Comparison of call set-up $\tau_{95\ \%}$ for different characteristics of system data base (curves for delay in 0,5 s to 2 s and in 0,1 s to 1,6 s overlap)

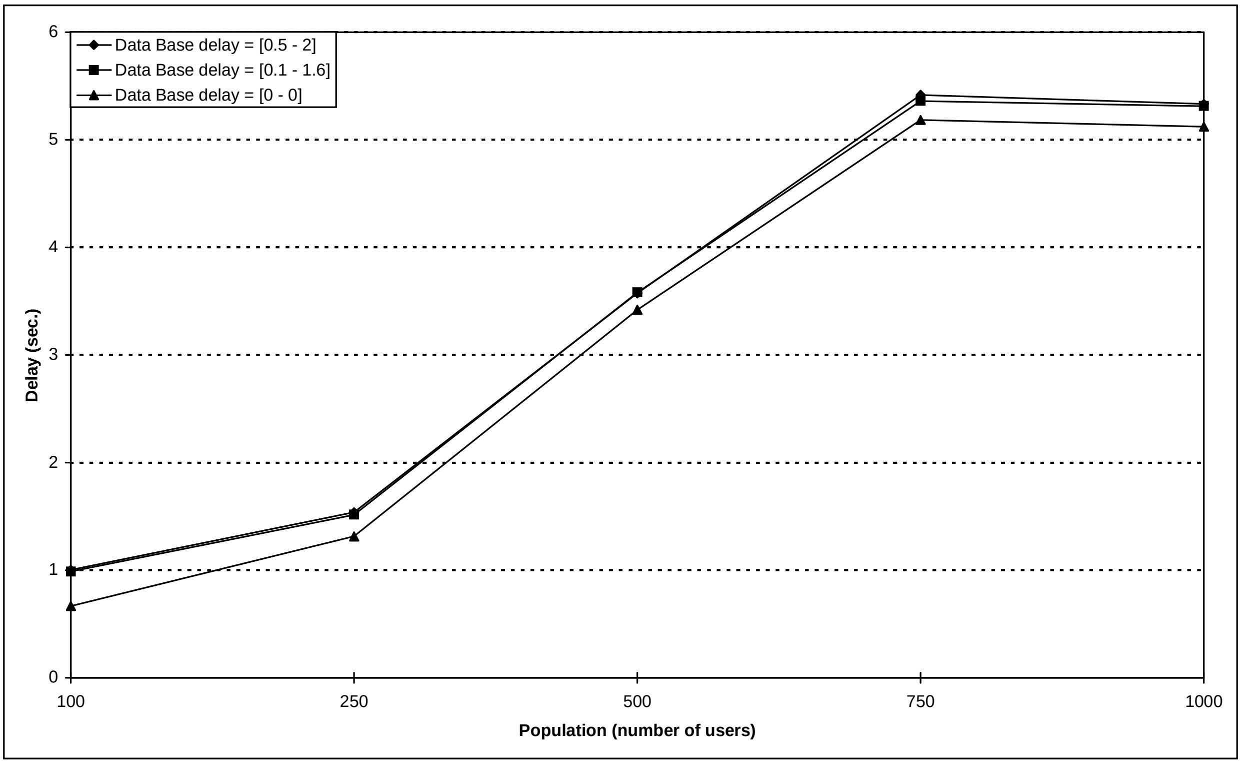

Figure 82: Comparison of call set-up $\tau_{97\ \%}$ for different characteristics of system data base (curves for delay in 0,5 s to 2 s and in 0,1 s to 1,6 s overlap)

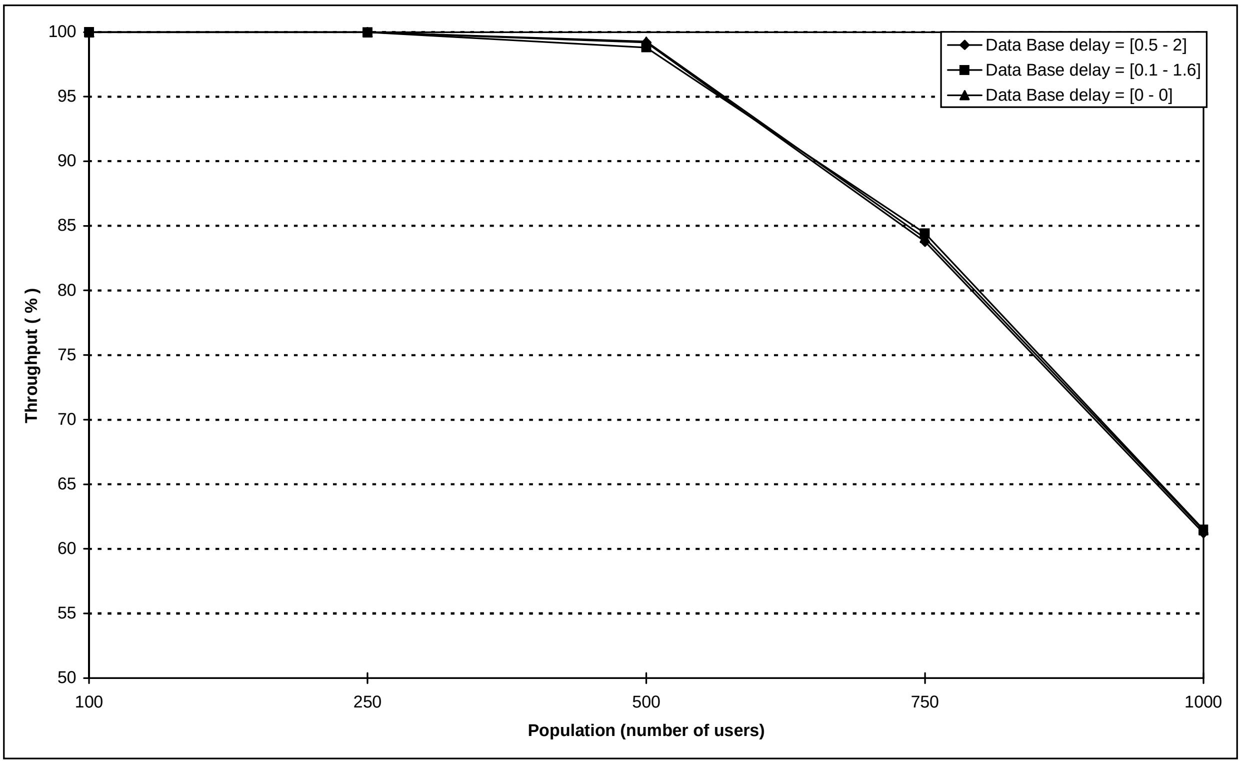

Figure 83: Comparison of random access throughput for different characteristics of system data base (all curves overlap)

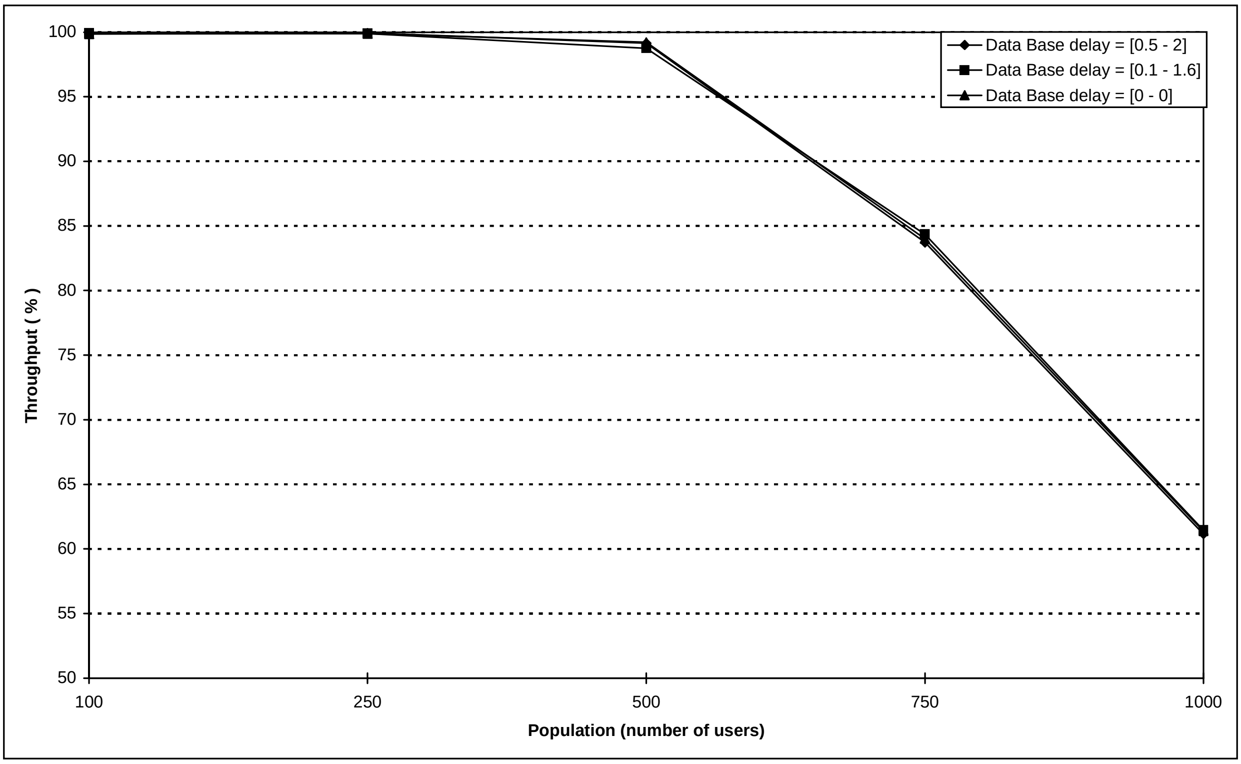

Figure 84: Comparison of call set-up throughput for different characteristics of system data base (all curves overlap)

5.5.2.4 Main control channel allocation

5.5.2.4.1 Single MCCH

In order to evaluate the capacity of a single Control Channel, a set of different traffic profiles has been analysed. The initial single user traffic profile (see table 7) has been modified in order to have a significant number of traffic profiles, characterized by a different composition of circuit services and short data transmission.

The traffic profile for circuit services has been kept the same of the reference configuration. The four traffic profiles have been obtained for different levels of Short Data transmission requests. Table 10 summarizes the analysed traffic profiles.

The following figures report the performance in case of a single Control Channel. Network configuration and access control parameters are kept as in the reference configuration illustrated in table 8. Figures show the performance of service access as a function of the cell population. For each traffic profile, the analysis regards all the supported service categories (individual circuit calls, group circuit calls, short data transmission). For a given configuration and traffic profile, the random access procedure is the same for all the supported services. For this reason group calls and individual calls present the same random access performance. In order to show the most significant performance, individual call set-up and short data transmission are examined. Each figure reports delays and throughput of a single access procedure. In accordance with clause 5.5.2.2 all circuit service set-up times (mean value and $\tau_{xx\,\%}$) are represented subtracting the mean value of the system data base delay.

It is important to observe that two populations with the same number of users but different traffic profiles generate a different amount of offered traffic. As a consequence, fixing some performance thresholds (maximum delay or minimum throughput) on the signalling procedures, the maximum population that a cell can support is different depending on the traffic profile. For this reason the abscissa of the figures is different depending on the traffic profile that is analysed.

Table 10: Summary of the traffic profiles employed for the study of the single MCCH

Service	Parameter	Scenario			
		1A	1B	1C	1D (REF)
M-M individual voice call	Frequency of requests	0,3 calls/h (POISSON)			
	Call duration	20 s to 40 s (UNIF)			
M-F individual voice call	Frequency of requests	0,9 calls/h (POISSON)			
	Call duration	20 s to 40 s (UNIF)			
F-M individual voice call	Frequency of requests	0,9 calls/h (POISSON)			
	Call duration	20 s to 40 s (UNIF)			
M-M group #1 voice call	Frequency of requests	0,045 calls/h (POISSON)			
	Call duration	20 s to 40 s (UNIF)			
	Group size	10			
M-M group #2 voice call	Frequency of requests	0,045 calls/h (POISSON)			
	Call duration	20 s to 40 s (UNIF)			
	Group size	20			
M-M group #3 voice call	Frequency of requests	0,21 calls/h (POISSON)			
	Call duration	20 s to 40 s (UNIF)			
	Group size	20			
M-F individual circuit Data call	Frequency of requests	0,4 calls/h (POISSON)			
	Call duration	10 Kbytes (FIXED)			
F-M individual circuit Data call	Frequency of requests	0,4 calls/h (POISSON)			
	Call duration	10 Kbytes (FIXED)			
M-M group circuit Data call	Frequency of requests	0,1 calls/h (POISSON)			
	Call duration	10 Kbytes			
	Group size	20			
M-F Short Data transmission	Frequency of requests	5 trasm/h	10 trasm/h	15 trasm/h	20 trasm/h
	Call duration	100 bytes	100 bytes	100 bytes	100 bytes

The following figures report the performance of individual voice or circuit data call set-up procedures and of short data transmission (Mobile to Network). Each figure presents the delays (mean value and delay boundaries) and the throughput for each service and scenario. Due to the good quality of the radio link, all curves related to the throughput of random access and call set-up procedure overlap.

Figures 85 and 86 illustrate the performance respectively of Mobile to Mobile voice (or circuit data) call and Short Data transmission in case of single user traffic profile '1A' as reported table 10.

Figures 87 and 88 illustrate the performance respectively of Mobile to Mobile voice (or circuit data) call and Short Data transmission in case of single user traffic profile '1B' as reported table 10.

Figures 89 and 90 illustrate the performance respectively of Mobile to Mobile voice (or circuit data) call and Short Data transmission in case of single user traffic profile '1C' as reported table 10.

Figures 91 and 92 illustrate the performance respectively of Mobile to Mobile voice (or circuit data) call and Short Data transmission in case of single user traffic profile '1D' as reported table 10. These performance are related to the reference configuration defined in clause 5.4. They are reported for completeness also in this clause.

Observing the reported figures, the control channel capacity decreases when the short data transmission frequency increases. This is strongly related to the user traffic profile and particularly to the length of transmitted messages (100 bytes require at least 7 uplink reserved slots). On the other side the circuit services set-up procedures require less channel capacity, then the most important contribution to the traffic is due to the short data transmission.

Table 11 reports the number of TCHs allocated to the simulated cell in order to give a low blocking probability for all services. Two categories of services are reported depending on the number of channels required. The reported blocking probability values are shown for each analysed scenario.

Table 11: Blocking probability for the simulated configurations

Scenario	Number of users	Number of allocated TCHs (Frequency Carriers)	Blocking probability of services requesting two TCHs	Blocking probability of services requesting one TCH
1A	**1 000**	23 (6)	2,7 %	1,1 %
	1 500	43 (11)	2,5 %	1 %
	2 000	51 (13)	4,5 %	2 %
	2 500	63 (16)	2 %	1 %
	3 000	75 (19)	0,5 %	0,2 %
1B	**500**	19 (5)	2 %	0,5 %
	750	23 (6)	5 %	2 %
	1 000	31 (8)	2,6 %	1,1 %
	1 250	43 (11)	0,2 %	0,1 %
	1 500	39 (10)	3 %	1 %
1C	**100**	7 (2)	2 %	0,5 %
	250	11 (3)	3,5 %	1,5 %
	500	19 (5)	2 %	1 %
	750	23 (6)	4 %	2 %
	1 000	31 (6)	1 %	0,3 %
1D	**100**	7 (2)	2 %	0,5 %
	250	11 (3)	4 %	1,5 %
	500	19 (5)	2 %	1 %
	750	23 (6)	2,5 %	1 %
	1 000	23 (6)	5 %	2 %

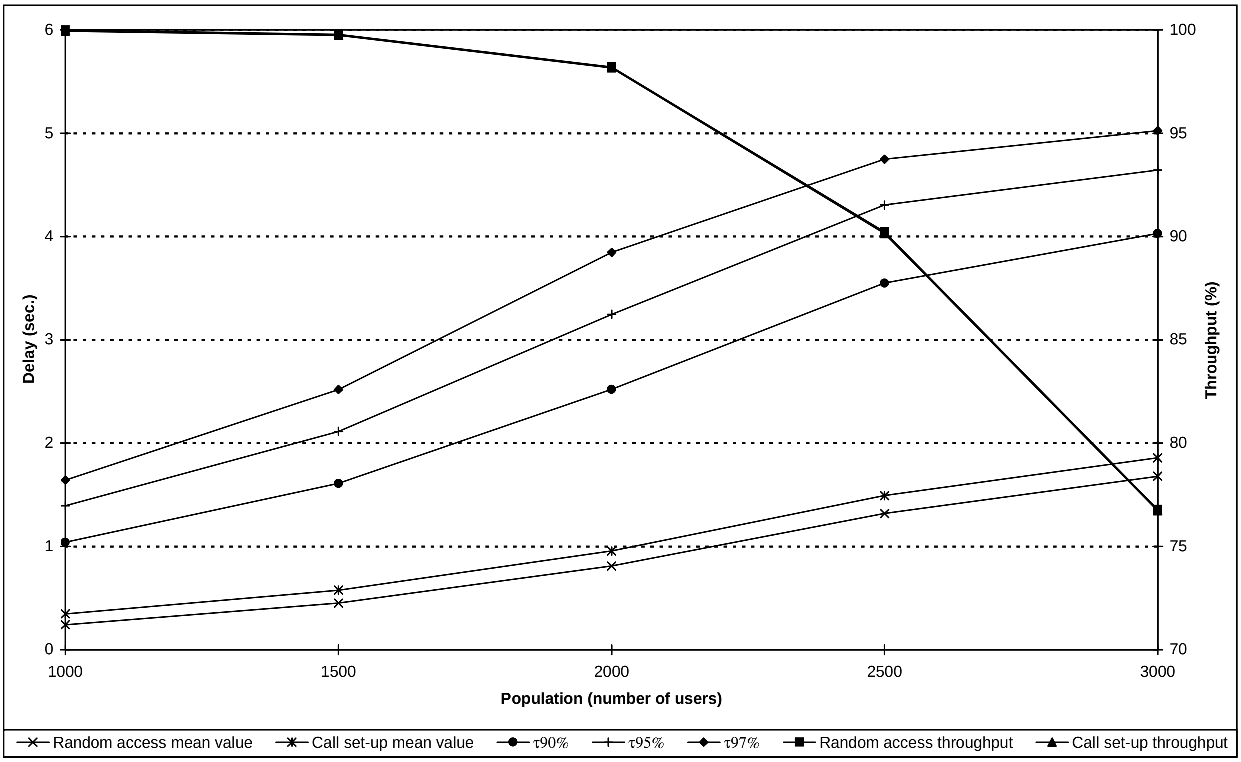

Figure 85: Individual M-M voice or circuit data call performance for scenario 1A (throughput curves overlap)

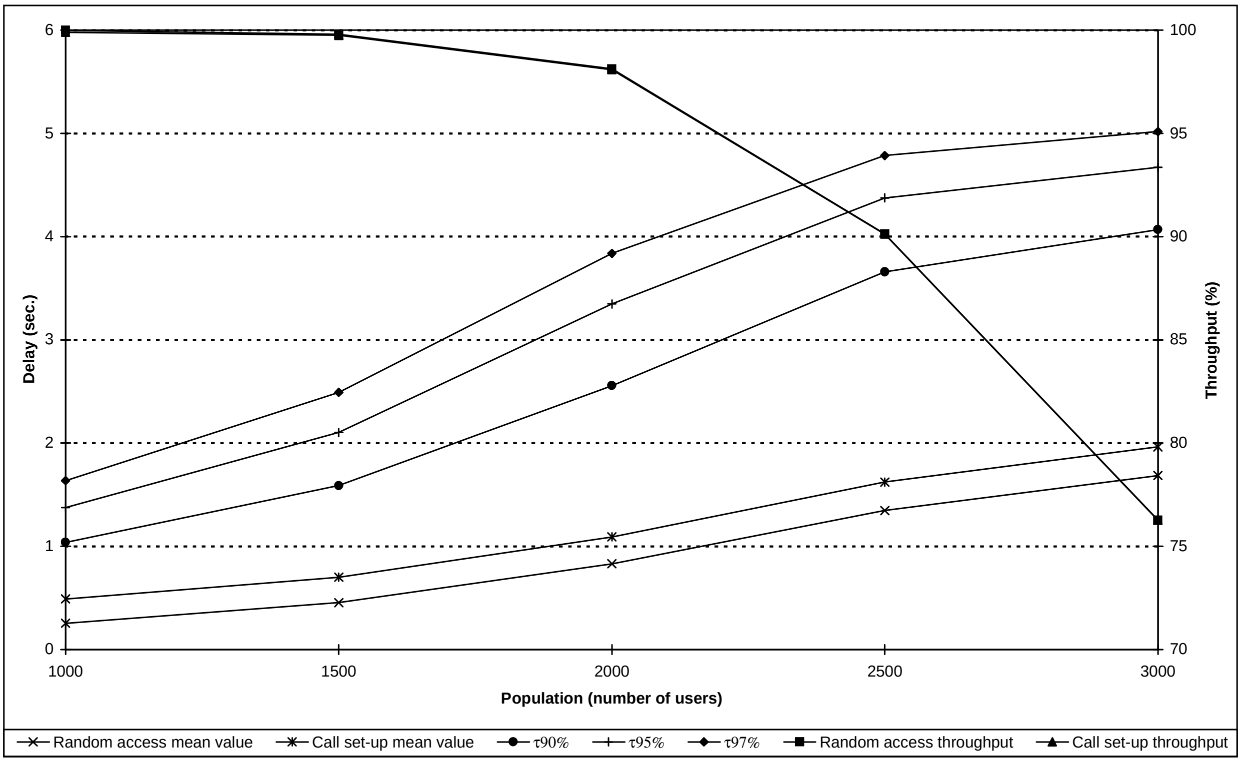

Figure 86: Individual M-F short data transmission performance for scenario 1A (throughput curves overlap)

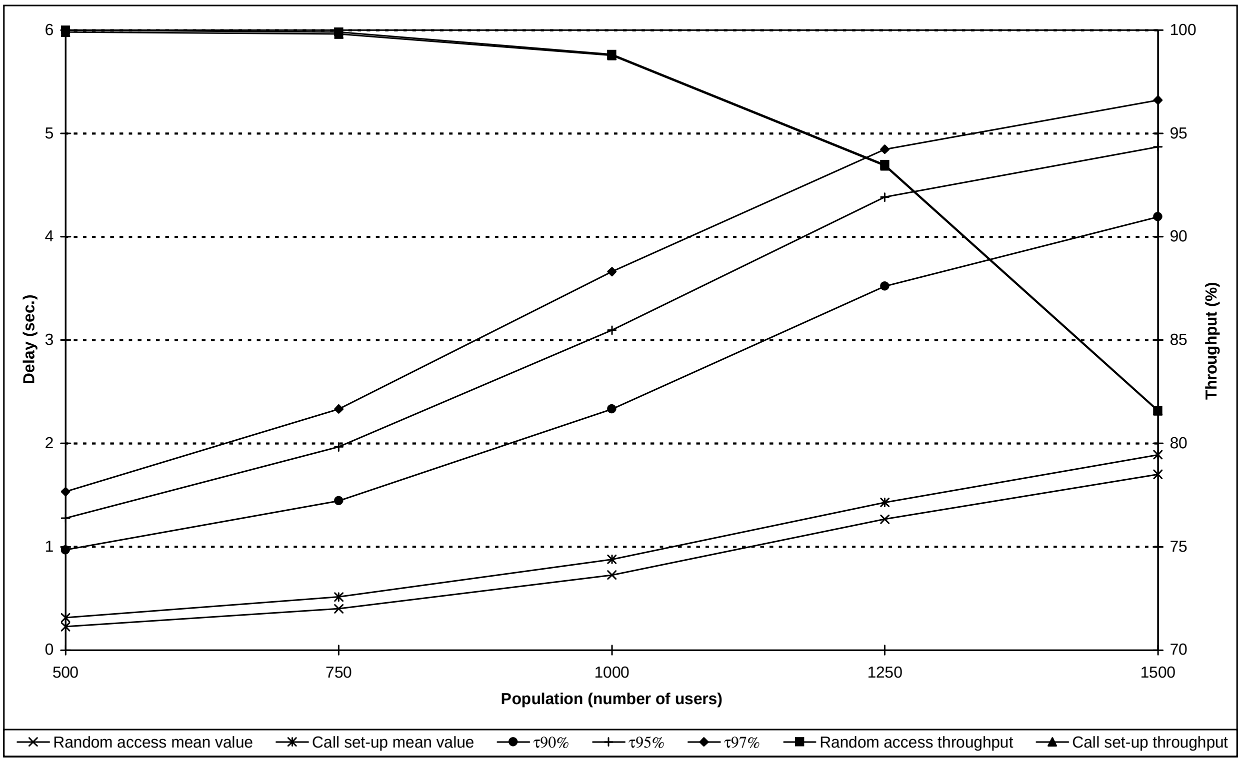

Figure 87: Individual M-M voice or circuit data call performance for scenario 1B (throughput curves overlap)

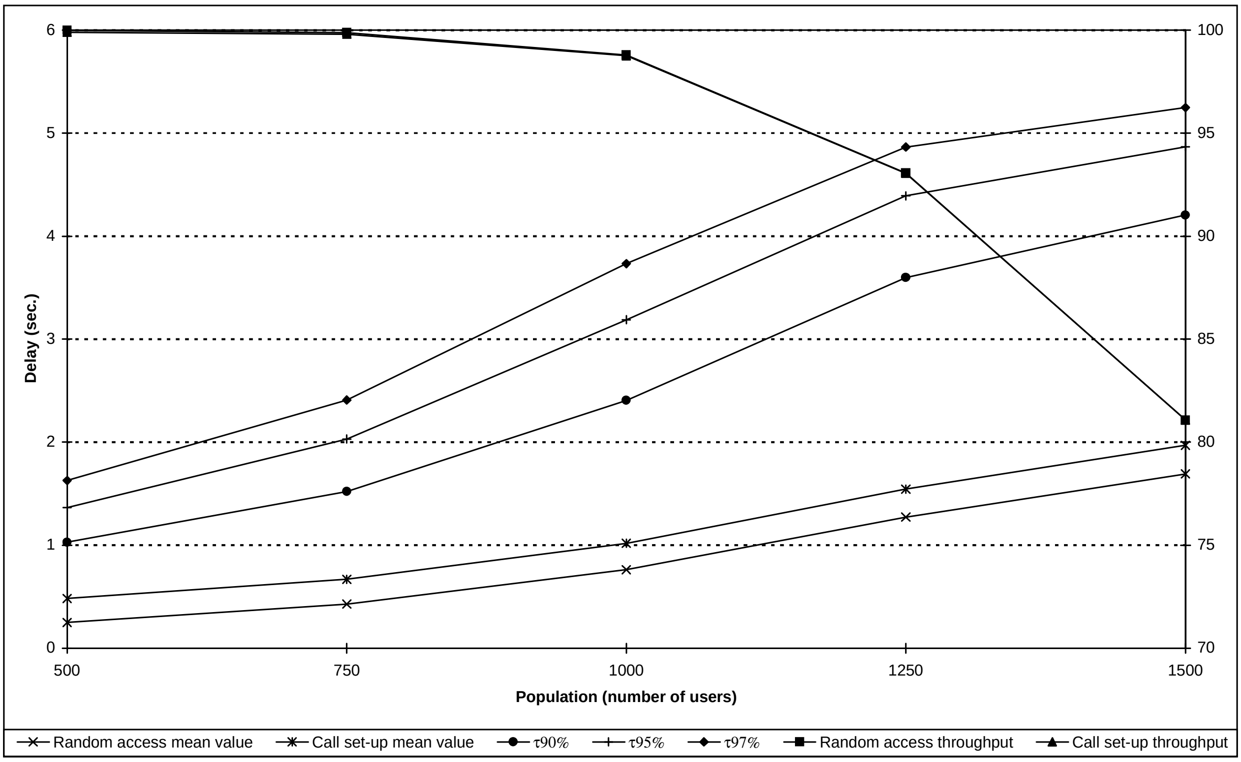

Figure 88: Individual M-F short data transmission performance for scenario 1B (throughput curves overlap)

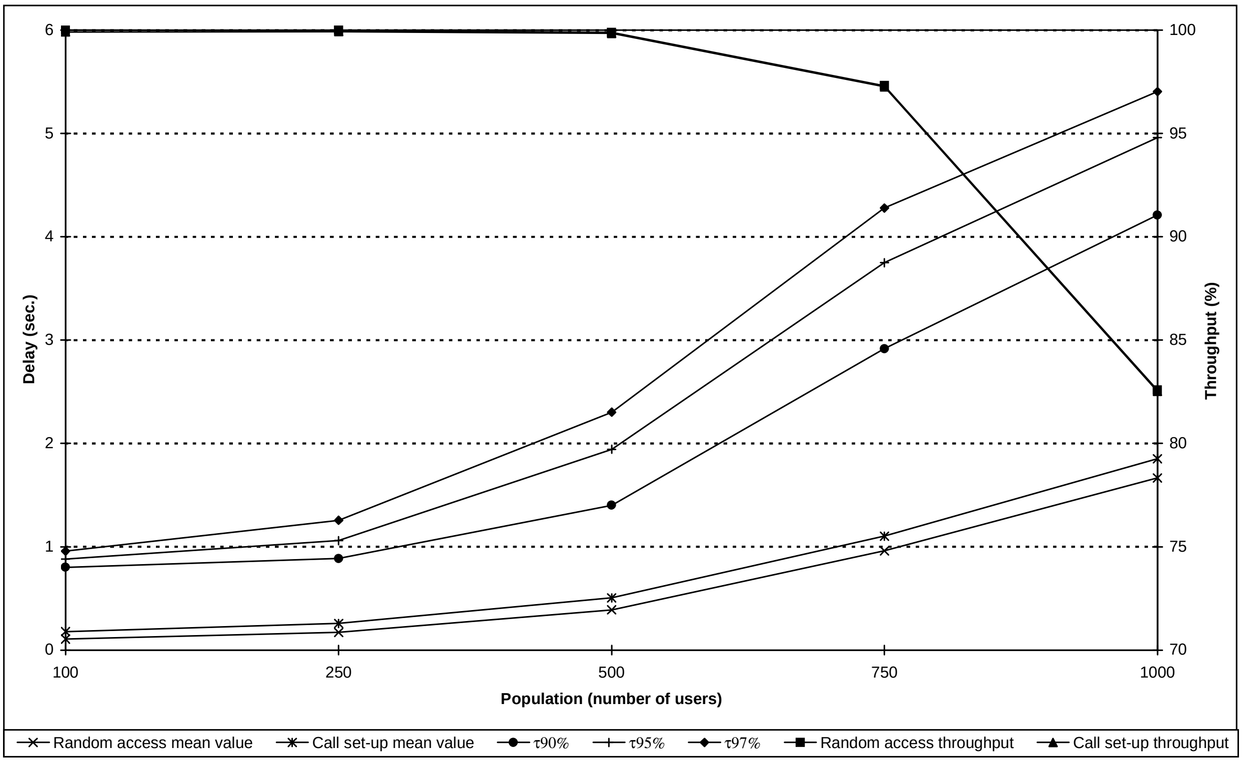

Figure 89: Individual M-M voice or circuit data call performance for scenario 1C (throughput curves overlap)

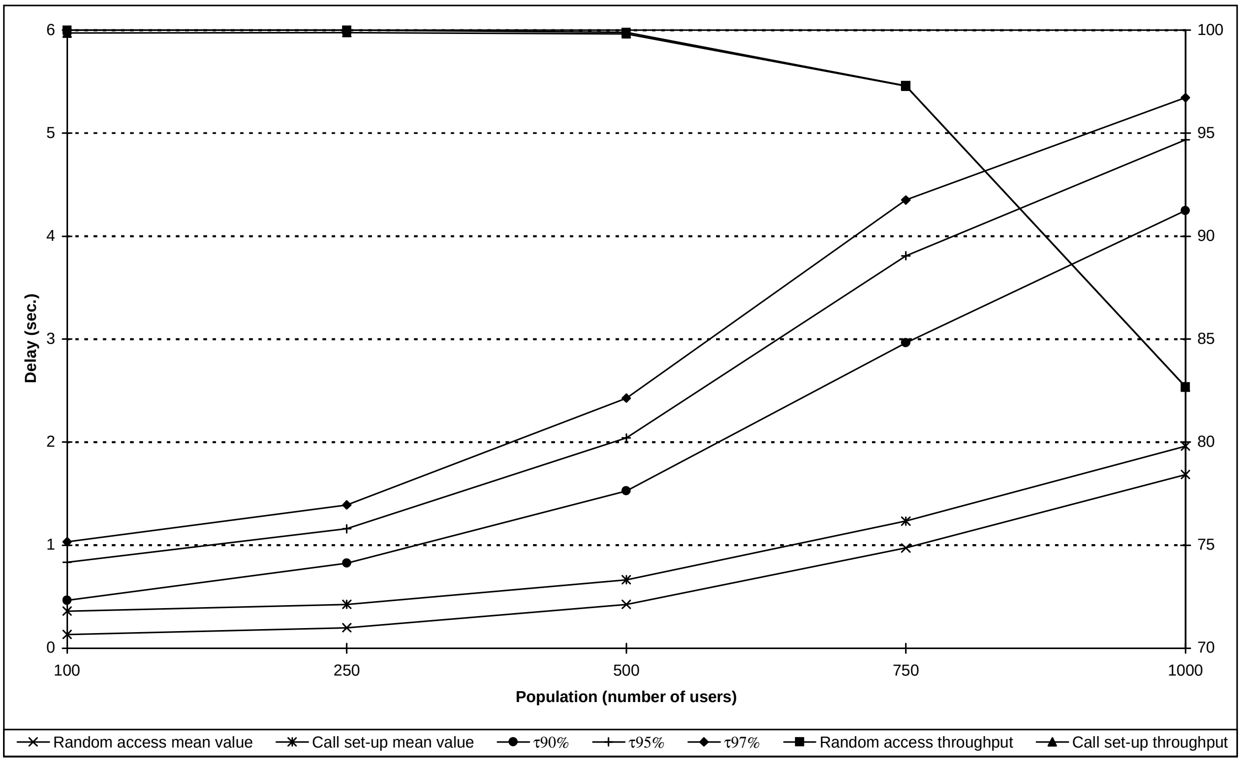

Figure 90: Individual M-F short data transmission performance for scenario 1C (throughput curves overlap)

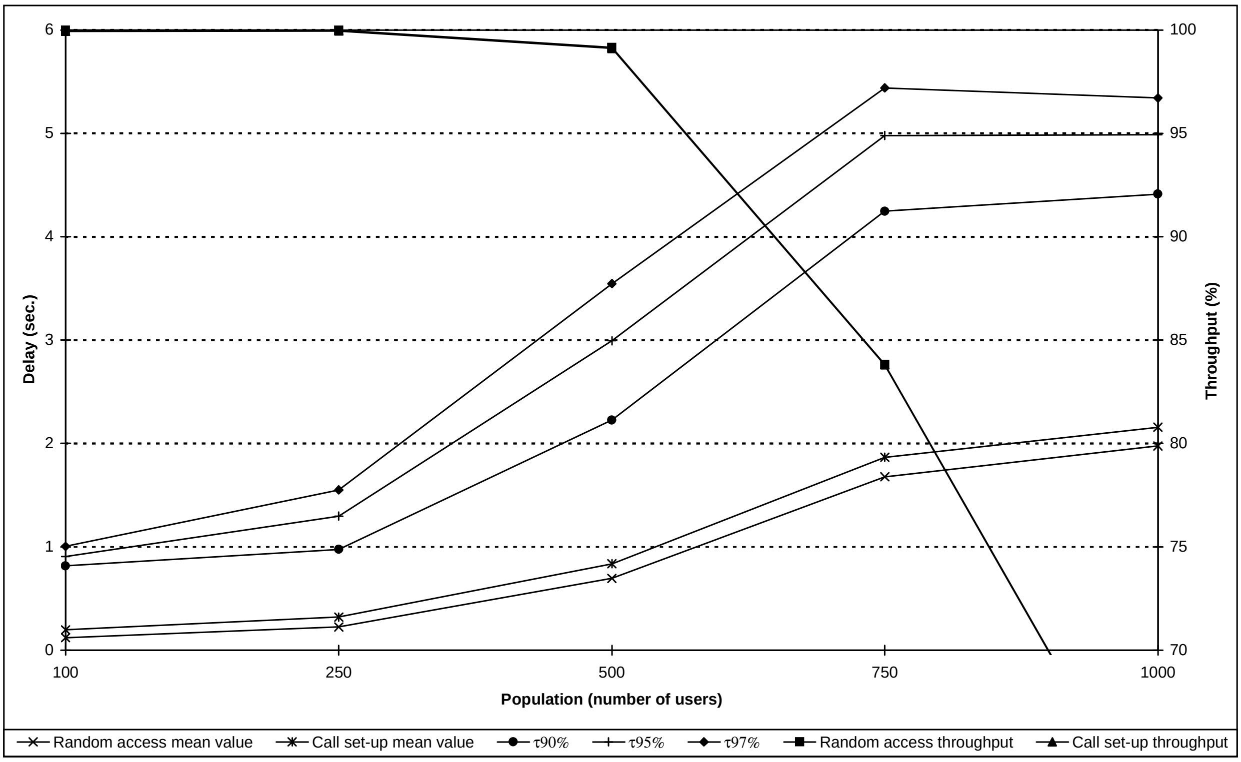

Figure 91: Individual M-M voice or circuit data call performance for scenario 1D (reference) (throughput curves overlap)

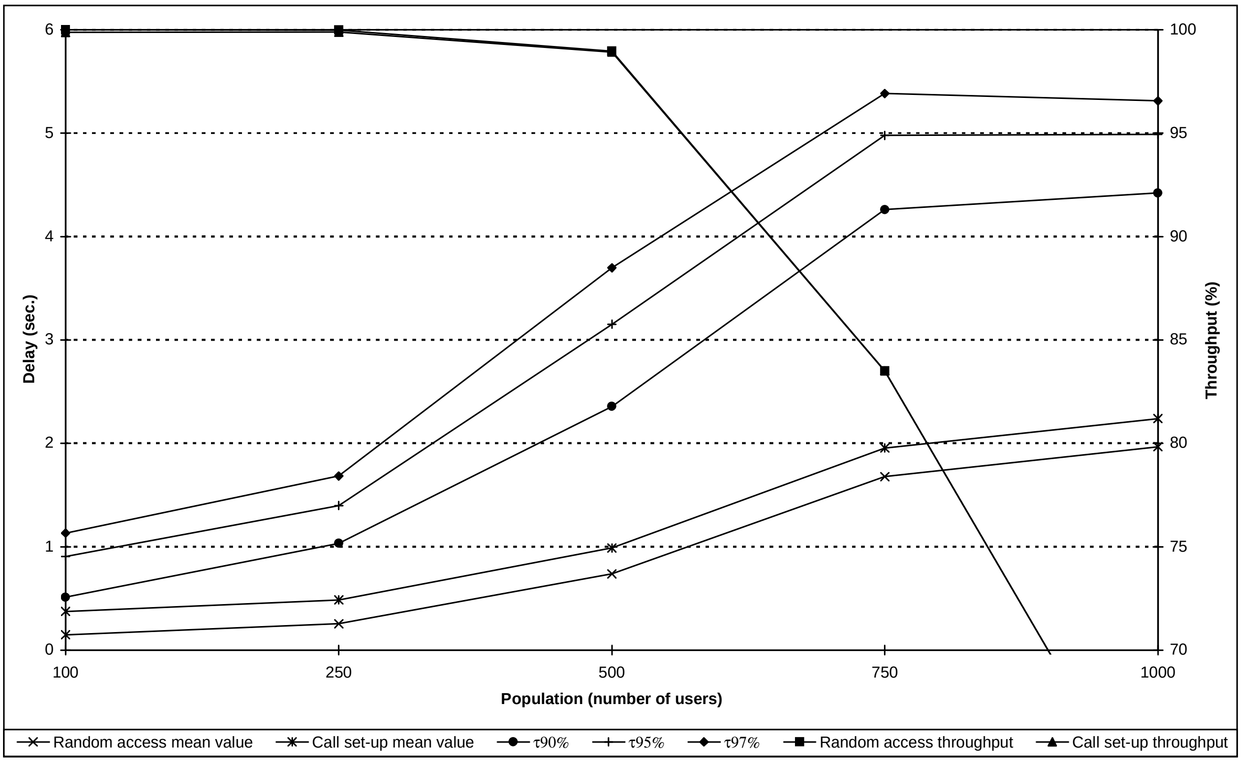

Figure 92: Individual M-F short data transmission performance for scenario 1D (reference) (throughput curves overlap)

5.5.2.4.2 Multiple MCCH

In case of a MCCH that consists of two control channels, it is relevant to study the possibility of splitting the total amount of traffic depending on the traffic type.

In this clause the situation of two channels that carry all kind of services is not analysed, because it can be derived from the preceding results (see clause 5.5.2.3.1).

For the case of different control channels two situations have been studied:

- Circuit service signalling traffic (individual voice call, group voice call, individual circuit data call and group circuit data call) without short data transmission.

- Short Data transmission without circuit service signalling.

The network configuration has been considered the same as defined in table 10. The traffic profile of users has been directly taken from the reference scenario. Table 13 reports the analysed traffic profiles.

Figure 93 reports the performance as a function of the number of users in the cell in case of a channel where only circuit service signalling is supported. As shown in table 13, circuit switched services comprise voice and circuit data services, with the possibility of both group and individual calls. All kind of services and their related signalling procedures have been considered in the study, however, only the individual Mobile to Mobile call is presented in accordance with the previous considerations. All circuit service set-up times (mean value and $\tau_{xx\,\%}$) are represented subtracting the mean value of the system data base delay.

Figure 94 presents the performance related to the short data transmission only (scenario 1F).

These figures highlight the difference in control channel capacity when circuit services or short data transmission are considered (see clause 5.5.2.3.1).

Table 12 reports the number of TCHs allocated to the simulated cell in order to give a low blocking probability for all services. Two categories of services are reported depending on the number of channels required. The reported blocking probability values are shown for the scenario 1E. Scenario 1F has not any circuit service simulated, then no blocking probability can be evaluated.

Table 12: Blocking probability for the simulated configurations

Scenario	Number of users	Number of allocated TCHs (Frequency Carriers)	Blocking probability of services requesting two TCHs	Blocking probability of services requesting one TCH
1E	**10 000**	227 (57)	2,7 %	1,5 %
	15 000	323 (81)	4,25 %	2,46 %
	20 000	423 (106)	4,23 %	2,7 %
	25 000	499 (125)	2,47 %	1,5 %
	30 000	499 (125)	1,5 %	0,8 %

Table 13: Traffic profiles for the analysis of multiple Control Channels

Service	Parameter	Scenario	
		1E	1F
M-M individual voice call	Frequency of requests	0,3 calls/h (POISSON)	---
	Call duration	20 s to 40 s (UNIF)	---
M-F individual voice call	Frequency of requests	0,9 calls/h (POISSON)	---
	Call duration	20 s to 40 s (UNIF)	---
F-M individual voice call	Frequency of requests	0,9 calls/h (POISSON)	---
	Call duration	20 s to 40 s (UNIF)	---
M-M group #1 voice call	Frequency of requests	0,045 calls/h (POISSON)	---
	Call duration	20 s to 40 s (UNIF)	---
	Group size	10	---
M-M group #2 voice call	Frequency of requests	0,045 calls/h (POISSON)	---
	Call duration	20 s to 40 s (UNIF)	---
	Group size	20	---
M-M group #3 voice call	Frequency of requests	0,21 calls/h (POISSON)	---
	Call duration	20 s to 40 s (UNIF)	---
	Group size	20	---
M-F individual circuit Data call	Frequency of requests	0,23 calls/h (POISSON)	---
	Call duration	10 Kbytes (FIXED)	---
F-M individual circuit Data call	Frequency of requests	0,23 calls/h (POISSON)	---
	Call duration	10 Kbytes (FIXED)	---
M-M group circuit Data call	Frequency of requests	0,06 calls/h (POISSON)	---
	Call duration	10 Kbytes	---
	Group size	20	---
Short Data transmission	Frequency of requests	---	20 trasm/h
	Call duration	---	100 bytes

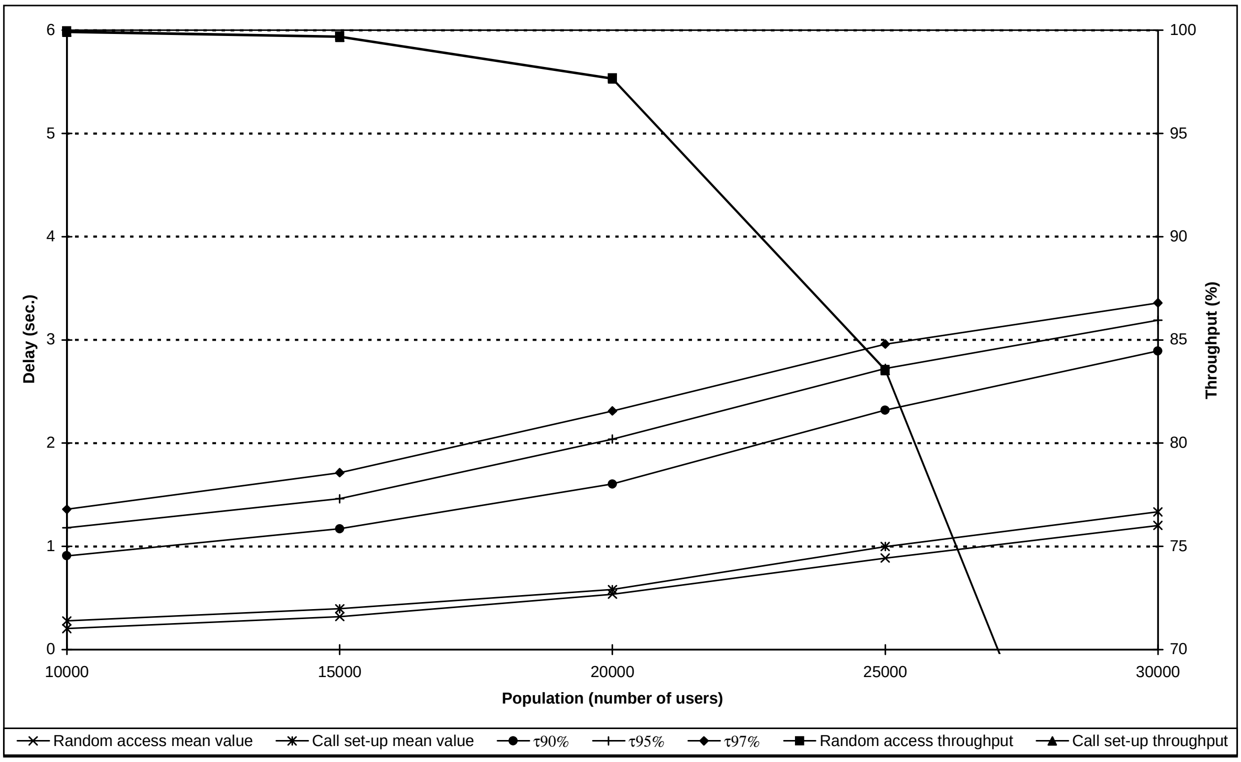

Figure 93: Individual M-M voice or circuit data call performance for scenario 1E (throughput curves overlap)

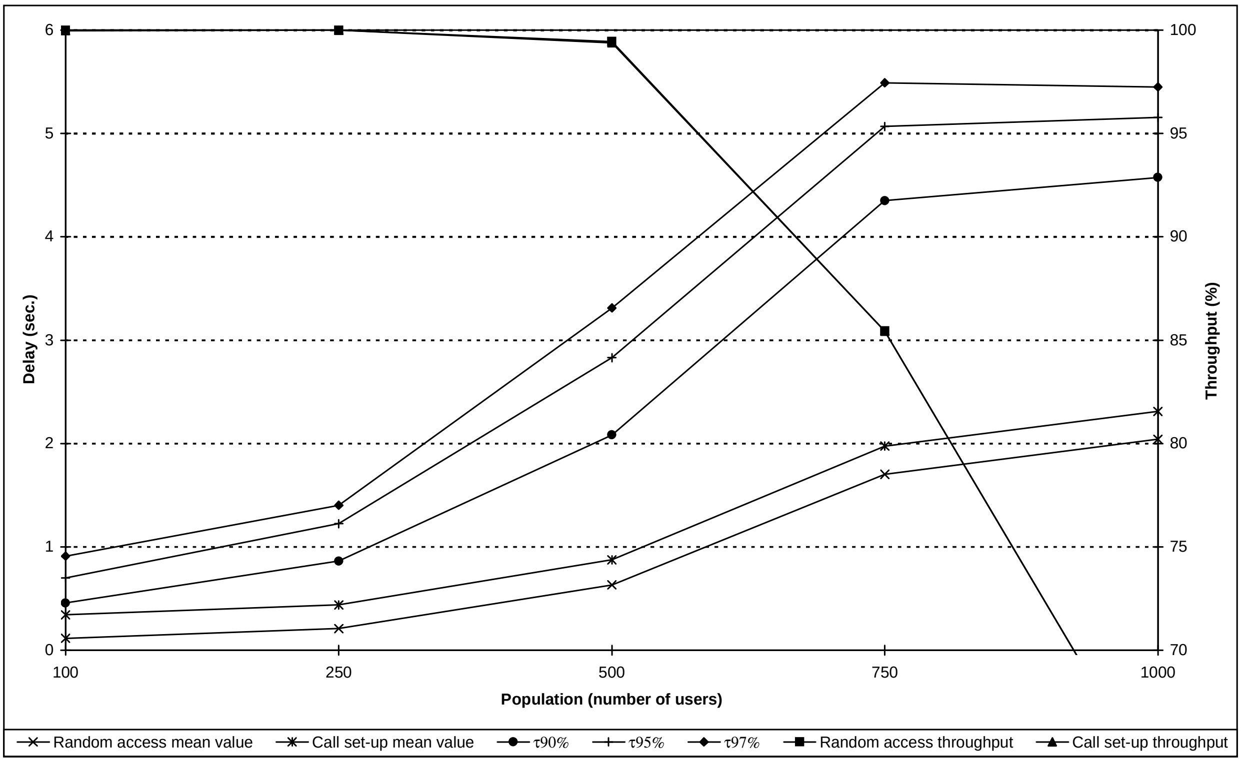

Figure 94: Individual M-F short data transmission performance for scenario 1F (throughput curves overlap)

5.5.2.5 Sensitivity to access control parameters and system configuration

Performance of signalling protocols and short data transmission is influenced by the choice of access protocol parameters and system configuration. In this clause the results of sensitivity analysis are reported in order to give some information about the influence of these parameters on the performance.

After a short presentation of the performance related to the reference configuration (see clause 5.4), the consequences due to the change of parameters are reported. Parameters are changed one by one in order to select the wanted effect. The following list summarizes the parameters that are analysed:

- random access retry timer;
- maximum number of re-transmissions of the random access protocol;
- random access frame length;
- maximum number of re-transmissions of the basic link;
- random access technique.

5.5.2.5.1 Reference configuration

The reference configuration for all the simulations is described in general in clause 5.4 and in detail in clause 5.5.2.2. The figures are the same as in the previous analysis. For completeness they are reported at the beginning of the whole sensitivity analysis.

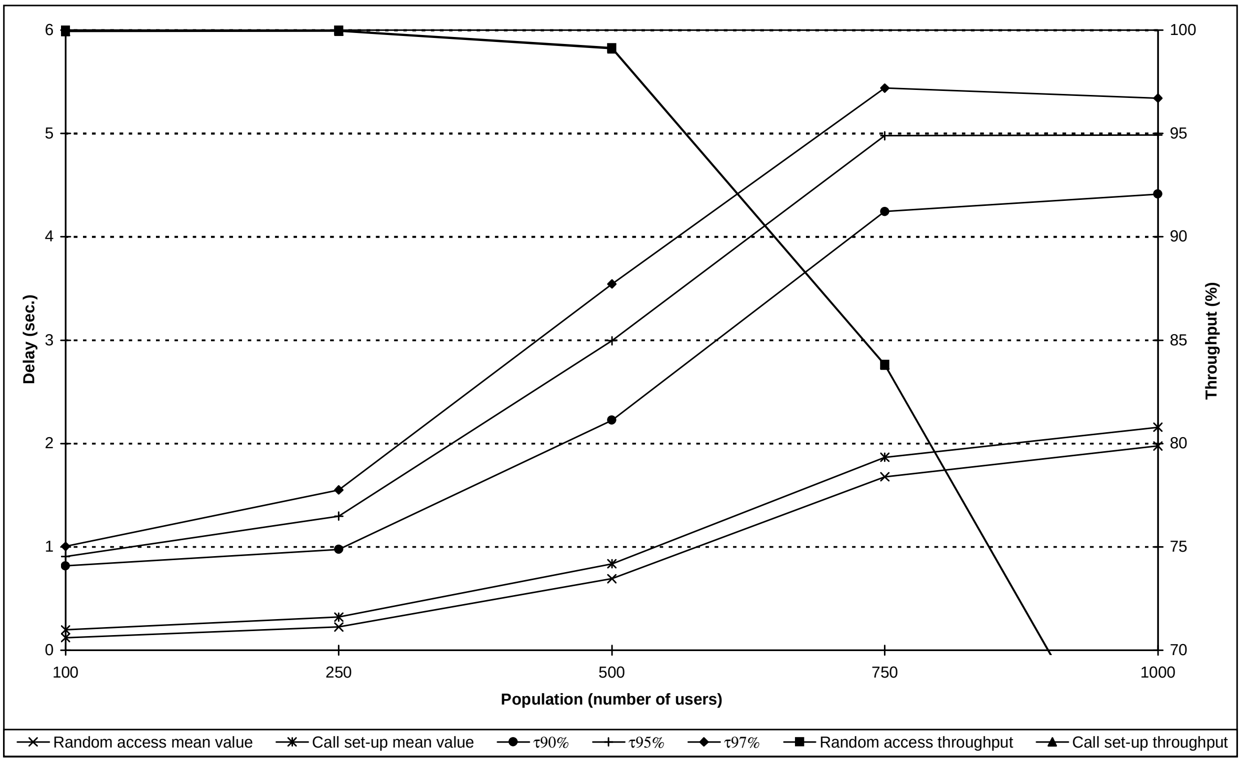

Figure 95: Individual M-M voice or circuit data call performance for the reference scenario (throughput curves overlap)

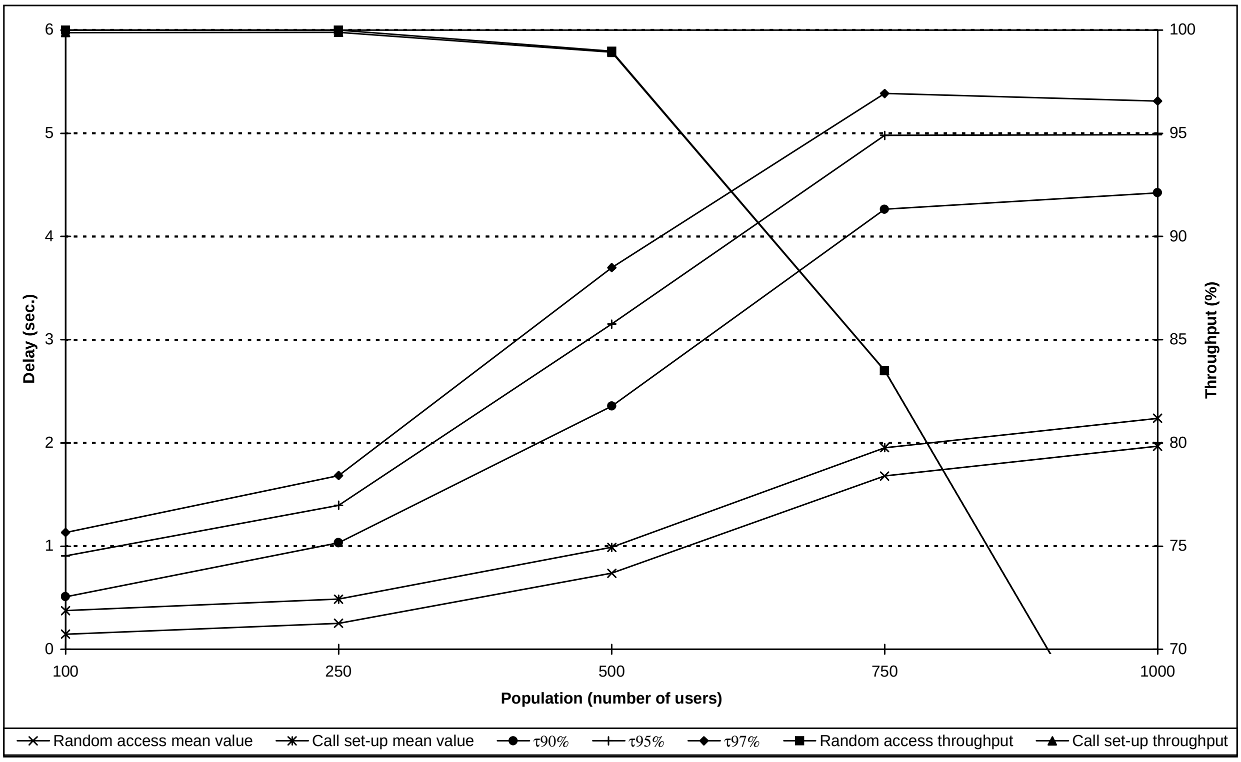

Figure 96: Individual M-F short data transmission performance for the reference scenario (throughput curves overlap)

5.5.2.5.2 Influence of random access retry timer

The following analysis aims to study the influence of the value of the random access retry timer on the overall performance. This parameter, WT, (see EN 300 392-2 [i.2]) is sent in the ACCESS DEFINE PDU from the network to the MSs. It is the number of TDMA frames that an accessing MS waits before beginning a new access re-transmission. Standard values are in the range 1-15.

Figures have been obtained for different values of WT parameter (1-5-10-15).

Figures 97 and 98 report respectively the mean value of delay and the throughput of the random access delay.

Figures 99 and 100 show the mean value of delay and the throughput of the individual M-M circuit switched call set-up procedure. Figure 101 reports the $\tau_{95\ \%}$ boundary delay for the same procedure.

Figures 102 and 103 show the mean value of delay and the throughput of the individual M-F short data transmission procedure. Figure 104 reports the $\tau_{95\ \%}$ boundary delay for the same procedure.

Performance of different configuration show that only the random access delay is affected by the parameter WT. Call set-up delays are simply a shifted copy of the random access delay. The difference is bigger in case of high traffic load because of the high probability of re-transmissions.

It is important to observe that these results have been evaluated for a stationary system. In case of traffic peaks these values can change due to transitorial phenomena. For this reason, when a suitable value of WT has to be chosen for a particular cell, these transitorial phenomena have to be taken into account.

Table 14 reports the number of TCHs allocated to the simulated cell in order to give a low blocking probability for all services. Two categories of services are reported depending on the number of channels required. The reported blocking probability values are not dependent on the particular value of parameter WT.

Table 14: Blocking probability for the simulated configurations

Number of users	Number of allocated TCHs (Frequency Carriers)	Blocking probability of services requesting two TCHs	Blocking probability of services requesting one TCH
100	7 (2)	2 %	0,5 %
250	11 (3)	4 %	1,5 %
500	19 (5)	2 %	1 %
750	23 (6)	2,5 %	1 %
1 000	23 (6)	5 %	2 %

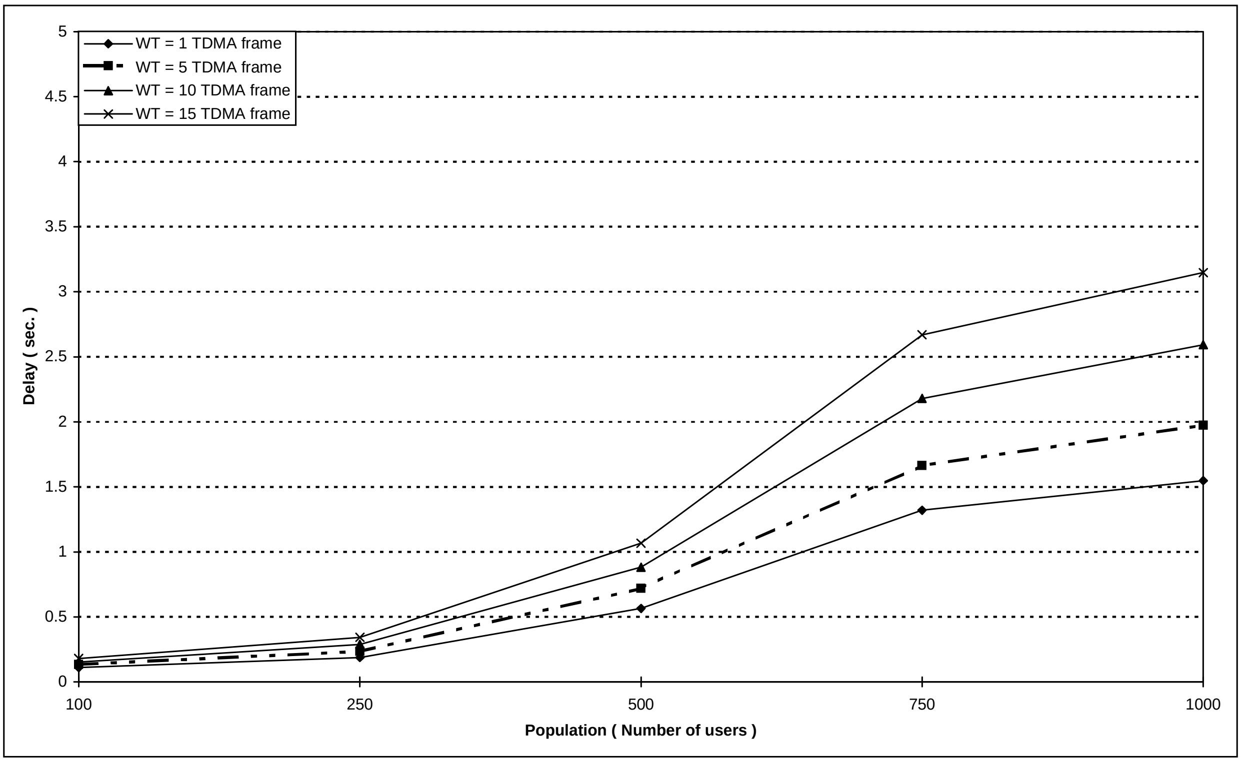

Figure 97: Random access mean delay versus number of users for different values of the retransmission timer WT

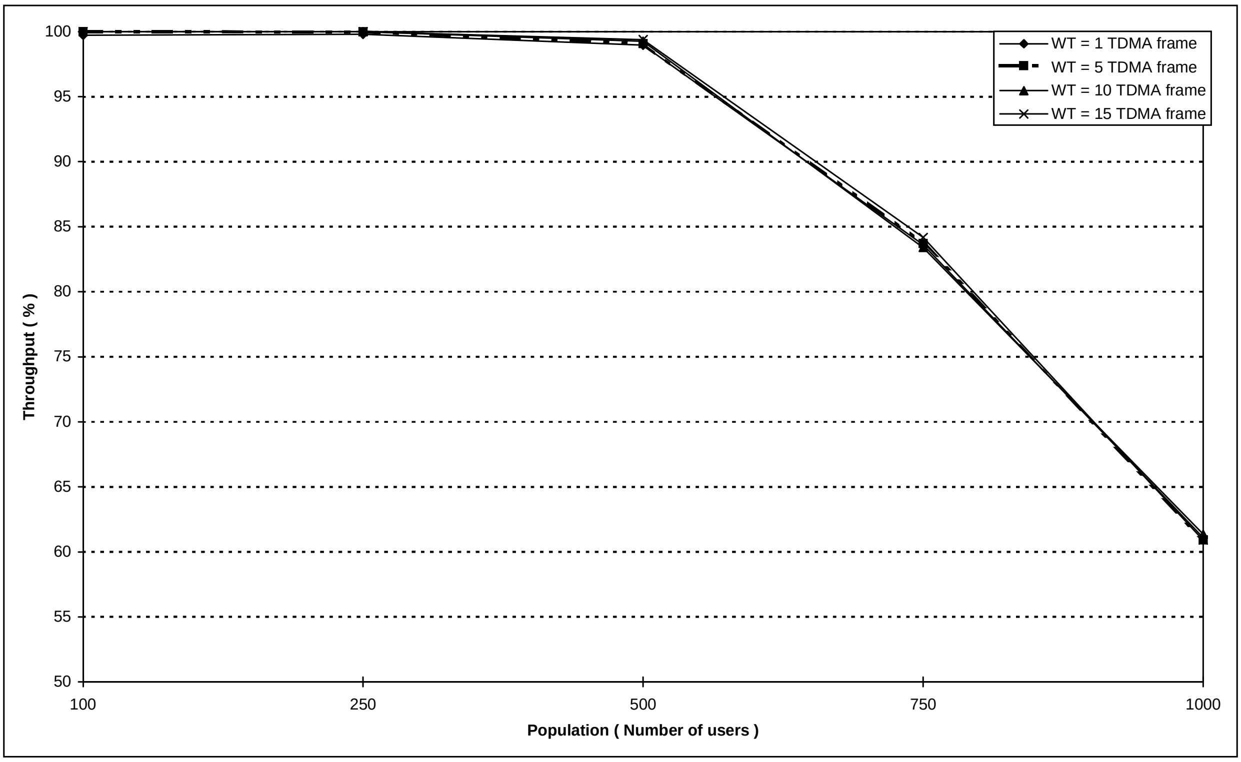

Figure 98: Random access throughput versus number of users for different values of the retransmission timer WT (all curves overlap)

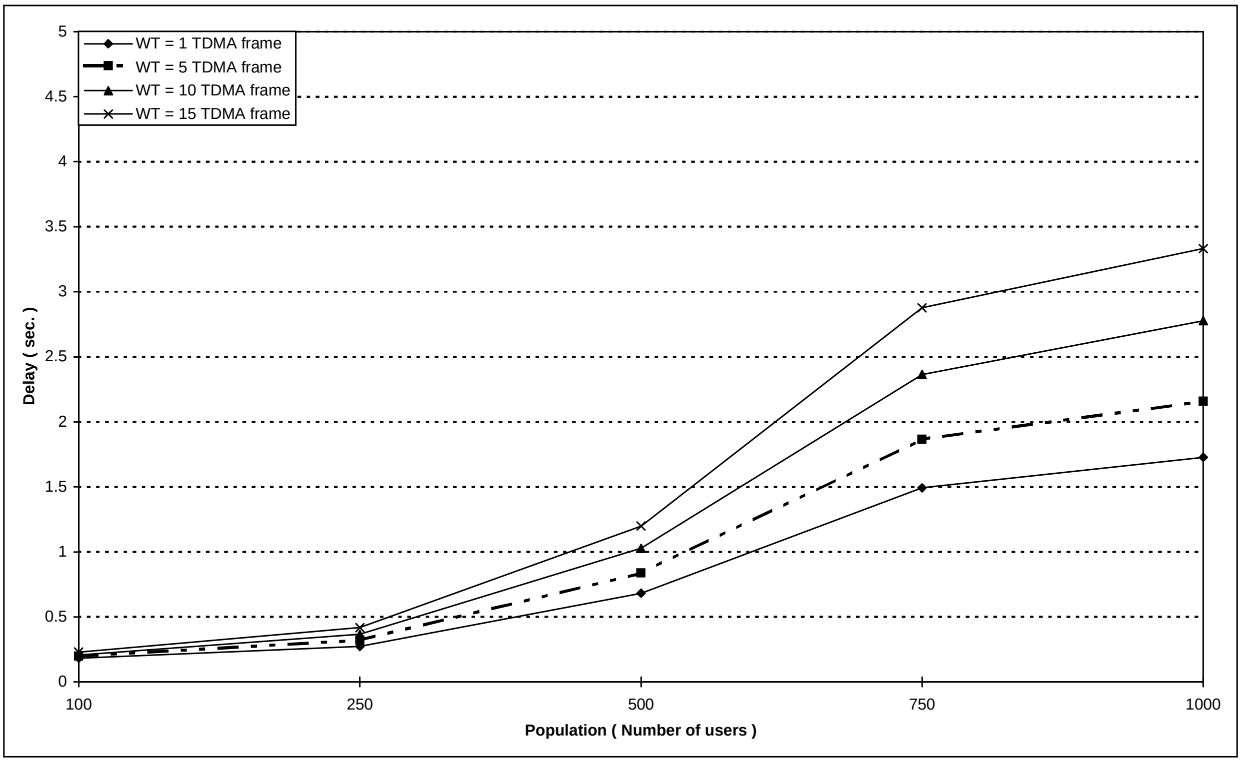

Figure 99: Individual M-M circuit switched call set-up mean delay versus number of users for different values of the retransmission timer WT

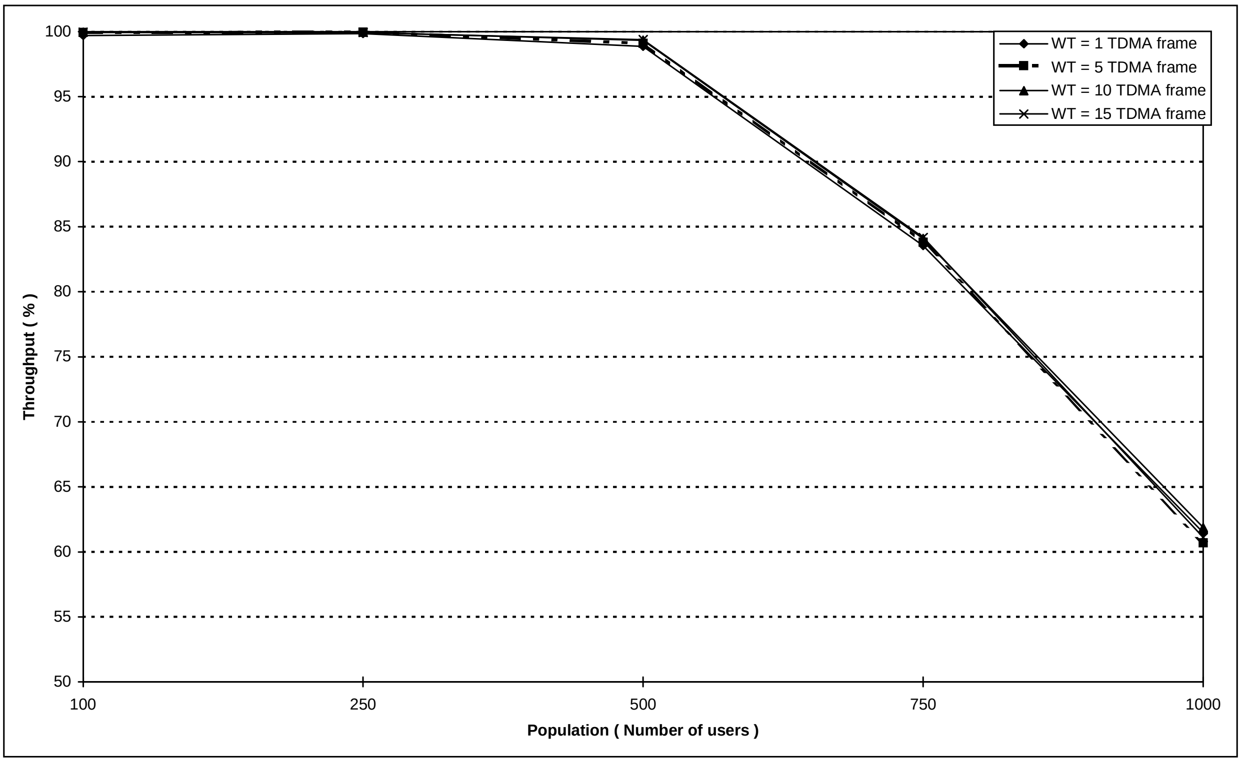

Figure 100: Individual M-M circuit switched call set-up throughput versus number of users for different values of the retransmission timer WT (all curves overlap)

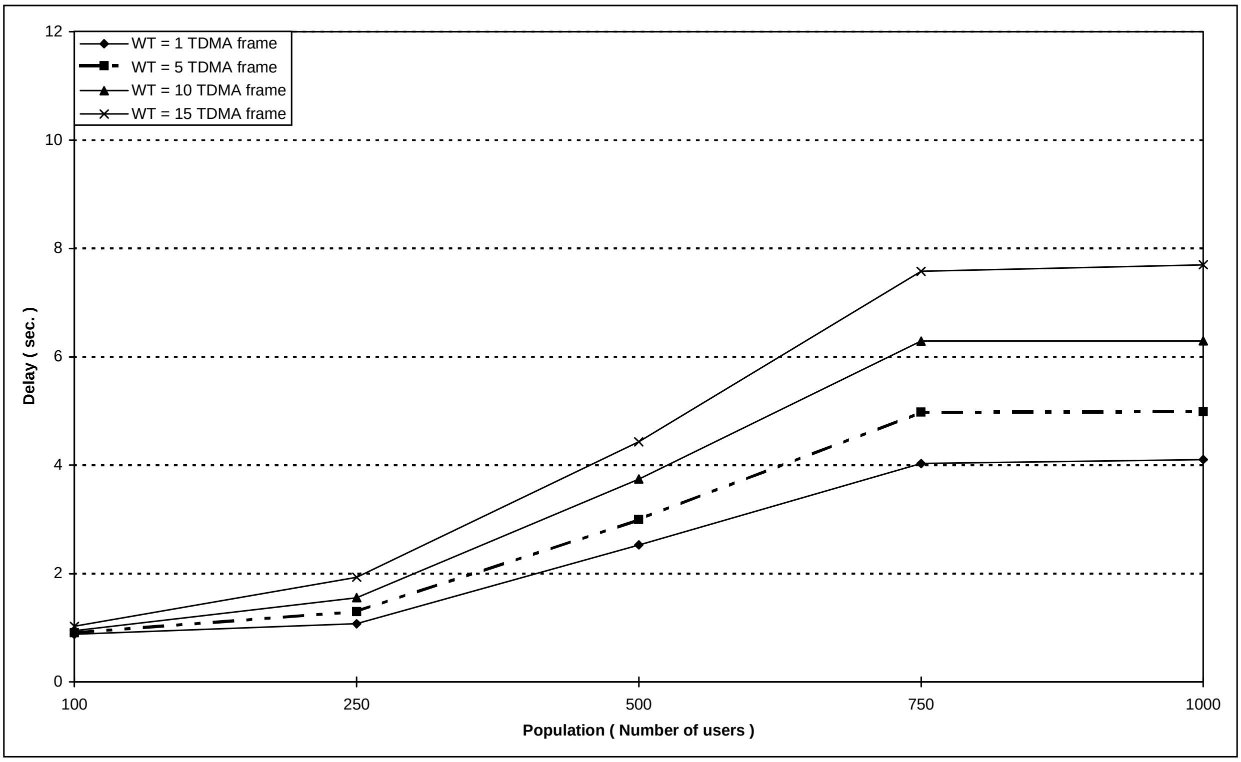

Figure 101: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users for different values of the retransmission timer WT

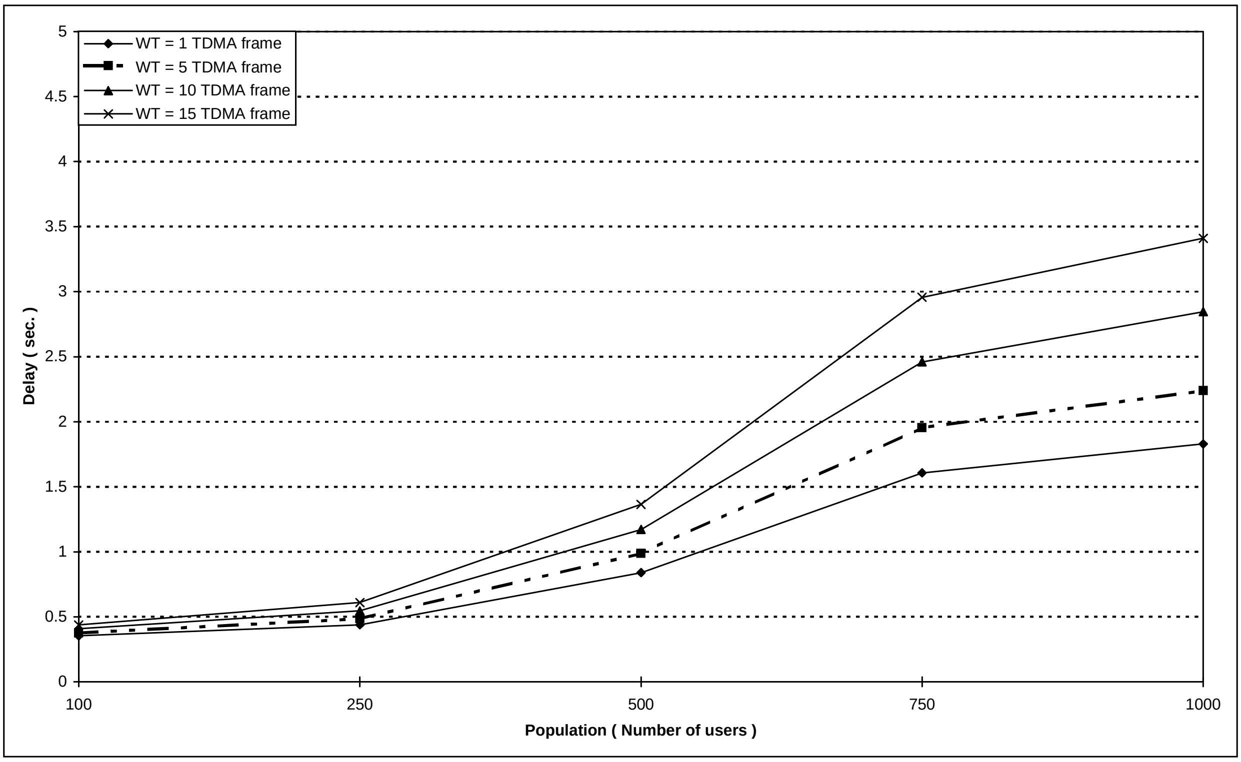

Figure 102: Individual M-F short data transmission mean delay versus number of users for different values of the retransmission timer WT

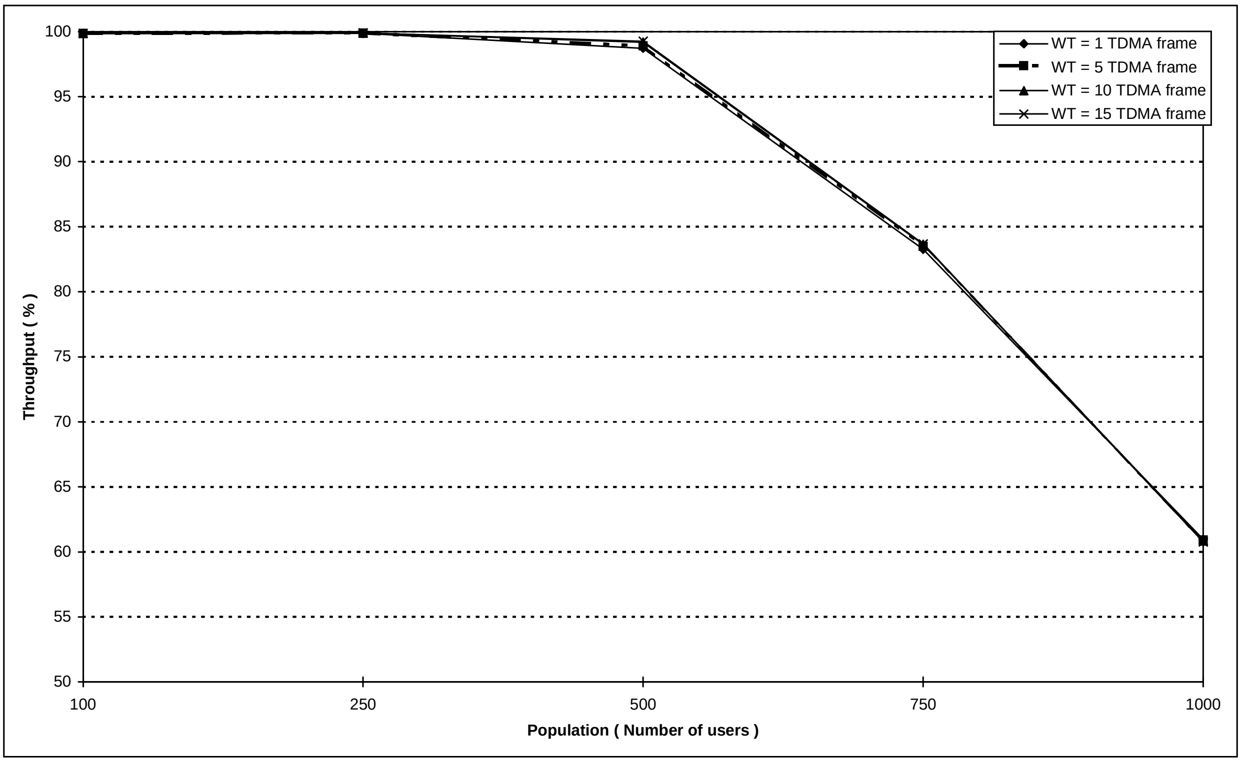

Figure 103: Individual M-F short data transmission throughput versus number of users for different values of the retransmission timer WT (all curves overlap)

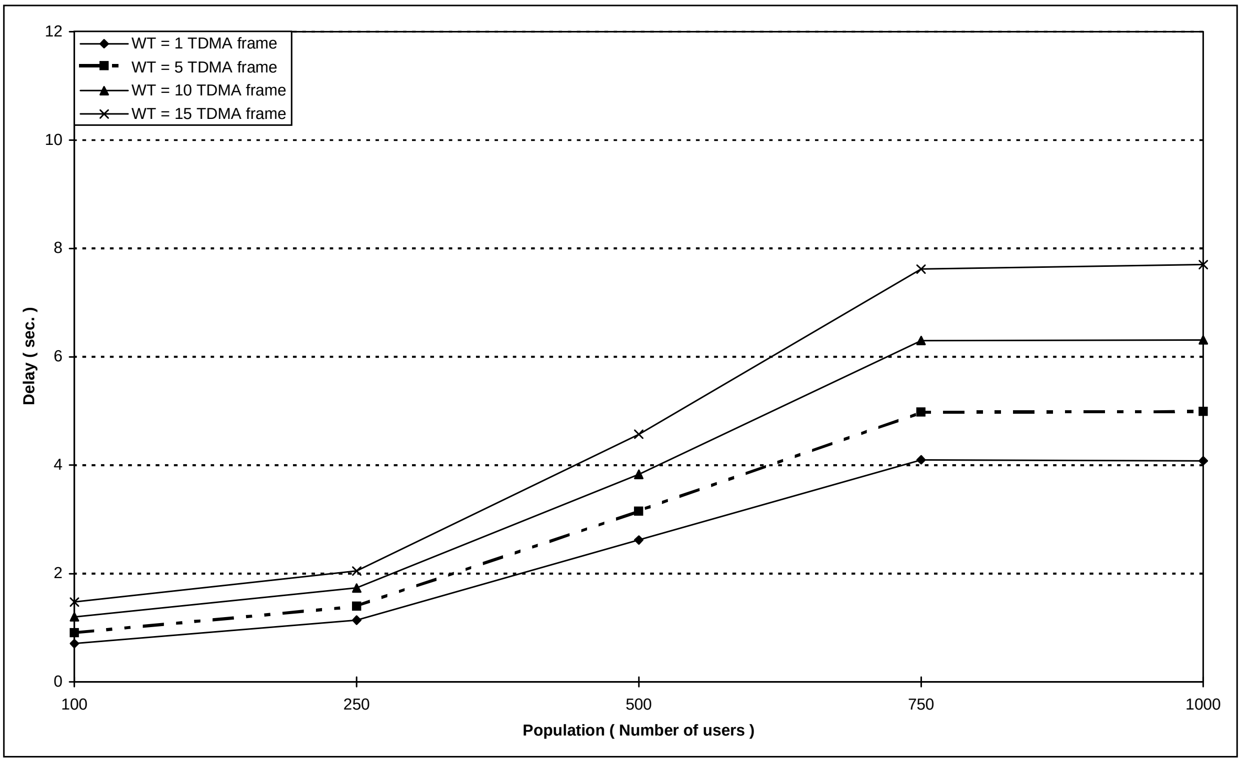

Figure 104: Individual M-F short data transmission $\tau_{95\ \%}$ boundary delay versus number of users for different values of the retransmission timer WT

5.5.2.5.3 Influence of random access maximum number of re-transmissions (Nu)

The following analysis aims to study the influence of the value of the maximum number of re-transmissions allowed for random access on the overall performance. This parameter, N_u, (see EN 300 392-2 [i.2]) is sent in the ACCESS DEFINE PDU from the network to the MSs. Standard values are in the range 0-15.

Figures have been obtained for different values of N_u parameter (0-5-10-15).

Figures 105 and 106 report respectively the mean value of delay and the throughput of the random access delay.

Figures 107 and 108 show the mean value of delay and the throughput of the individual M-M circuit switched call set-up procedure. Figure 109 reports the $\tau_{95\ \%}$ boundary delay for the same procedure.

Figures 110 and 111 show the mean value of delay and the throughput of the individual M-F short data transmission procedure. Figure 112 reports the $\tau_{95\ \%}$ boundary delay for the same procedure.

Both delay and throughput of random access procedure (and consequently of call set-up procedures) are sensitive to a change of the maximum number of random access re-transmissions (Nu). The difference in delays becomes evident when re-transmissions are more frequent. The Nu parameter represents in this case a limitation for both delay and throughput. Higher is Nu and higher are delays but also throughput.

It is interesting to observe the case with Nu = 0 (no re-transmissions). The reported delays are almost constant; when the random access is successfully performed only one transmission attempt is made, independently by the total amount of traffic. The correspondent throughput is linearly linked to the offered traffic. The overall performance for Nu = 0 is poor if compared with the reference configuration.

It is important to observe that these results have been evaluated for a stationary system. In case of traffic peaks these values can change due to transitorial phenomena. For this reason, when a suitable value of Nu has to be chosen for a particular cell, these transitorial phenomena have to be taken into account.

Table 15 reports the number of TCHs allocated to the simulated cell in order to give a low blocking probability for all services. Two categories of services are reported depending on the number of channels required. The reported blocking probability values are not dependent on the particular value of parameter Nu.

Table 15: Blocking probability for the simulated configurations

Number of users	Number of allocated TCHs (Frequency Carriers)	Blocking probability of services requesting two TCHs	Blocking probability of services requesting one TCH
100	7 (2)	2 %	0,5 %
250	11 (3)	4 %	1,5 %
500	19 (5)	2 %	1 %
750	23 (6)	2,5 %	1 %
1 000	23 (6)	5 %	2 %

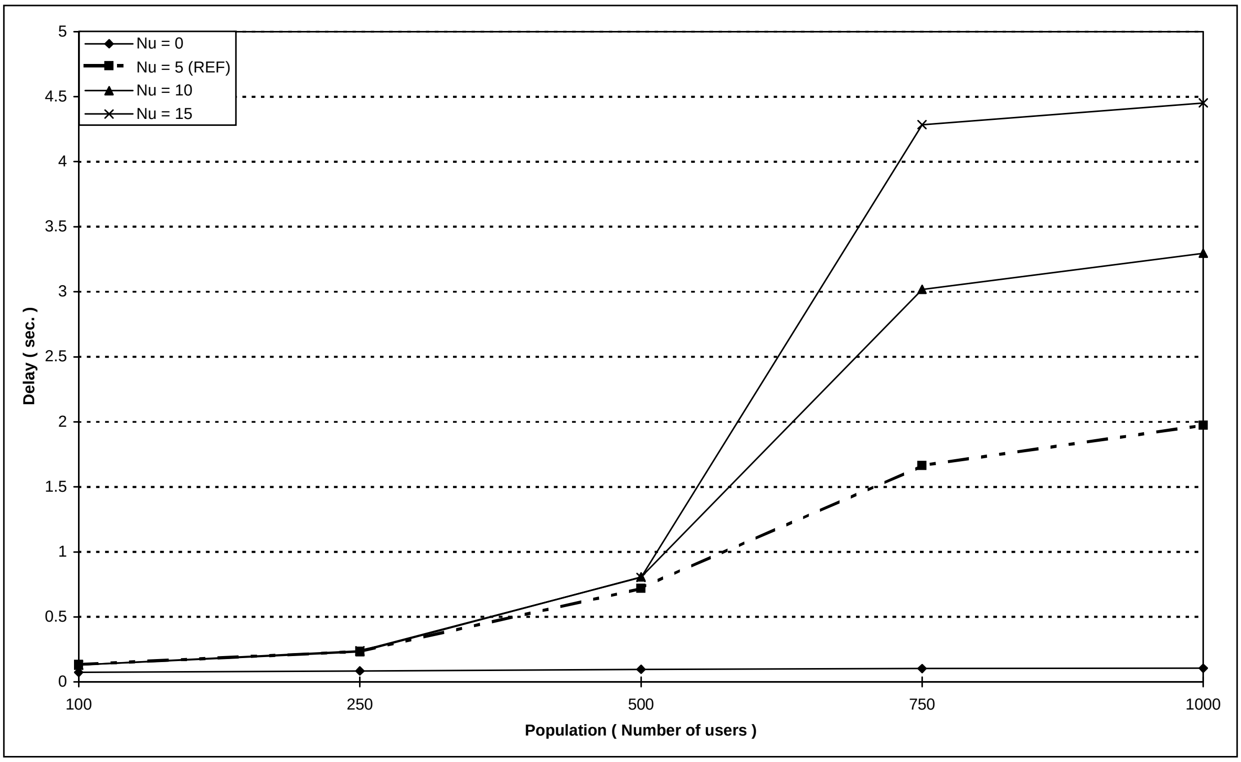

Figure 105: Random access mean delay versus number of users for different values of the maximum number of re-transmissions in the random access Nu

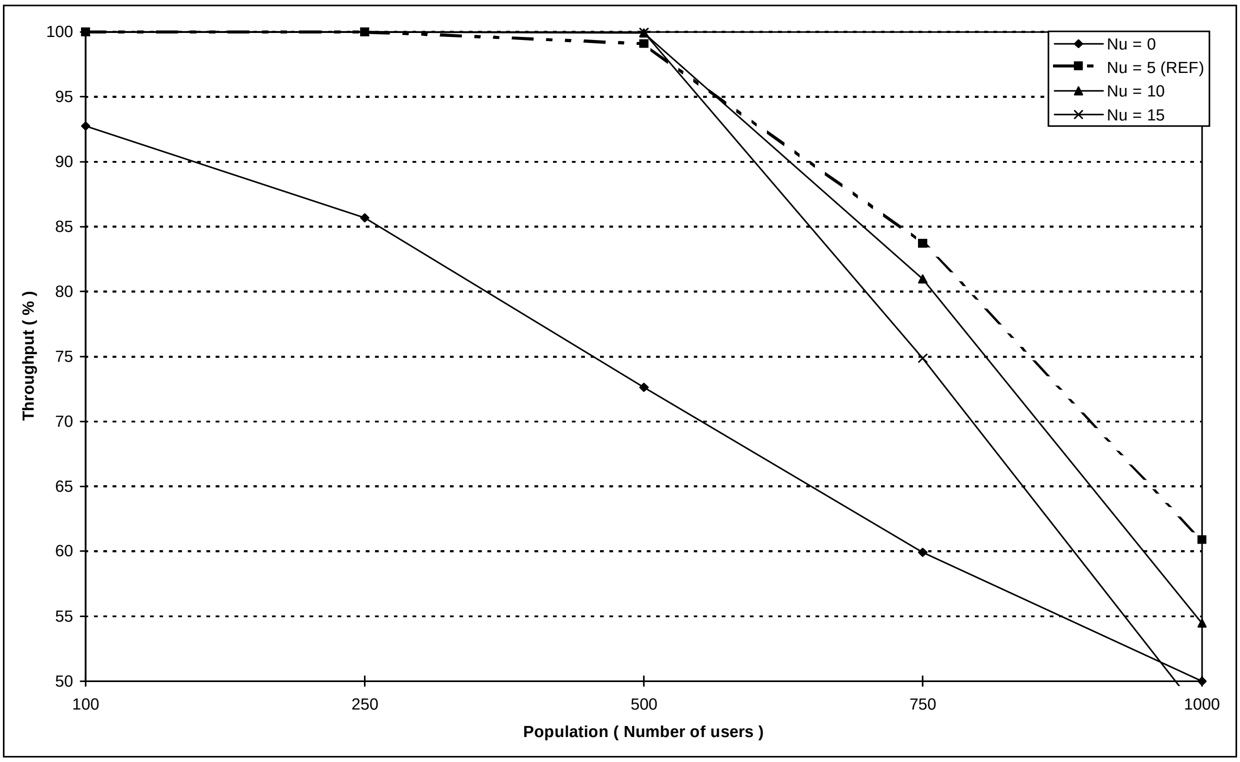

Figure 106: Random access throughput versus number of users for different values of the maximum number of re-transmissions in the random access Nu

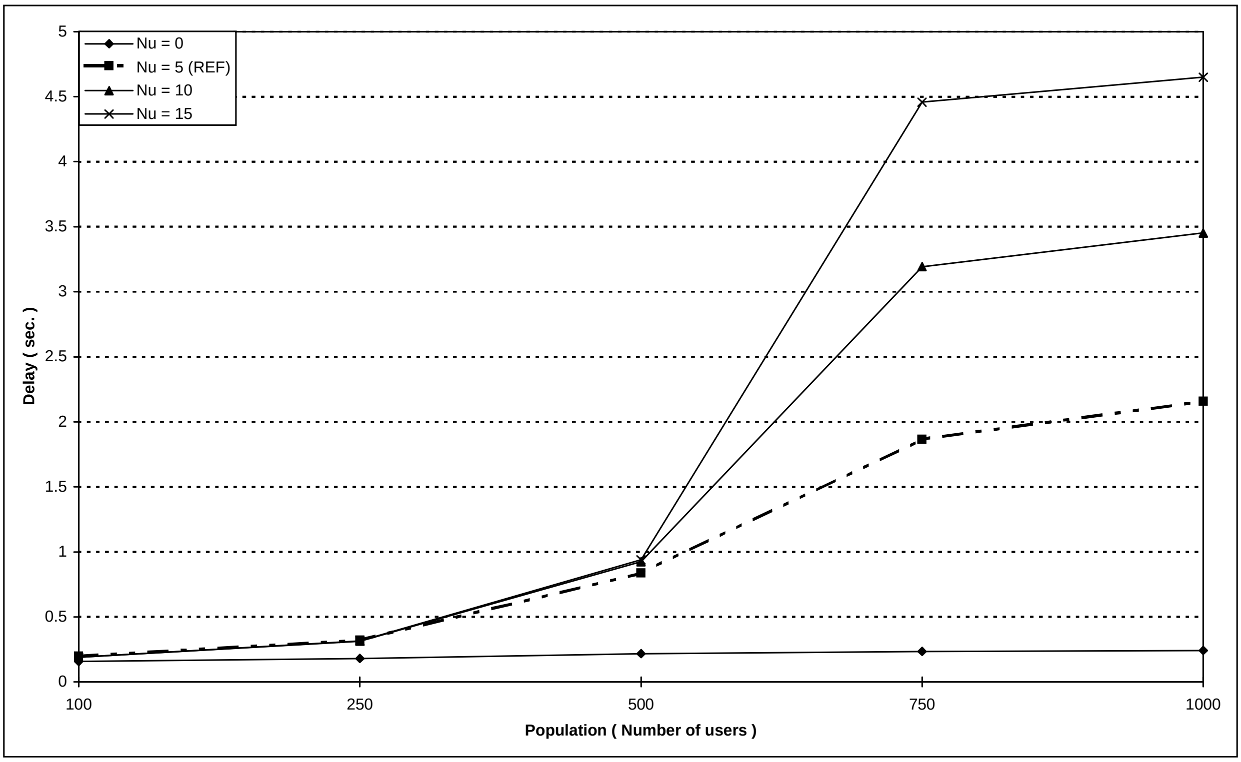

Figure 107: Individual M-M circuit switched call set-up mean delay versus number of users for different values of the maximum number of re-transmissions in the random access Nu

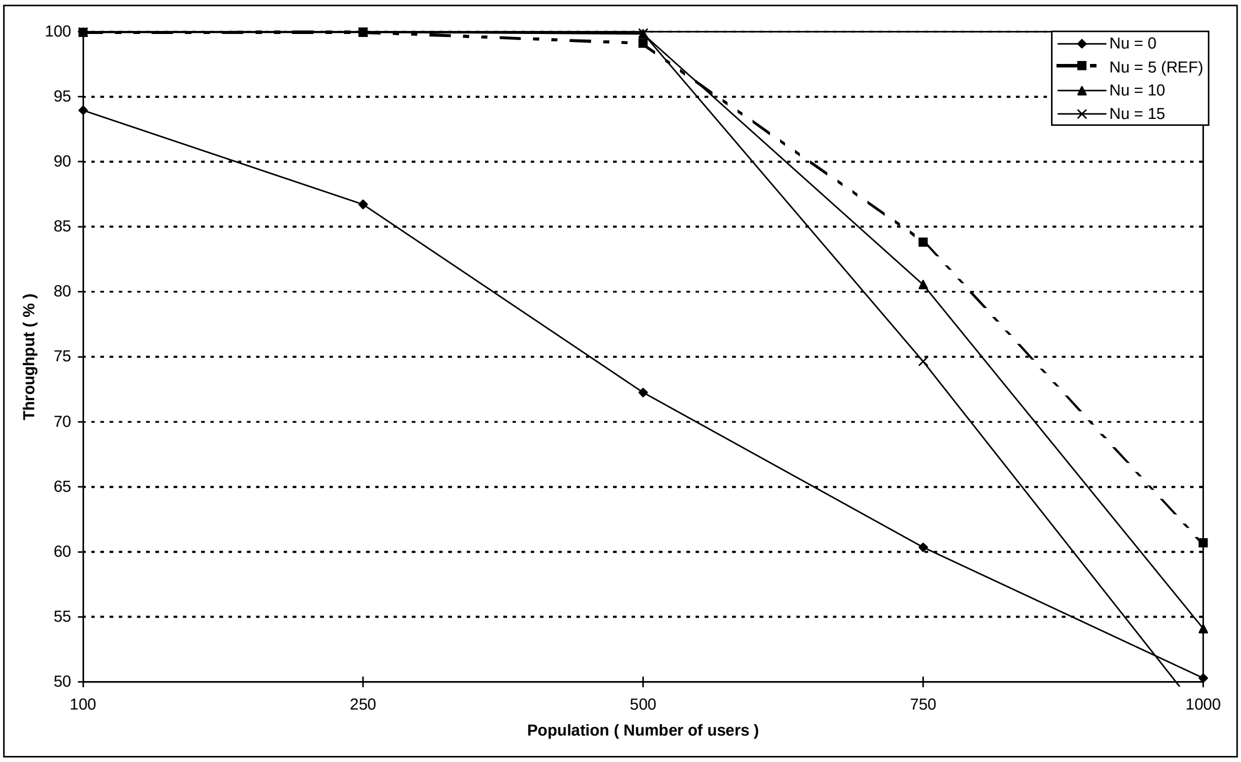

Figure 108: Individual M-M circuit switched call set-up throughput versus number of users for different values of the maximum number of re-transmissions in the random access Nu

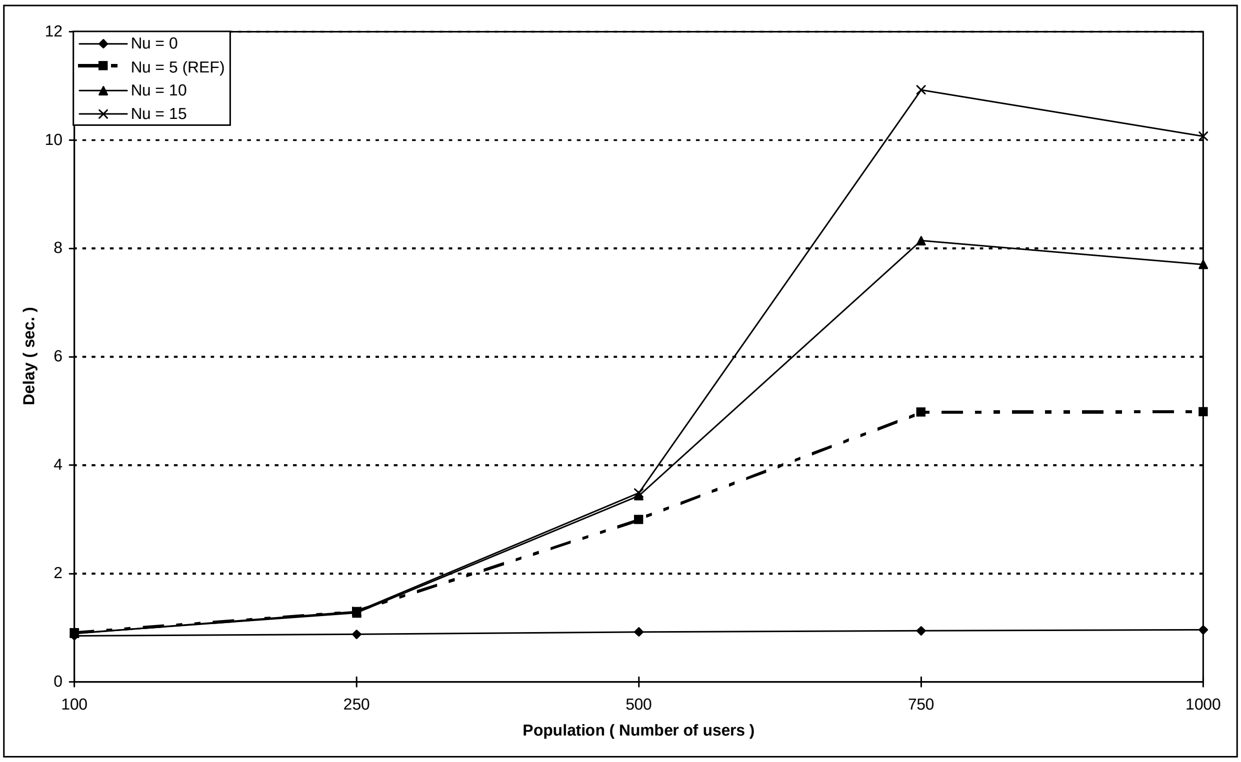

Figure 109: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users for different values of the maximum number of re-transmissions in the random access Nu

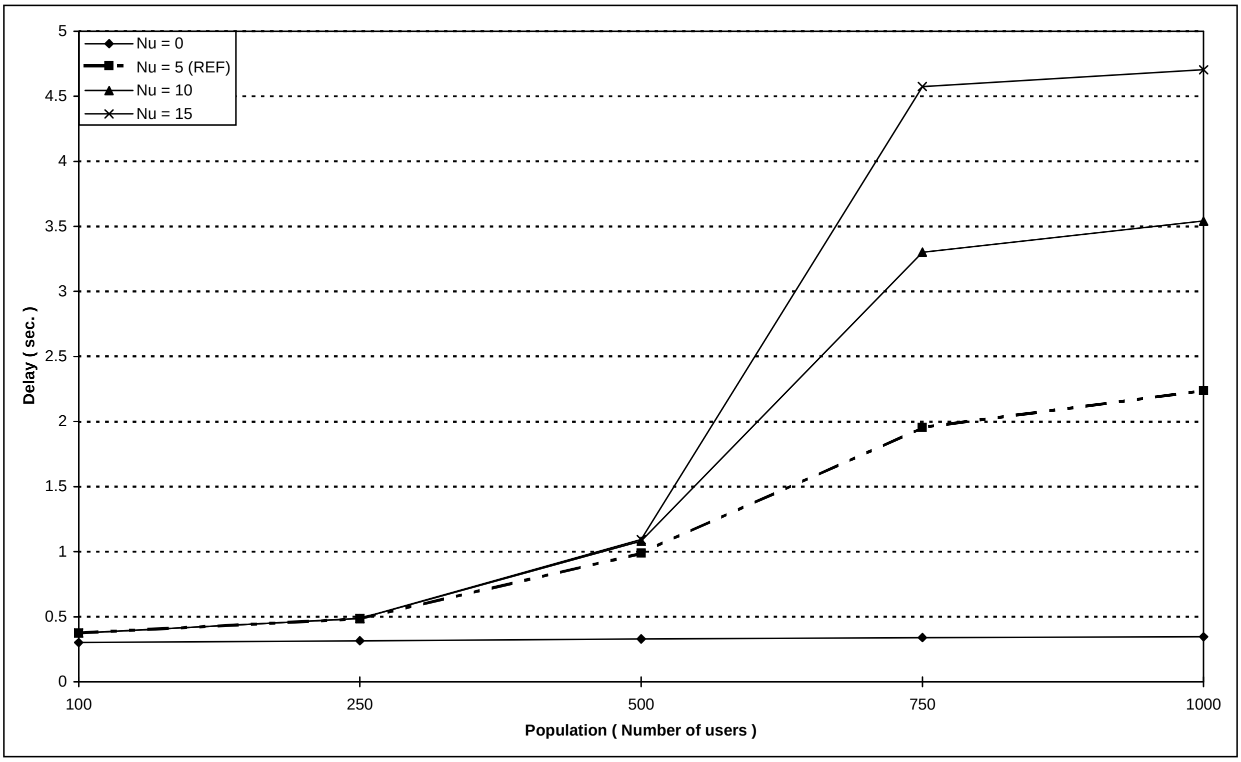

Figure 110: Individual M-F short data transmission mean delay versus number of users for different values of the maximum number of re-transmissions in the random access Nu

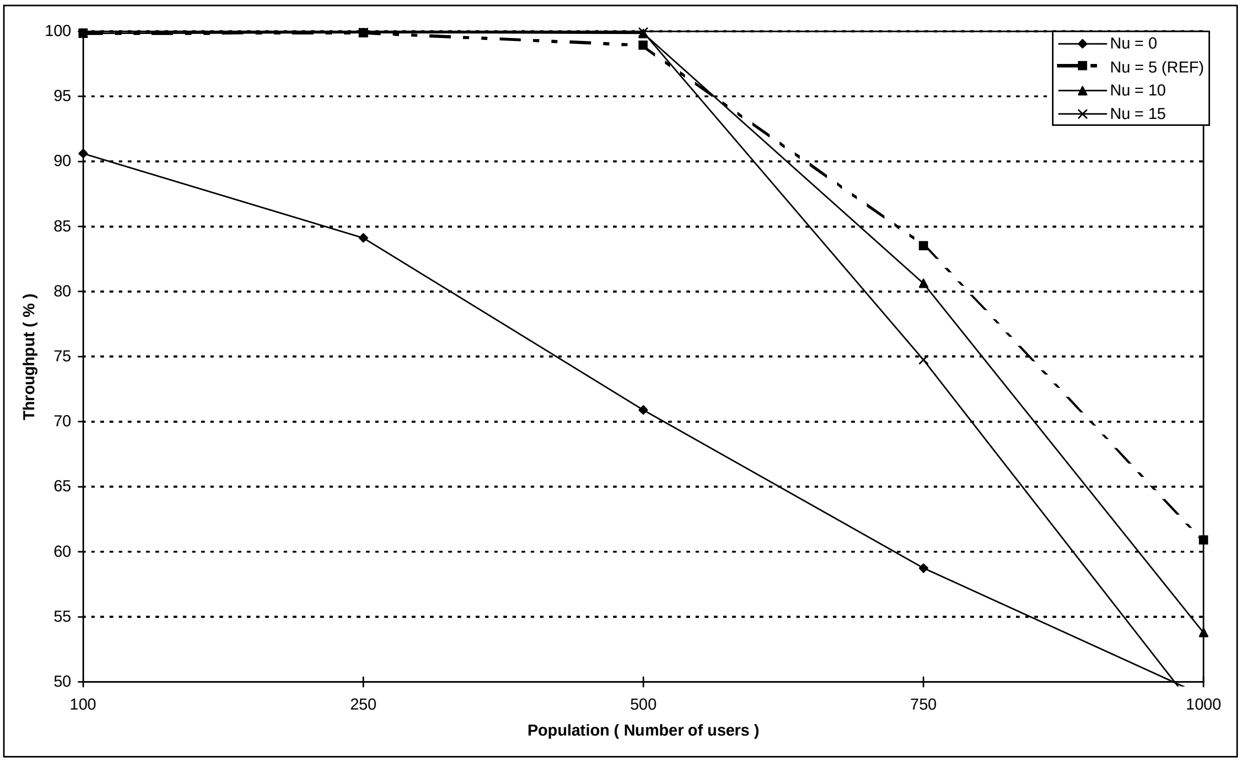

Figure 111: Individual M-F short data transmission throughput versus number of users for different values of the maximum number of re-transmissions in the random access Nu

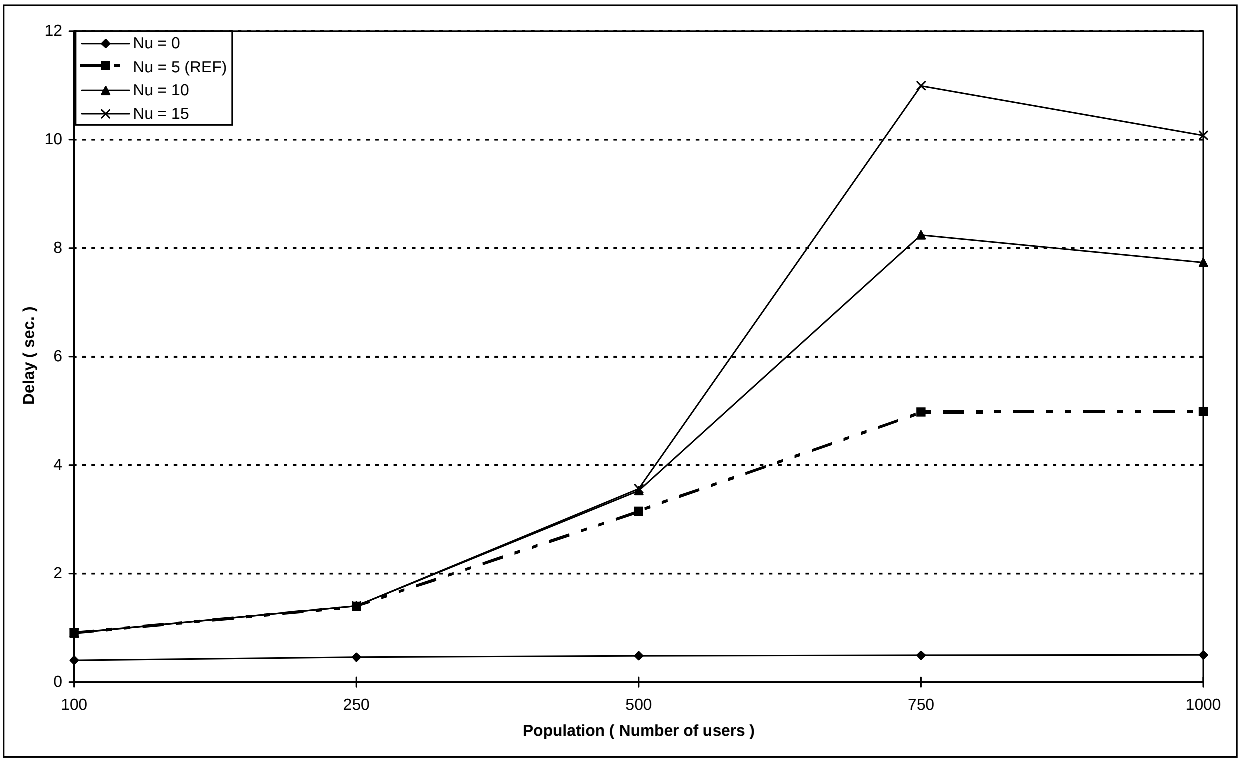

Figure 112: Individual M-F short data transmission $\tau_{95\,\%}$ boundary delay versus number of users for different values of the maximum number of re-transmissions in the random access Nu

5.5.2.5.4 Influence of random access frame length

The following analysis aims to study the influence of the value of the random access frame length on the overall performance. This parameter is the dimension of the random access frame (a set of random access opportunities) and consists of the association of two other parameters:

1) the base frame length sent in the ACCESS ASSIGN PDU (logical channel AACH) in the first access opportunity (see EN 300 392-2 [i.2]) of the random access frame;

2) the frame length factor, that is sent in the ACCESS DEFINE PDU.

The access frame length is given by the product of the two parameters. When a new random access attempt has to take place, the MS draws lots the transmission slot within this frame (see EN 300 392-2 [i.2]).

Standard values are in the range 0-124. Not all values are allowed (see EN 300 392-2 [i.2], clause 21.4.7).

Figures have been obtained for different values of frame length (1-10-40-80-124).

Figures 113 and 114 report respectively the mean value of delay and the throughput of the random access delay.

Figures 115 and 116 show the mean value of delay and the throughput of the individual M-M circuit switched call set-up procedure. Figure 117 reports the $\tau_{95\,\%}$ boundary delay for the same procedure.

Figures 118 and 119 show the mean value of delay and the throughput of the individual M-F short data transmission procedure. Figure 120 reports the $\tau_{95\,\%}$ boundary delay for the same procedure.

Both random access delay and throughput (and consequently call set-up delays and throughput for circuit calls and for short data transmission) are sensitive to the access frame length. Longer is the access frame, longer is the random access delay and higher is the throughput. Because of the random access procedure definition (see EN 300 392-2 [i.2], clause 23.5) a wide access frame reduces the probability of collision for access re-transmissions (then higher throughput), but delays are increased.

In the reported figures the difference in delays becomes higher and higher for increasing values of traffic. This can be explained with the presence of short data transmission service; with high traffic loads, the percentage of reserved uplink slots on the control channel is high. As a consequence, access opportunities are few and the effective duration of an access frame increases with traffic load.

It is important to observe that these results have been evaluated for a stationary system. In case of traffic peaks these values can change due to transitorial phenomena. For this reason, when a suitable value of the access frame length has to be chosen for a particular cell, these transitorial phenomena have to be taken into account. The unstable behaviour of delays shows that in case of traffic peaks the delays can reach very high values. It is then important to foresee a management procedure that changes the frame length in order to minimize the impact of traffic peaks.

Table 16 reports the number of TCHs allocated to the simulated cell in order to give a low blocking probability for all services. Two categories of services are reported depending on the number of channels required. The reported blocking probability values are not dependent on the particular value of the random access frame.

Table 16: Blocking probability for the simulated configurations

Number of users	Number of allocated TCHs (Frequency Carriers)	Blocking probability of services requesting two TCHs	Blocking probability of services requesting one TCH
100	7 (2)	2 %	0,5 %
250	11 (3)	4 %	1,5 %
500	19 (5)	2 %	1 %
750	23 (6)	2,5 %	1 %
1 000	23 (6)	5 %	2 %

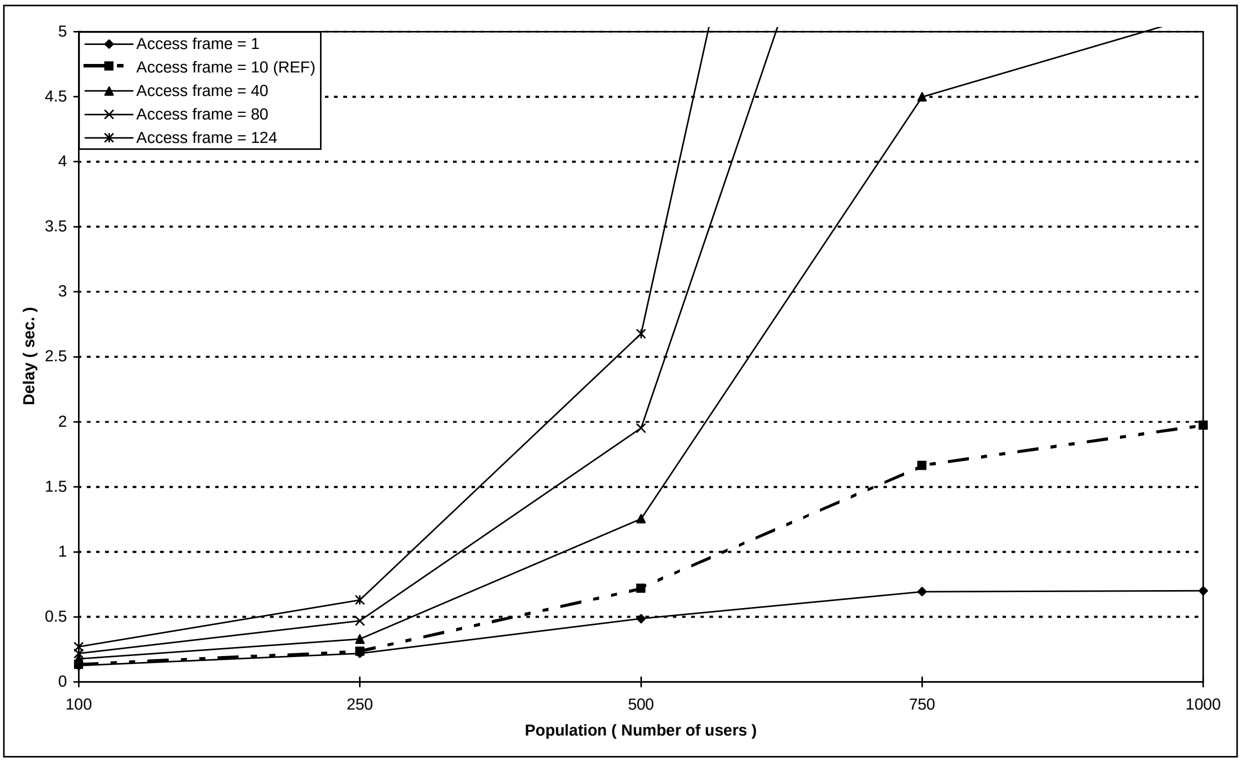

Figure 113: Random access mean delay versus number of users for different values of the random access frame length

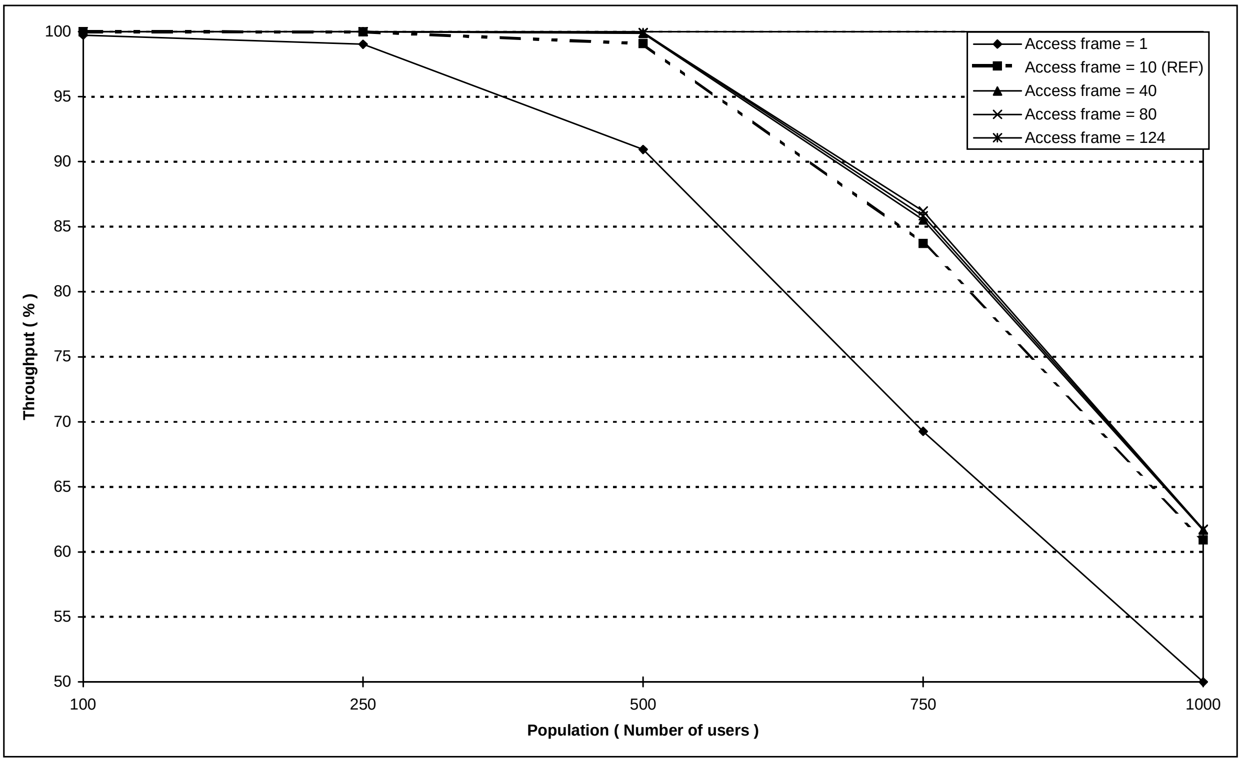

Figure 114: Random access throughput versus number of users for different values of the random access frame length

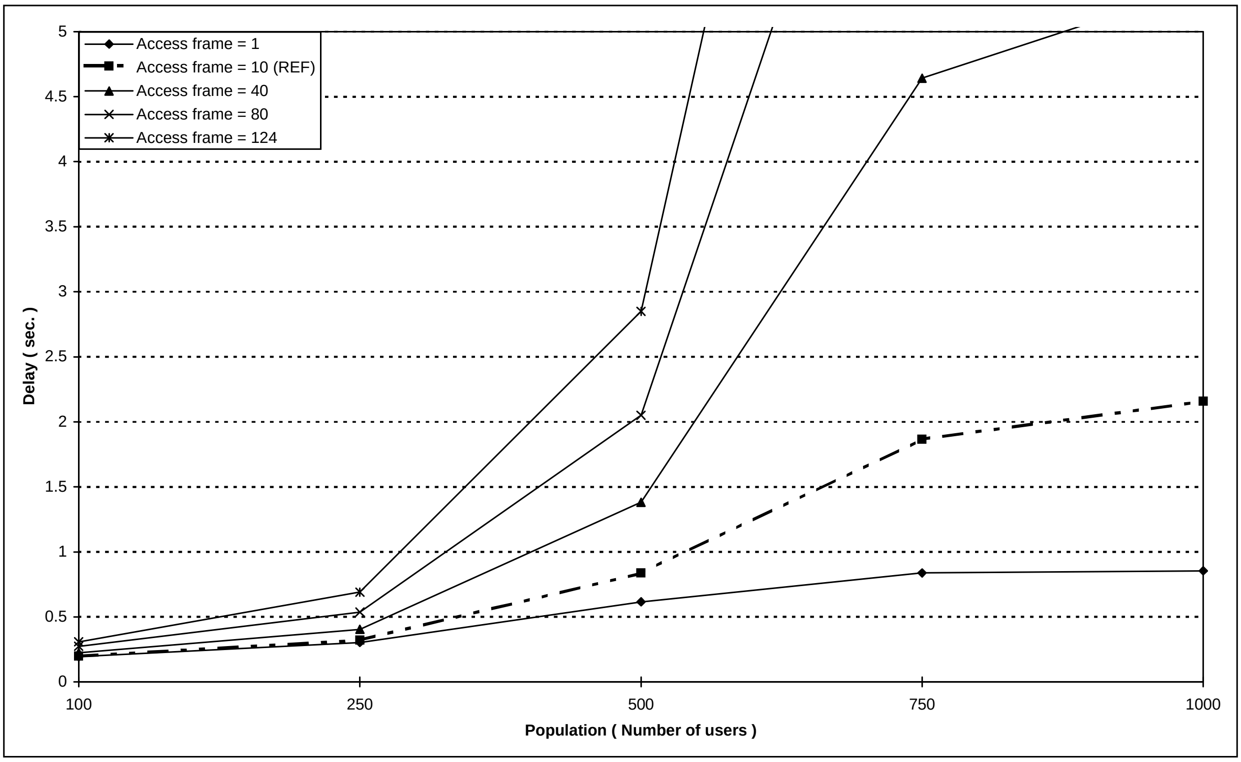

Figure 115: Individual M-M circuit switched call set-up mean delay versus number of users for different values of the random access frame length

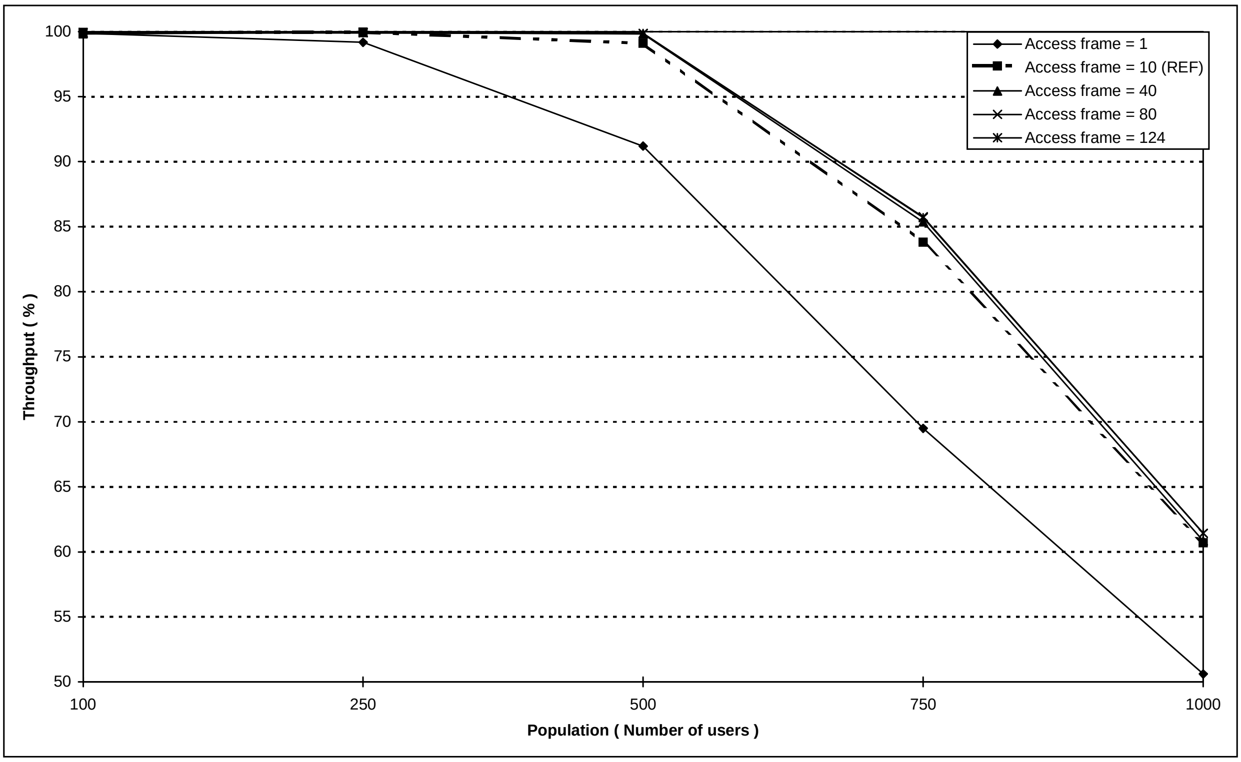

Figure 116: Individual M-M circuit switched call set-up throughput versus number of users for different values of the random access frame length

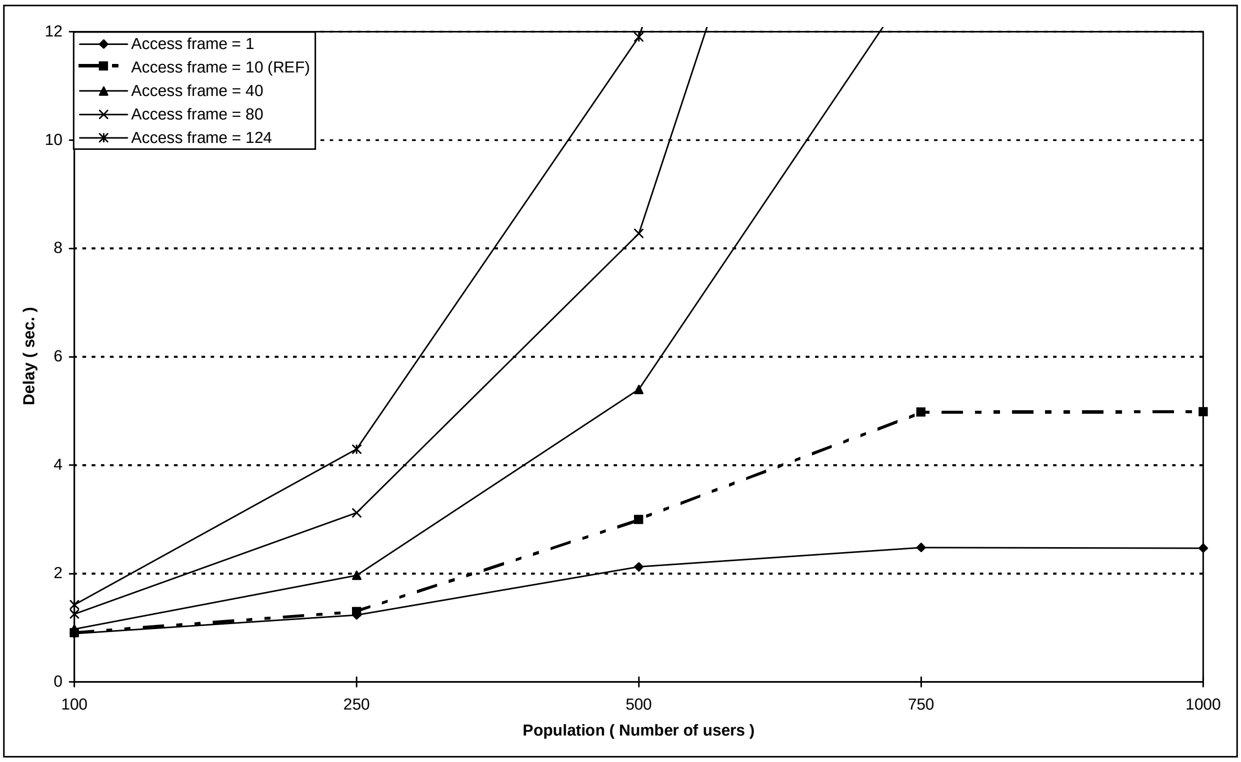

Figure 117: Individual M-M circuit switched call set-up $\tau_{95\ \%}$ boundary delay versus number of users for different values of the random access frame length

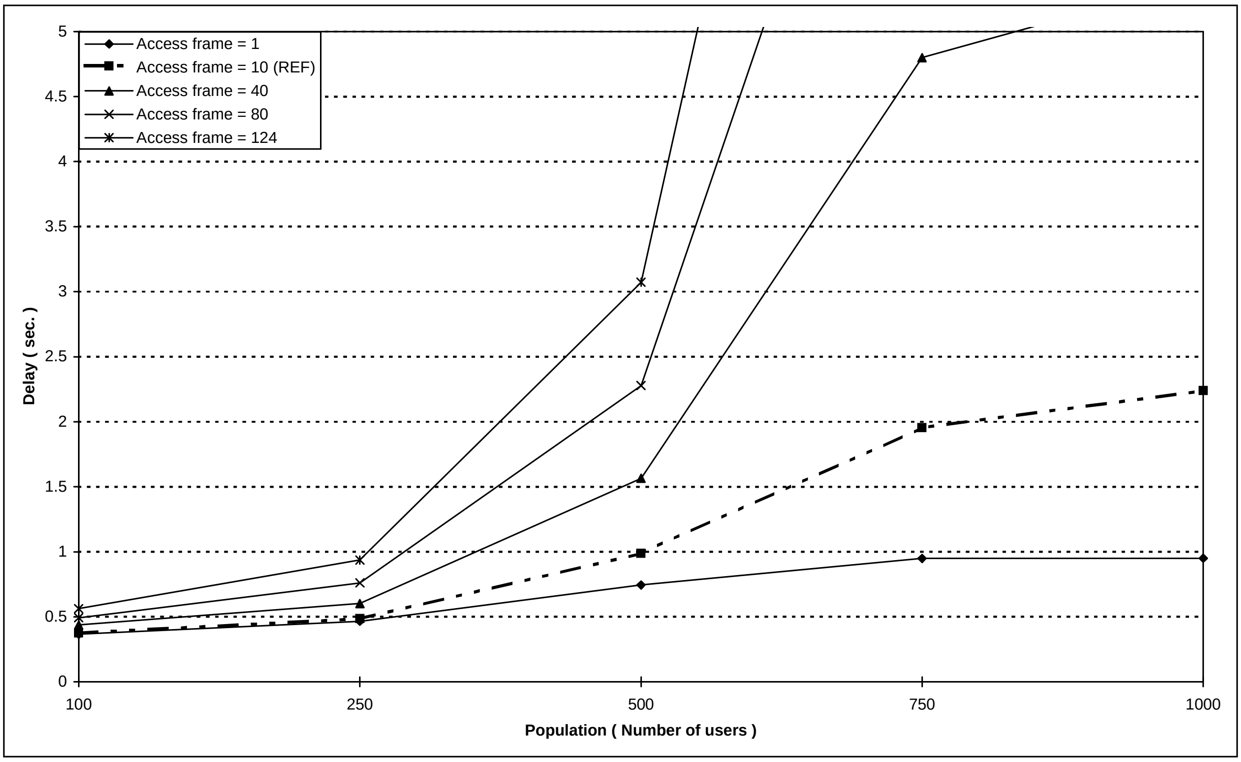

Figure 118: Individual M-F short data transmission mean delay versus number of users for different values of the random access frame length

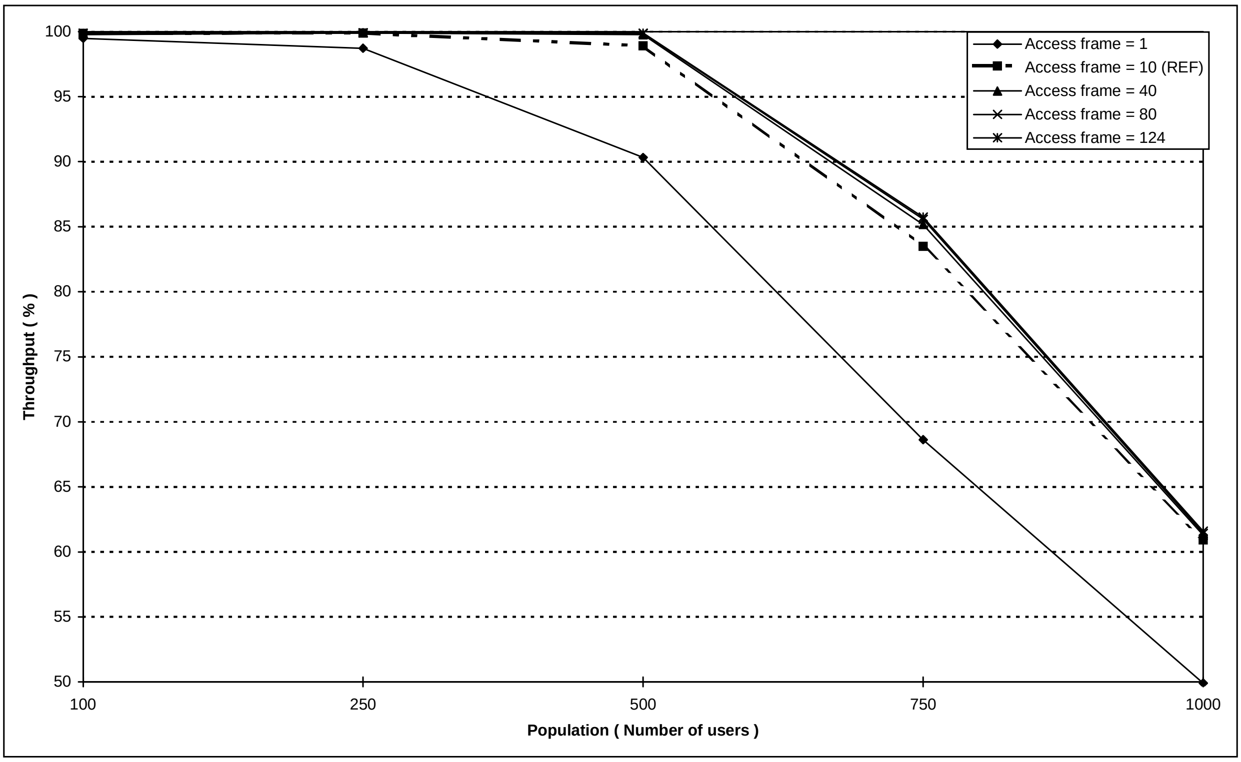

Figure 119: Individual M-F short data transmission throughput versus number of users for different values of the random access frame length

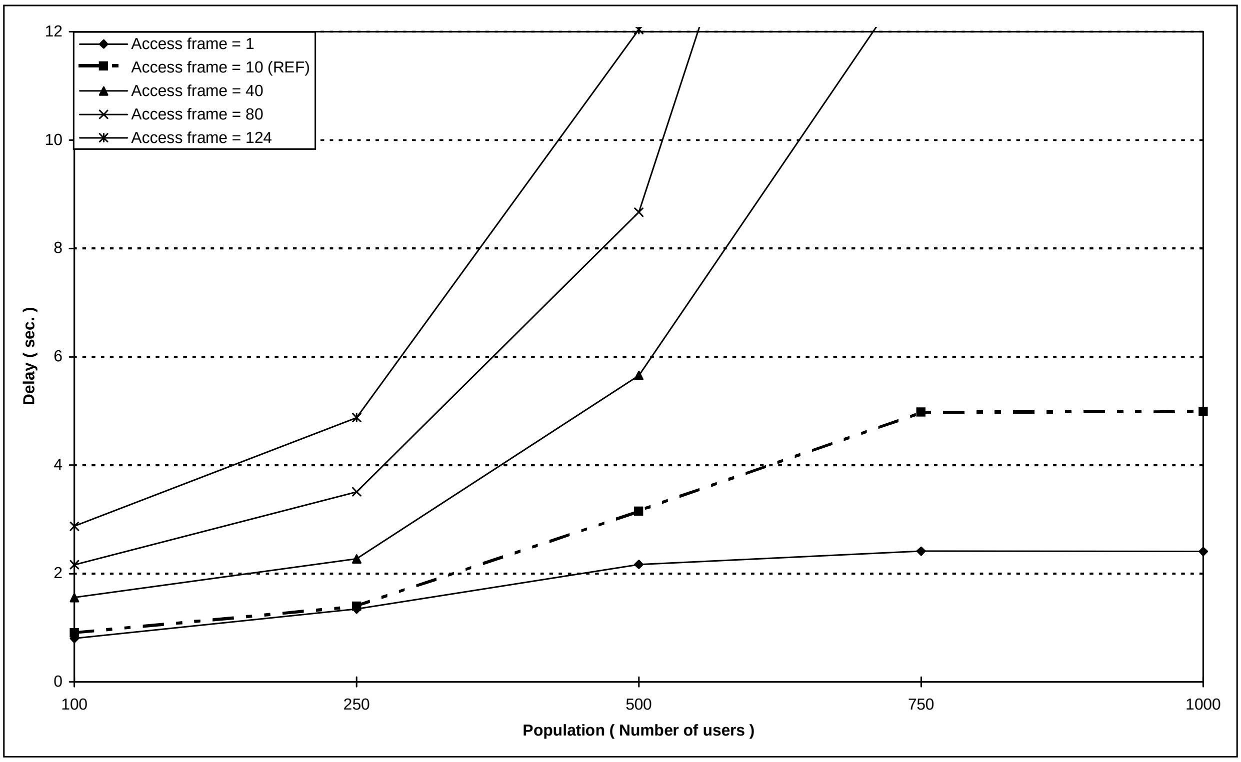

Figure 120: Individual M-F short data transmission $\tau_{95\,\%}$ boundary delay versus number of users for different values of the random access frame length

5.5.2.5.5 Influence of basic link maximum number of re-transmissions

The following analysis aims to study the influence of the maximum number of attempts in Basic Link transmissions (timer N.252, see EN 300 392-2 [i.2], annex A).

Standard values are in the range 1-5.

Figures have been obtained for different values of the maximum number of re-transmissions on basic link (1-3-5).

Figures 121 and 122 report respectively the mean value of delay and the throughput of the random access delay.

Figures 123 and 124 show the mean value of delay and the throughput of the individual M-M circuit switched call set-up procedure. Figure 125 reports the $\tau_{95\,\%}$ boundary delay for the same procedure.

Figures 126 and 127 show the mean value of delay and the throughput of the individual M-F short data transmission procedure. Figure 128 reports the $\tau_{95\,\%}$ boundary delay for the same procedure.

This parameter affects the performance of the set-up procedures after the random access. Then, random access performance is not affected by changing N.252. Due to the good quality of the radio links (90 % Location Probability) the delays are not strongly affected.

Nevertheless the call set-up throughput (for both circuit calls and short data transmissions) is low when N.252 is 1. It is the case when LLC sends the BL_DATA PDU just once, without re-transmissions. This means a paging procedure and a CONNECT message transmission with only one attempt.

Despite of a good quality radio channel, the probability of failure of the call set-up procedure is given by the sum of the failure probability of paging transmission, CONNECT message transmission and CONNECT-ACK transmission.

It is important to observe that these results have been evaluated for a stationary system. In case of traffic peaks these values can change due to transitorial phenomena. For this reason, when a suitable value of N.252 has to be chosen for a particular cell, these transitorial phenomena have to be taken into account.

Nevertheless the influence of this parameter on the performance is not strong, then this parameter can be kept constant.

Table 17 reports the number of TCHs allocated to the simulated cell in order to give a low blocking probability for all services. Two categories of services are reported depending on the number of channels required. The reported blocking probability values are not dependent on the particular value of the maximum number of retransmission's for the basic link.

Table 17: Blocking probability for the simulated configurations

Number of users	Number of allocated TCHs (Frequency Carriers)	Blocking probability of services requesting two TCHs	Blocking probability of services requesting one TCH
100	7 (2)	2 %	0,5 %
250	11 (3)	4 %	1,5 %
500	19 (5)	2 %	1 %
750	23 (6)	2,5 %	1 %
1 000	23 (6)	5 %	2 %

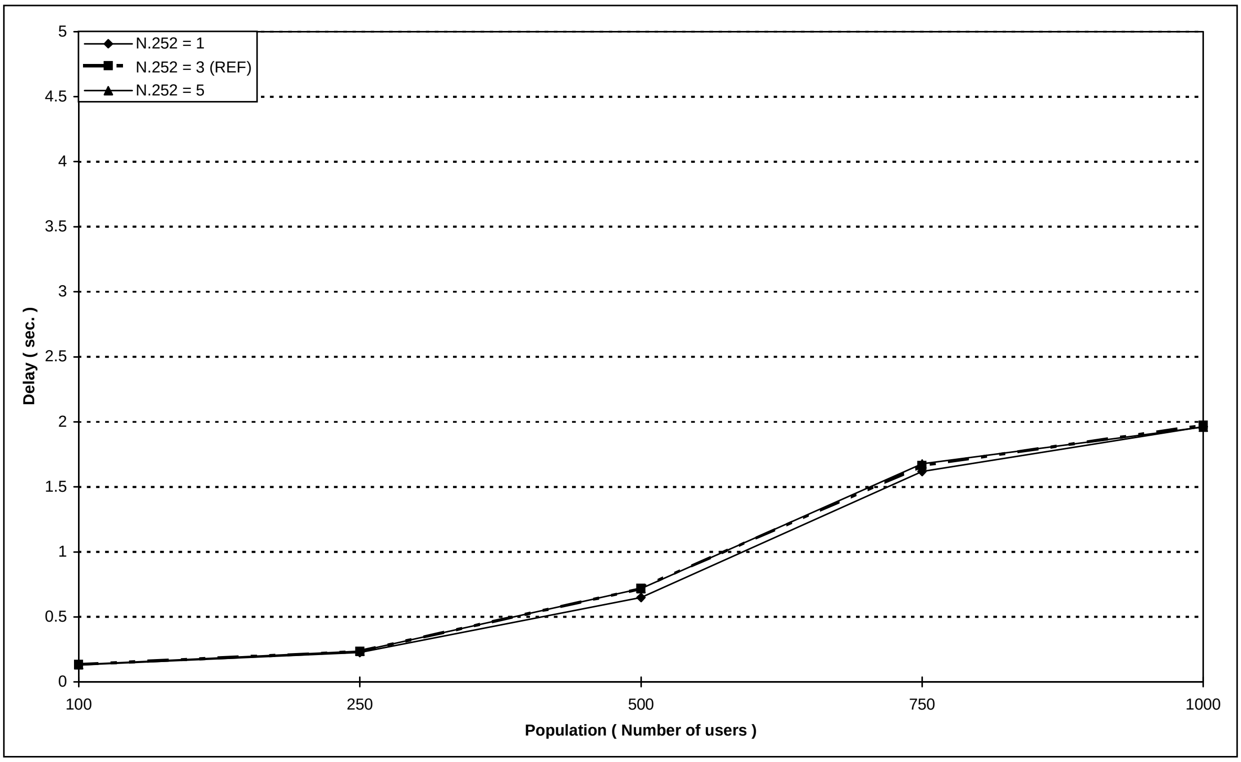

Figure 121: Random access mean delay versus number of users for different values of the basic link maximum number of re-transmissions

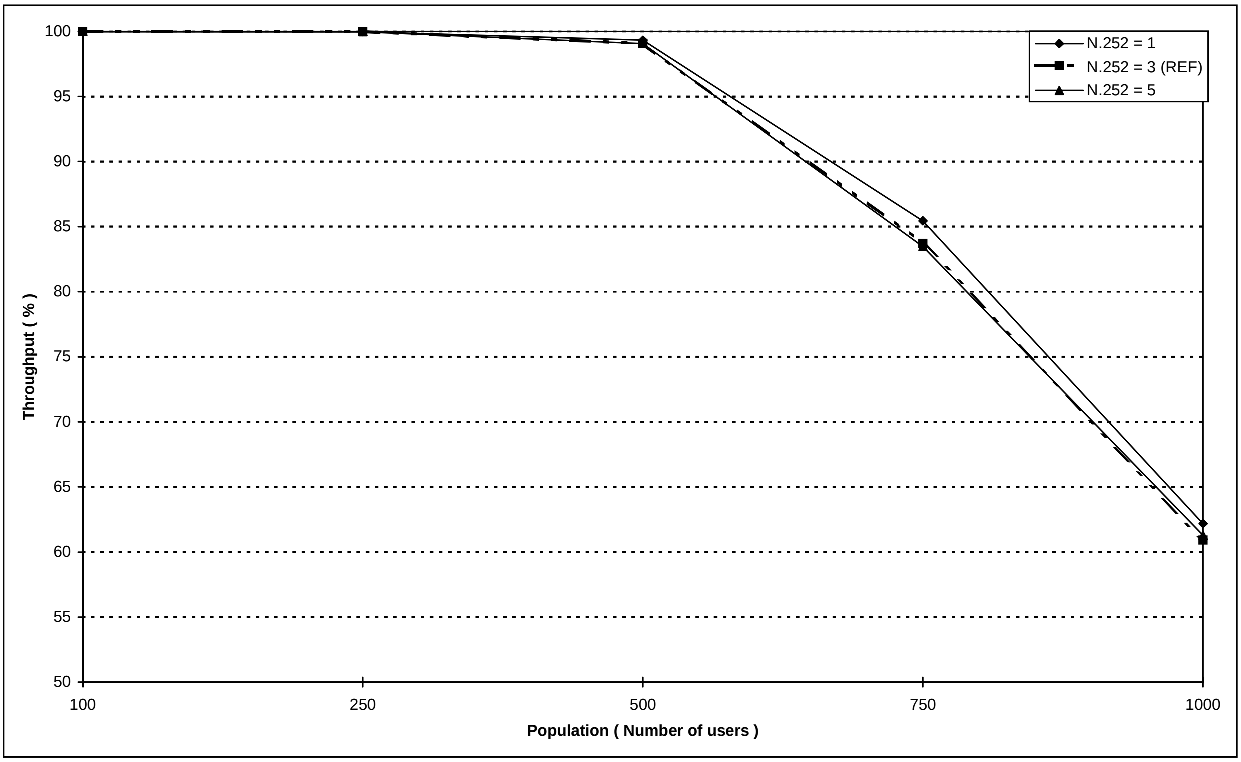

Figure 122: Random access throughput versus number of users for different values of the basic link maximum number of re-transmissions

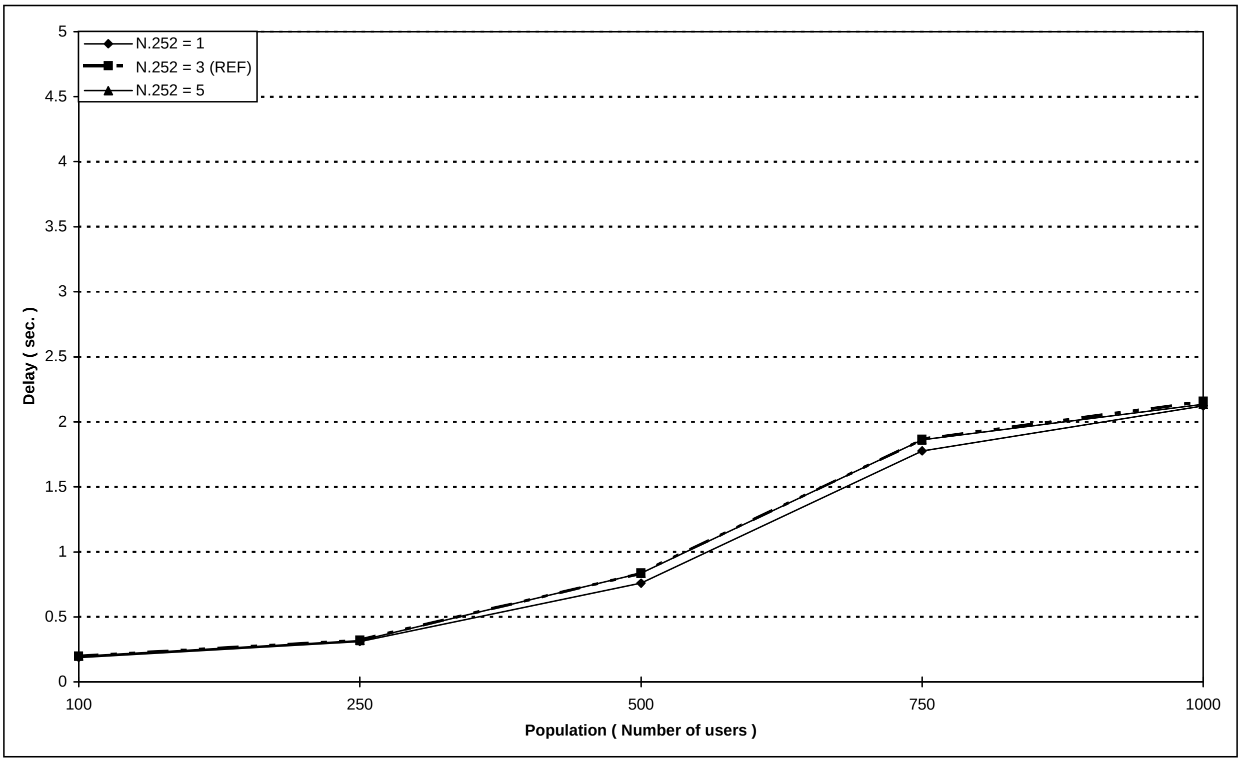

Figure 123: Individual M-M circuit switched call set-up mean delay versus number of users for different values of the basic link maximum number of re-transmissions

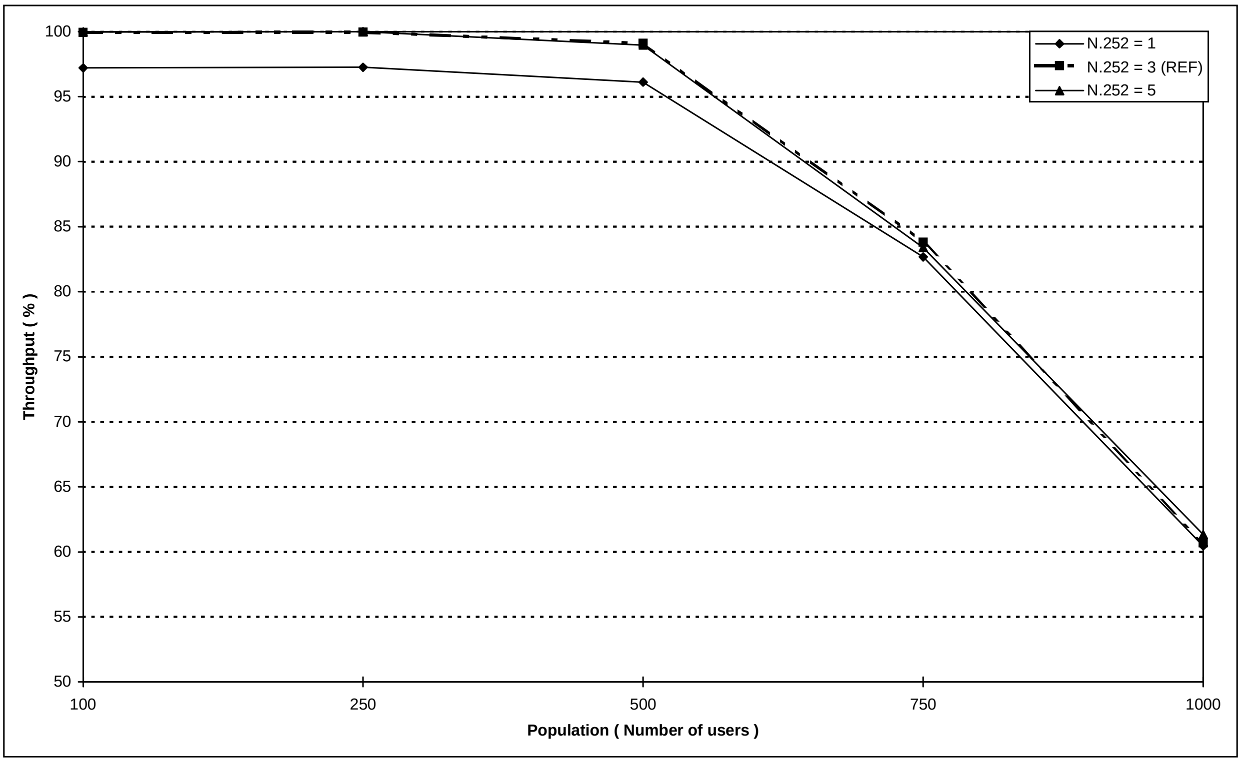

Figure 124: Individual M-M circuit switched call set-up throughput versus number of users for different values of the basic link maximum number of re-transmissions

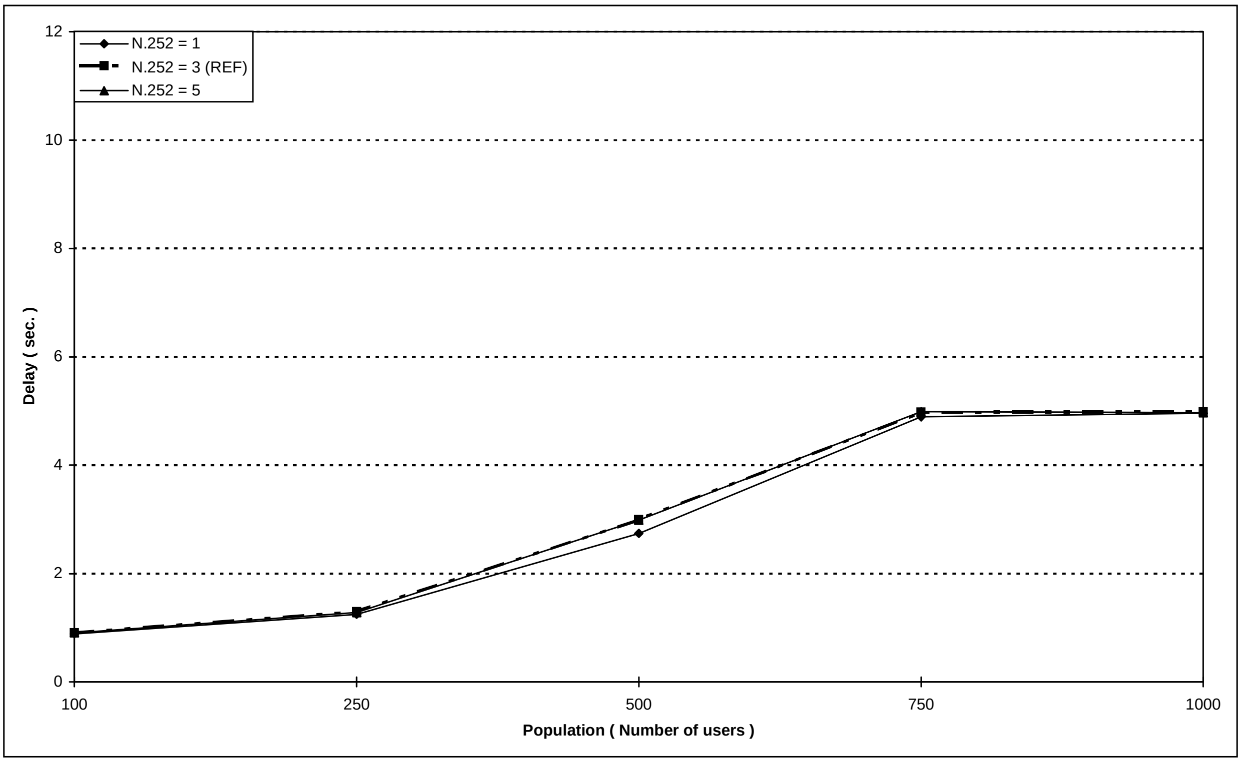

Figure 125: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users for different values of the basic link maximum number of re-transmissions

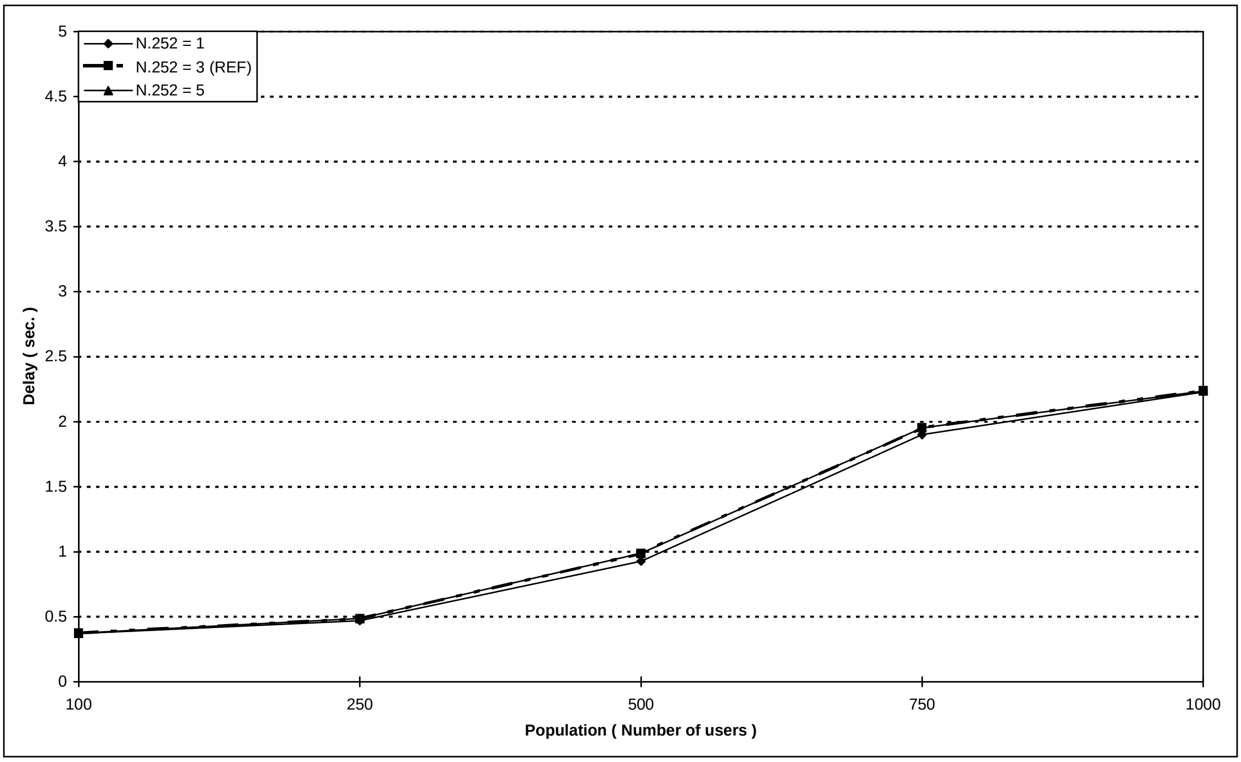

Figure 126: Individual M-F short data transmission mean delay versus number of users for different values of the basic link maximum number of re-transmissions

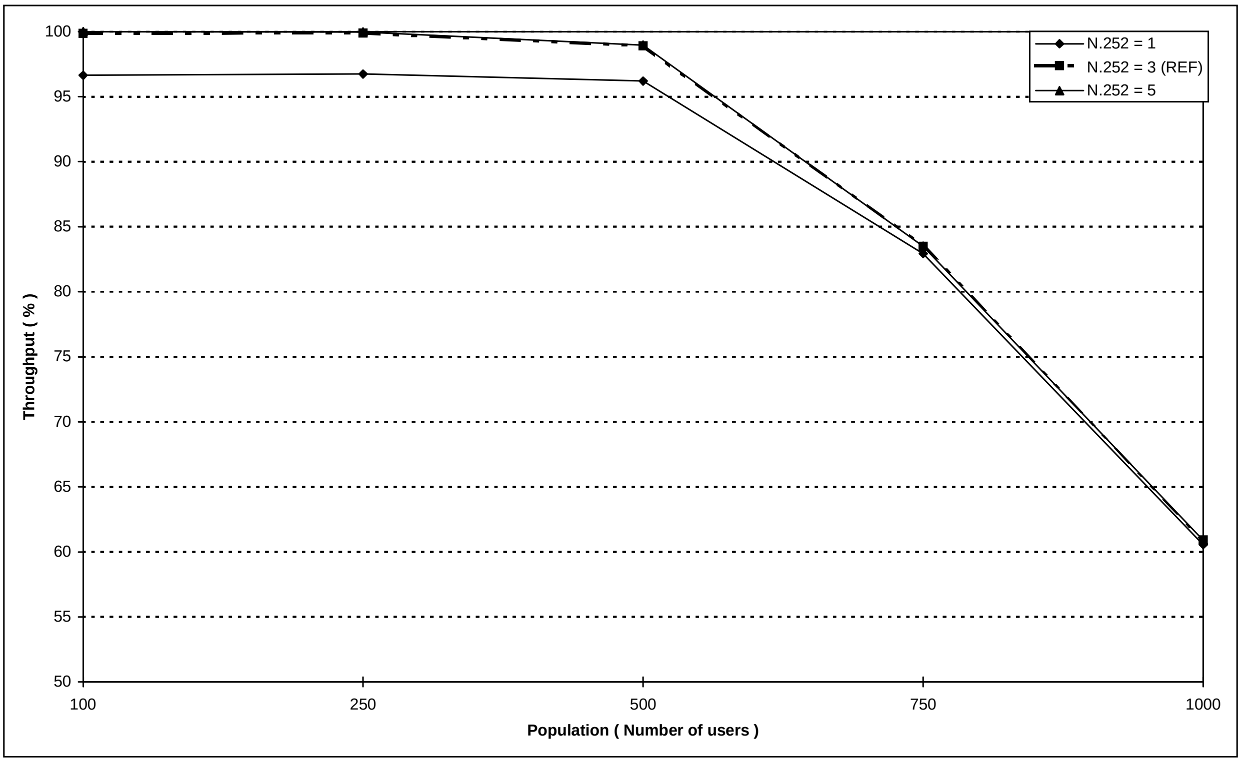

Figure 127: Individual M-F short data transmission throughput versus number of users for different values of the basic link maximum number of re-transmissions

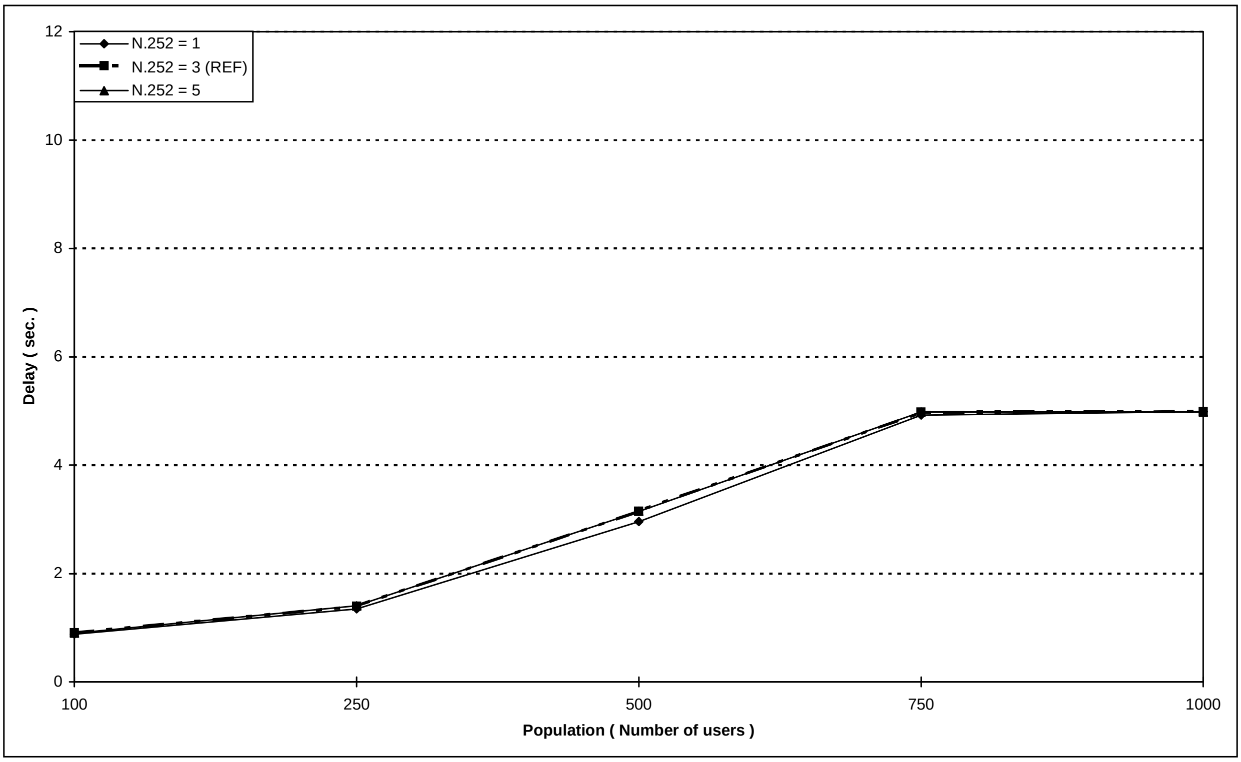

Figure 128: Individual M-F short data transmission $\tau_{95\ \%}$ boundary delay versus number of users for different values of the basic link maximum number of re-transmissions

5.5.2.5.6 Influence of random access technique

The following analysis aims to study the influence of the random access technique on the overall performance.

Making reference to EN 300 392-2 [i.2], clause 23.5.1, two techniques can be identified depending on the scheduling policy of random access frames on the common control channel:

- rolling access frames:
    - each access opportunity is considered the beginning of a new access frame;
- discrete access frames:
    - access frames are put in sequence. A new access frame can start only when the preceding frame has finished.

The flexible method that is used by the BS to allocate the access frames (ACCESS ASSIGN PDUs on AACH) allows all kind of intermediate techniques. In this clause only the two main techniques are considered.

Figures 129 and 130 report respectively the mean value of delay and the throughput of the random access delay.

Figures 131 and 132 show the mean value of delay and the throughput of the individual M-M circuit switched call set-up procedure. Figure 133 reports the $\tau_{95\,\%}$ boundary delay for the same procedure.

Figures 134 and 135 show the mean value of delay and the throughput of the individual M-F short data transmission procedure. Figure 136 reports the $\tau_{95\,\%}$ boundary delay for the same procedure.

The random access technique affects both random access delay and throughput (and consequently call set-up delays for circuit calls and short data transmission). The difference is low, but it is amplified for high traffic loads.

This effect can be explained with the presence of short data transmission; during the random access procedure, the accessing MS starts counting the access opportunities after the beginning of an access frame. In case of discrete access frame, on the average this waiting time is equal to a half of an access frame duration. For rolling access frames this waiting time is limited to the half of the average time between access opportunities. When access opportunities are few due to a high number of reserved slots (high traffic load) the effective duration of an access frame increases more than the distance between access opportunities; consequently the difference of delay performance between the two techniques is more evident.

It is important to observe that these results have been evaluated for a stationary system. In case of traffic peaks these values can change due to transitorial phenomena. For this reason, when a suitable random access technique has to be chosen for a particular cell, these transitorial phenomena have to be taken into account.

Table 18 reports the number of TCHs allocated to the simulated cell in order to give a low blocking probability for all services. Two categories of services are reported depending on the number of channels required. The reported blocking probability values are not dependent on the particular random access technique.

Table 18: Blocking probability for the simulated configurations

Number of users	Number of allocated TCHs (Frequency Carriers)	Blocking probability of services requesting two TCHs	Blocking probability of services requesting one TCH
100	7 (2)	2 %	0,5 %
250	11 (3)	4 %	1,5 %
500	19 (5)	2 %	1 %
750	23 (6)	2,5 %	1 %
1 000	23 (6)	5 %	2 %

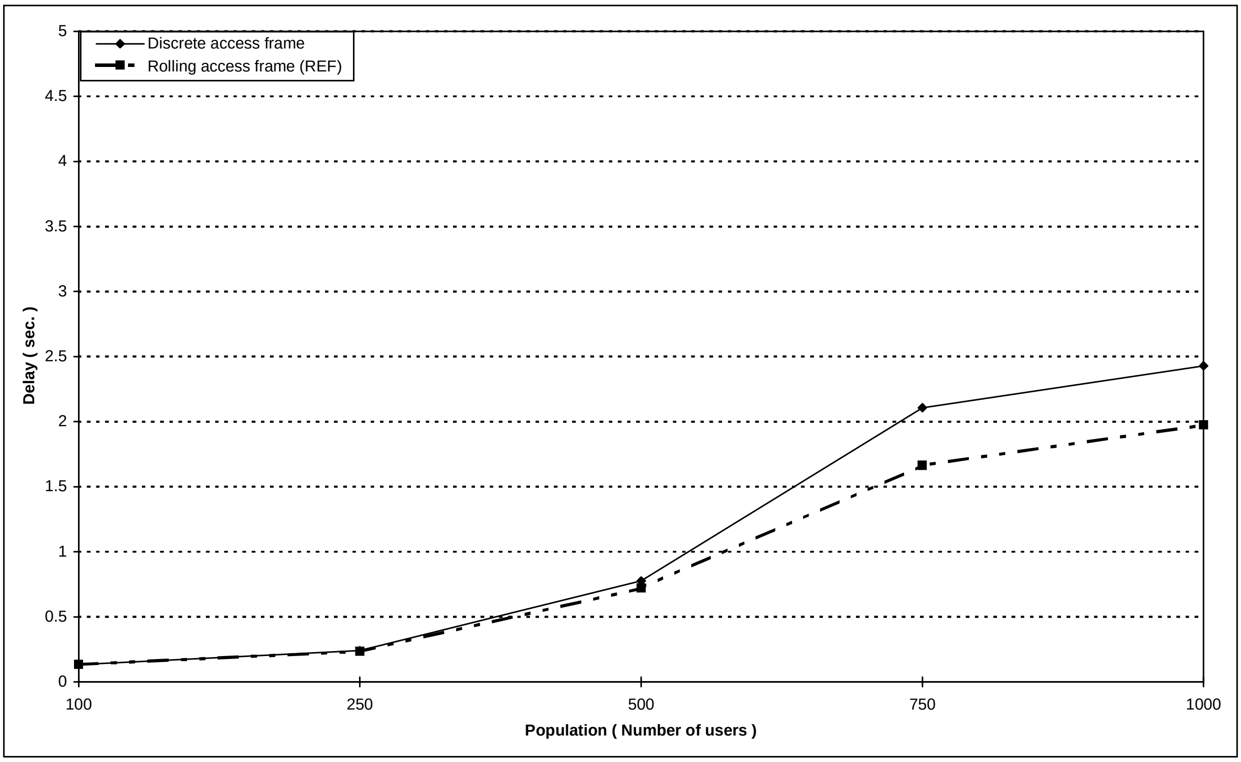

Figure 129: Random access mean delay versus number of users for different access techniques

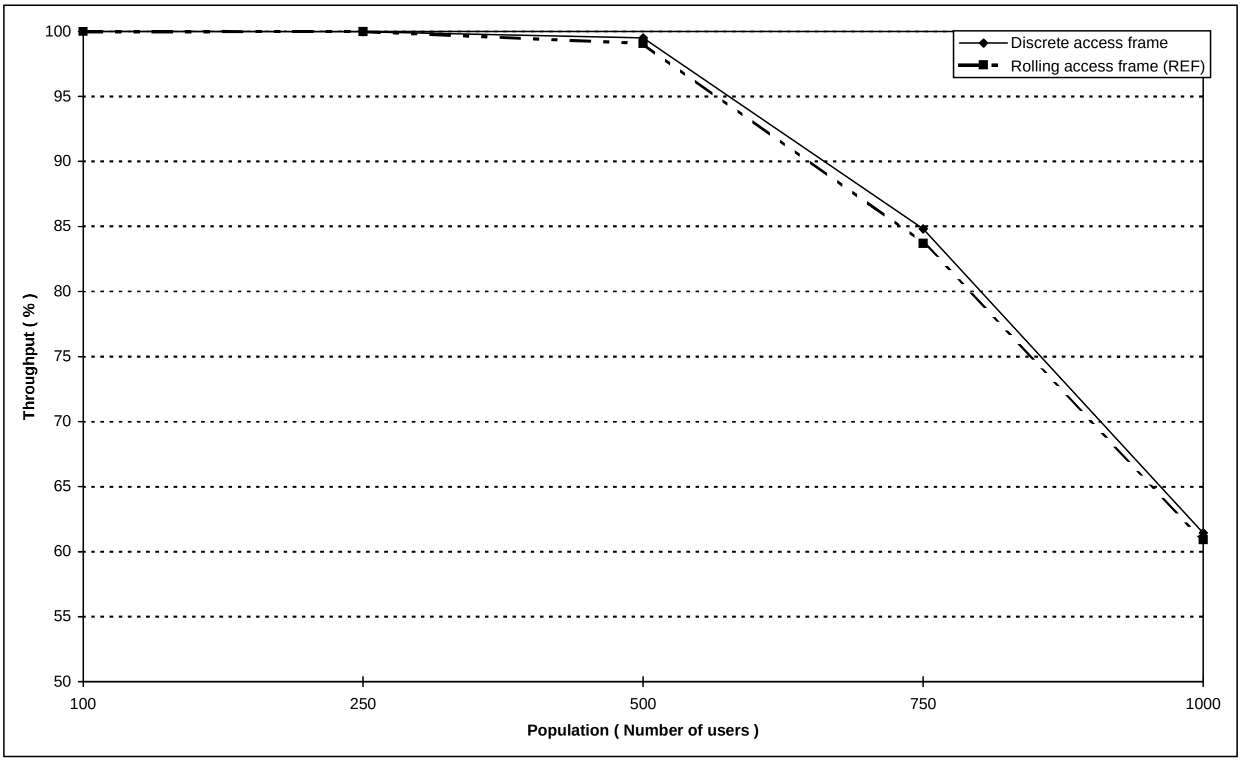

Figure 130: Random access throughput versus number of users for different access techniques

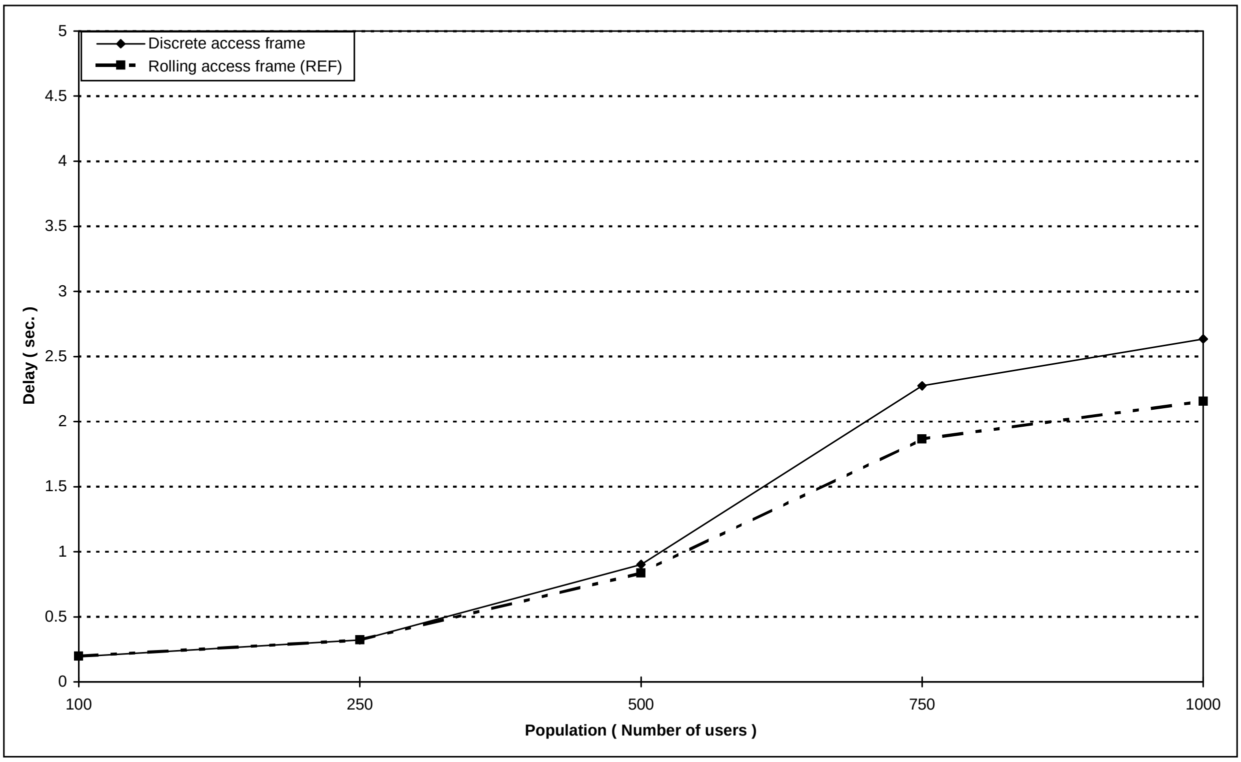

Figure 131: Individual M-M circuit switched call set-up mean delay versus number of users for different access techniques

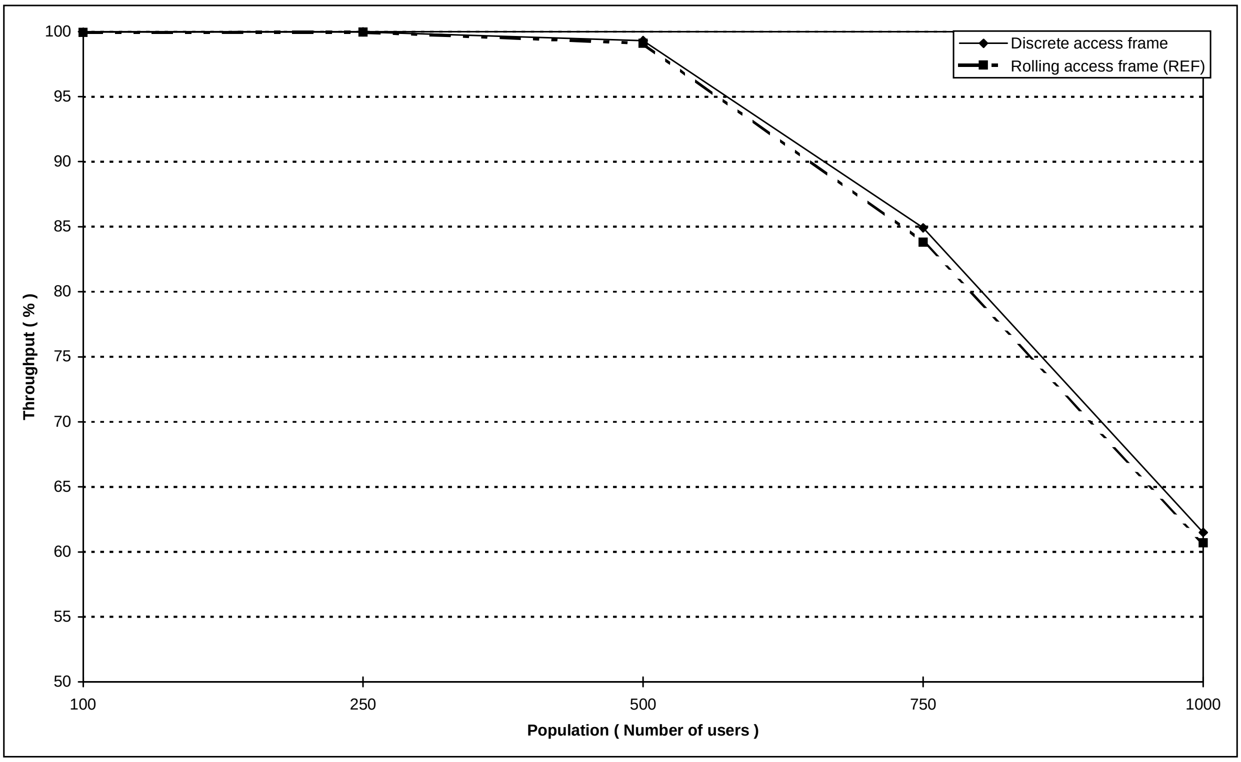

Figure 132: Individual M-M circuit switched call set-up throughput versus number of users for different access techniques

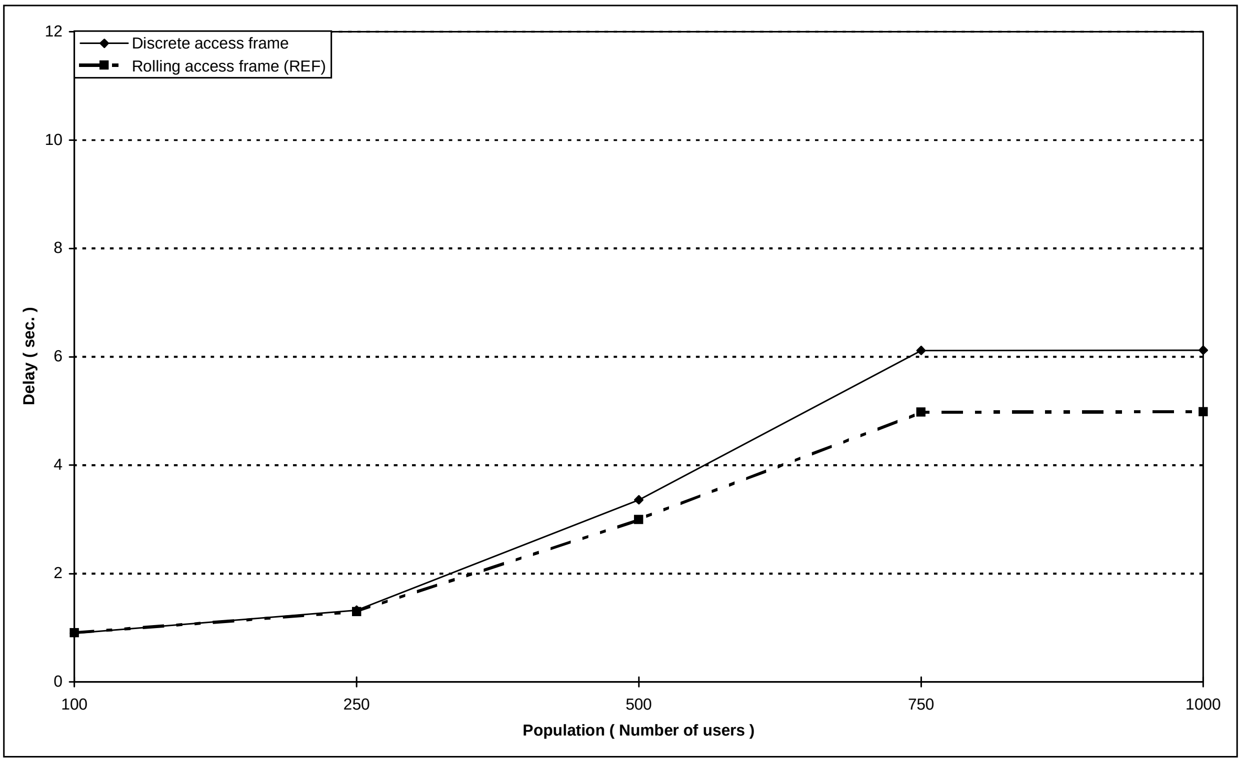

Figure 133: Individual M-M circuit switched call set-up $\tau_{95\ \%}$ boundary delay versus number of users for different access techniques

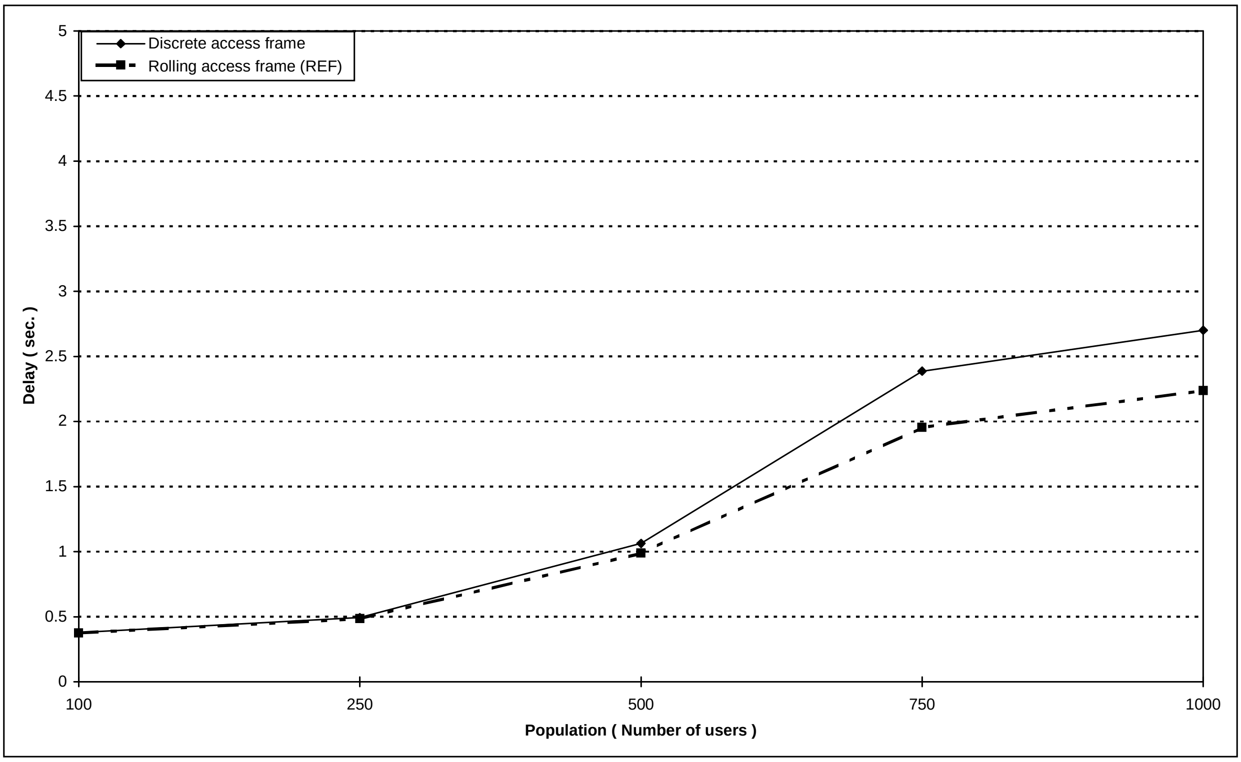

Figure 134: Individual M-F short data transmission mean delay versus number of users for different access techniques

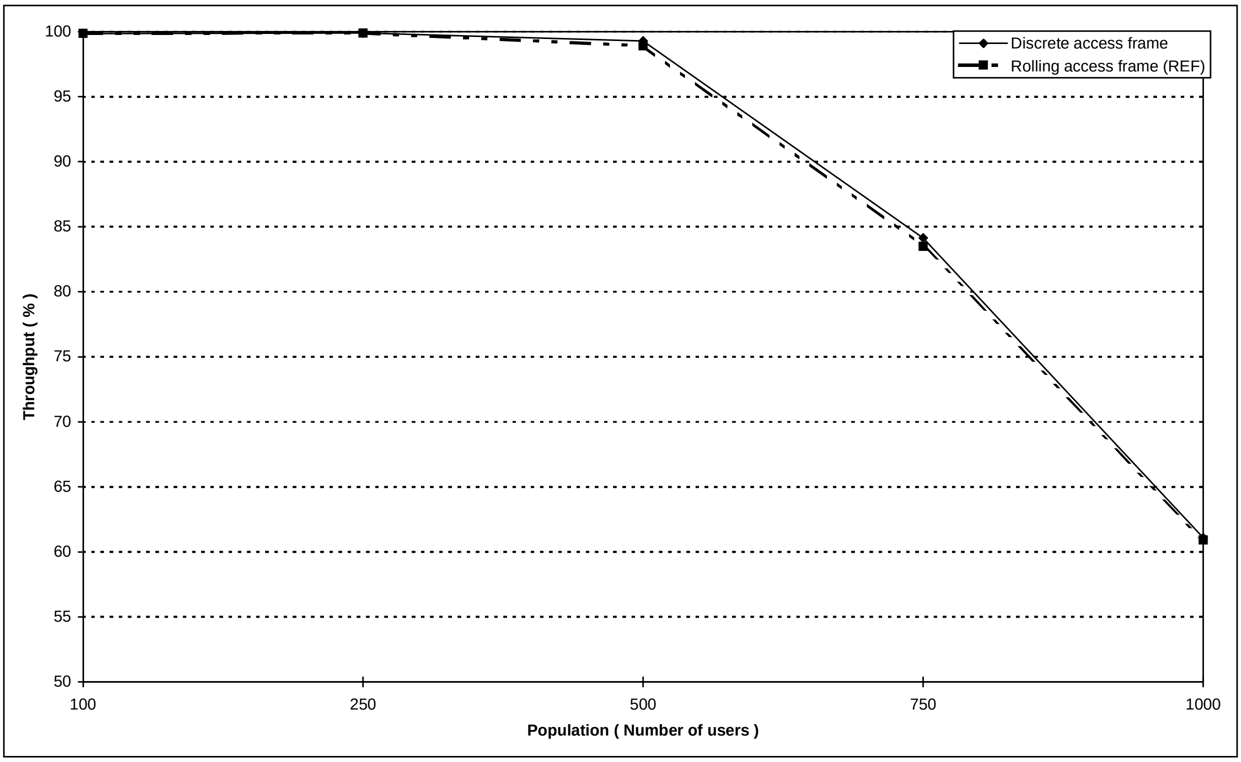

Figure 135: Individual M-F short data transmission throughput versus number of users for different access techniques

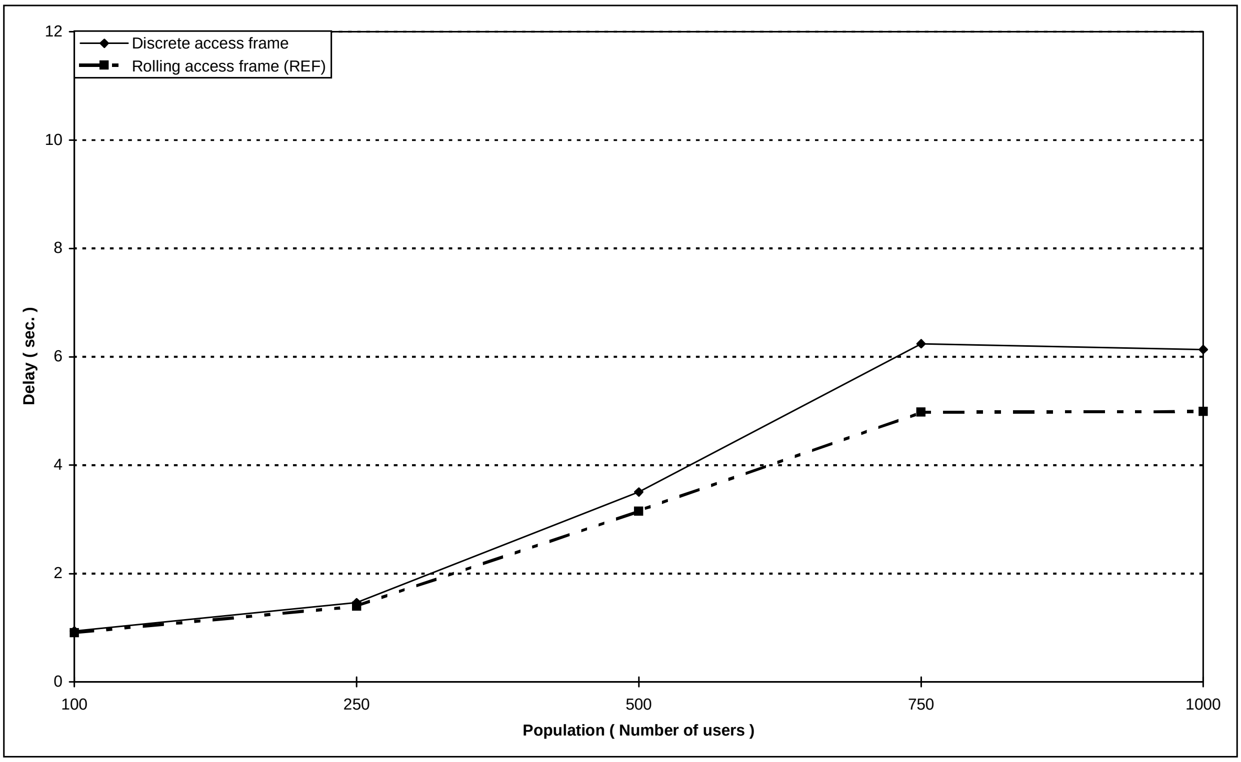

Figure 136: Individual M-F short data transmission $\tau_{95\ \%}$ boundary delay versus number of users for different access techniques

5.5.3 Scenario 8: Urban and sub-urban PMR network

5.5.3.1 Introduction

This clause reports the performance and some sensitivity analysis of a significant number of network configurations, all making reference to scenario 8 (see annex A).

NOTE 1: The simulated traffic profile has been derived from scenario 8, however some characteristics can be different. For this reason the simulation results are valid for the simulated scenario, that is described in this clause.

Clause 5.5.3.2 collects all the particular assumptions that have been done for the implementation of simulations for scenario 8. The general assumptions on the simulations (as illustrated in clause 5.3) apply.

After a presentation of the performance for the reference configuration of scenario 8, the following clauses report some investigations about the influence of network parameters and management strategies:

The first group of investigations analyses some different traffic profiles, each one derived from the reference scenario 8:

- analysis of different values of packet data service profile generated by the single user;
- analysis of different amount of Dispatcher traffic;
- analysis of different service priorities distributions;
- impact of full duplex individual calls on the overall performance.

The second group analyses the influence of some call management policy parameters on the overall performance:

- analysis of different values of cell allocated TCHs;
- analysis of varying the maximum hold time in priority queues.

NOTE 2: In general, the low amount of radio resources makes the priority queuing delay the heaviest part of the call set-up delay, and the failures of calls for long holding in queue the most frequent cause of call failure. For this reason only the system throughput is presented. The radio interface throughput is always high.

5.5.3.2 Simulation assumptions for Scenario 8

5.5.3.2.1 Simulated traffic scenario

Annex A reports a detailed description of different traffic profiles. The results reported in this clause are based on scenario 8, that is a Private urban network. User spatial distribution has been considered uniform in the observed network. Table 19 reports the detailed single user traffic profile employed in simulations of scenario 8. Reference call priorities distribution is given in table 20.

Table 19: Reference traffic profile for Scenario 8 (scenario 8A)

Service	Parameter	Reference Scenario 8
M-M individual voice call	Frequency of requests	0,324 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
M-F individual voice call	Frequency of requests	0,756 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
F-M individual voice call	Frequency of requests	0,756 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
M-M group #1 voice call	Frequency of requests	0,72 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	10
Dispatcher-M group #1 voice call	Frequency of requests	0,72 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	10
M-M group #2 voice call	Frequency of requests	0,36 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	15
Dispatcher-M group #2 voice call	Frequency of requests	0,36 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	15
M-M individual circuit data call	Frequency of requests	0,2 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
M-F individual circuit data call	Frequency of requests	0,5 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
F-M individual circuit data call	Frequency of requests	0,5 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
M-M group #1 circuit data call	Frequency of requests	0,2 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	10
M-M group #2 circuit data call	Frequency of requests	0,1 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	15
Short Data transmission	Frequency of requests	10 trasm/h (POISSON)
	Call duration	100 bytes (FIXED)

Table 20: Priority distribution for the reference configuration of scenario 8

Service	Pre-emptive priority	Priority #1	Priority #2
Voice	1 %	10 %	89 %
Circuit data	- - -	10 %	90 %

5.5.3.2.2 Simulated network procedures and reference access parameters

Annex B collects the MSCs of the TETRA signalling procedures employed in the simulations in case of positive radio transmissions. SDL diagrams related to the single network entities are the reference for negative and erroneous cases. Annex C, D and E report the detailed behaviour of all the network entities in SDL notation.

The simulated procedures in scenario 8 are the following:

- individual voice call from TETRA MS to TETRA MS (Half and Full duplex);
- individual voice call from TETRA MS to external fixed terminal (Half and Full duplex);
- individual voice call from external fixed terminal to TETRA MS (Half and Full duplex);
- group voice call from TETRA MS to a group of TETRA Mss (Half duplex);
- group voice call from Dispatcher to a group of TETRA Mss (Half duplex);
- individual circuit data call from TETRA MS to TETRA MS (Half and Full duplex);
- individual circuit data call from TETRA MS to external fixed terminal (Half and Full duplex);

- individual circuit data call from external fixed terminal to TETRA MS (Half and Full duplex);
- group circuit data call from TETRA MS to a group of TETRA MS (Half duplex);
- group circuit data call from Dispatcher to a group of TETRA MS (Half duplex);
- individual packet data call from a TETRA MS to TETRA MS.

It is supposed that the network cells are not affected by Co-channel interference and are covered through omni-directional antennas.

NOTE 1: Scenario 8 represents a private network, then a suitable strategy for the call management in case of lack of resources is to queue the calls in the SwMI until some resources become available. A priority scheme has been associated with the call queue. TETRA standard allows up to 8 priority levels plus pre-emptive priority. In the simulations the priority scheme can be represented as in figure 137. A queue is active for each priority level. When some resources become available the system polls the queues in descending order of priority and gives service to the first found call. Pre-emptive priority calls are put in a separate queue and are usually served immediately: the eldest and the lowest priority active call in the system is disconnected by the system and its resources given to the new call. A timer is associated with each queued call. When the hold time is longer than a fixed threshold, the call is released (see annex C, D, E for the call release procedure). In the simulations the threshold is the same for every priority level.

NOTE 2: Simulated MSs are not able to support parallel transactions. When a new call is generated by the user and the MS is busy, the new transaction is cancelled.

NOTE 3: During the call set-up procedure, the TCH assignment policy in the SwMI is an implementation option; in the standard document two possibilities are given: early assignment and late assignment. In scenario 8 simulations late assignment has been adopted.

NOTE 4: In the case of M-M packet data service, the downlink transmission to the called user is done only when the MCCH has no other signalling procedures pending. This assumption is in order to give priority to the circuit call set-up procedures, that already suffer from the delays of queuing mechanism.

All network and access control parameters in the reference situation for the simulations are summarized in table 21. The results have been evaluated for a suitable set of network scenarios, derived by this reference configuration.

The definition of the evaluated performance given in clause 5.4 apply.

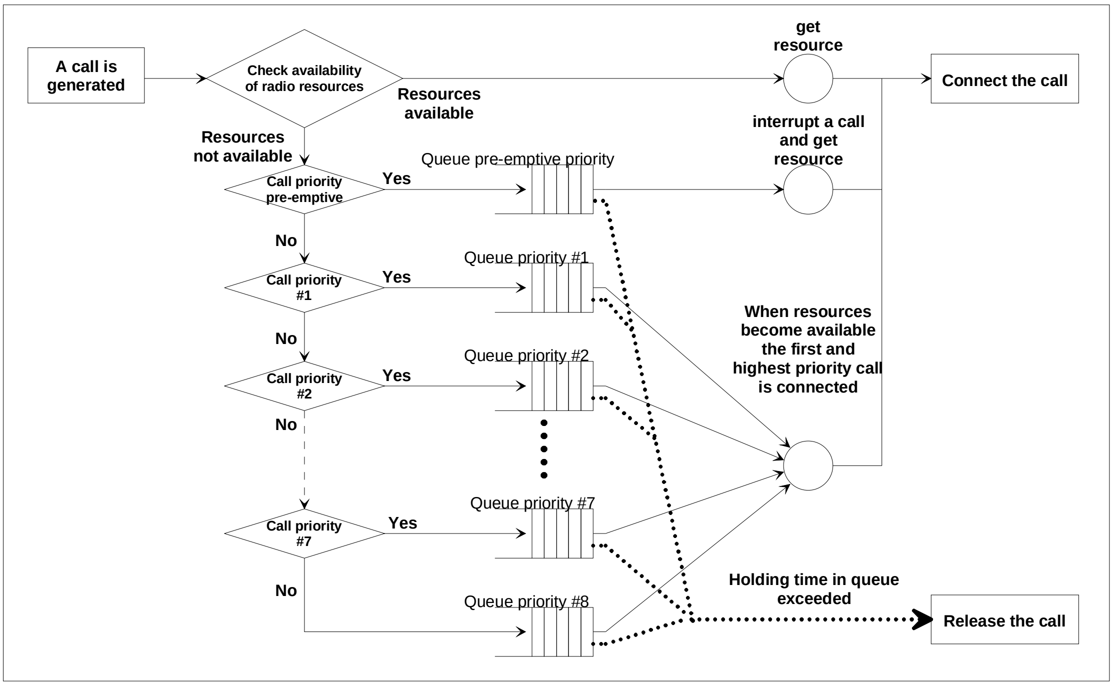

Figure 137: Call management policy with priority for scenario 8

Table 21: Summary of network parameters of the reference scenario 8

Parameter	Reference value
Random access: value of the timer regulating the first access attempt (IMM)	15
Random access: maximum number of access attempts (Nu)	5
Random access: Back off time (WT)	5 TDMA frames
Random access: Access frame length	10 access opportunities
Basic link: Maximum number of re-transmissions (N.252)	3
Basic link: Sender retry timer (T.251)	4 TDMA frames
Propagation scenario	TU50
Power gap between signals received on the mobile and on the BS	0 dB
MS antenna height	1,5 m
User distribution on the cell	uniform (flat) distribution
BS antenna height	30 m
Type of cell antenna	Omni directional
Reuse factor	∞
Location probability	90 %
Call management policy in case of lack of network resources	QUEUING with priorities and maximum hold time 100 TDMA frames (see figure 137)
Number of Control Channels allocated on the cell	1
Number of Traffic Channels allocated on the cell	7
Number of User Access Sets that are in the coverage area of the cell	1
Traffic channel used for circuit data transmission	TCH/4,8 with interleaving depth 1
Access Codes allocation on the Control Channels	A=100 %, B=0 %, C=0 %, D=0 %

5.5.3.2.3 Confidence analysis for scenario 8 results

The simulation results have been derived by averaging the outputs from five fixed length simulation runs. The fixed length simulation run time was set at 74 000 TETRA TDMA frames of which results from the initial transitory period of 10 000 frames were not used. The used fixed length simulation time per run of 64 000 TDMA frames is equivalent to approximately 1 hour system run time.

No statistic confidence analysis is available.

5.5.3.3 Reference configuration for scenario 8 (scenario 8A)

The reference scenario simulation results are presented in this clause in order to provide the basis for all further analysis. In some cases, for giving an easy comparison, this performance is reported in the other clauses.

The reported performance has been obtained for different values of user population. Each user generates traffic to the network in accordance with the reference traffic profile reported in clause 5.5.3.2.1.

Even if the number of the simulated services is high, the reported figures are only related to individual circuit and packet service because in the simulated system the critic part is related to the resource management procedure, then the behaviour of the system can be summarized by the services that require different resources to the network. In the reference configuration, all individual and group calls require one TCH (because they are half duplex calls), while the packet data affects the MCCH only.

Results related to the Dispatcher group calls are reported to allow a comparison of two situations:

- network with line connected Dispatcher;
- network with radio connected Dispatcher.

Figure 138 reports the mean value of the M-M individual circuit call set-up procedure. Each curve in the figure is related to a particular value of call priority.

Figure 139 reports the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure. Each curve in the figure is related to a particular value of call priority.

Figure 140 reports the system throughput of the M-M individual circuit call set-up. Each curve in the figure is related to a particular value of call priority.

Figure 141 reports the mean value of the M-M individual packet data call service. Each curve in the figure is related to a particular value of call priority.

Figure 142 reports the mean value of the Dispatcher to Mobile group voice call set-up procedure. Each curve in the figure is related to a particular value of call priority.

Figure 143 reports the $\tau_{95\,\%}$ boundary delay of the Dispatcher to Mobile group voice call set-up procedure. Each curve in the figure is related to a particular value of call priority.

Figure 144 reports the system throughput of the Dispatcher to Mobile group voice call set-up. Each curve in the figure is related to a particular value of call priority.

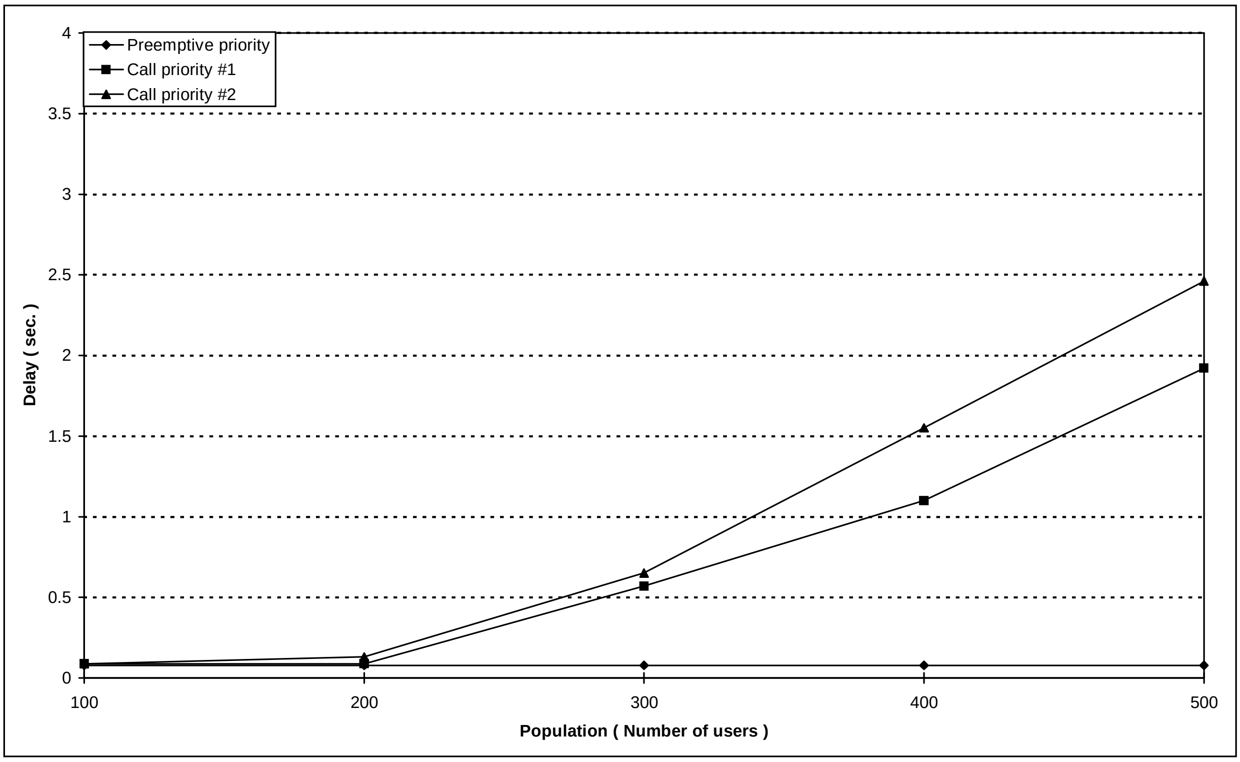

Figure 138: Individual M-M circuit switched call set-up mean delay versus number of users for the reference configuration

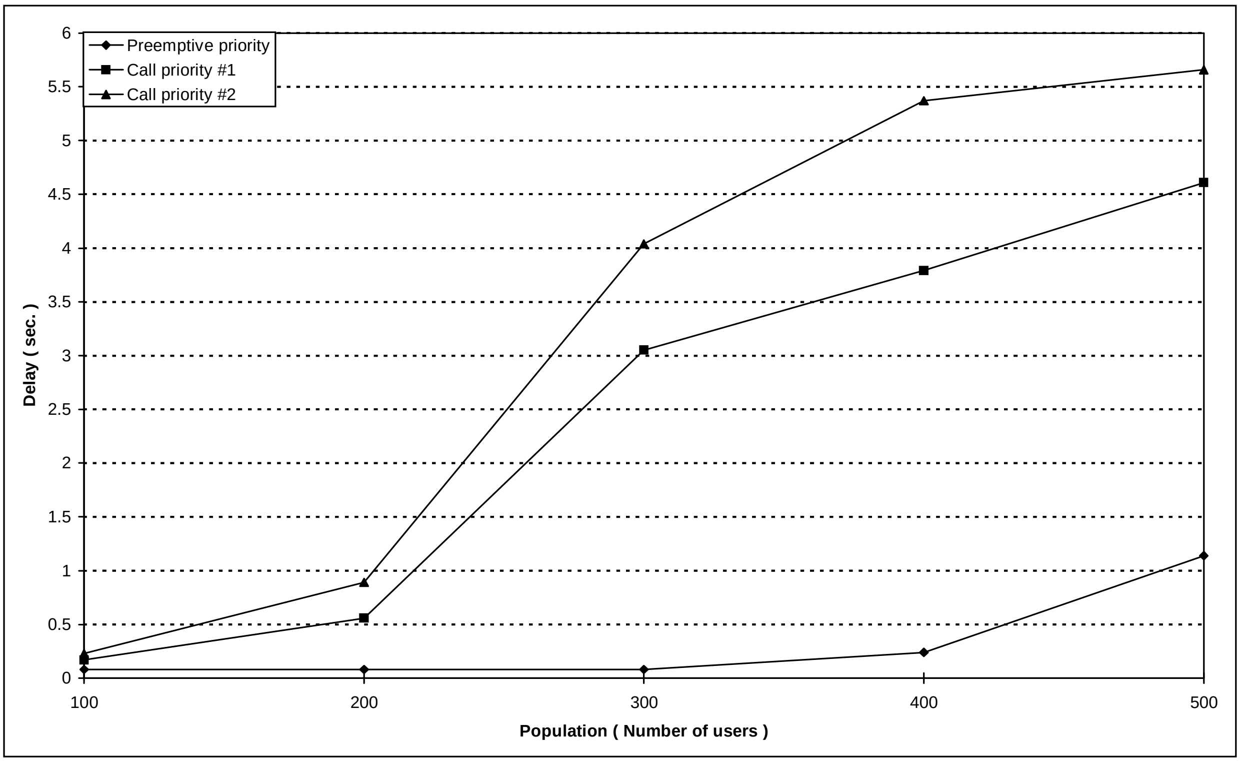

Figure 139: Individual M-M circuit switched call set-up $\tau_{95\ \%}$ boundary delay versus number of users for the reference configuration

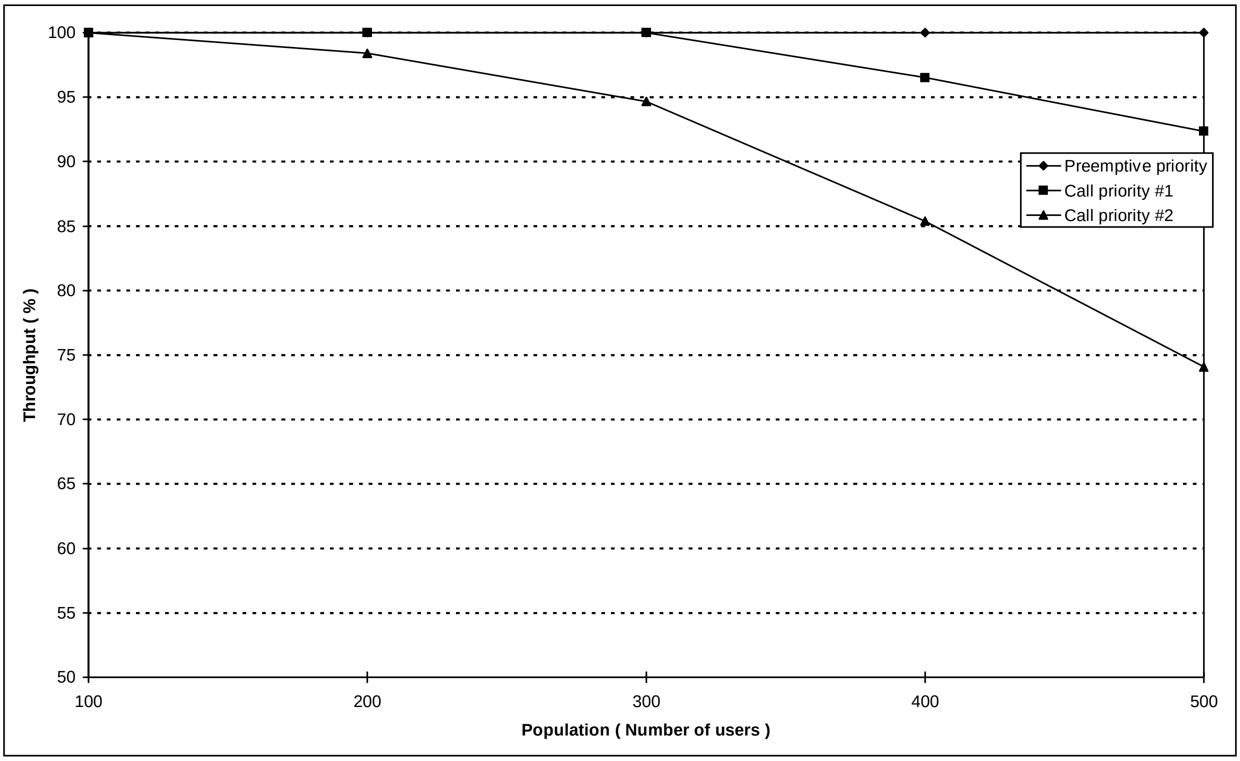

Figure 140: Individual M-M circuit switched call set-up system throughput versus number of users for the reference scenario

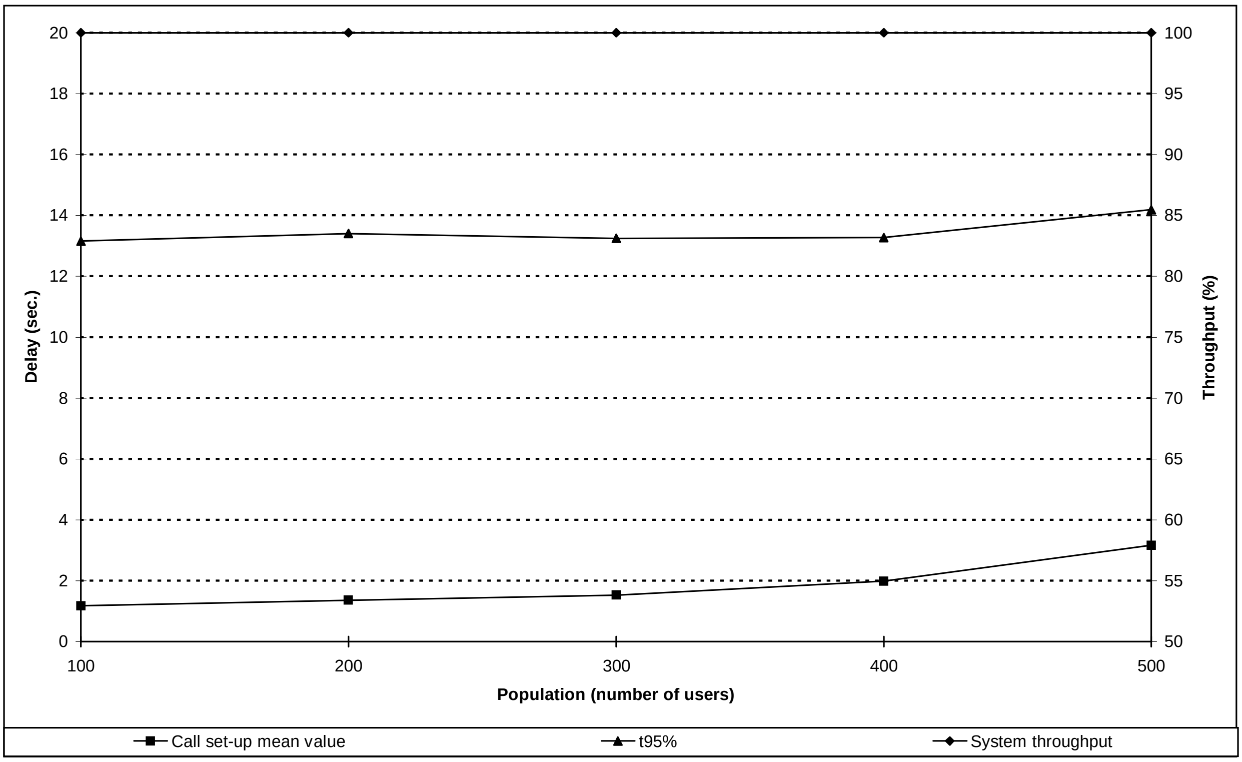

Figure 141: Individual M-M packet data call set-up performance versus number of users for the reference scenario

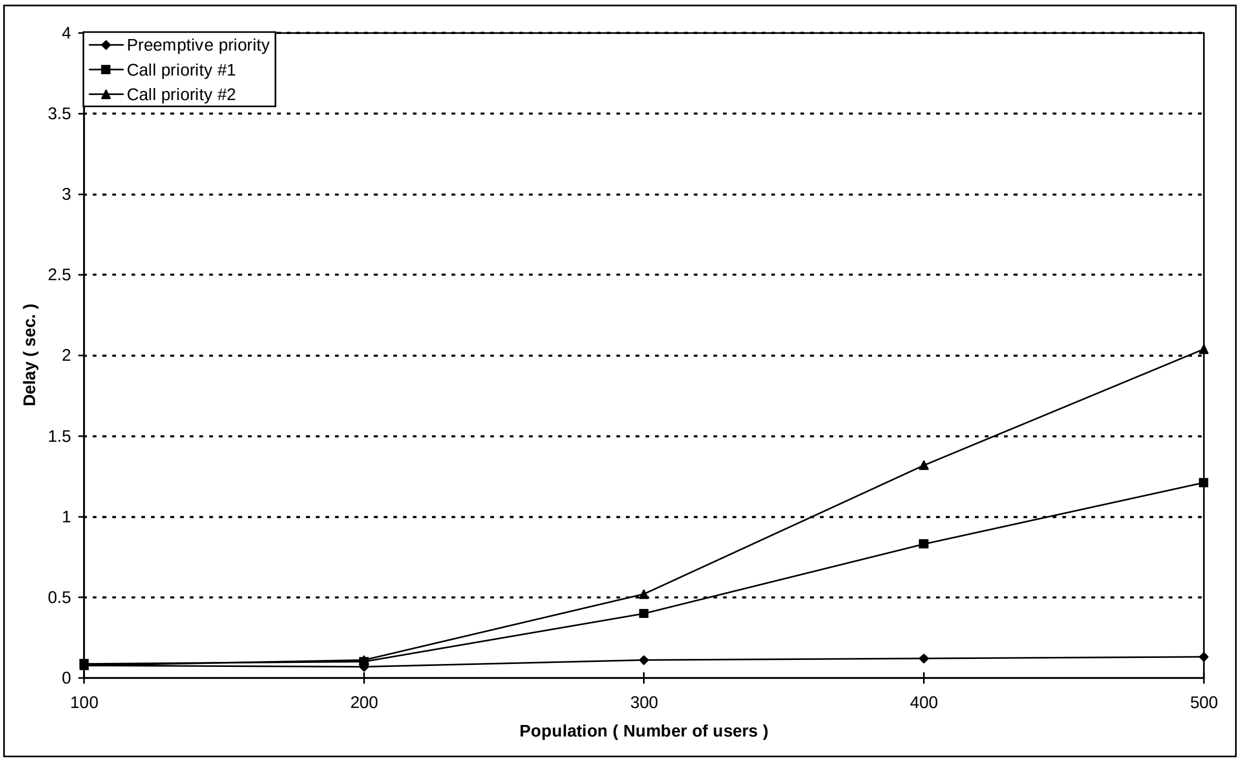

Figure 142: Dispatcher to Mobile group voice call set-up mean delay versus number of users for the reference configuration

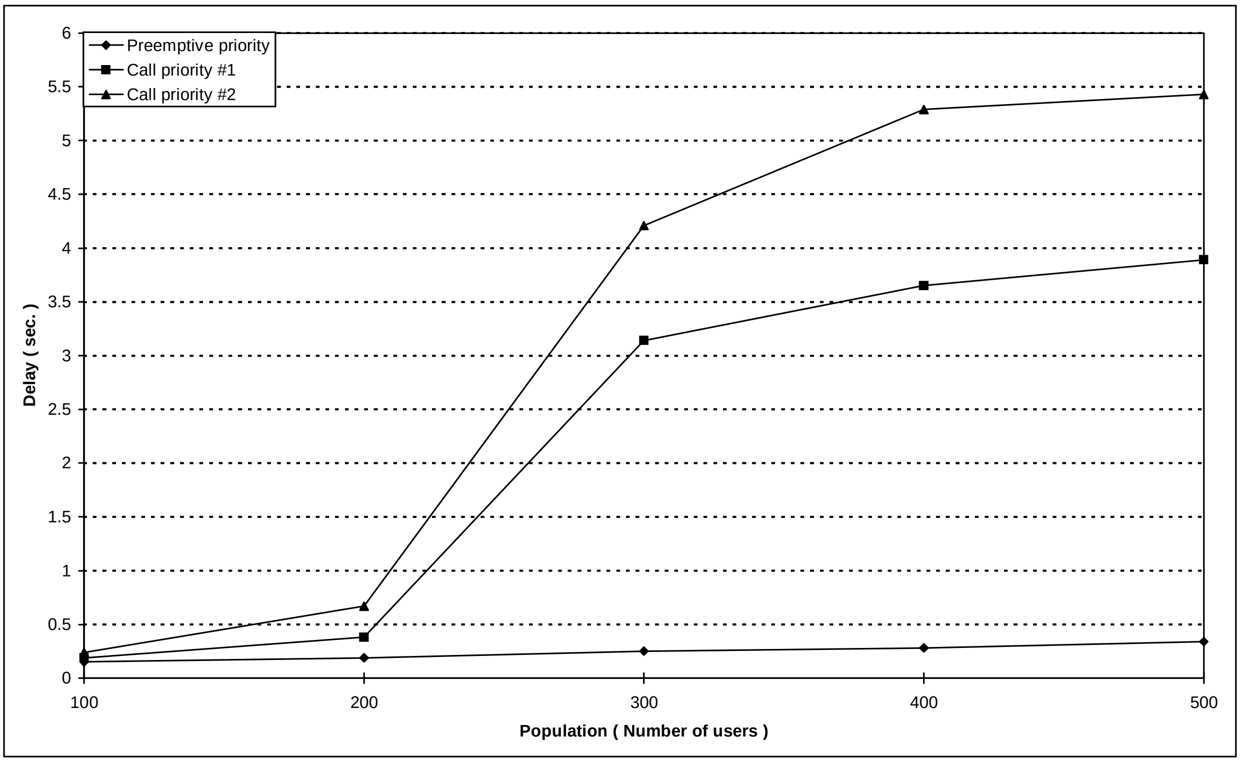

Figure 143: Dispatcher to Mobile group call set-up $\tau_{95\,\%}$ boundary delay versus number of users for the reference configuration

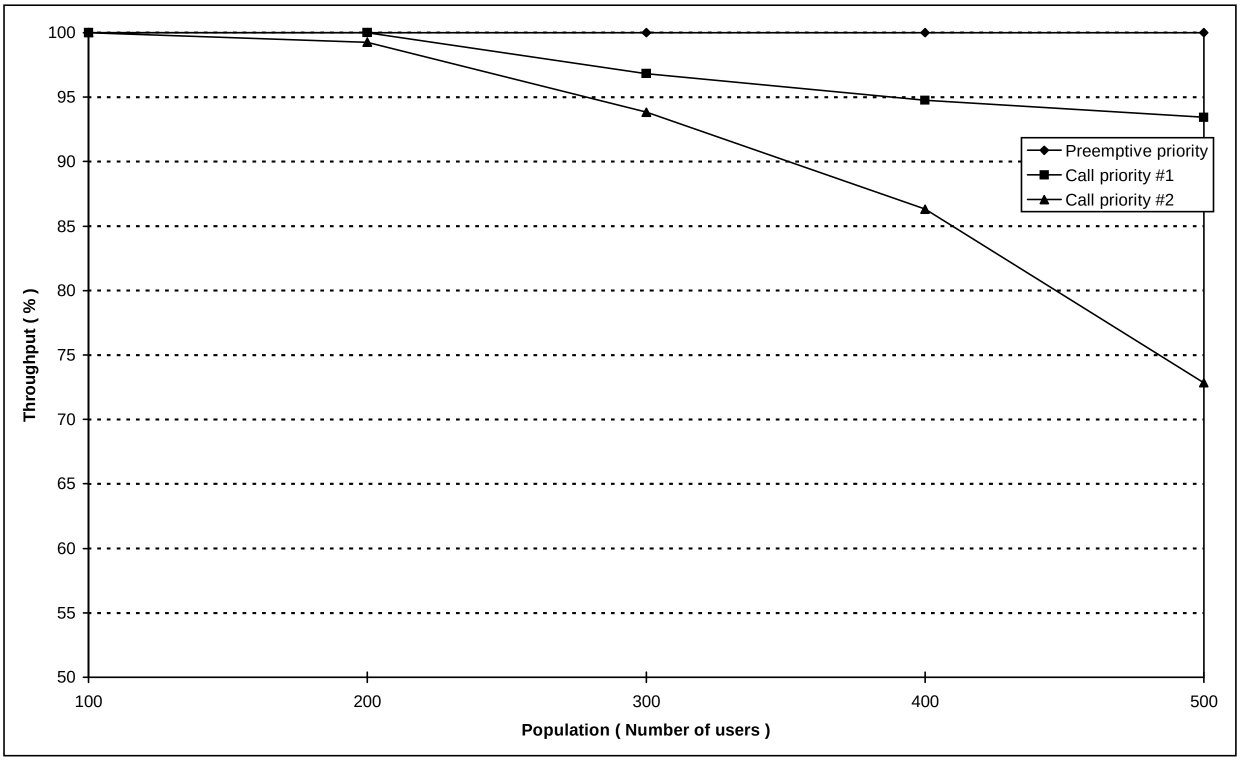

Figure 144: Dispatcher to Mobile group voice call set-up system throughput versus number of users for the reference scenario

5.5.3.4 Analysis of the system with different traffic profiles

The performance of some different traffic profiles is reported and analysed in this clause. They have been obtained changing only one parameter in the reference profile.

5.5.3.4.1 Variation of packet data traffic

The following analysis shows the influence of different levels of packet data traffic on the system. Starting from the reference scenario (it is now represented as 8A), two other scenarios have been identified with different packet data call generation rates. Table 22 reports in detail the analysed traffic profiles.

Figures 145 and 146 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure for scenario 8B. Each curve in the figure is related to a particular value of call priority.

Figure 147 reports the system throughput of the M-M individual circuit call set-up for scenario 8B. Each curve in the figure is related to a particular value of call priority.

Figure 148 reports the mean value of the M-M individual packet data call service for scenario 8B. Each curve in the figure is related to a particular value of call priority.

Figures 149 and 150 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure for scenario 8C. Each curve in the figure is related to a particular value of call priority.

Figure 151 reports the system throughput of the M-M individual circuit call set-up for scenario 8C. Each curve in the figure is related to a particular value of call priority.

Figure 152 reports the mean value of the M-M individual packet data call service for scenario 8C. Each curve in the figure is related to a particular value of call priority.

All these presented figures have to be compared with figures 138 to 144 (reference scenario 8A).

Looking to these figures and comparing with the reference scenario curves, only packet data performance is affected by a change in the traffic. On uplink the random access channel is lightly loaded by signalling, then no big changes in access times can be found in all kind of service. On downlink, the low of packet data transmissions priority on the MCCH generates a small impact on the circuit data signalling procedures, and then a longer and longer delay in the infrastructure for packet data itself.

Table 22: Traffic profiles with different packet data traffic load

Service	Parameter	Scenario 8A (Reference)	Scenario 8B	Scenario 8C
M-M individual voice call	Frequency of requests	0,324 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
M-F individual voice call	Frequency of requests	0,756 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
F-M individual voice call	Frequency of requests	0,756 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
M-M group #1 voice call	Frequency of requests	0,72 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
	Group size	10		
Dispatcher-M group #1 voice call	Frequency of requests	0,72 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
	Group size	10		
M-M group #2 voice call	Frequency of requests	0,36 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
	Group size	15		
Dispatcher-M group #2 voice call	Frequency of requests	0,36 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
	Group size	15		
M-M individual circuit data call	Frequency of requests	0,2 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
M-F individual circuit data call	Frequency of requests	0,5 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
F-M individual circuit data call	Frequency of requests	0,5 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
M-M group #1 circuit data call	Frequency of requests	0,2 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
	Group size	10		
M-M group #2 circuit data call	Frequency of requests	0,1 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
	Group size	15		
Short Data transmission	Frequency of requests	10 trasm/h (POISSON)	15 trasm/h (POISSON)	30 trasm/h (POISSON)
	Call duration	100 bytes (FIXED)	100 bytes (FIXED)	100 bytes (FIXED)

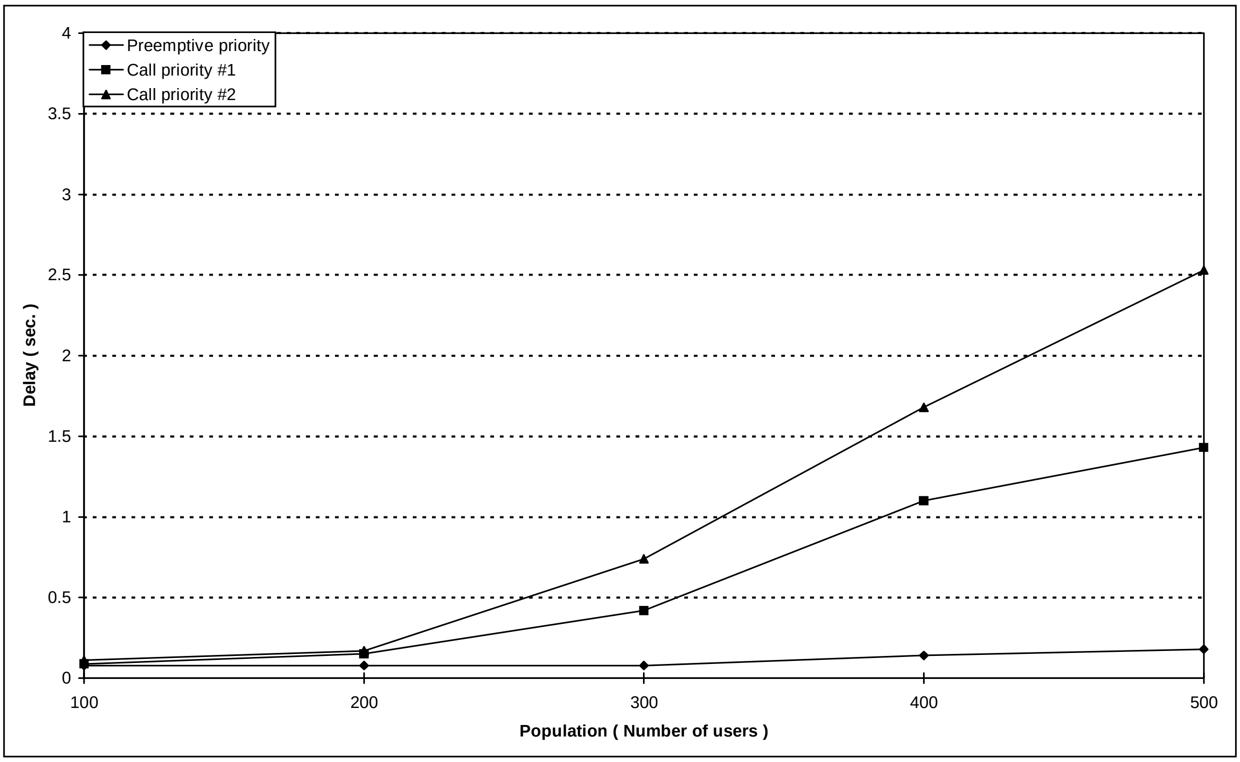

Figure 145: Individual M-M circuit switched call set-up mean delay versus number of users for scenario 8B (Packet Data generation rate = 15/h)

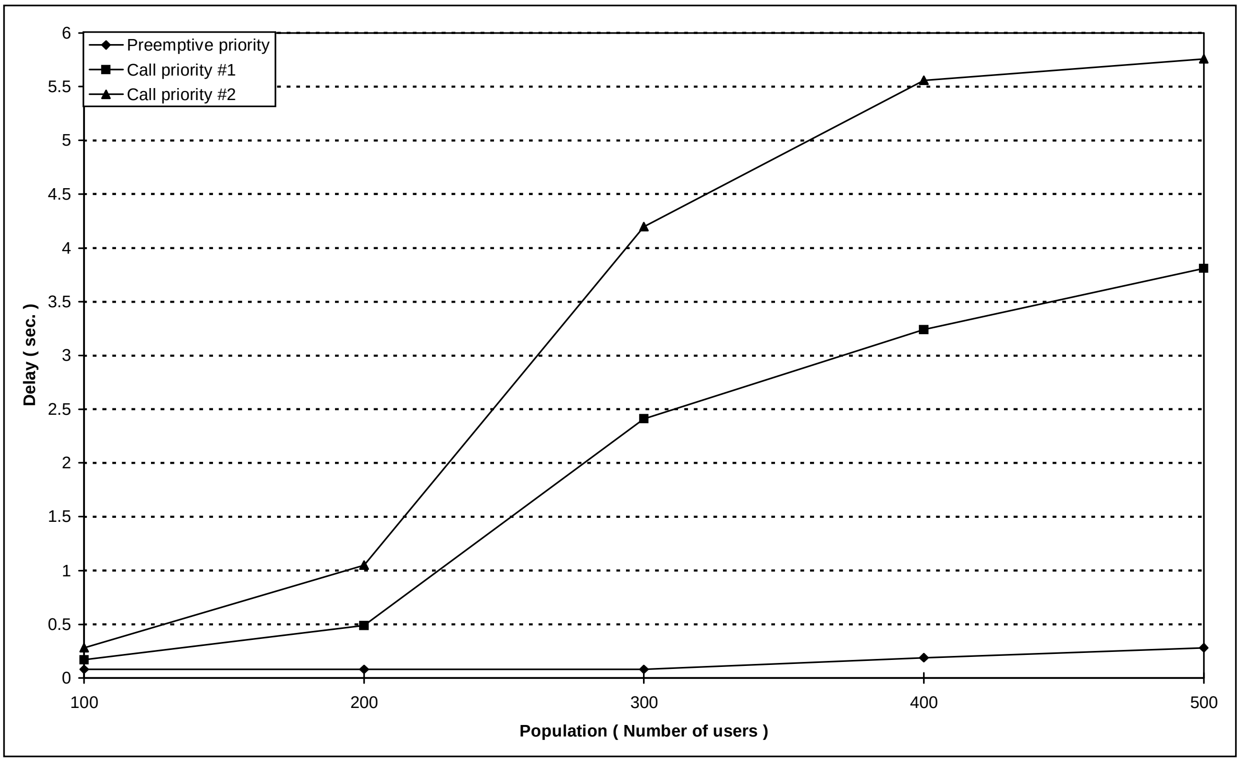

Figure 146: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users for scenario 8B (Packet data generation rate = 15/h)

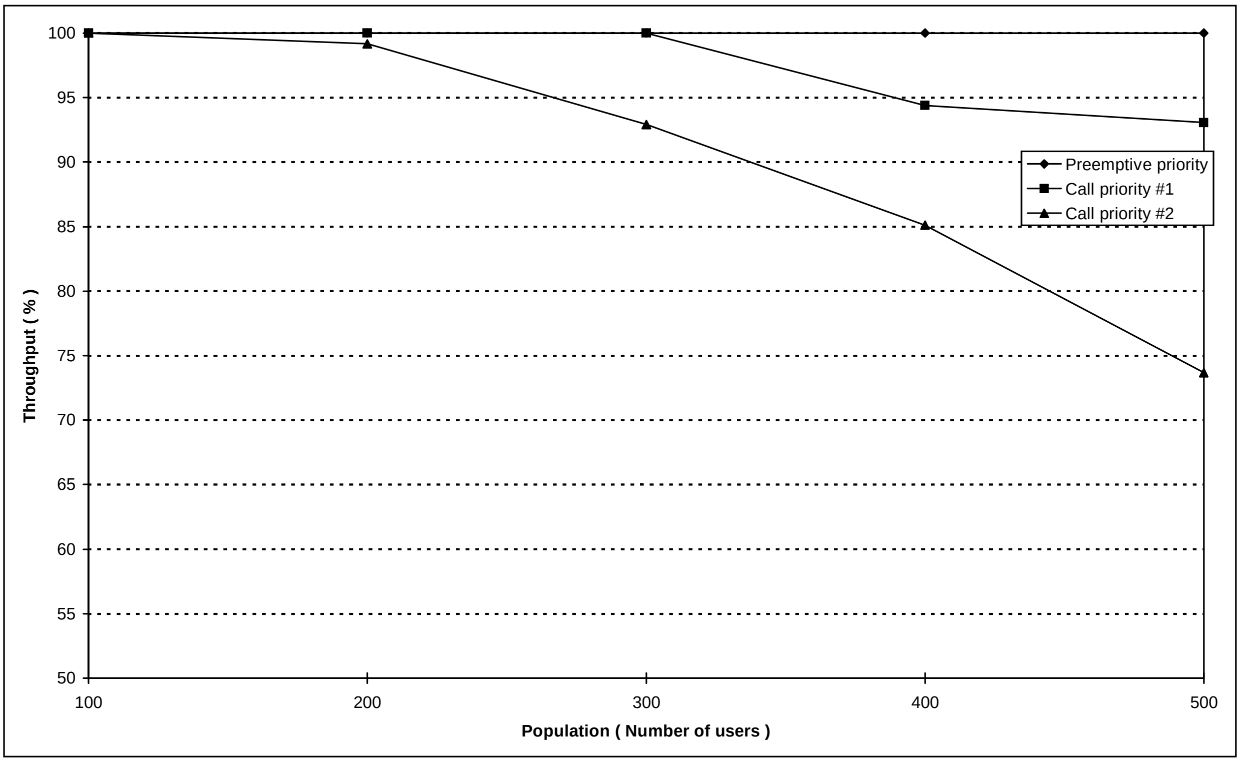

Figure 147: Individual M-M circuit switched call set-up system throughput versus number of users for scenario 8B (Packet data generation rate = 15/h)

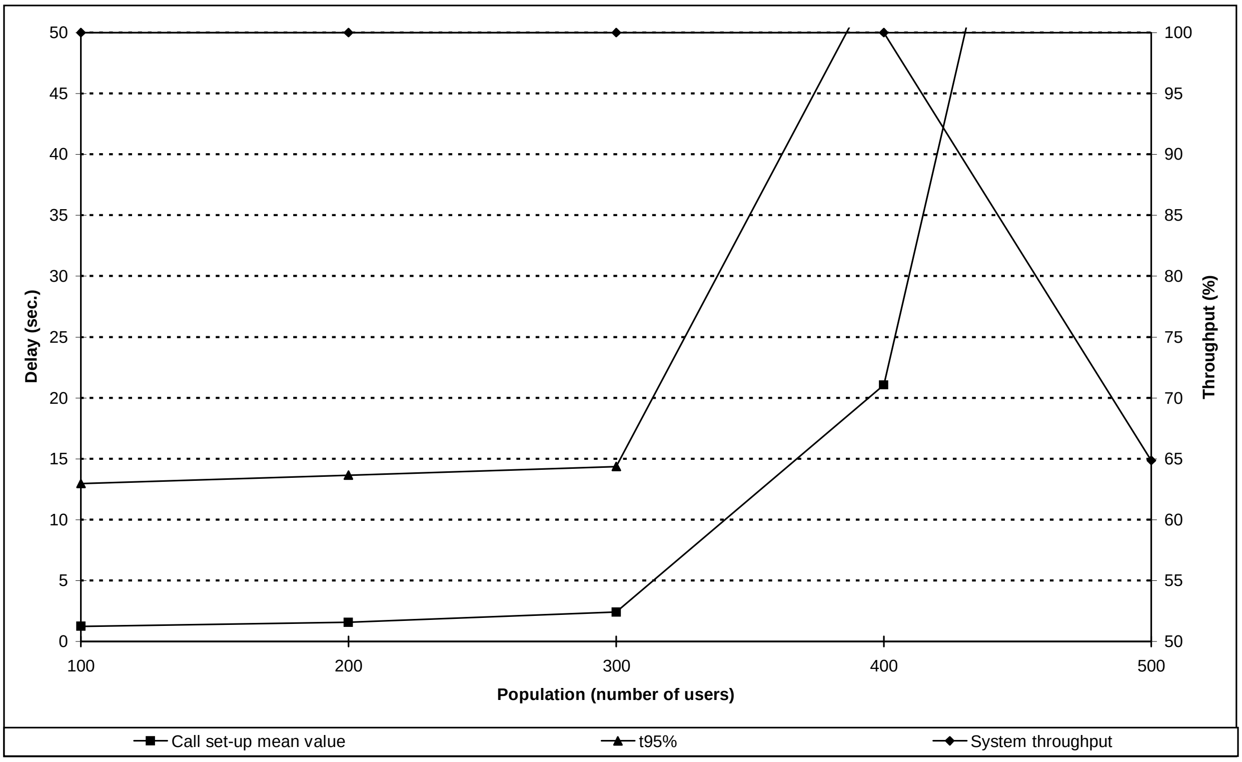

Figure 148: Individual M-M packet data call set-up performance versus number of users for scenario 8B (Packet data generation rate = 15/h)

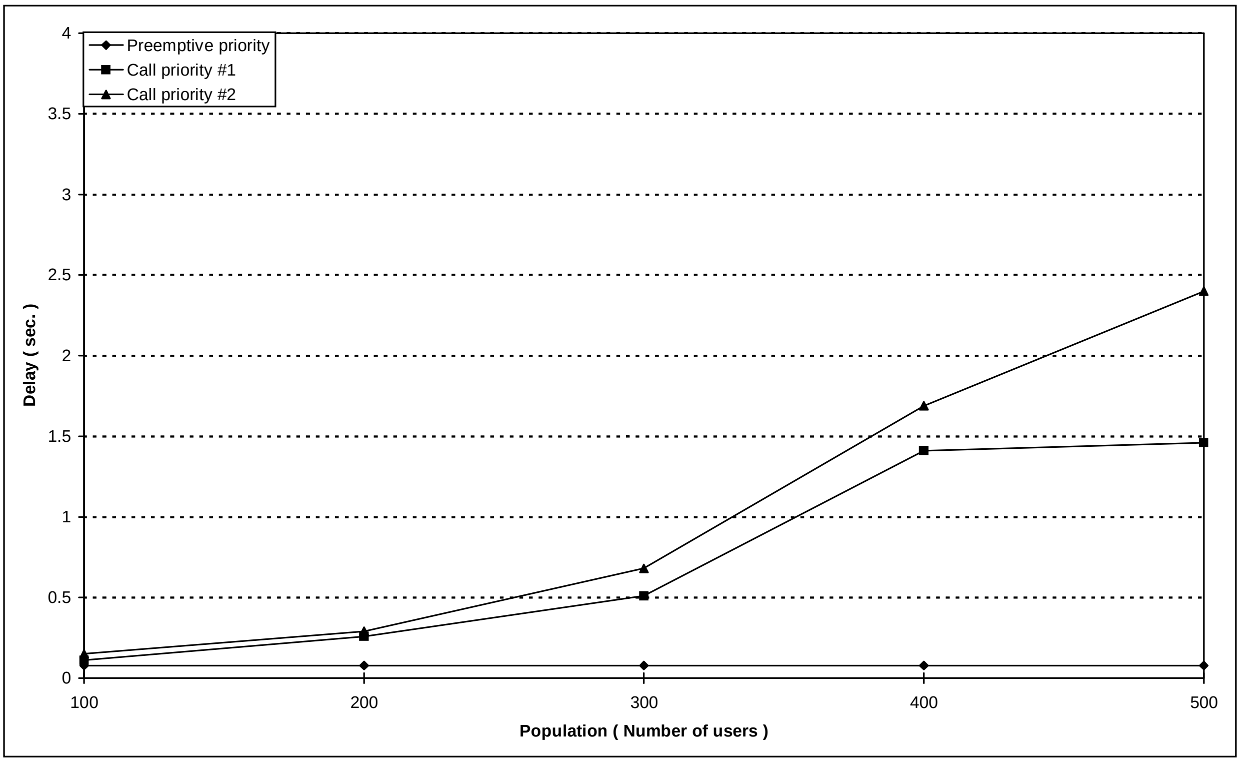

Figure 149: Individual M-M circuit switched call set-up mean delay versus number of users for scenario 8C (Packet data generation rate = 30/h)

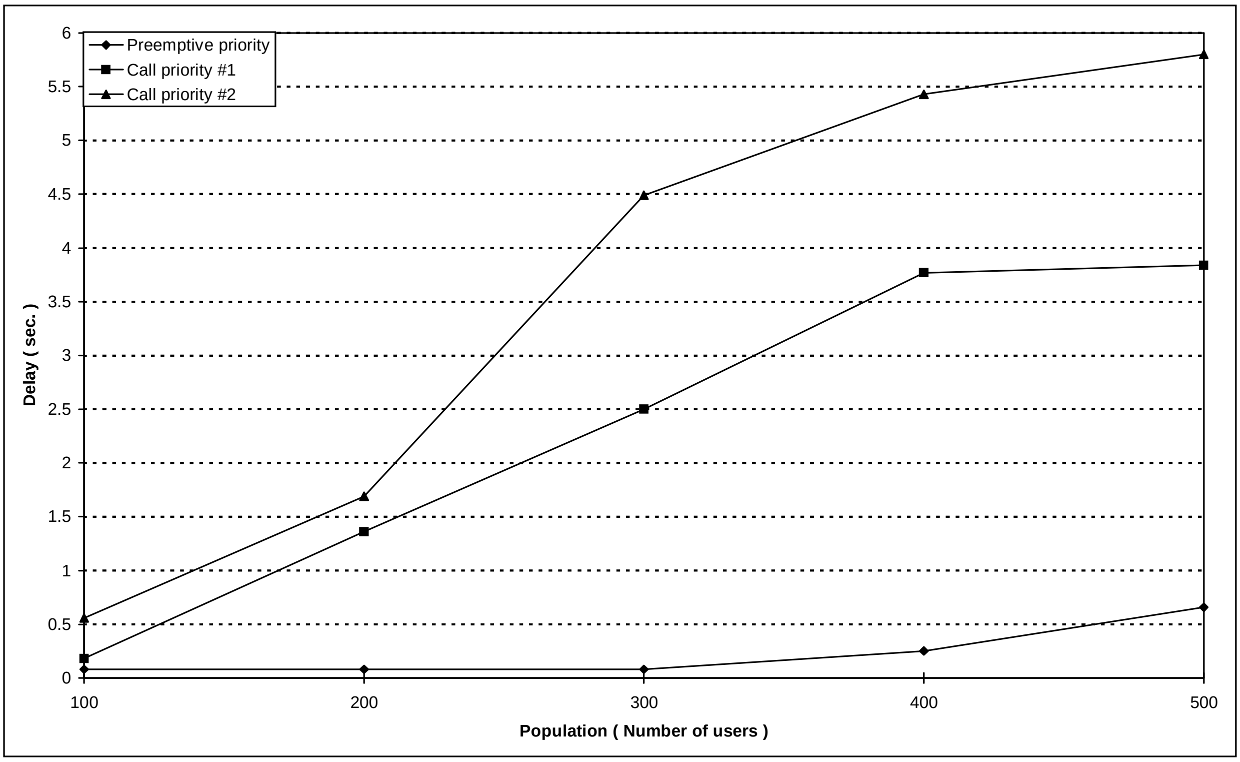

Figure 150: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users for scenario 8C (Packet data generation rate = 30/h)

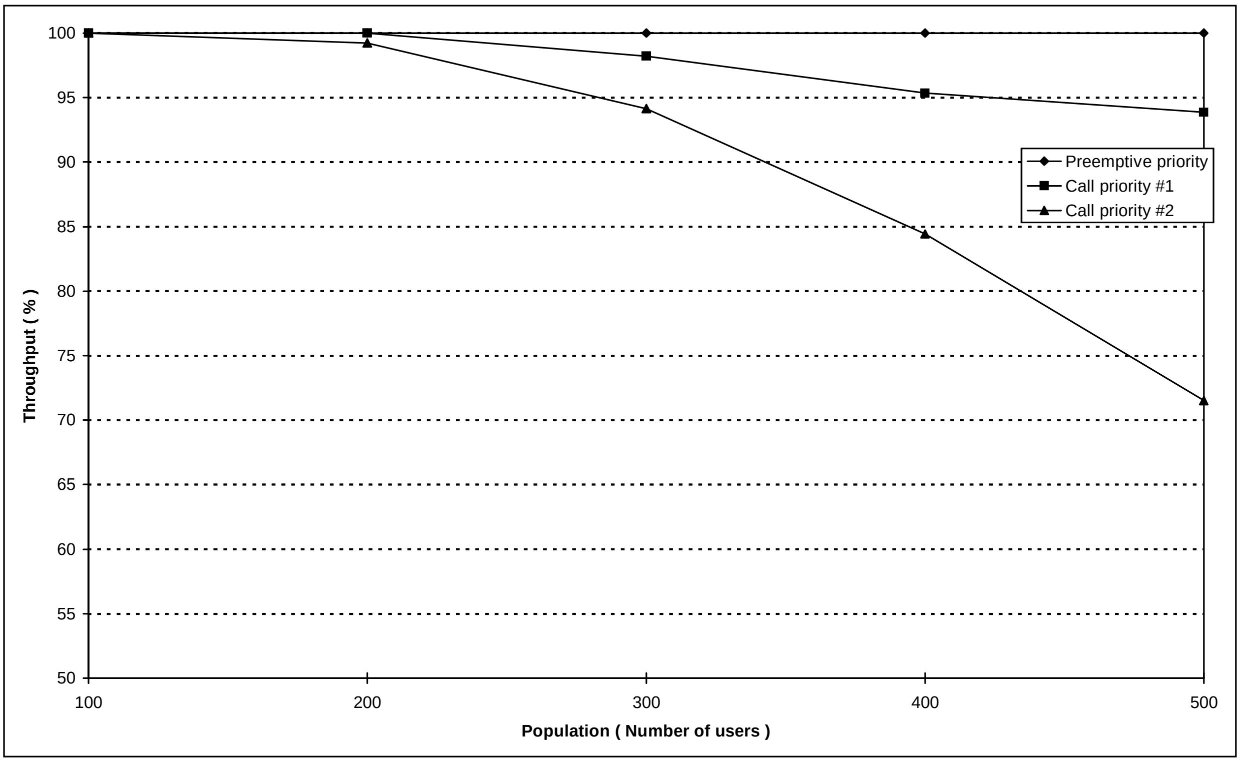

Figure 151: Individual M-M circuit switched call set-up system throughput versus number of users for scenario 8C (Packet data generation rate = 30/h)

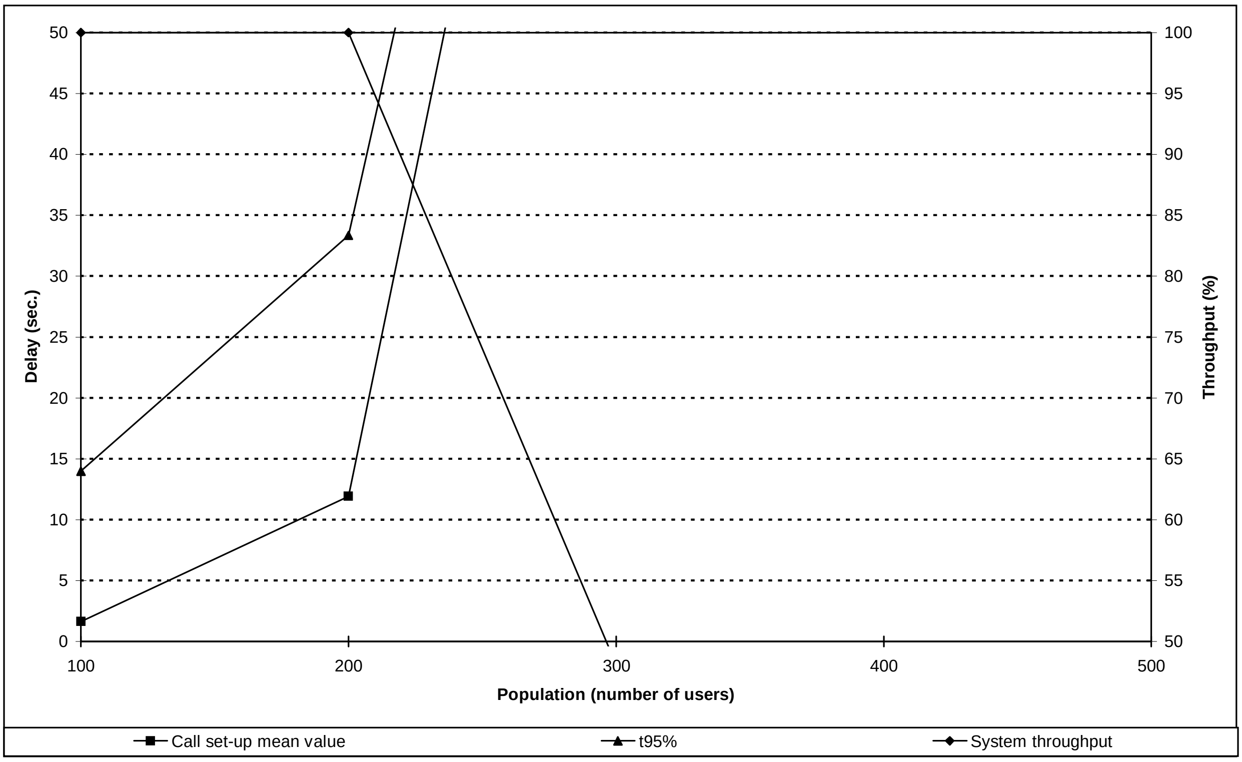

Figure 152: Individual M-M packet data call set-up performance versus number of users for scenario 8C (Packet data generation rate = 30/h)

5.5.3.4.2 Variation of Dispatcher traffic level

The following analysis shows the influence of different levels of Dispatcher traffic on the system. Starting from the reference scenario (represented as 8A), two new scenarios are introduced. Table 23 reports in detail the two new traffic profiles compared with the reference (8A).

In scenario 8D Dispatchers are radio connected, whilst in scenario 8E no Dispatchers are present.

Figures 153 and 154 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure for scenario 8D. Each curve in the figure is related to a particular value of call priority.

Figure 155 reports the system throughput of the M-M individual circuit call set-up for scenario 8D. Each curve in the figure is related to a particular value of call priority.

Figure 156 reports the mean value of the M-M individual packet data call service for scenario 8D. Each curve in the figure is related to a particular value of call priority

Figure 157 reports the mean value of the Dispatcher to Mobile group voice call set-up procedure. Each curve in the figure is related to a particular value of call priority.

Figure 158 reports the $\tau_{95\,\%}$ boundary delay of the Dispatcher to Mobile group voice call set-up procedure. Each curve in the figure is related to a particular value of call priority.

Figure 159 reports the system throughput of the Dispatcher to Mobile group voice call set-up. Each curve in the figure is related to a particular value of call priority.

Figures 160 and 161 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure for scenario 8E. Each curve in the figure is related to a particular value of call priority.

Figure 162 reports the system throughput of the M-M individual circuit call set-up for scenario 8E. Each curve in the figure is related to a particular value of call priority.

Figure 163 reports the mean value of the M-M individual packet data call service for scenario 8E. Each curve in the figure is related to a particular value of call priority.

All these presented figures have to be compared with figures 138 to 144 (reference scenario 8A).

Radio connected Dispatchers present more control channel load than Line connected Dispatchers, nevertheless the difference in performance is small. This is a confirmation that radio interface works efficiently with scenario 8 traffic loading (the most critical part being the call management entity). It is to be observed that the presence of Dispatcher (radio or line connected) causes a sensible degradation of the overall performance.

Table 23: Traffic profiles with different group calls traffic levels

Service	Parameter	Scenario 8A (Reference with line connected Dispatcher)	Scenario 8D (Reference with radio connected Dispatcher)	Scenario 8E (No Dispatcher)
M-M individual voice call	Frequency of requests	0,324 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
M-F individual voice call	Frequency of requests	0,756 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
F-M individual voice call	Frequency of requests	0,756 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
M-M group #1 voice call	Frequency of requests	0,72 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
	Group size	10		
Dispatcher-M group #1 voice call	Frequency of requests	0,72 calls/h (POISSON)	0,72 calls/h (POISSON)	- - -
	Call duration	10 s to 30 s (UNIF)	10 s to 30 s (UNIF)	- - -
	Group size	10	10	- - -
M-M group #2 voice call	Frequency of requests	0,36 calls/h (POISSON)		
	Call duration	10 s to 30 s (UNIF)		
	Group size	15		
Dispatcher-M group #2 voice call	Frequency of requests	0,36 calls/h (POISSON)	0,36 calls/h (POISSON)	- - -
	Call duration	10 s to 30 s (UNIF)	10 s to 30 s (UNIF)	- - -
	Group size	15	15	- - -
M-M individual circuit data call	Frequency of requests	0,2 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
M-F individual circuit data call	Frequency of requests	0,5 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
F-M individual circuit data call	Frequency of requests	0,5 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
M-M group #1 circuit data call	Frequency of requests	0,2 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
	Group size	10		
M-M group #2 circuit data call	Frequency of requests	0,1 calls/h (POISSON)		
	Call duration	2 Kbytes (FIXED)		
	Group size	15		
Short Data transmission	Frequency of requests	10 trasm/h (POISSON)		
	Call duration	100 bytes (FIXED)		

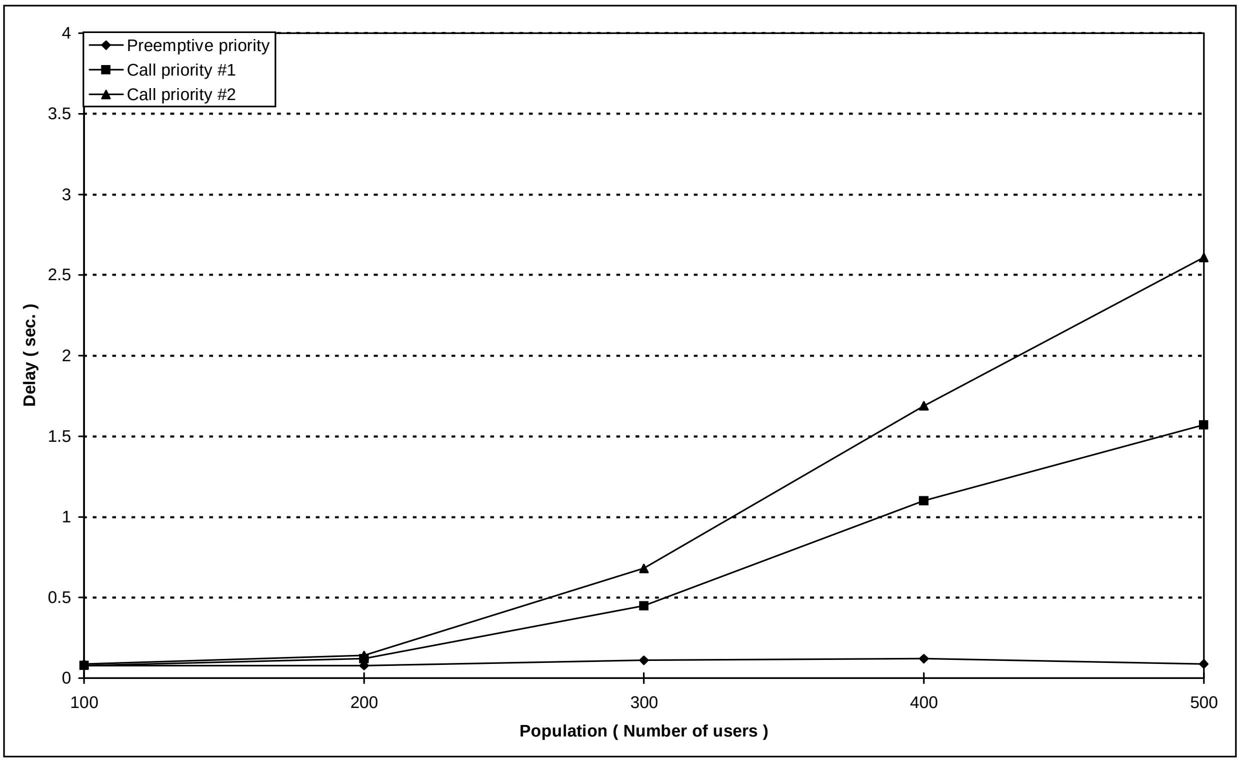

Figure 153: Individual M-M circuit switched call set-up mean delay versus number of users for scenario 8D (Reference with radio Dispatcher)

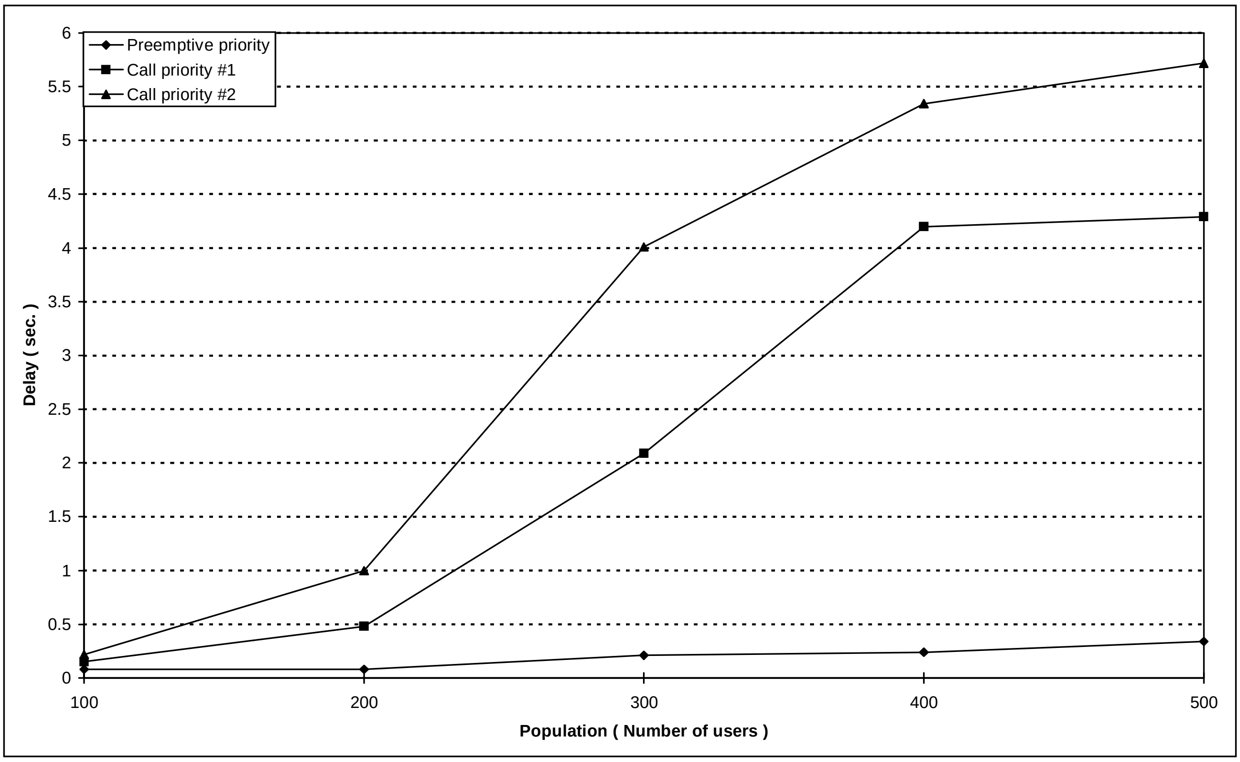

Figure 154: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users for scenario 8D (Reference with radio Dispatcher)

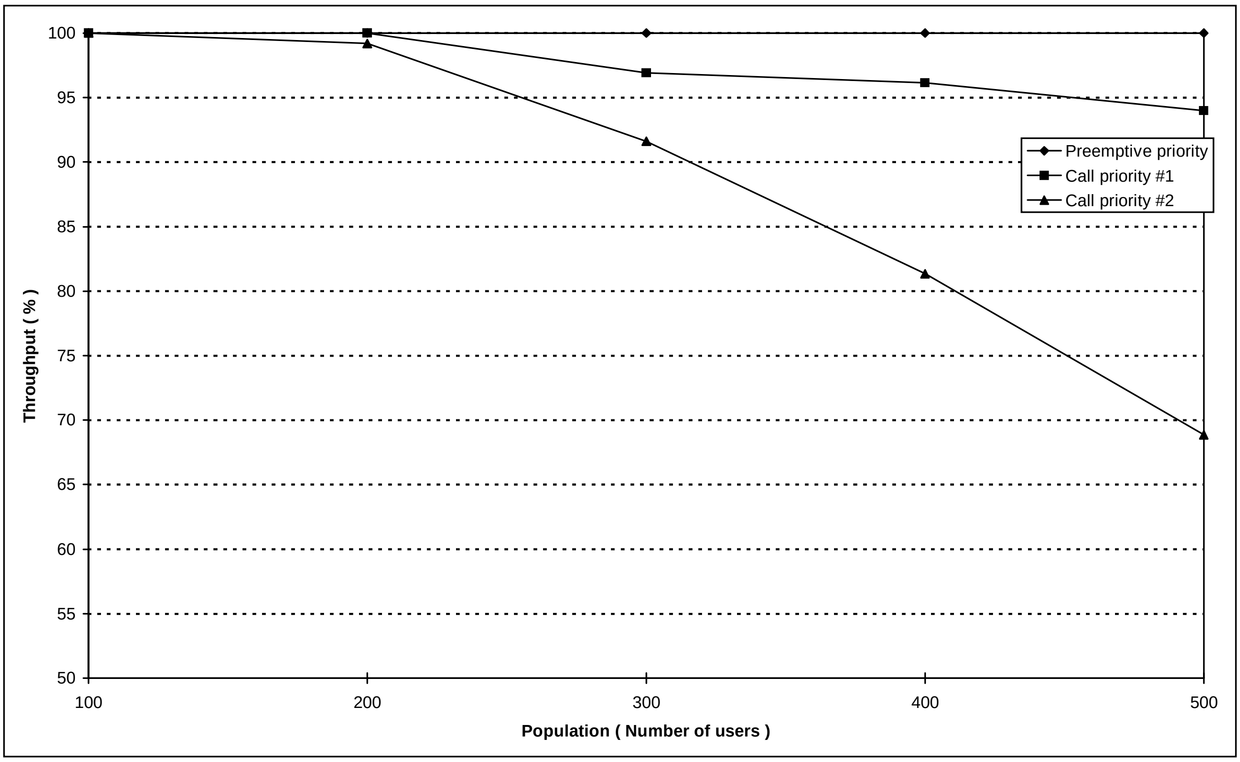

Figure 155: Individual M-M circuit switched call set-up system throughput versus number of users for scenario 8D (Reference with radio Dispatcher)

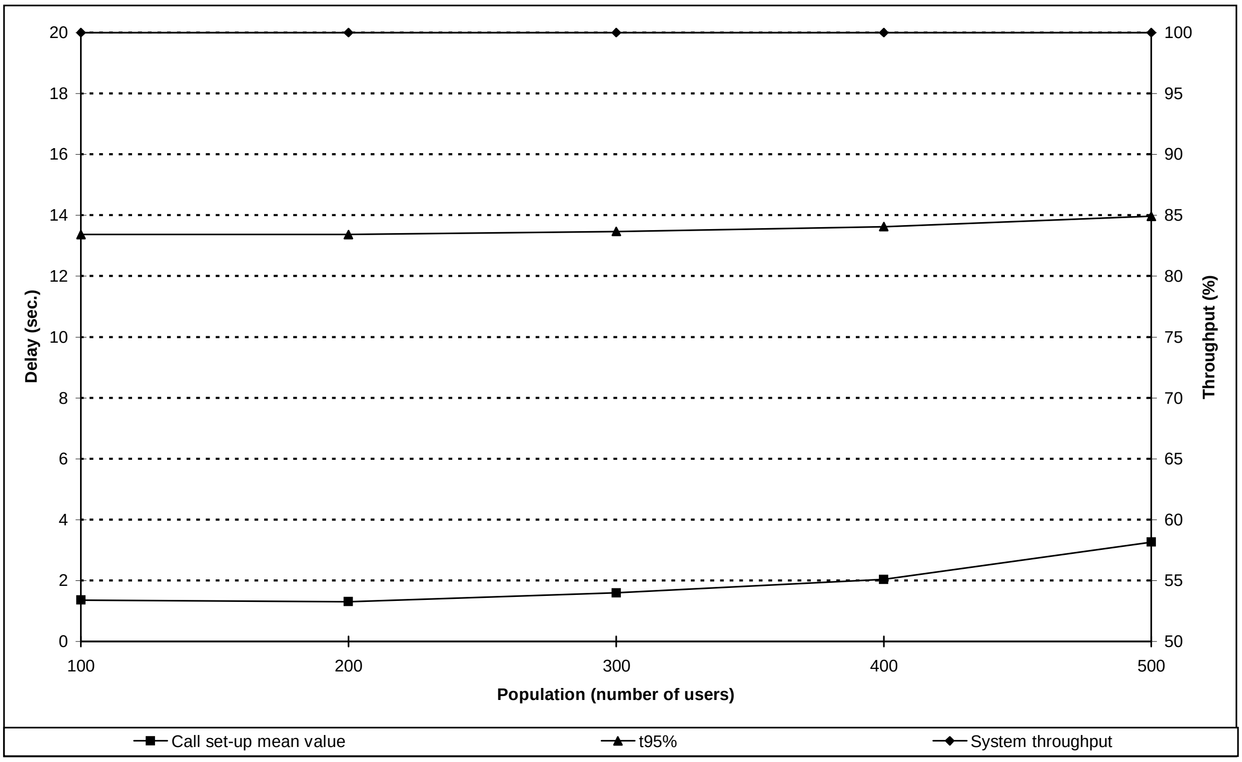

Figure 156: Individual M-M packet data call set-up performance versus number of users for scenario 8D (Reference with radio Dispatcher)

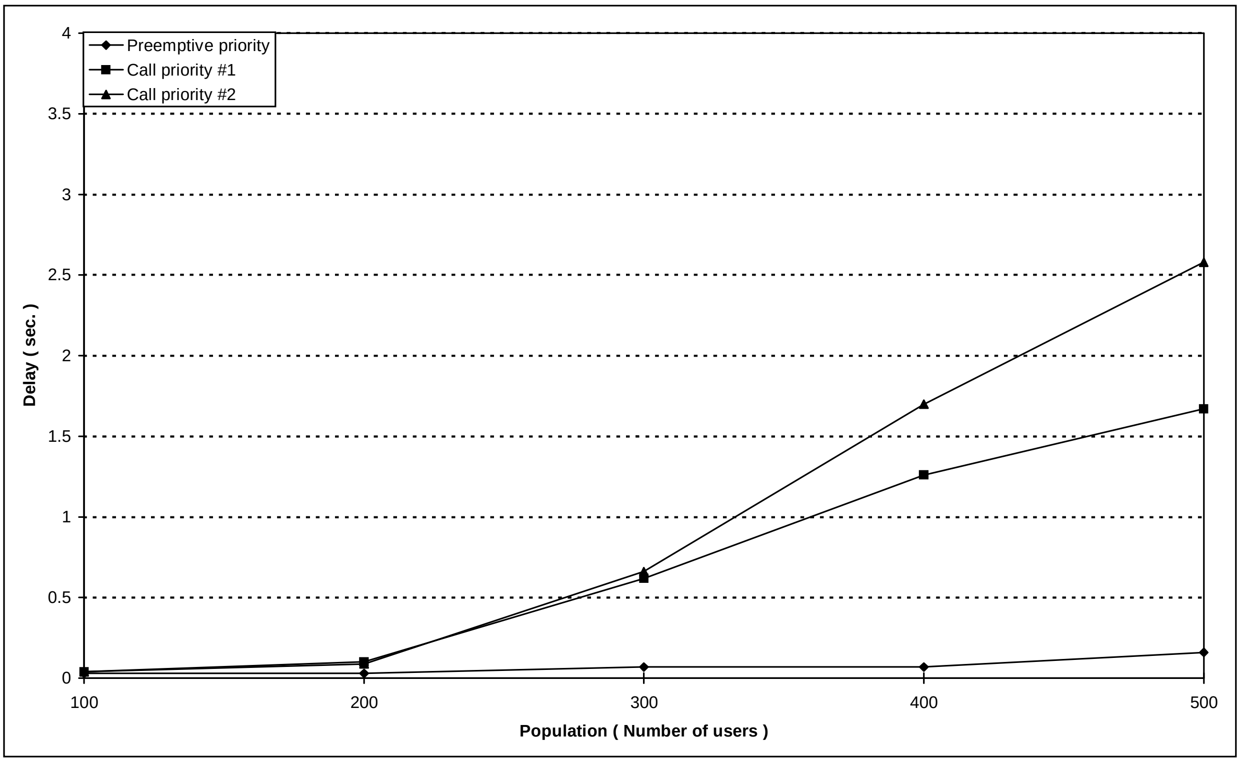

Figure 157: Dispatcher to Mobile group voice call set-up mean delay versus number of users for the reference configuration

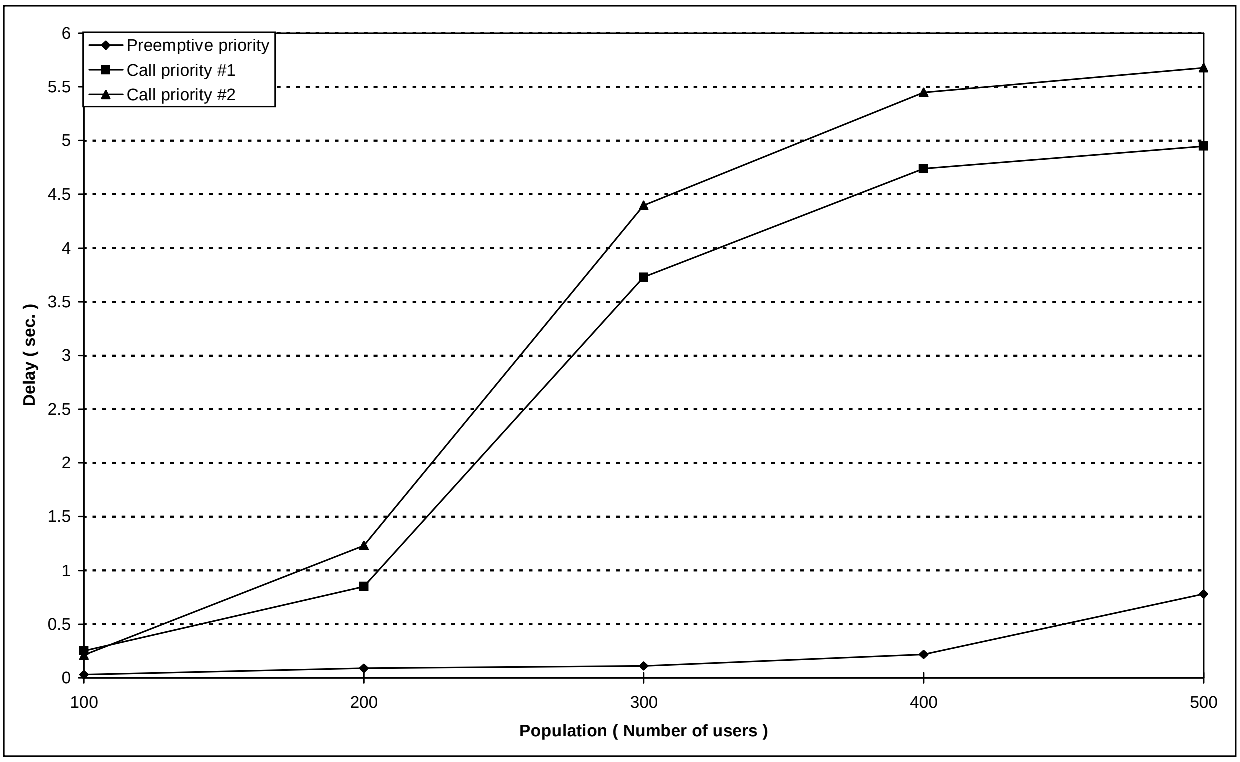

Figure 158: Dispatcher to Mobile group call set-up $\tau_{95\,\%}$ boundary delay versus number of users for the reference configuration

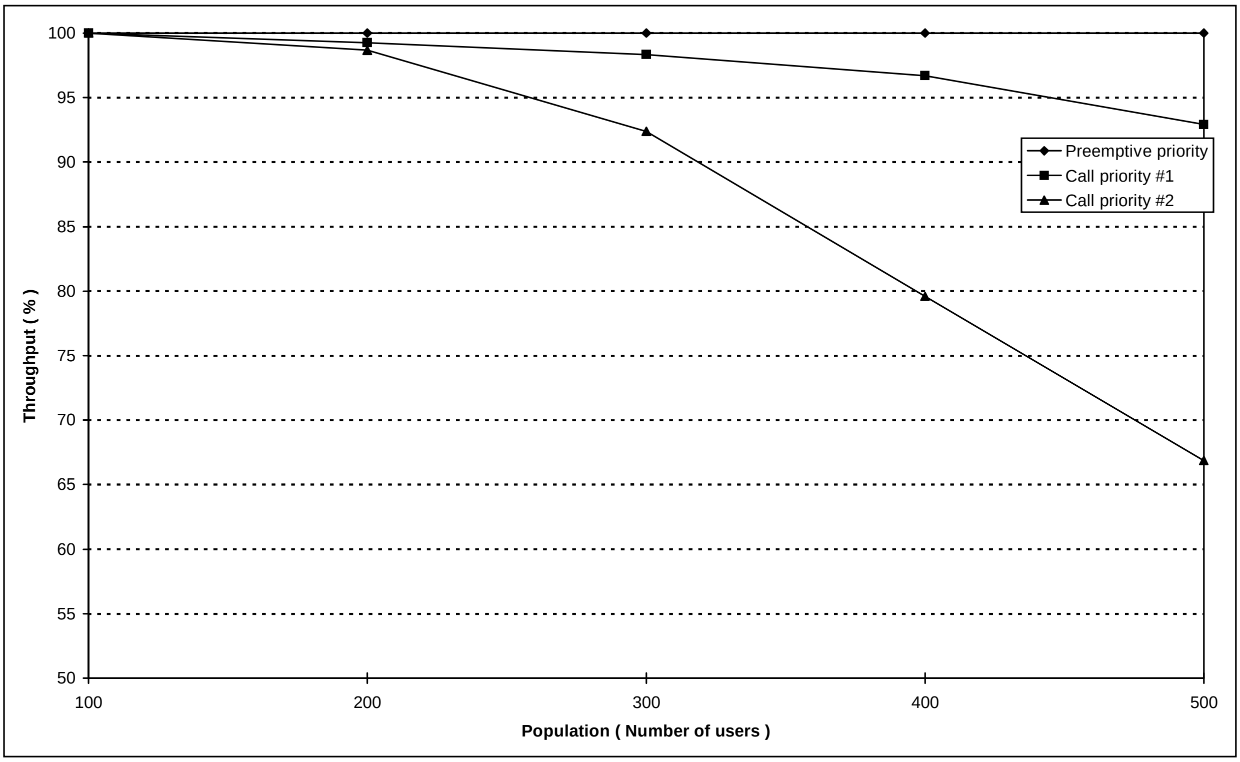

Figure 159: Dispatcher to Mobile group voice call set-up system throughput versus number of users for the reference scenario

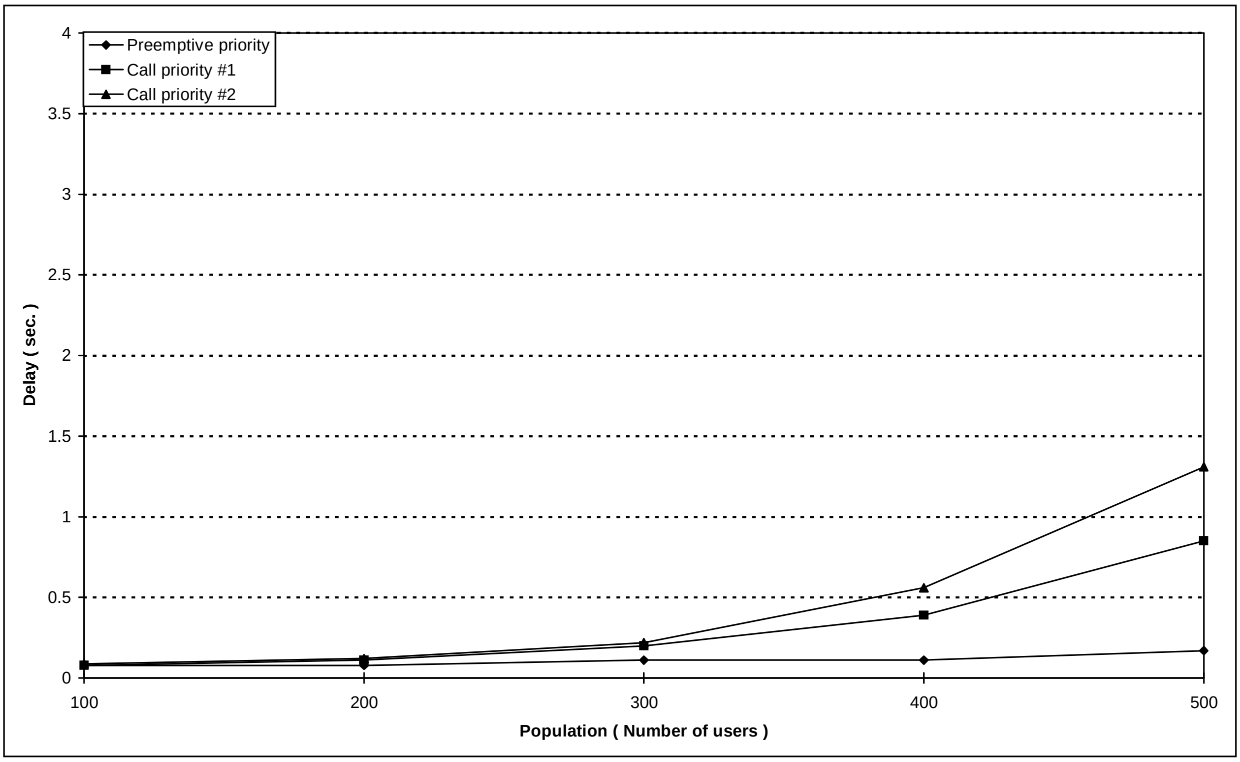

Figure 160: Individual M-M circuit switched call set-up mean delay versus number of users for scenario 8E (No Dispatcher)

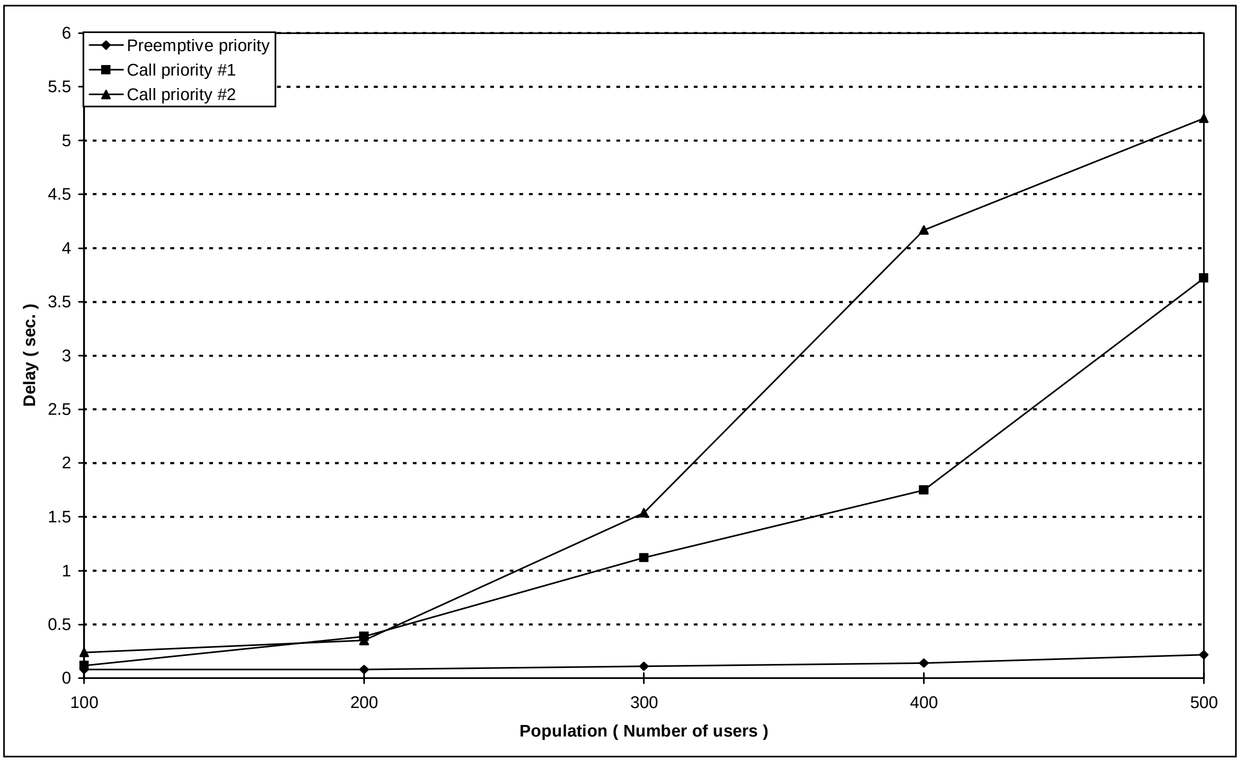

Figure 161: Individual M-M circuit switched call set-up $\tau_{95\ \%}$ boundary delay versus number of user for scenario 8E (No Dispatcher)

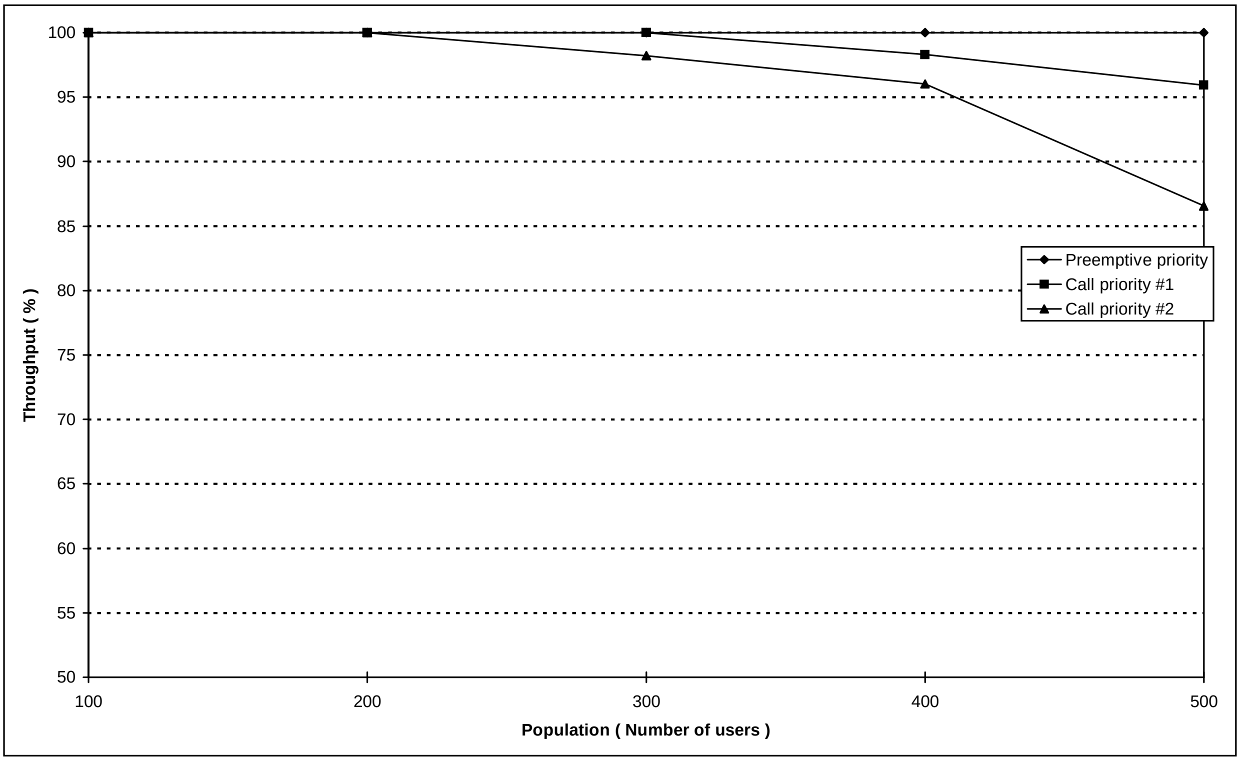

Figure 162: Individual M-M circuit switched call set-up system throughput versus number of users for scenario 8E (No Dispatcher)

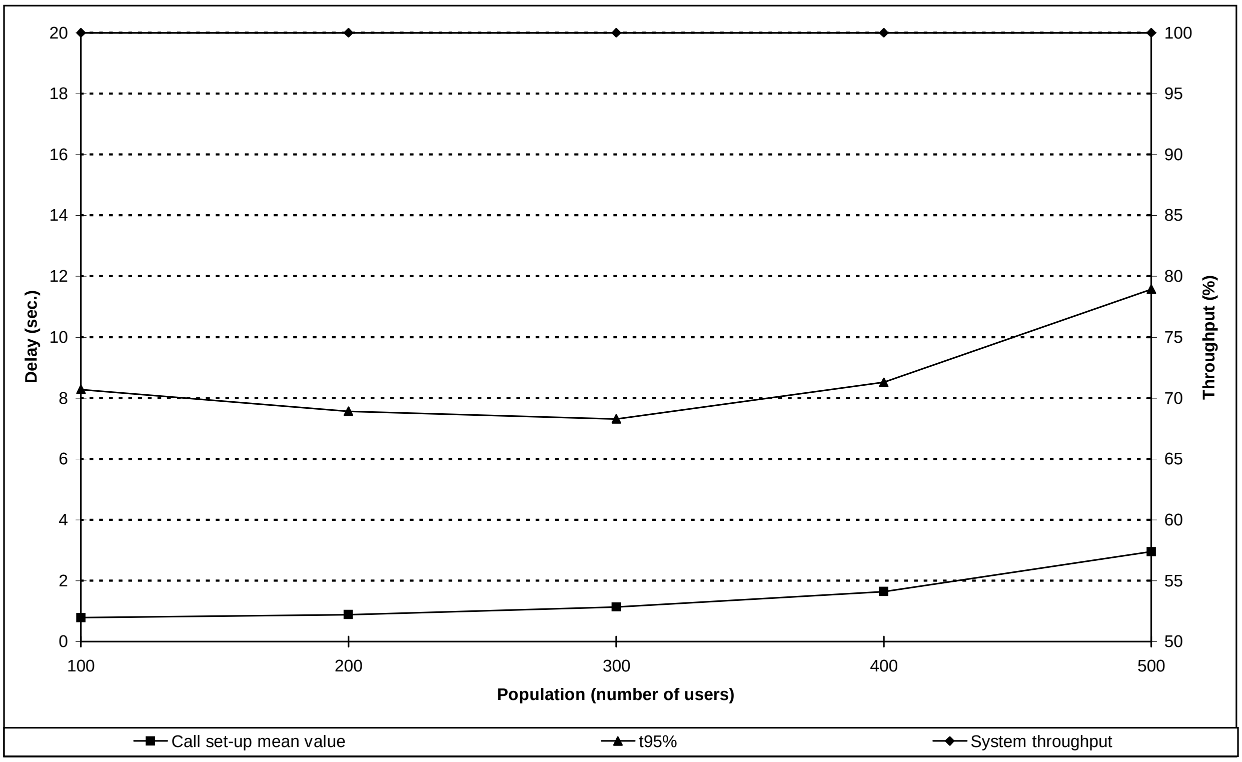

Figure 163: Individual M-M packet data call set-up performance versus number of users for scenario 8E (No Dispatcher)

5.5.3.4.3 Analysis of different service priorities distributions

The following analysis shows the influence of different priority distributions on the system performance. Starting from the reference priority distribution (table 20) three different distributions have been analysed in this clause. They are reported in detail in table 24.

Figures 164 and 165 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure for priority distribution A. Each curve in the figure is related to a particular value of call priority.

Figure 166 reports the system throughput of the M-M individual circuit call set-up for priority distribution A. Each curve in the figure is related to a particular value of call priority.

Figure 167 reports the mean value of the M-M individual packet data call service for priority distribution A. Each curve in the figure is related to a particular value of call priority.

Figures 168 and 169 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure for priority distribution B. Each curve in the figure is related to a particular value of call priority.

Figure 170 reports the system throughput of the M-M individual circuit call set-up for priority distribution B. Each curve in the figure is related to a particular value of call priority.

Figure 171 reports the mean value of the M-M individual packet data call service for priority distribution B. Each curve in the figure is related to a particular value of call priority.

Figures 172 and 173 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure for priority distribution C. Each curve in the figure is related to a particular value of call priority.

Figure 174 reports the system throughput of the M-M individual circuit call set-up for priority distribution C. Each curve in the figure is related to a particular value of call priority.

Figure 175 reports the mean value of the M-M individual packet data call service for priority distribution C. Each curve in the figure is related to a particular value of call priority.

All these presented figures have to be compared with figures 138 to 144 (reference scenario 8A).

A first observation is that packet data calls figures are almost the same because the priorities affect the circuit services only. Looking to the different figures, passing from profile A to profile C, priority #2 calls performance decreases for throughput and increases for delay. Priority #1 calls performance changes only for the throughput figure, while pre-emptive priority calls obtain always the minimum times and highest throughput.

Priority #1 and #2 performance are not very different in delay as they are in throughput. This is because of the timer of maximum holding in the queue: when a lot of high priority calls are in the system, low priority calls are put in the queue and are released with a high probability. However, when a call is taken from the queue, the hold time can be very low independently by the priority value.

Table 24: Priority distribution for the reference configuration of scenario 8

Priority distribution	Service	Pre-emptive priority	Priority #1	Priority #2
Reference	Voice	1 %	10 %	89 %
	Circuit data	- - -	10 %	90 %
A	Voice	- - -	- - -	100 %
	Circuit data	- - -	- - -	100 %
B	Voice	10 %	10 %	80 %
	Circuit data	- - -	10 %	90 %
C	Voice	- - -	50 %	50 %
	Circuit data	- - -	50 %	50 %

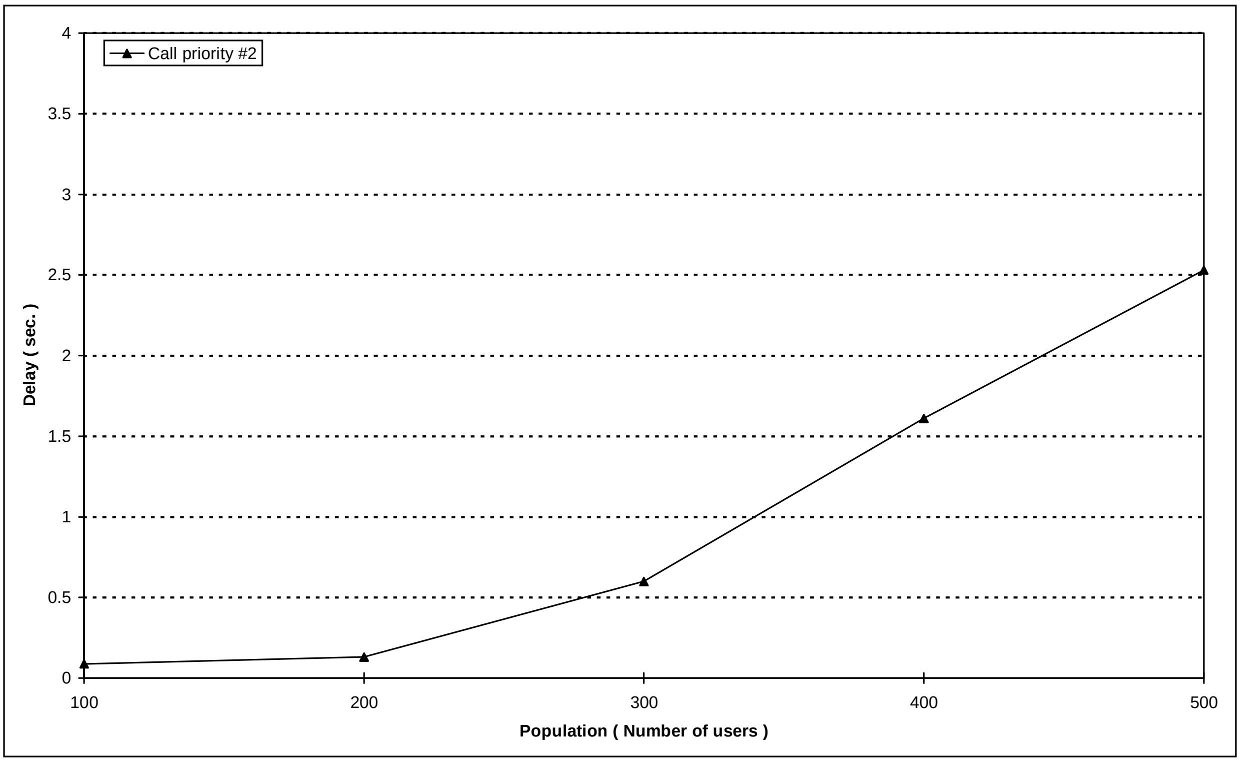

Figure 164: Individual M-M circuit switched call set-up mean delay versus number of users for priority distribution A

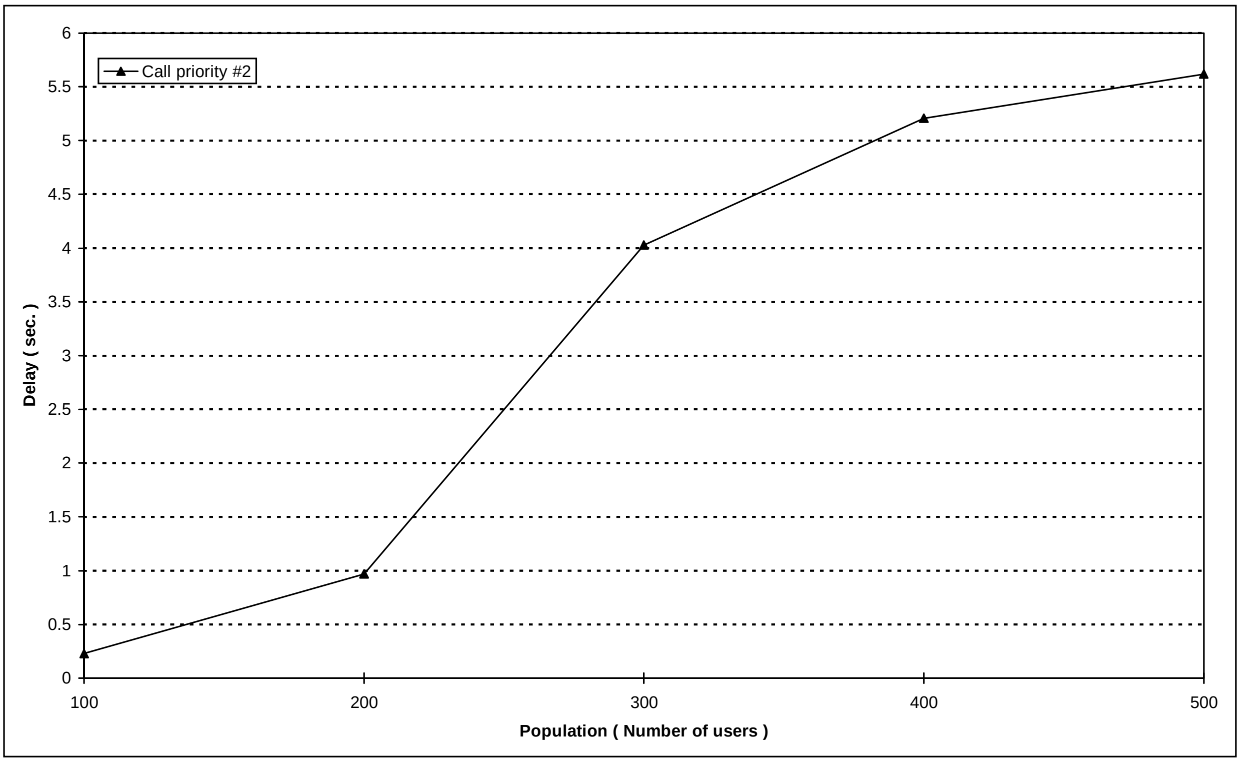

Figure 165: Individual M-M circuit switched call set-up $\tau_{95\ \%}$ boundary delay versus number of users for priority distribution A

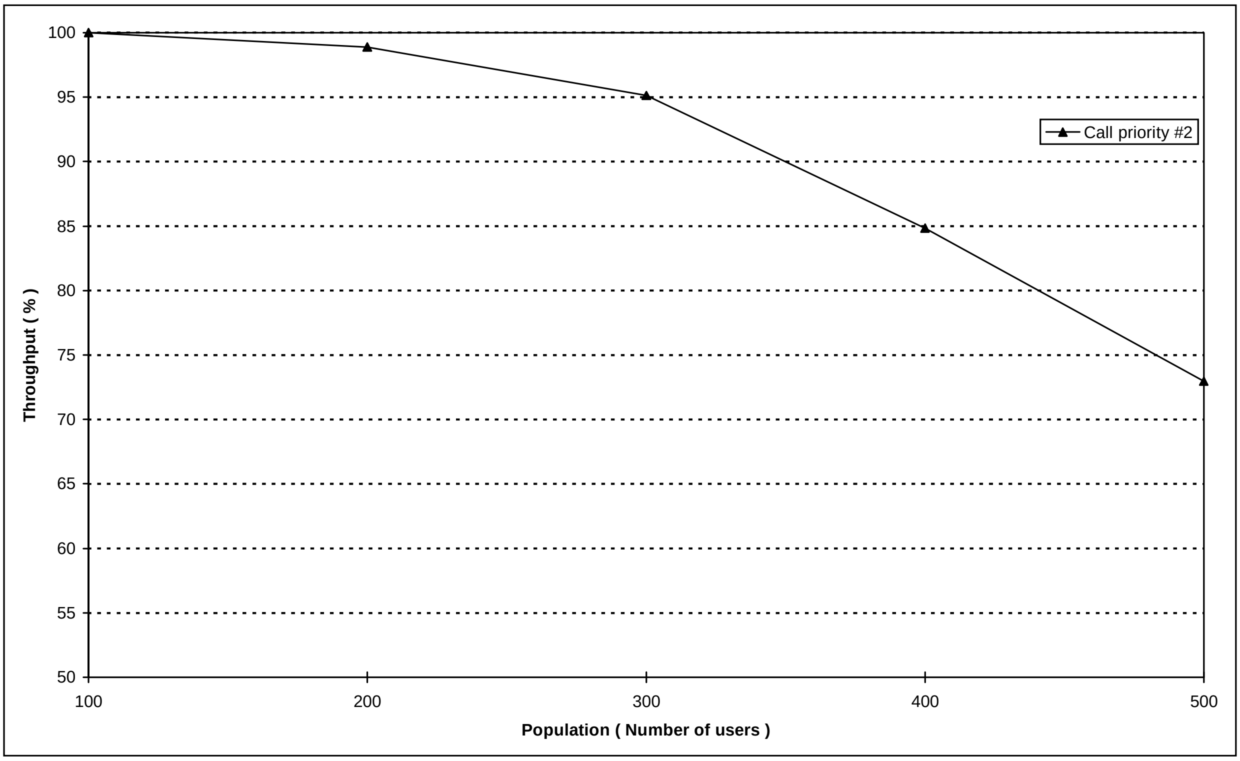

Figure 166: Individual M-M circuit switched call set-up system throughput versus number of users for priority distribution A

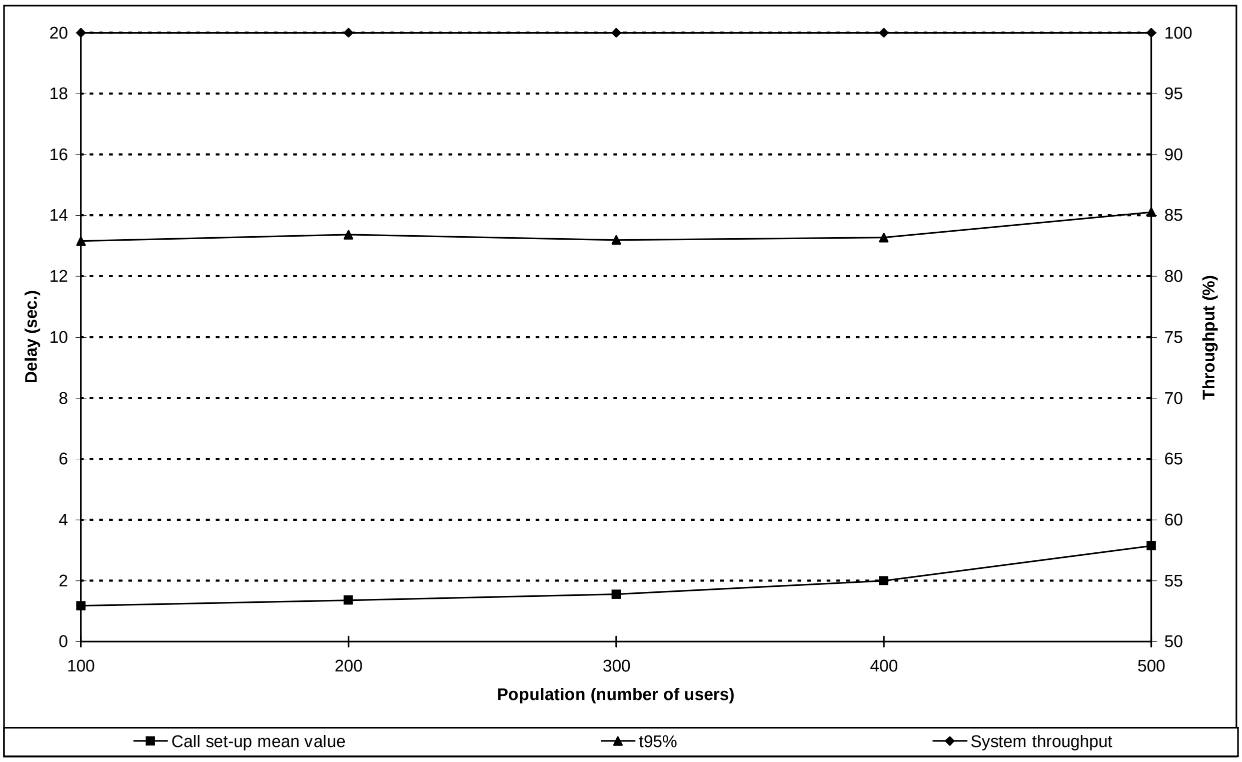

Figure 167: Individual M-M packet data call set-up performance versus number of users for priority distribution A

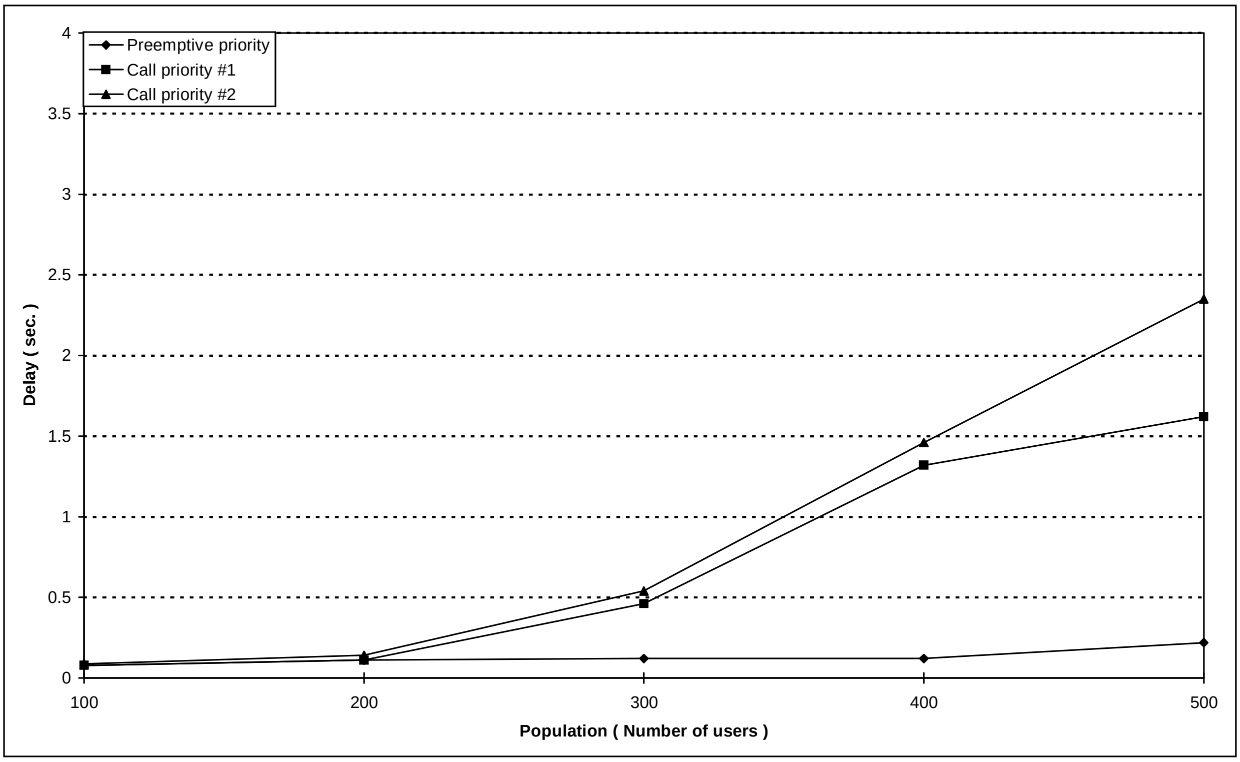

Figure 168: Individual M-M circuit switched call set-up mean delay versus number of users for priority distribution B

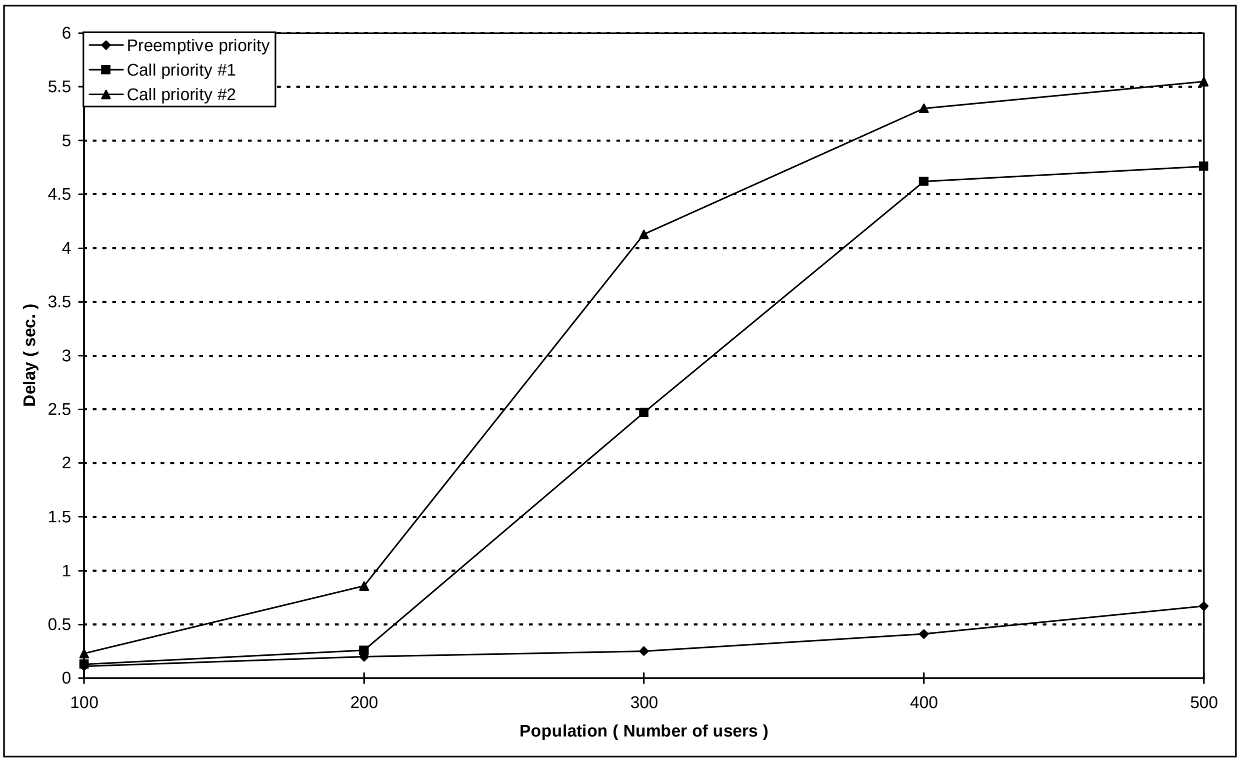

Figure 169: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users for priority distribution B

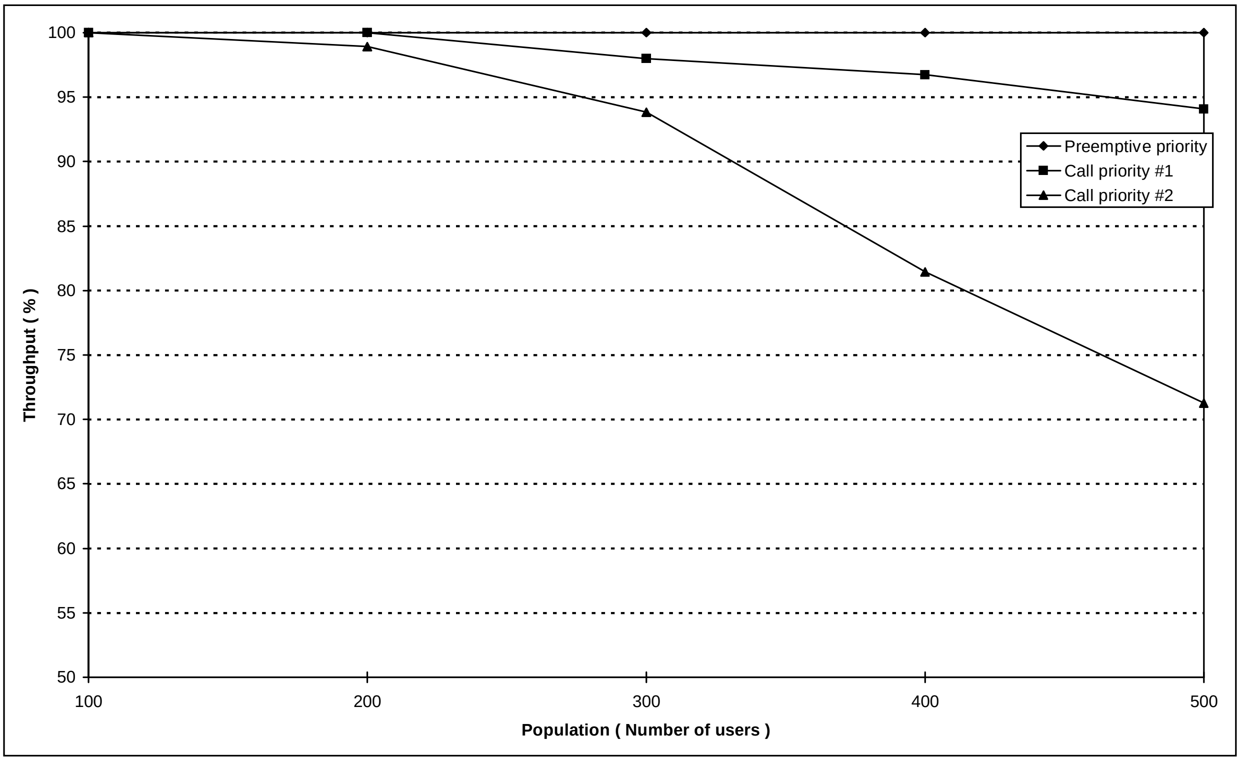

Figure 170: Individual M-M circuit switched call set-up system throughput versus number of users for priority distribution B

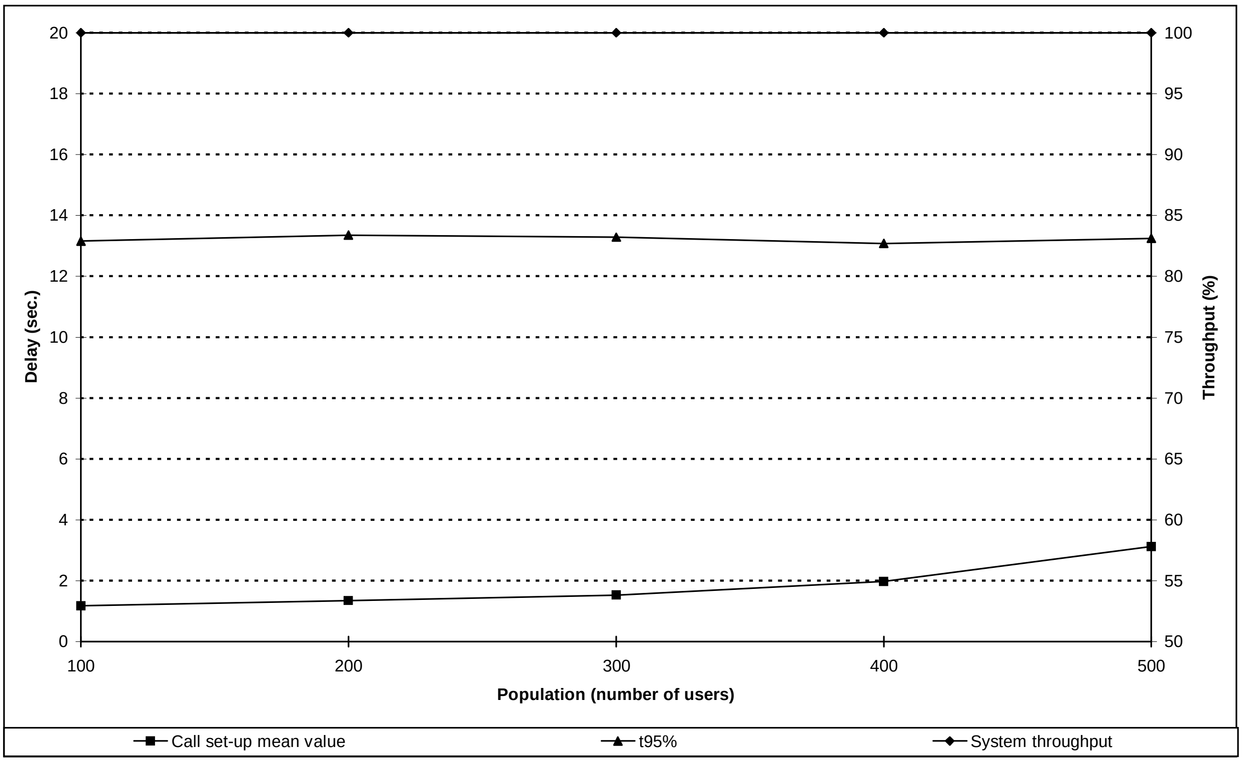

Figure 171: Individual M-M packet data call set-up performance versus number of users for priority distribution B

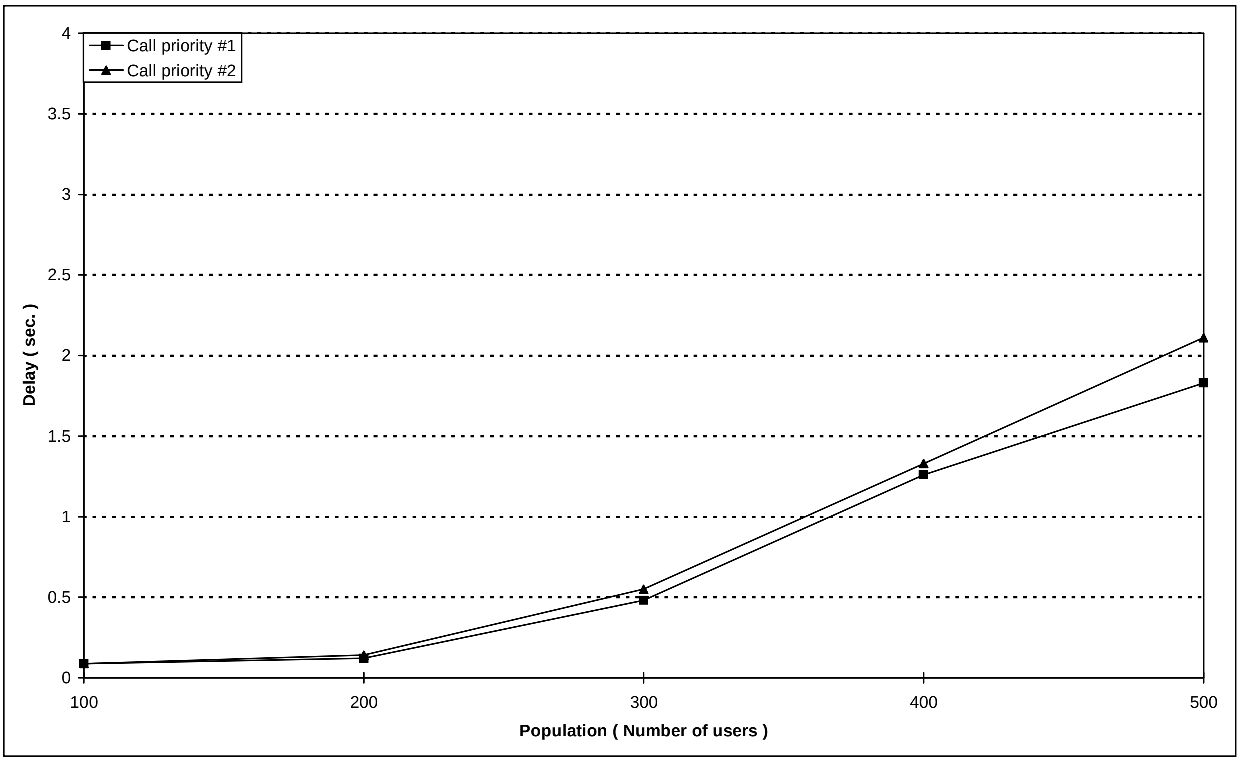

Figure 172: Individual M-M circuit switched call set-up mean delay versus number of users for priority distribution C

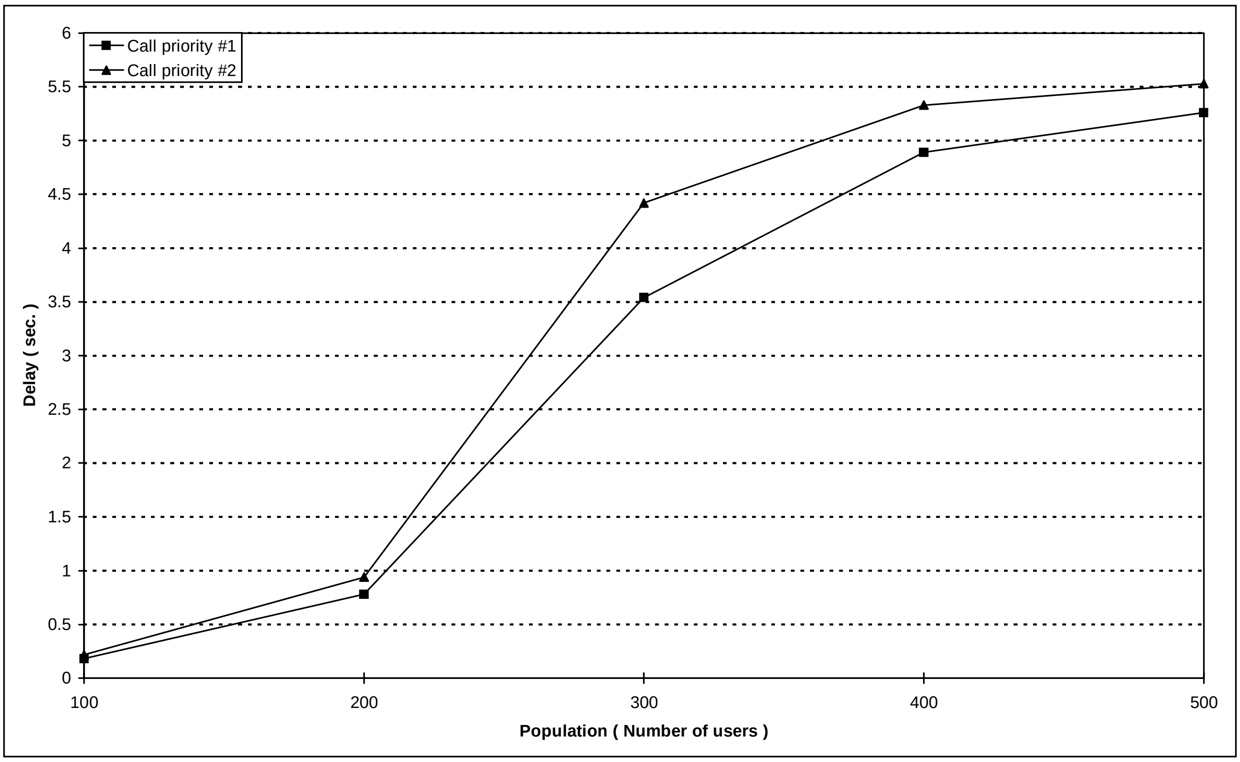

Figure 173: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users for priority distribution C

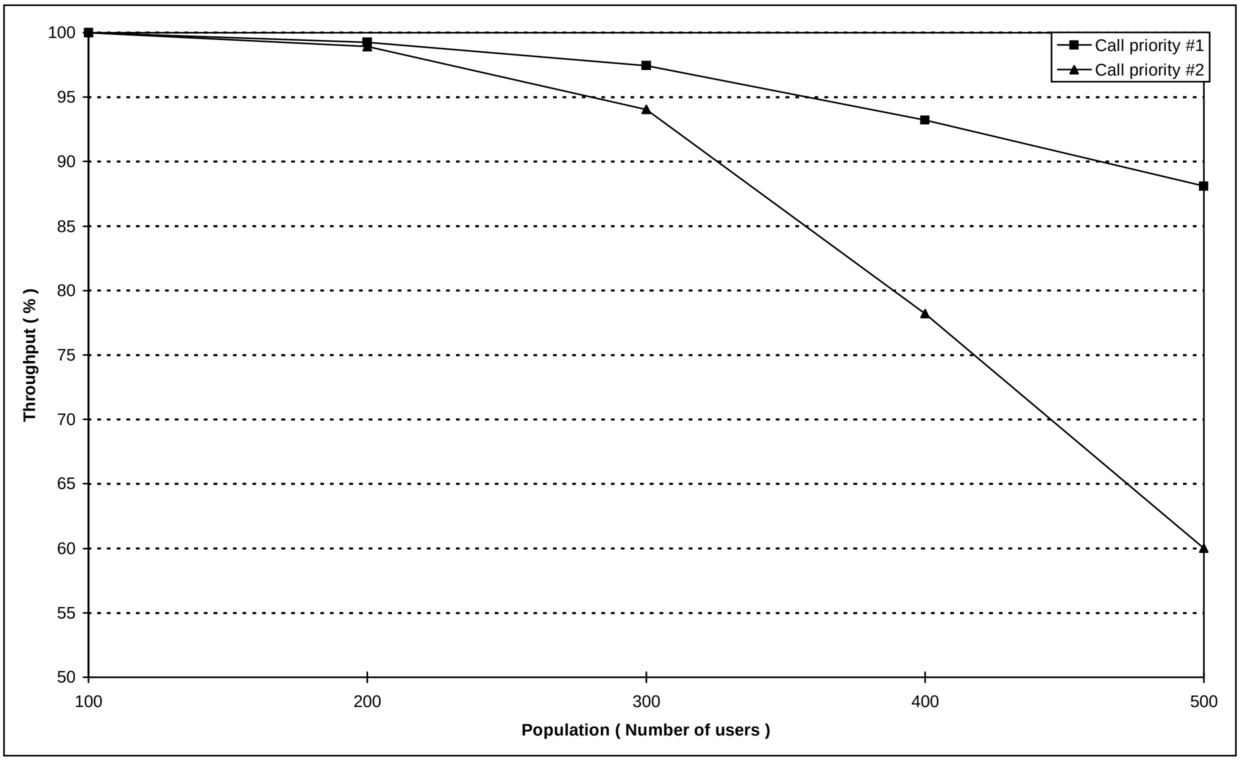

Figure 174: Individual M-M circuit switched call set-up system throughput versus number of users for priority distribution C

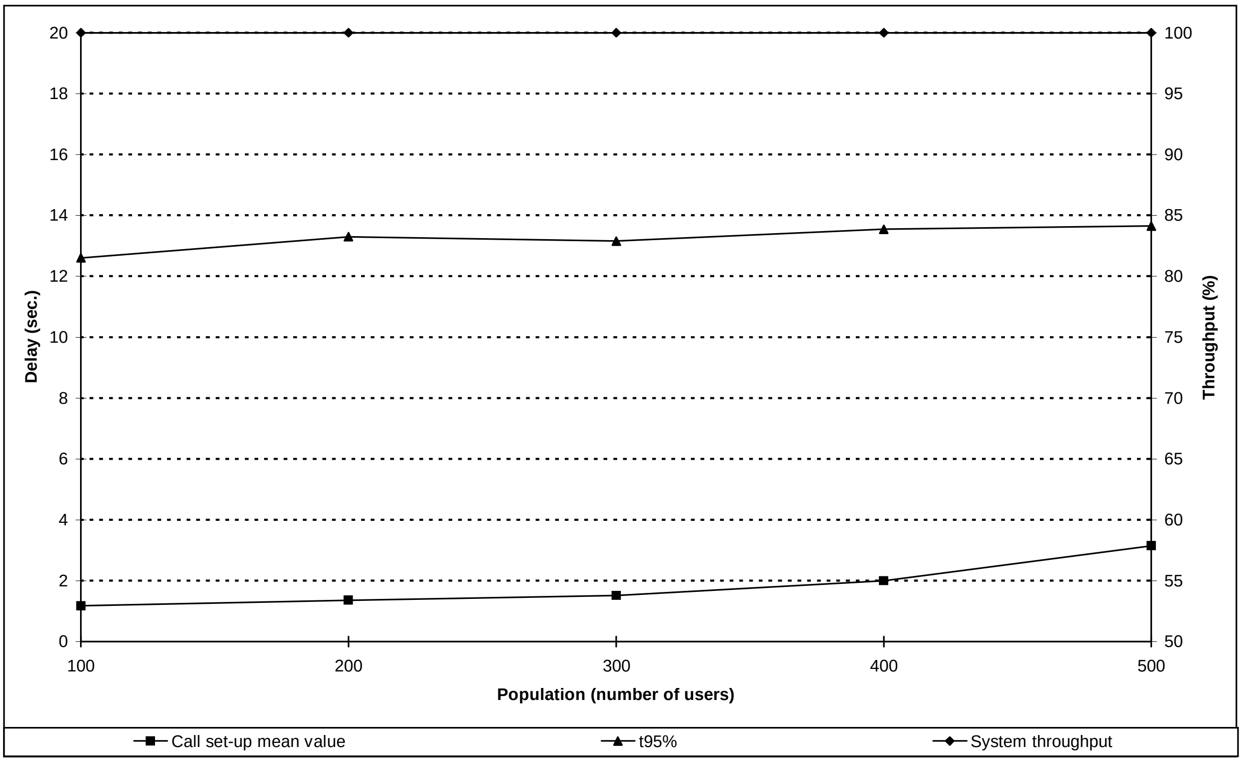

Figure 175: Individual M-M packet data call set-up performance versus number of users for priority distribution C

5.5.3.4.4 Analysis with full duplex circuit calls

The present analysis shows the degradation of performance due to a different amount of resources required by the circuit calls. Particularly, in the analysed scenario (to be compared with the reference) all individual circuit switched calls are set-up as full duplex connections. This means that in case of individual calls between users in the same network cell, the call requires two TCHs instead of 1. All other kind of calls (M-F and F-M individual calls, group calls) require 1 TCH only. For this reason performance is presented for both M-M calls (that require 2 TCHs) and M-F calls (that require 1 TCH).

Figures 176 and 177 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure in case of full duplex individual calls. Each curve in the figure is related to a particular value of call priority.

Figure 178 reports the system throughput of the M-M individual circuit call set-up in case of full duplex individual calls. Each curve in the figure is related to a particular value of call priority.

Figures 179 and 180 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-F individual circuit call set-up procedure in case of full duplex individual calls. Each curve in the figure is related to a particular value of call priority.

Figure 181 reports the system throughput of the M-F individual circuit call set-up in case of full duplex individual calls. Each curve in the figure is related to a particular value of call priority.

Figure 182 reports the mean value of the M-M individual packet data call service in case of full duplex individual calls. Each curve in the figure is related to a particular value of call priority.

All these presented figures have to be compared with figures 138 to 144 (reference scenario 8A).

Looking to the reported figures, it is straightforward to observe a worse performance for M-M calls when they are full duplex for both delay and throughput. Nevertheless M-F call set-up delays (that employ 1 TCH) present the same delay profile as the reference (throughput is lower because of the presence of full duplex calls, that limit the total amount of resources). Short Data transmission figures are similar to the reference scenario because they are not affected by the total amount of TCHs in the system.

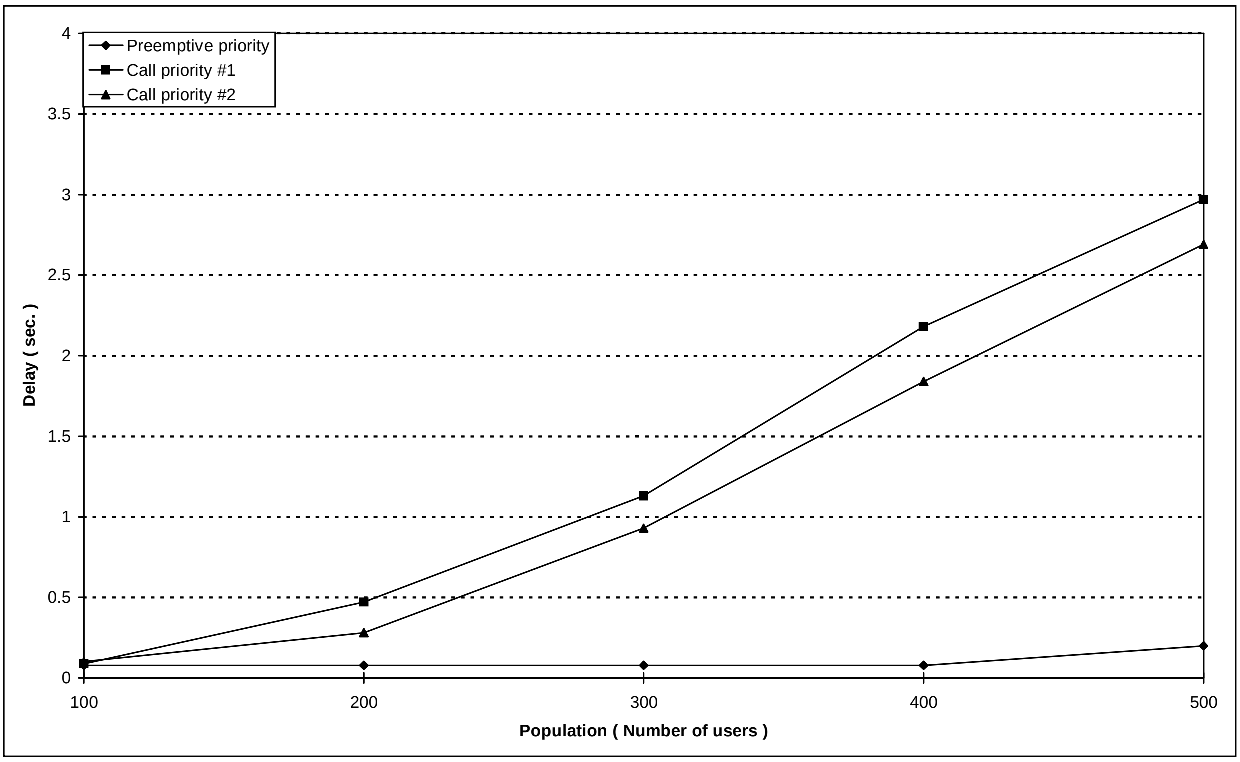

Figure 176: Individual M-M circuit switched call set-up mean delay versus number of users in case of full duplex circuit calls

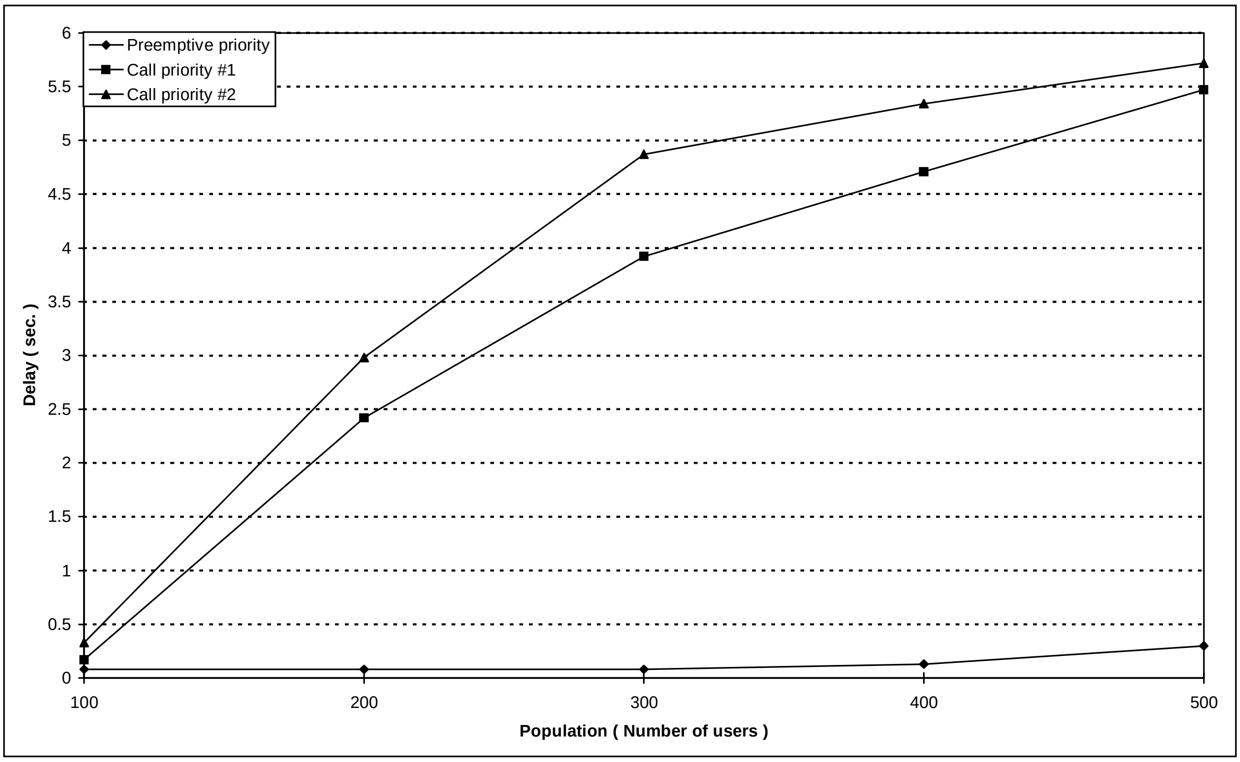

Figure 177: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users in case of full duplex circuit calls

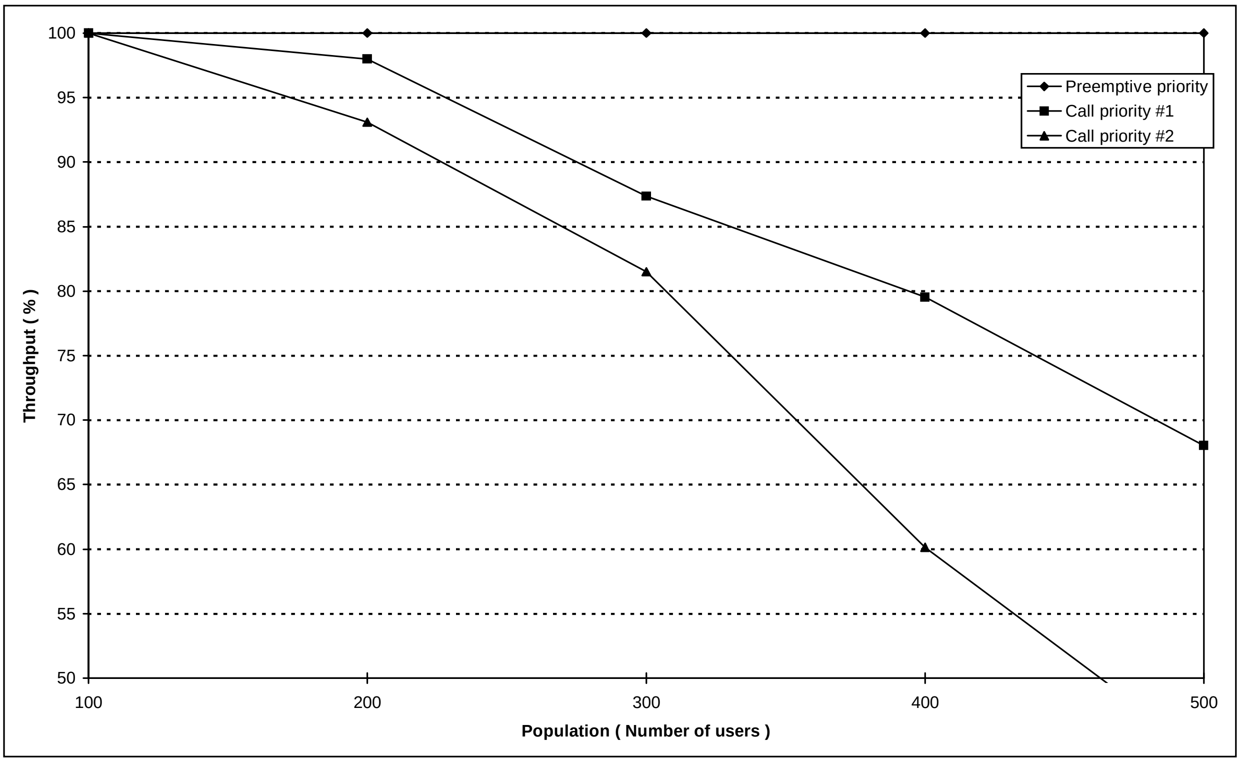

Figure 178: Individual M-M circuit switched call set-up system throughput versus number of users in case of full duplex circuit calls

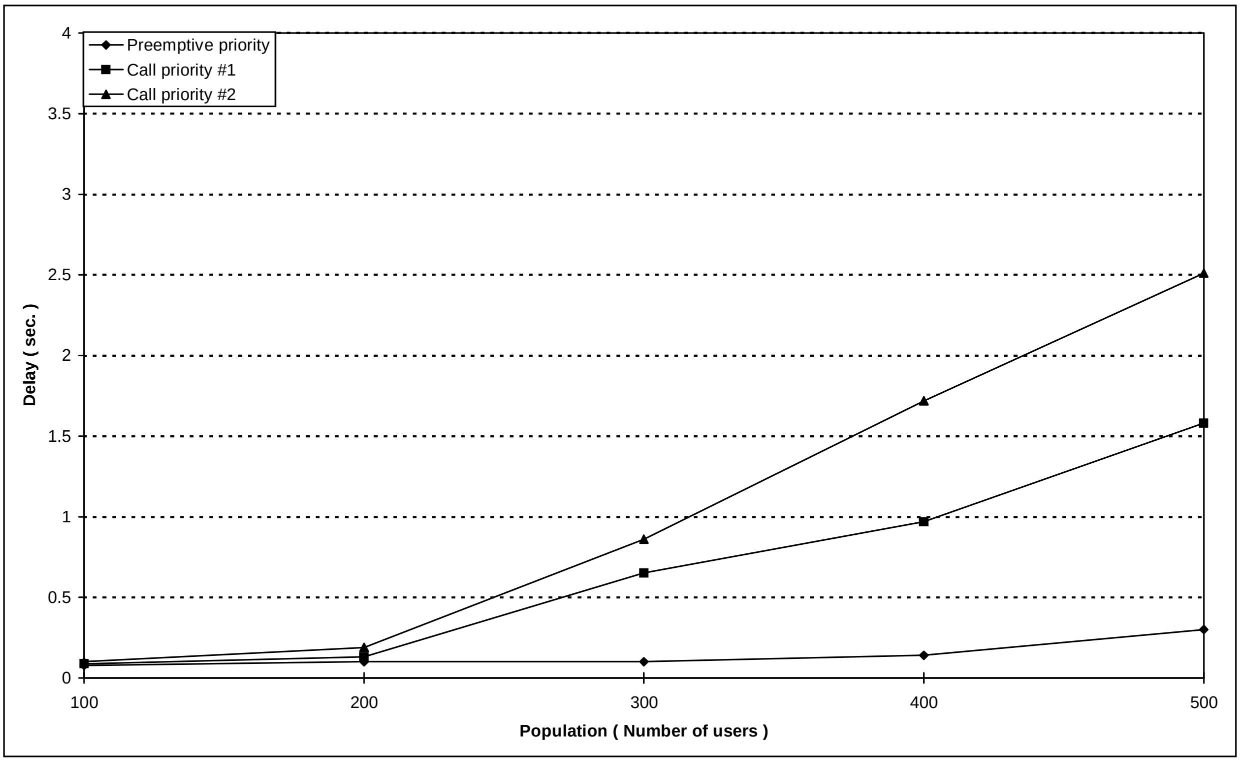

Figure 179: Individual M-F circuit switched call set-up mean delay versus number of users (full duplex calls)

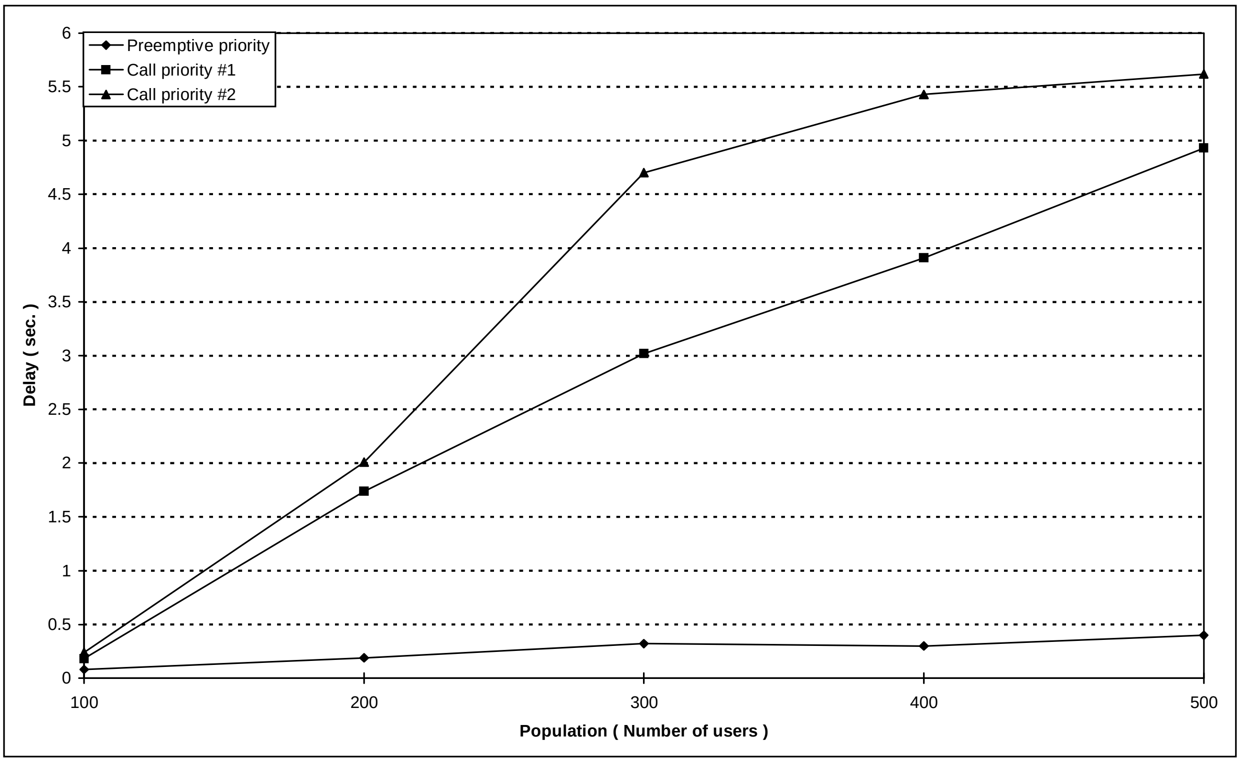

Figure 180: Individual M-F circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users in case of full duplex circuit calls

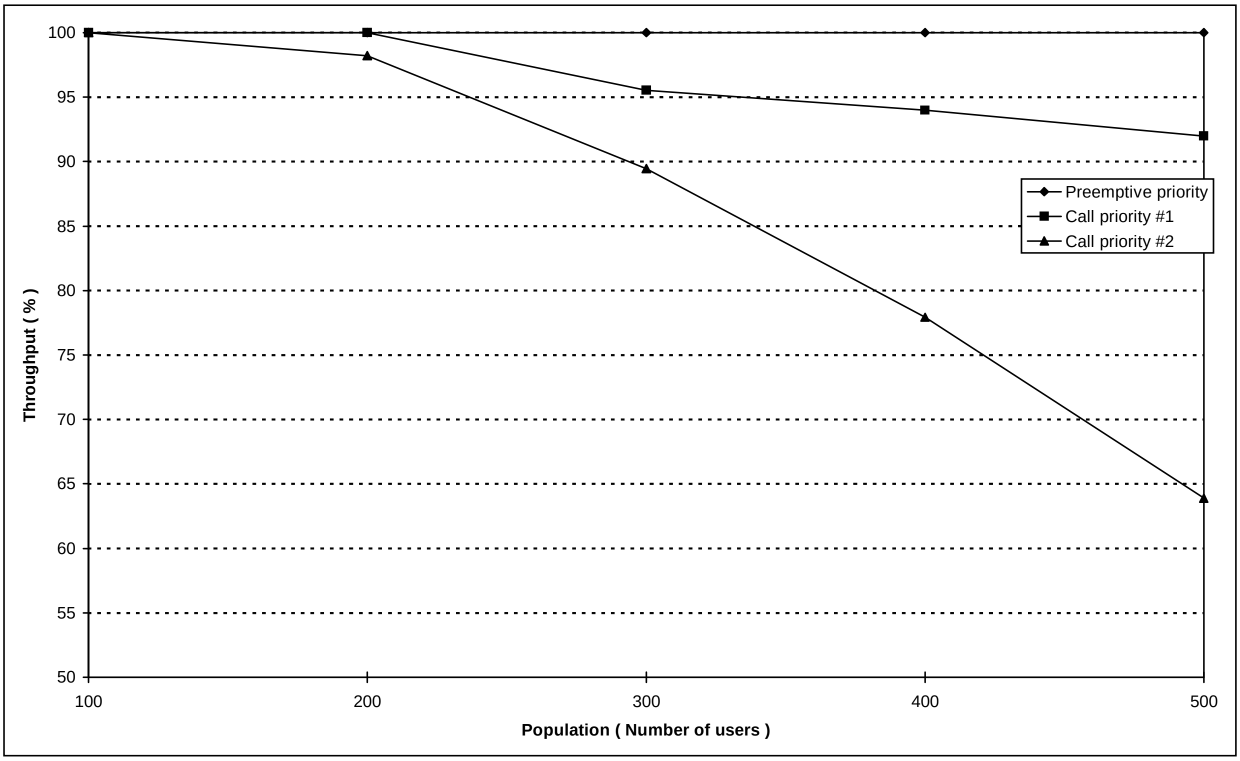

Figure 181: Individual M-F circuit switched call set-up system throughput versus number of users in case of full duplex circuit calls

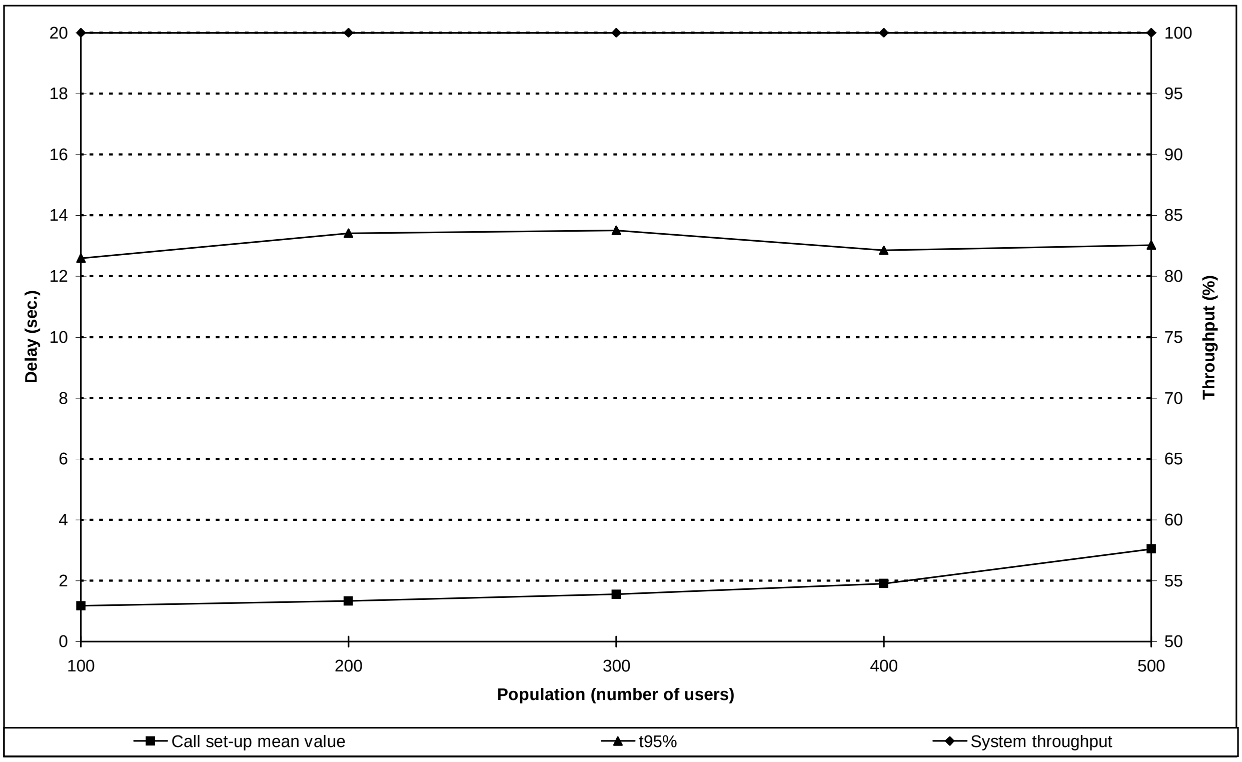

Figure 182: Individual M-M packet data call set-up performance versus number of users in case of full duplex circuit calls

5.5.3.5 Sensitivity analysis of network parameters

5.5.3.5.1 Variation of the cell allocated radio resources

The present analysis shows the influence of the number of cell allocated traffic channels on the overall performance. Two conditions are investigated and compared with the reference scenario. In the first case 3 TCHs are allocated to the cell, in the second 11 (the reference value is 7).

Figures 183 and 184 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure in case of 3 TCHs allocated to the cell site. Each curve in the figure is related to a particular value of call priority.

Figure 185 reports the system throughput of the M-M individual circuit call set-up in case of 3 TCHs allocated to the cell site. Each curve in the figure is related to a particular value of call priority.

Figure 186 reports the mean value of the M-M individual packet data call service in case of 3 TCHs allocated to the cell site. Each curve in the figure is related to a particular value of call priority.

Figures 187 and 188 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-F individual circuit call set-up procedure in case of 3 TCHs allocated to the cell site. Each curve in the figure is related to a particular value of call priority.

Figure 189 reports the system throughput of the M-F individual circuit call set-up in case of 3 TCHs allocated to the cell site. Each curve in the figure is related to a particular value of call priority.

Figure 190 reports the mean value of the M-M individual packet data call in case of 3 TCHs allocated to the cell site. Each curve in the figure is related to a particular value of call priority.

All these presented figures have to be compared with figures 138 to 144 (reference scenario 8A).

This analysis is done in order to give an estimate of the degradation of performance when the number of allocated traffic channels becomes low. Even if the call set-up delays are limited (this is due to the timer of maximum hold in the priority queue), the big differences between the figures can be found in the throughput values. When 3 TCHs are allocated the system throughput falls to very low values (with the exception of course of the pre-emptive priority calls).

This is a further confirmation that these figures are deeply influenced by the queuing mechanism in the infrastructure: neither by radio transmission impairments nor by access collisions.

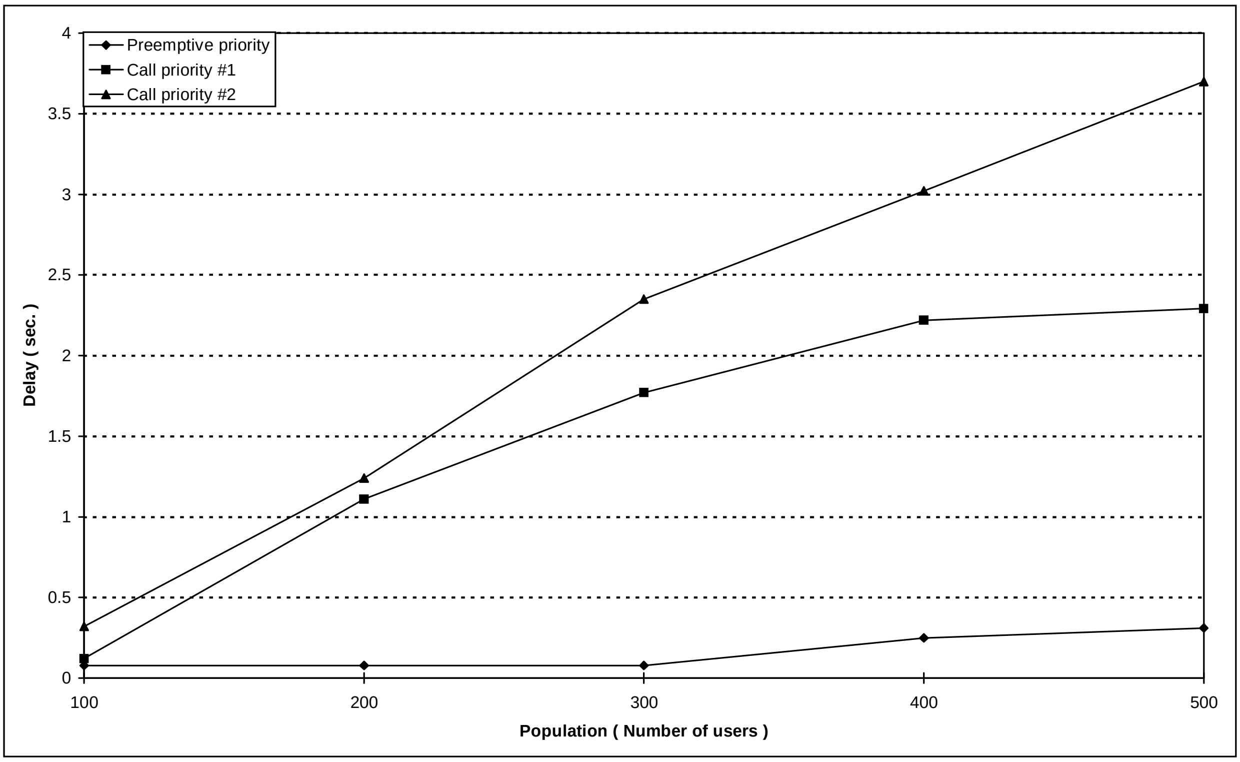

Figure 183: Individual M-M circuit switched call set-up mean delay versus number of users in a cell with 3 TCHs allocated

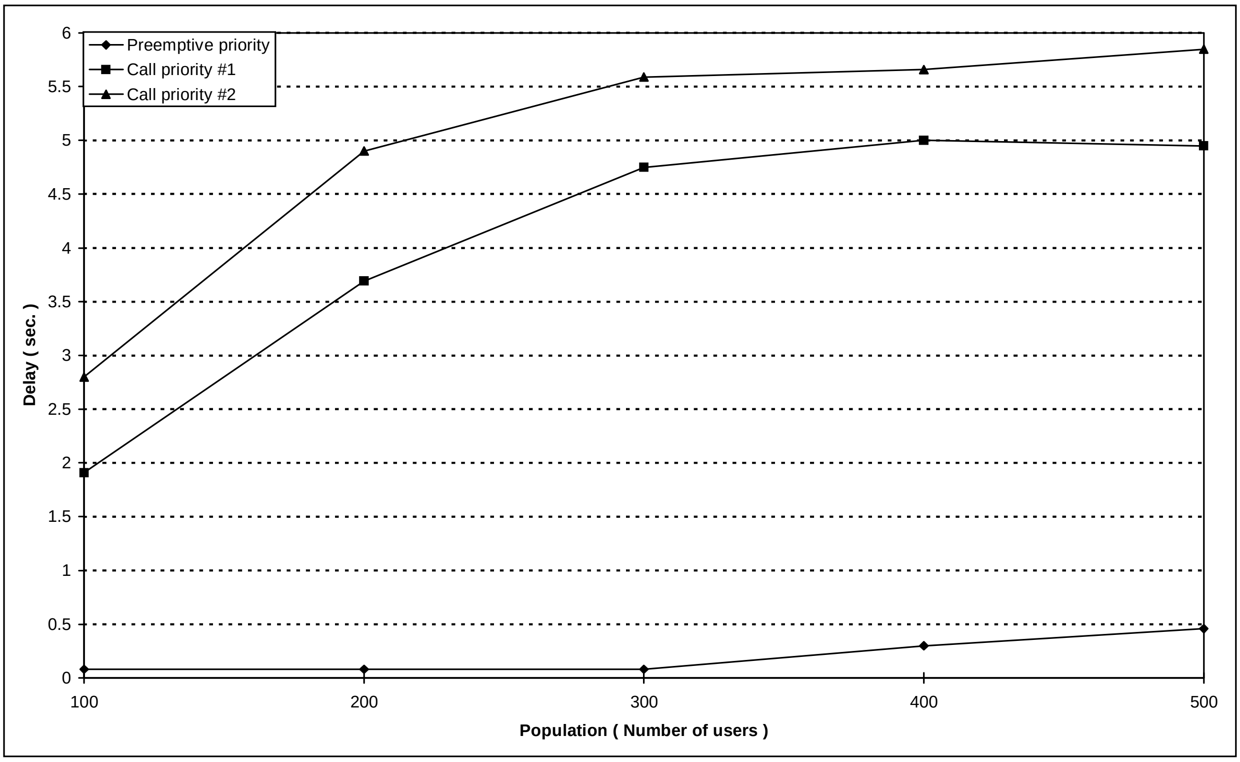

Figure 184: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users in a cell with 3 TCHs allocated

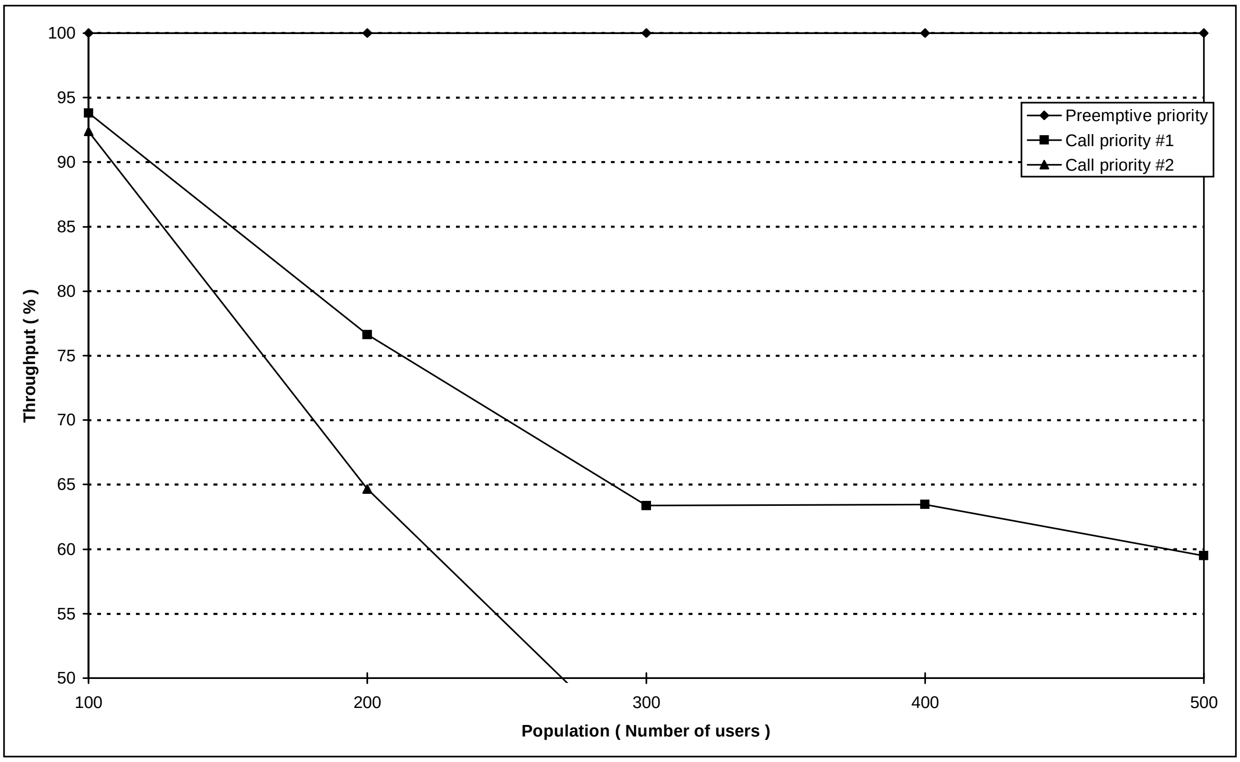

Figure 185: Individual M-M circuit switched call set-up system throughput versus number of users in a cell with 3 TCHs allocated

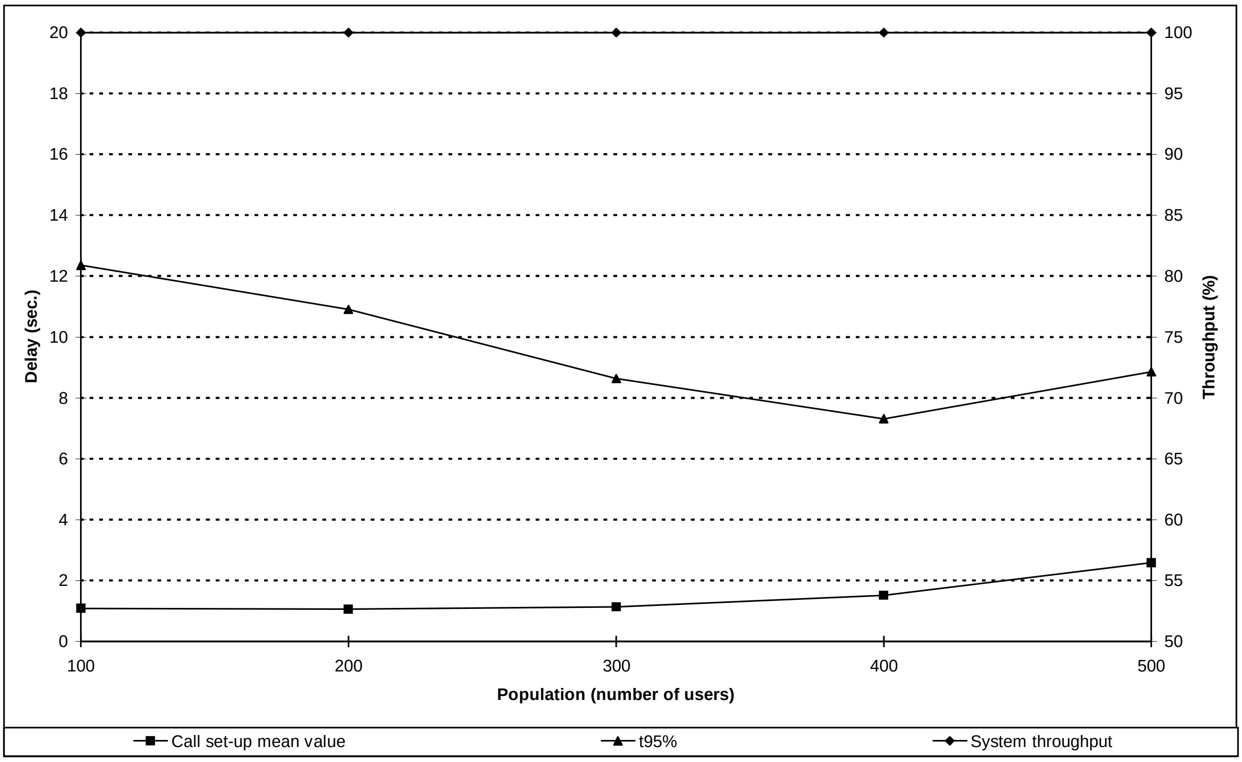

Figure 186: Individual M-M packet data call set-up performance versus number of users in a cell with 3 TCHs allocated

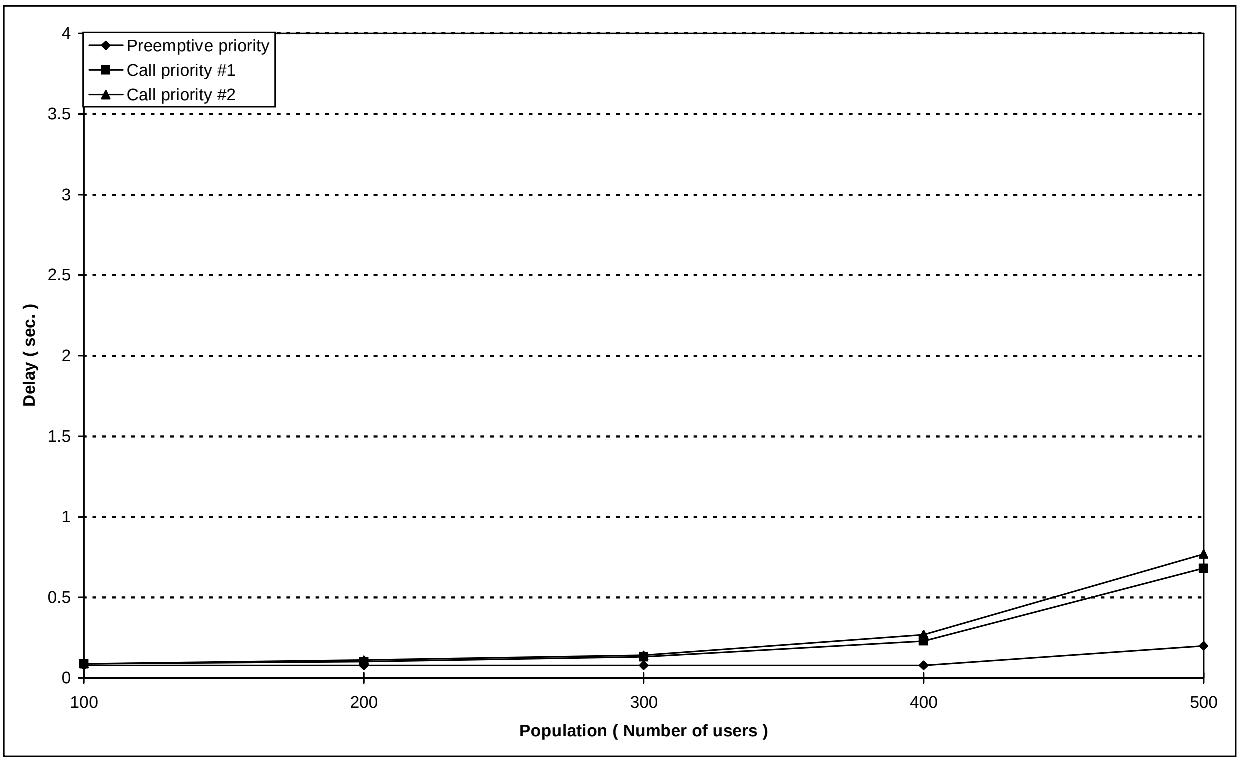

Figure 187: Individual M-M circuit switched call set-up mean delay versus number of in a cell with 11 TCHs allocated

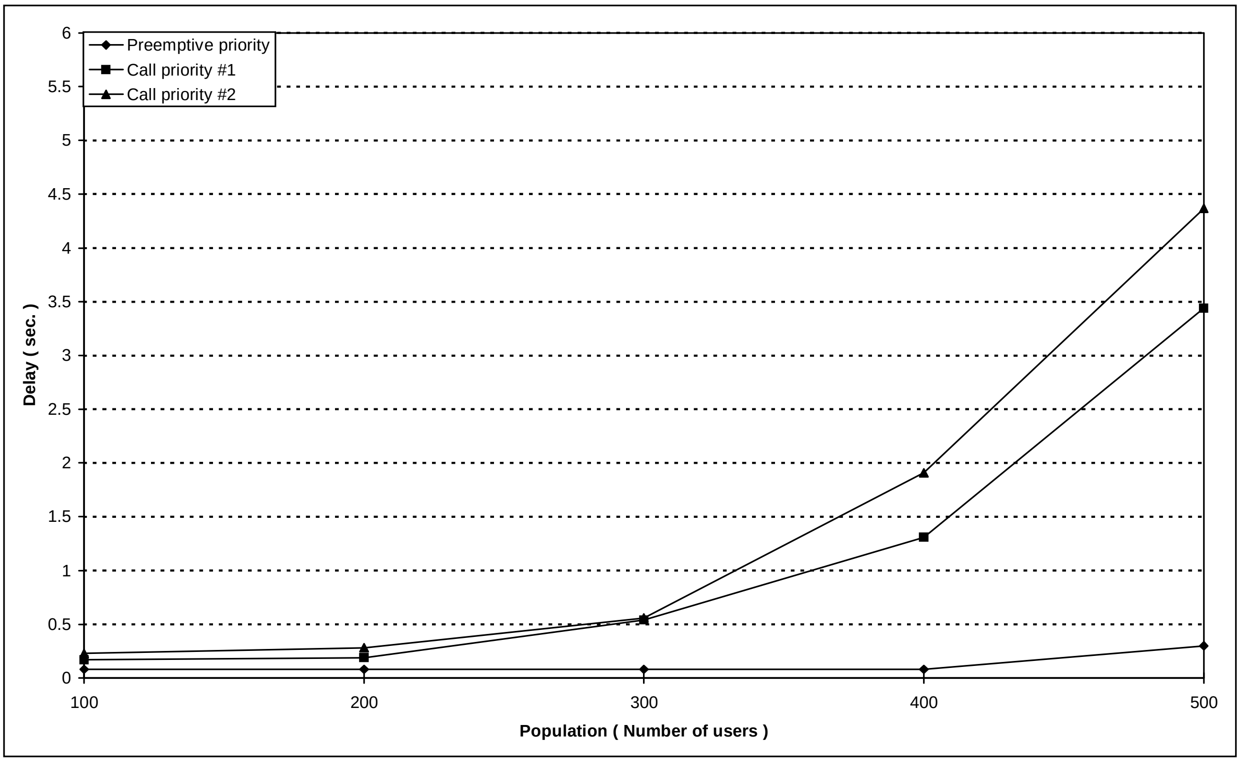

Figure 188: Individual M-M circuit switched call set-up $\tau_{95\,\%}$ boundary delay versus number of users in a cell with 11 TCHs allocated

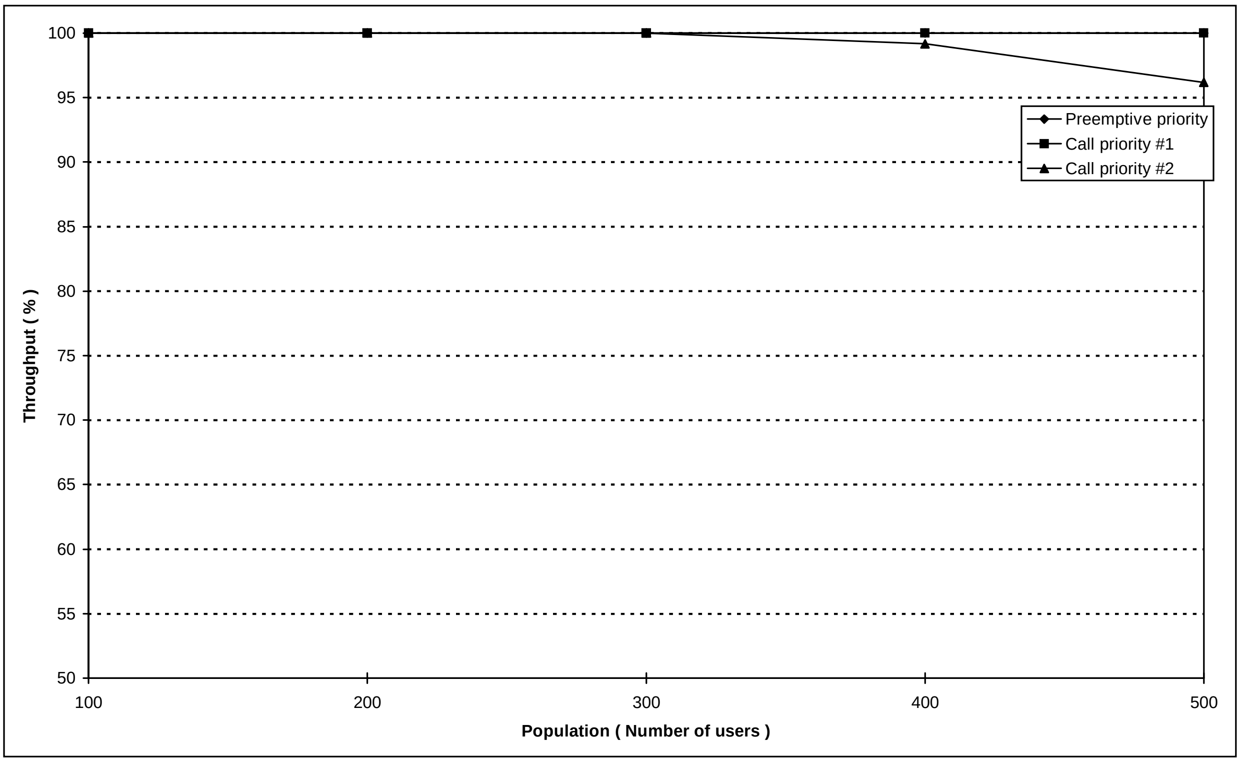

Figure 189: Individual M-M circuit switched call set-up system throughput versus number of users in a cell with 11 TCHs allocated

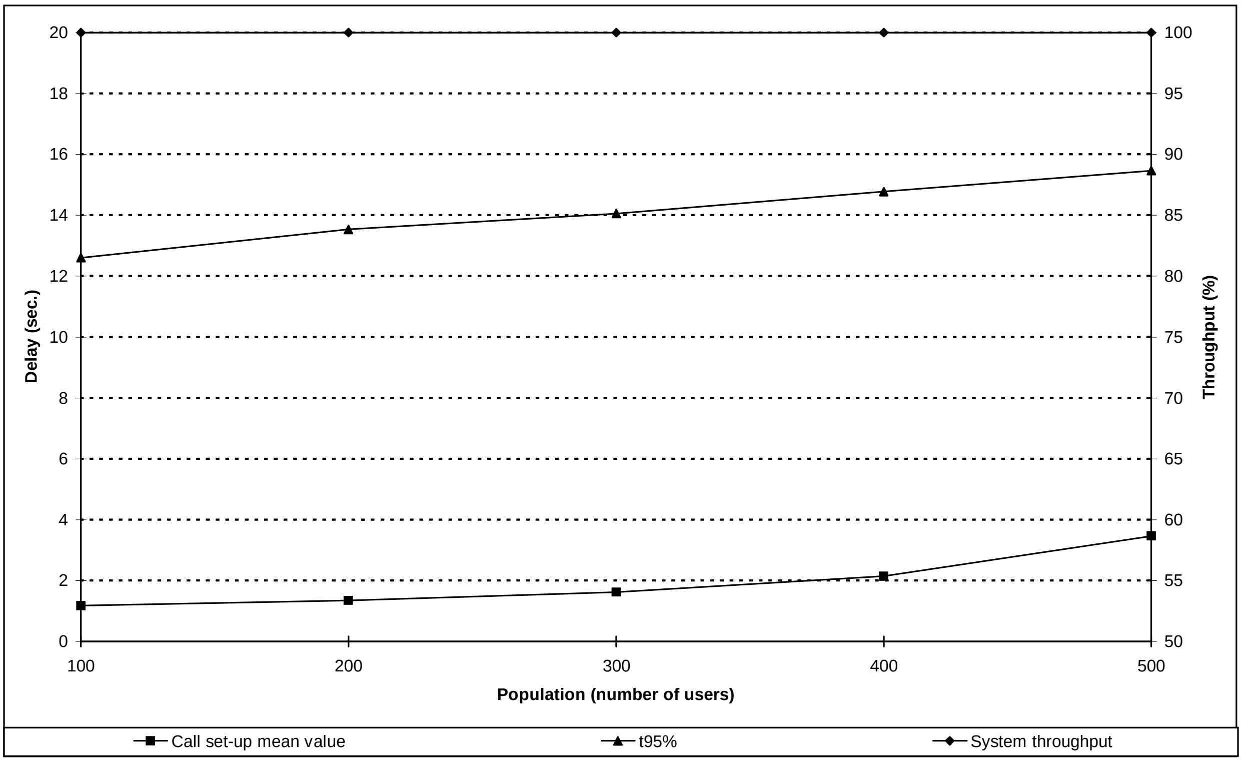

Figure 190: Individual M-M packet data call set-up performance versus number of users in a cell with 11 TCHs allocated

5.5.3.5.2 Variation of the maximum hold time in the priority queues

The present analysis shows the influence of the time of maximum holding in the priority queues on the service performance. One configuration (time threshold = 300 TDMA frames) is presented to be compared with the reference scenario (time threshold = 100 TDMA frames).

Figures 191 and 192 report respectively the mean value and the $\tau_{95\,\%}$ boundary delay of the M-M individual circuit call set-up procedure when the maximum hold time in the priority queue is 300 TDMA frames. Each curve in the figure is related to a particular value of call priority.

Figure 193 reports the system throughput of the M-M individual circuit call set- up when the maximum hold time in the priority queue is 300 TDMA frames. Each curve in the figure is related to a particular value of call priority.

Figure 194 reports the mean value of the M-M individual packet data call when the maximum hold time in the priority queue is 300 TDMA frames. Each curve in the figure is related to a particular value of call priority.

All these presented figures have to be compared with figures 138 to 144 (reference scenario 8A).

The comparison between these figures and the reference scenario shows that the call set-up delays grow very much together with the threshold value. At the same time the throughput values increase of about 10 %. The reason for that can be found in the call duration time. The present value of the maximum time is always short in respect of call duration. Throughput can be much better if the maximum time is close to the call duration.

This is a further confirmation that these figures are deeply influenced by the queuing mechanism in the infrastructure: neither by radio transmission impairments nor by access collisions.

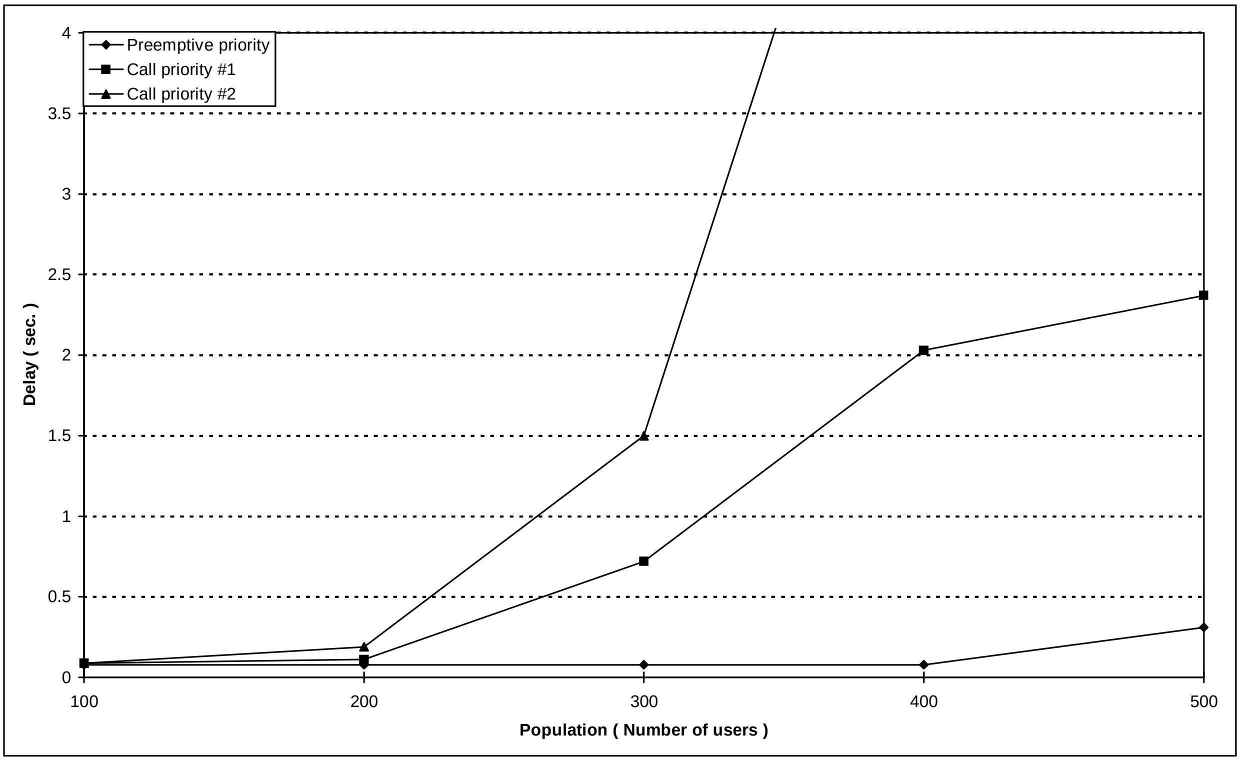

Figure 191: Individual M-M circuit switched call set-up mean delay versus number of users with maximum hold time in priority queue = 300 TDMA frames

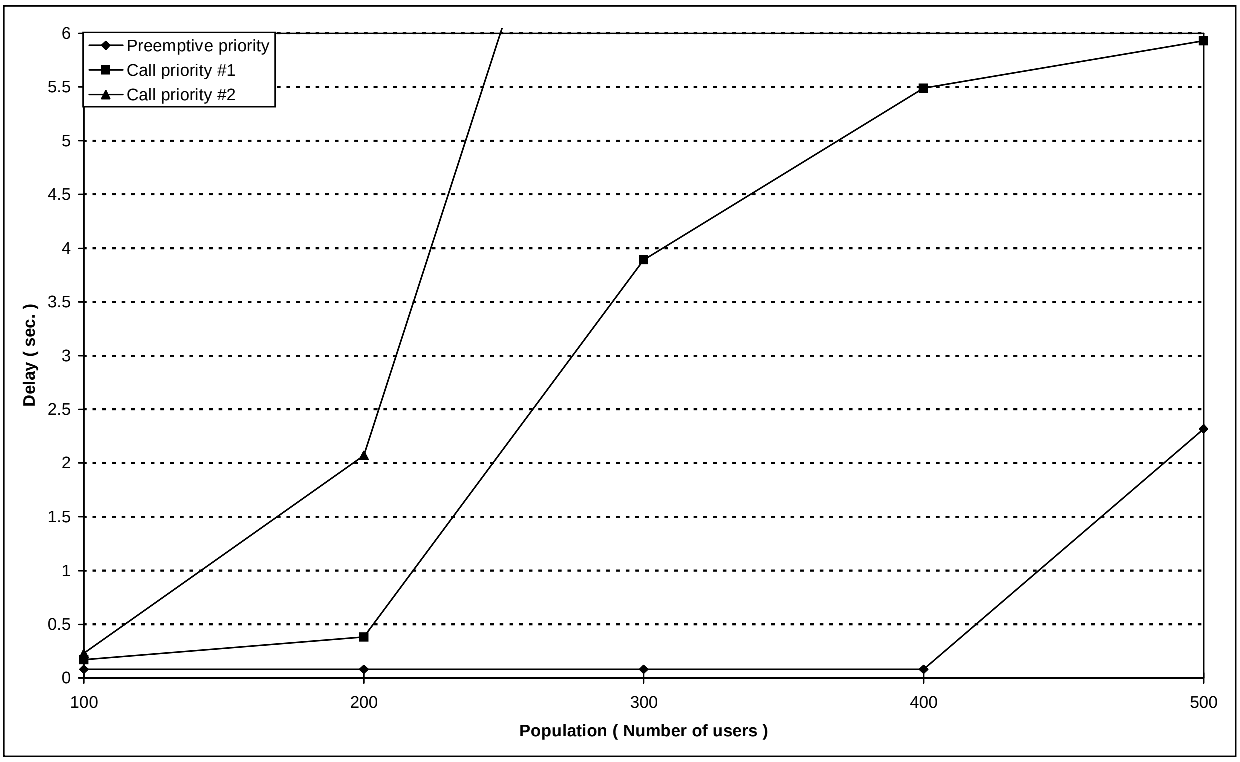

Figure 192: Individual M-M circuit switched call set-up $\tau_{95\ \%}$ boundary delay versus number of users with maximum hold time in priority queue = 300 TDMA frames

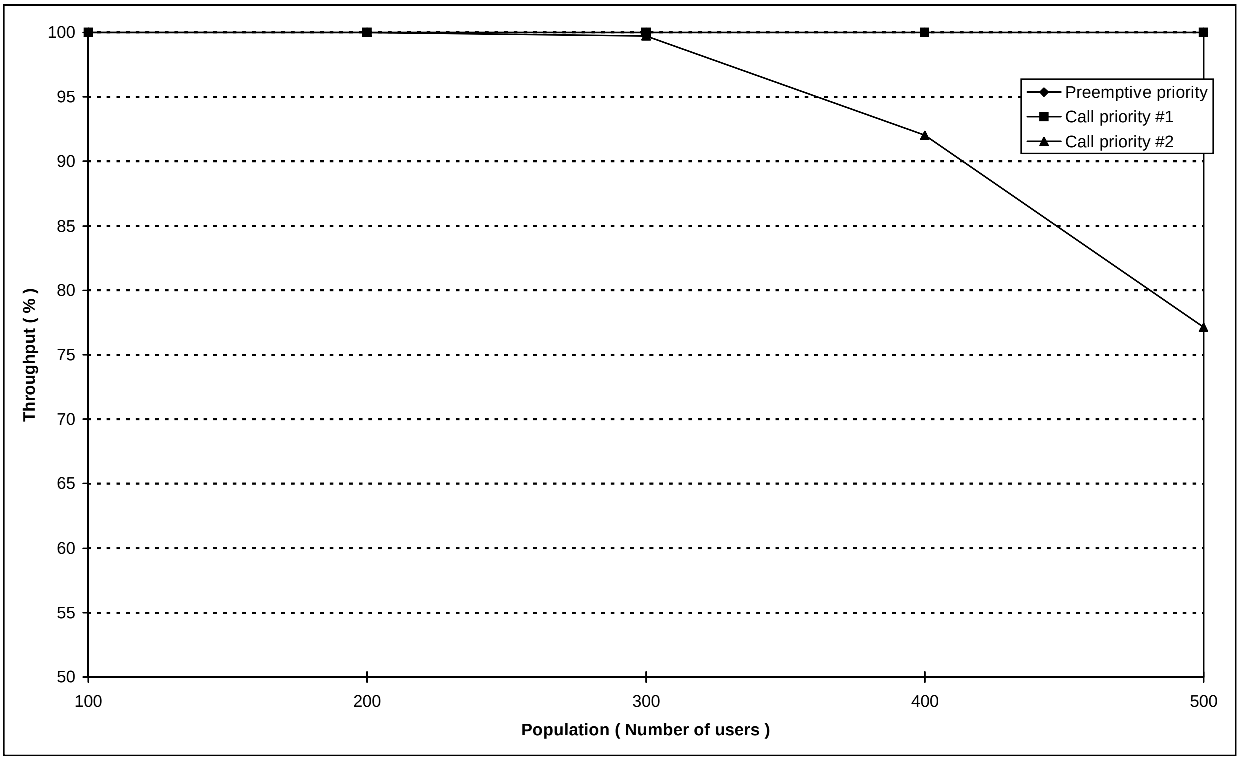

Figure 193: Individual M-M circuit switched call set-up system throughput versus number of users with maximum hold time in priority queue = 300 TDMA frames

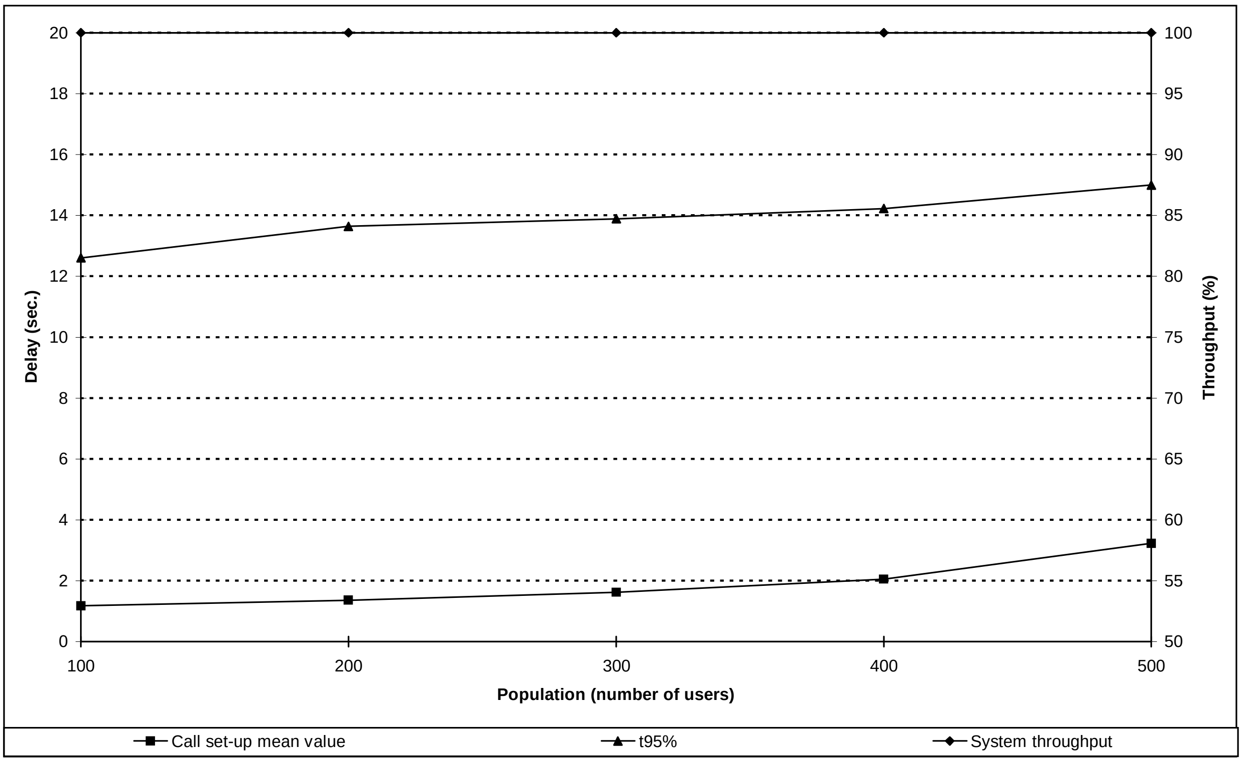

Figure 194: Individual M-M packet data call set-up performance versus number of users with maximum hold time in priority queue = 300 TDMA frames

5.6 Circuit services performance (BER versus probability)

5.6.1 Introduction

When the access procedure has been terminated, a radio channel is reserved to the circuit call. The quality of a circuit service is measured by the BER and capacity of the link that is set up between the two communicating parties. The channel capacity is fixed by the system specifications: 2,4, 4,8 and 7,2 kbit/s are the basic capacities for a single channel of a TETRA network. However higher capacity are allowed by joining up to 4 TETRA radio channels (respectively 7,2, 19,8 and 28,8 at maximum). The BER of a communication link depends on the radio propagation impairments; in the first part of the present document, all radio channels have been studied for measuring their performance. Starting from them, in this clause the measured BER for the complete link is reported.

For the evaluation of this performance two cases can be considered: mobile to fixed call and mobile to mobile call (group calls are also included in the evaluation). In the first case, a single radio link has to be studied, in the second the combination of two radio links has to be analysed. The following formulas describe the evaluation of the global BER for the two kind of calls:

- Mobile to fixed call: $BER_{global} = BER_{radio\ link}$
- Mobile to mobile call: $BER_{global} = BER_{radio\ link\ 1} \times (1-BER_{radio\ link\ 2}) + BER_{radio\ link\ 2} \times (1-BER_{radio\ link\ 1})$

Due to the dynamic behaviour of the radio mobile channels, these relations are always valid, but the actual value of BER is time variable. In order to have a reliable estimate of BER the evaluated performance is usually a probability function. These curves allow to evaluate statistic boundaries of the BER in the simulated environments.

In the following clauses a detailed analysis of channel performance has been provided for all the TETRA TCHs in all the defined propagation environments.

The presented results have been evaluated according to the following assumptions:

- Mobile to mobile call has been simulated;
- location probability at the edge of cell: 90 %;

- call duration in accordance with the reference in clause 5.4: uniform distribution between 20 s and 40 s;
- BS antenna height: 50 m;
- MS antenna height: 1,5 m;
- simulated radio receiver has ideal synchronization technique (see clause 4.2).

For each value of BER (on the x axis in logarithmic scale), the following figures report the probability to obtain a performance better or equal to it. In general, due to the available performance figures of the radio receiver, for low values of BER (around 10^{-6}) the reported numbers are less reliable than the others.

5.6.2 Performance in TU propagation environment

Figure 195 reports the performance of TCHs in TU5 propagation environment.

Figure 196 reports the performance of TCHs in TU50 propagation environment.

Figure 197 reports the performance of TCHs in TU100 propagation environment.

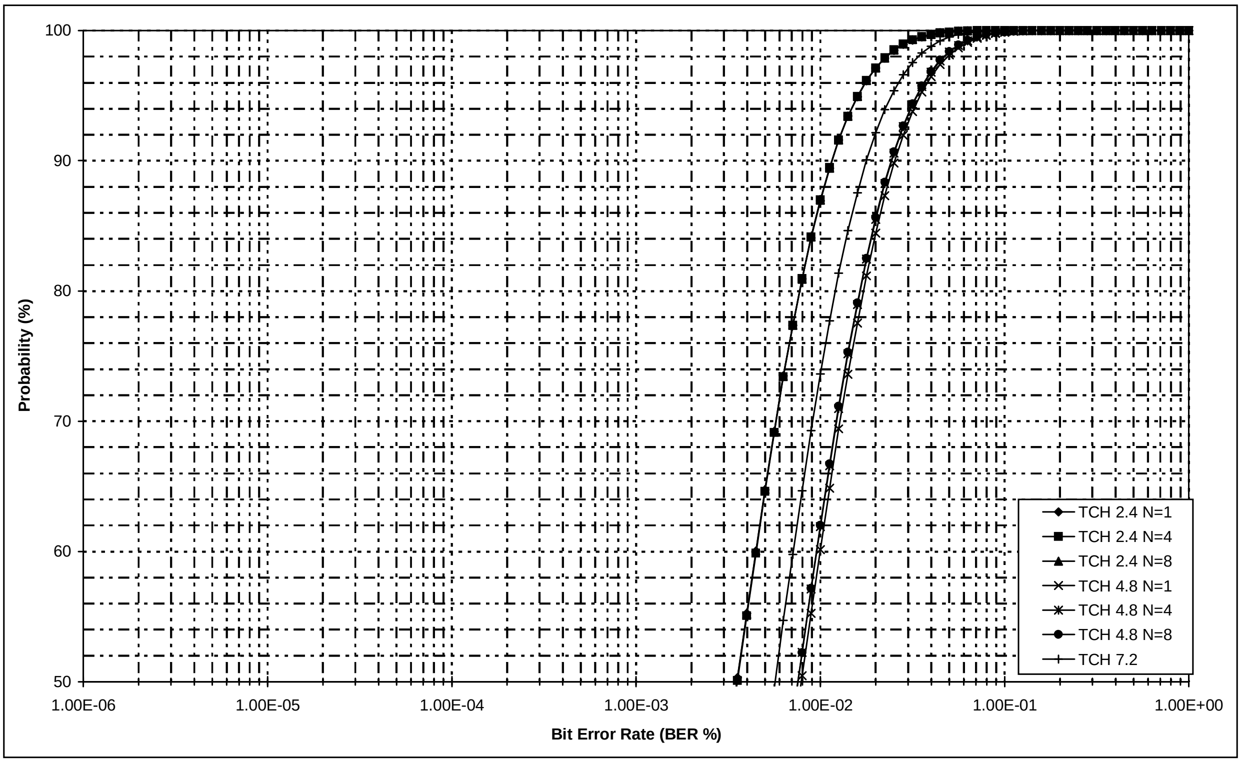

Figure 195: BER versus probability for different traffic channels in TU5 propagation environment

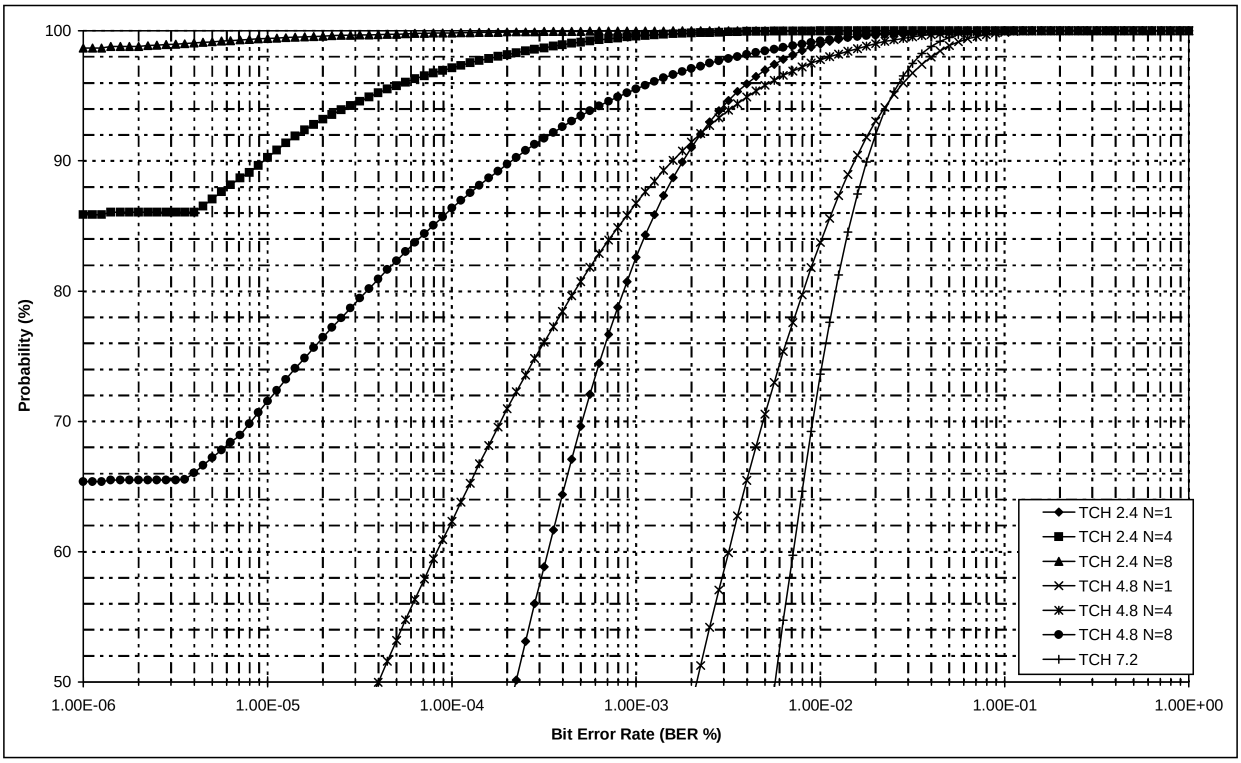

Figure 196: BER versus probability for different traffic channels in TU50 propagation environment

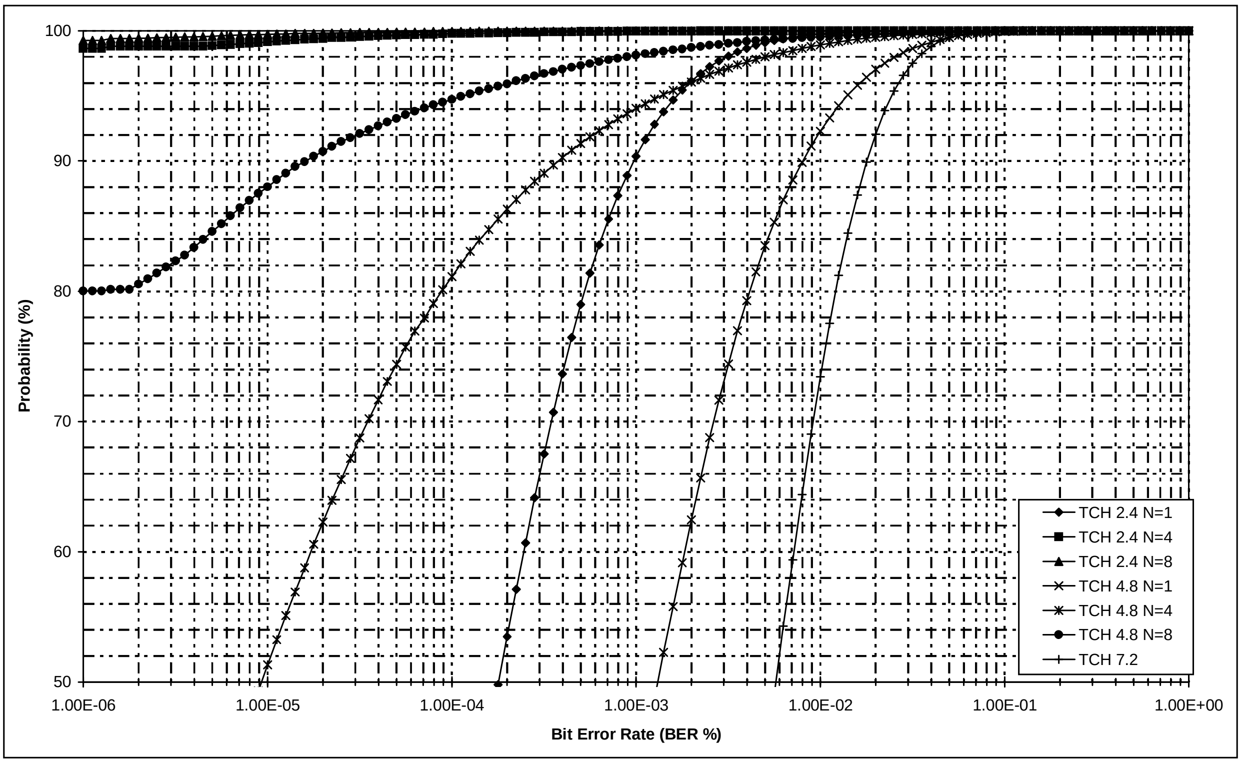

Figure 197: BER versus probability for different traffic channels in TU100 propagation environment

5.6.3 Performance in BU propagation environment

Figure 198 reports the performance of TCHs in BU50 propagation environment.

Figure 199 reports the performance of TCHs in BU100 propagation environment.

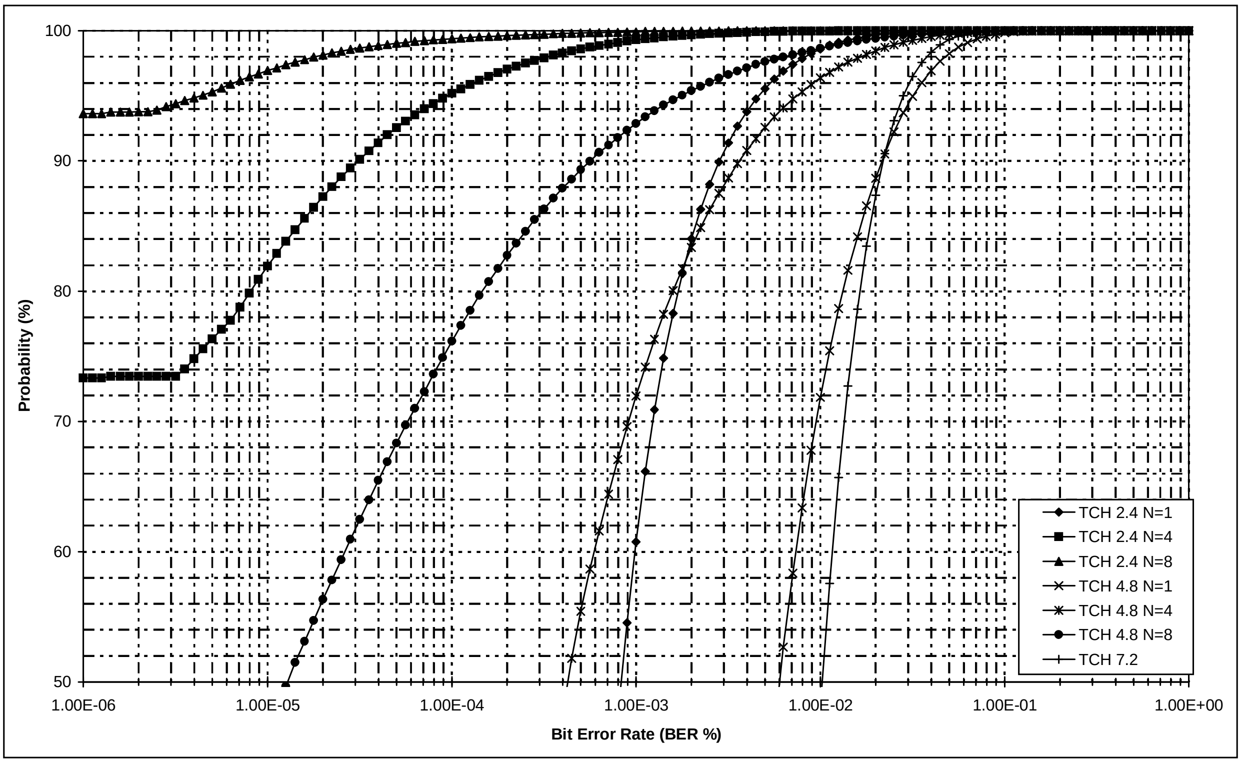

Figure 198: BER versus probability for different traffic channels in BU50 propagation environment

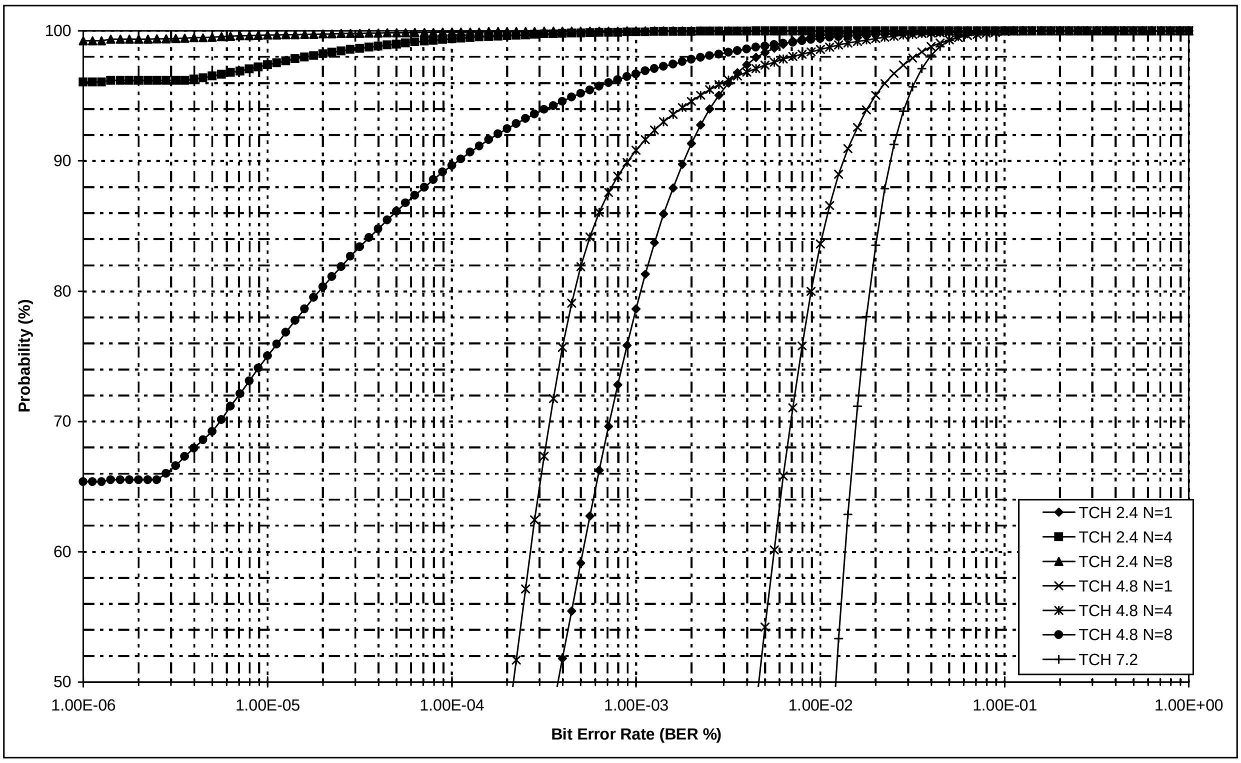

Figure 199: BER versus probability for different traffic channels in BU100 propagation environment

5.6.4 Performance in RA propagation environment

Figure 200 reports the performance of TCHs in RA 5 propagation environment.

Figure 201 reports the performance of TCHs in RA 50 propagation environment.

Figure 202 reports the performance of TCHs in RA 100 propagation environment.

Figure 203 reports the performance of TCHs in RA 200 propagation environment.

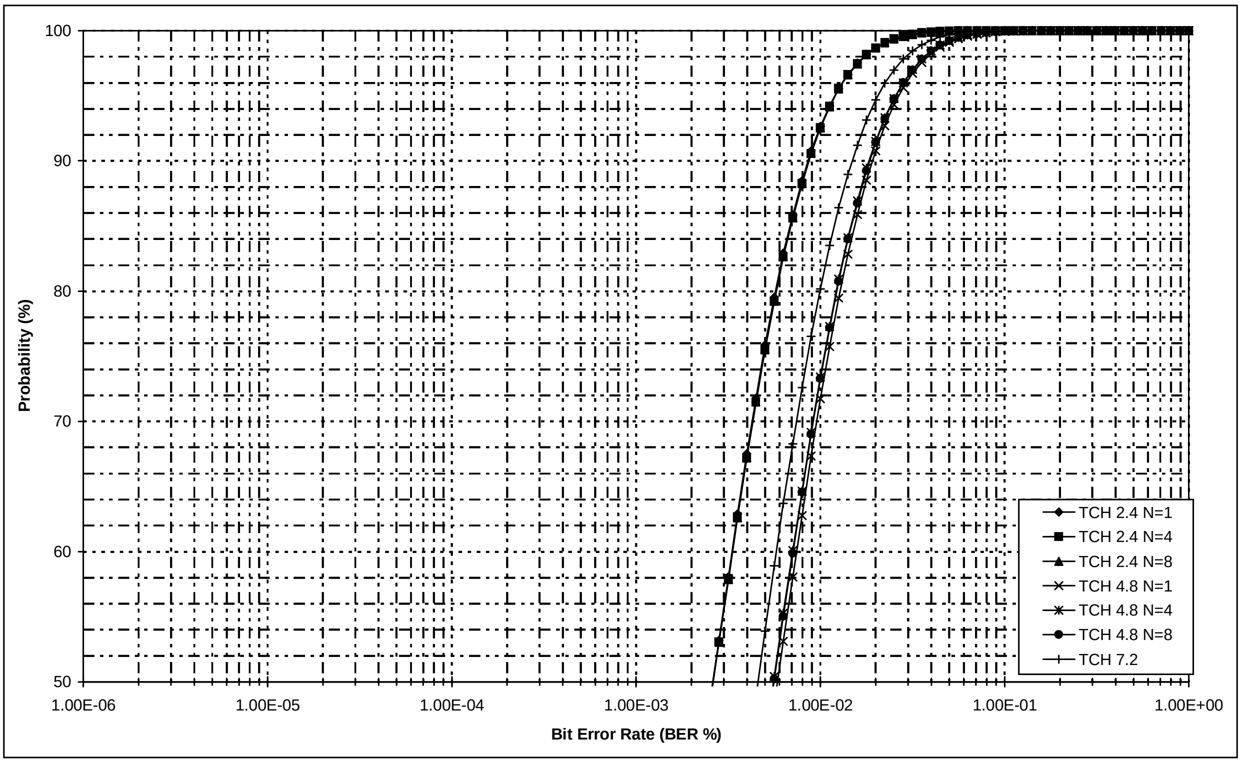

Figure 200: BER versus probability for different traffic channels in RA 5 propagation environment

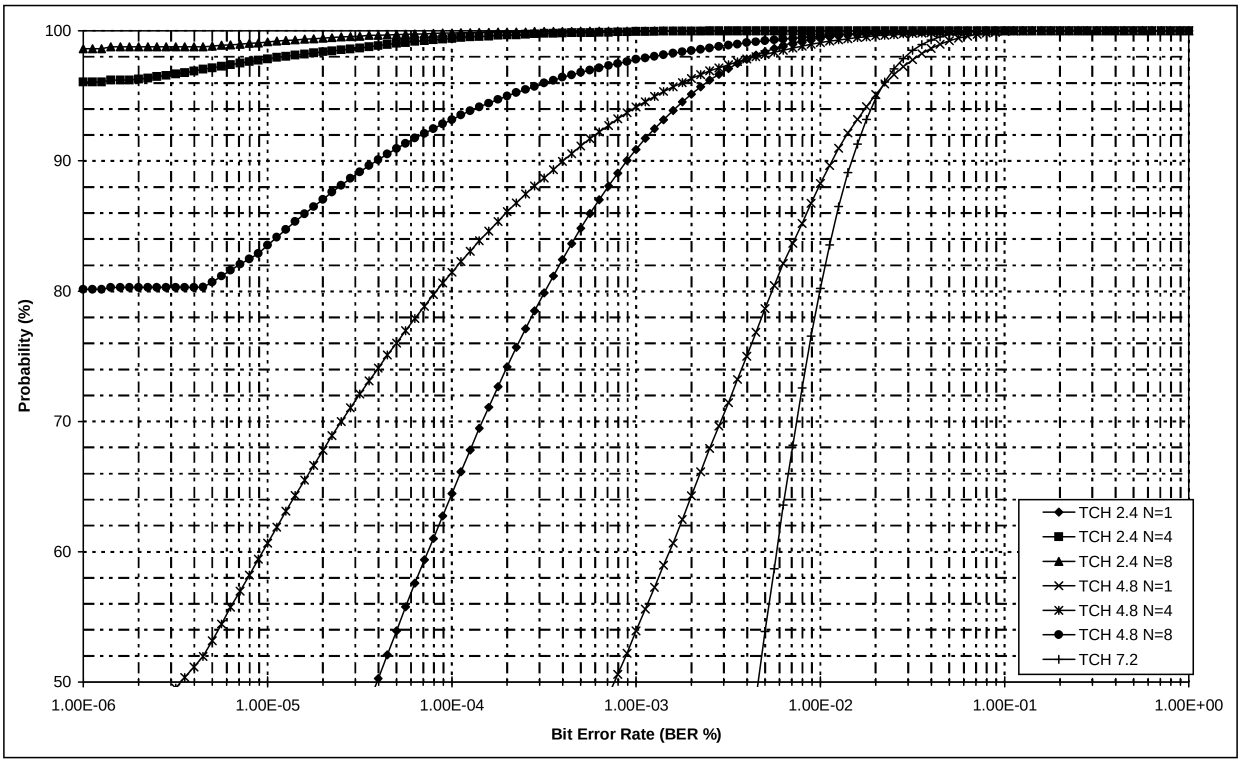

Figure 201: BER versus probability for different traffic channels in RA 50 propagation environment

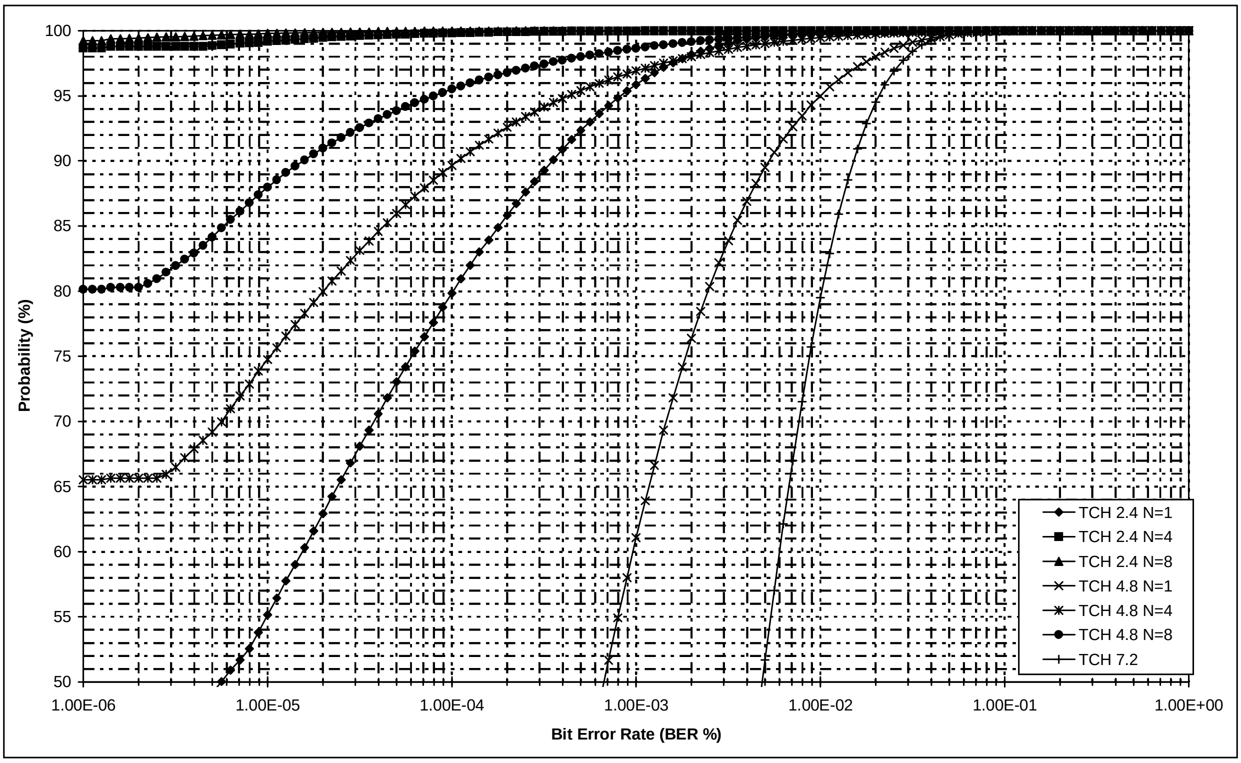

Figure 202: BER versus probability for different traffic channels in RA100 propagation environment

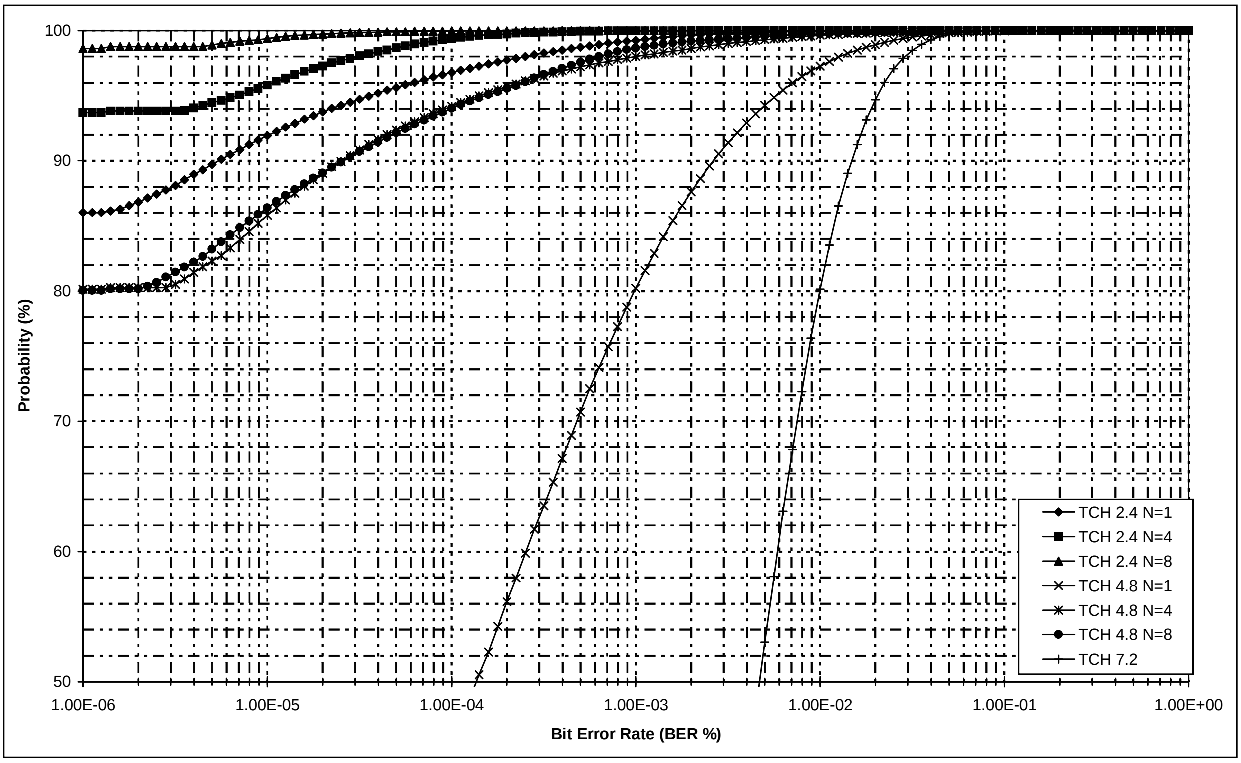

Figure 203: BER versus probability for different traffic channels in RA200 propagation environment

5.6.5 Performance in HT propagation environment

Figure 204 reports the performance of TCHs in HT 50 propagation environment.

Figure 205 reports the performance of TCHs in HT 100 propagation environment.

Figure 206 reports the performance of TCHs in HT 200 propagation environment.

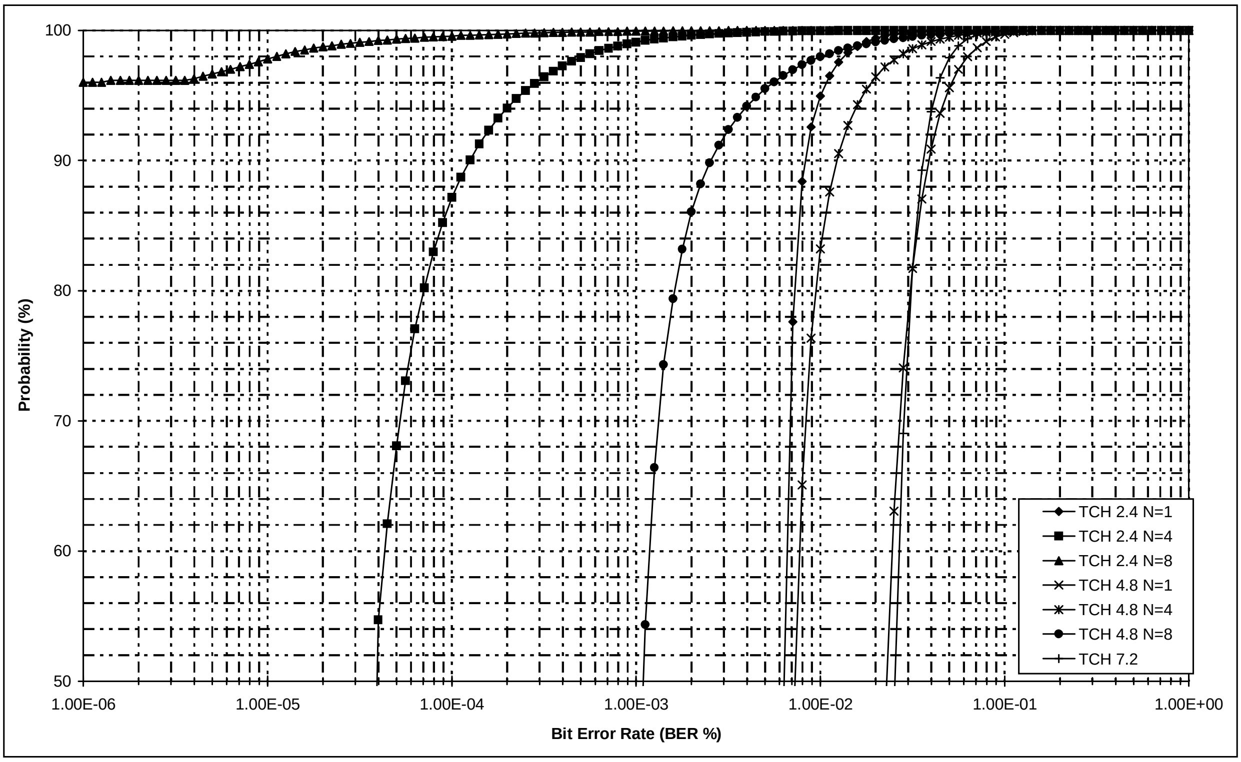

Figure 204: BER versus probability for different traffic channels in HT 50 propagation environment

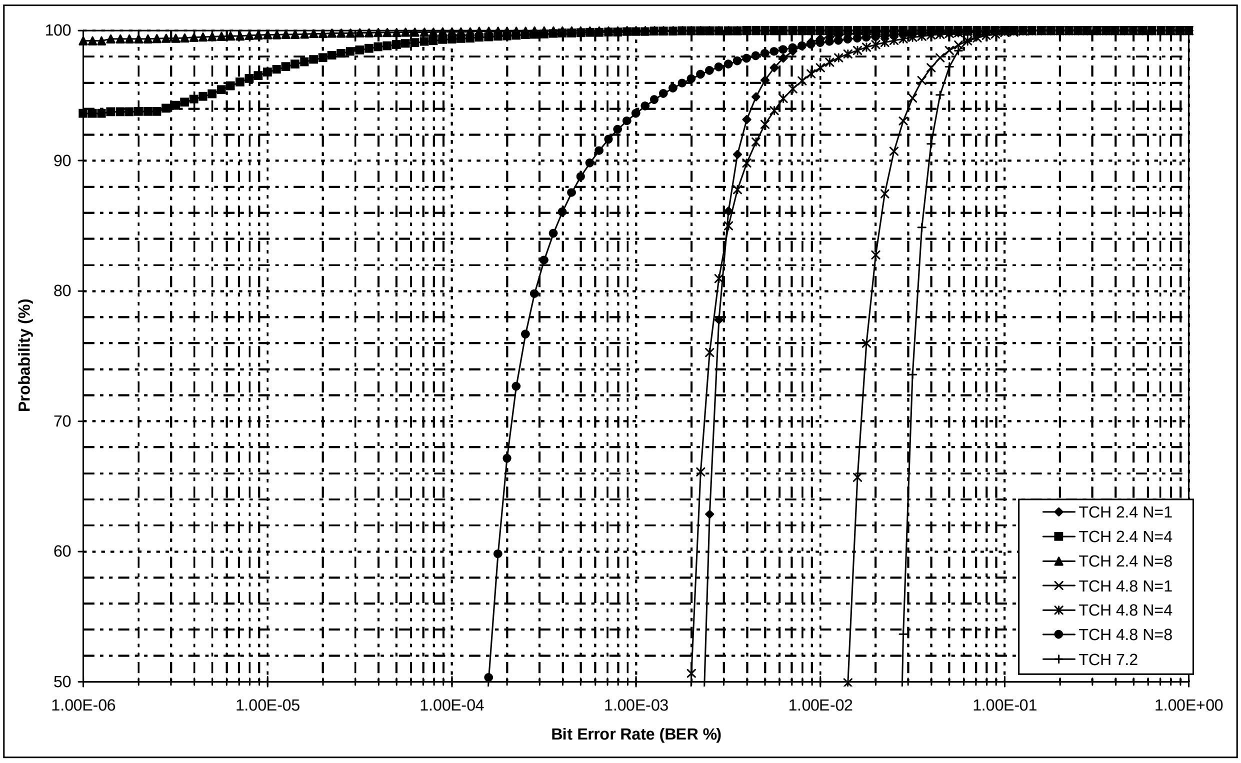

Figure 205: BER versus probability for different traffic channels in HT 100 propagation environment

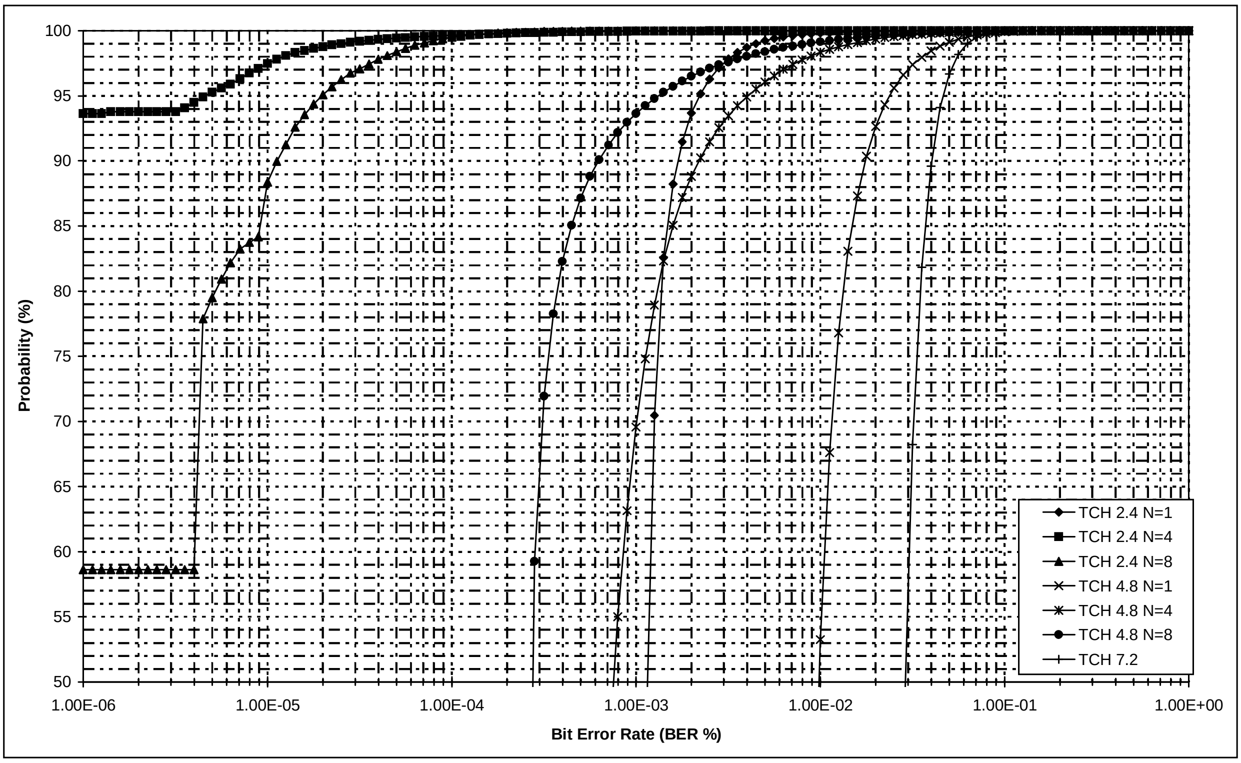

Figure 206: BER versus probability for different traffic channels in HT200 propagation environment

Annex A:
Traffic scenarios for TETRA V+D networks

A.1 Introduction

Some reference traffic scenarios for TETRA networks have been studied in order to provide a basis for the choice of radio modulation for this system. Some of these original scenarios have been re-examined and improved with the aim of defining detailed examples of applications for a TETRA V+D network. The identification number of the scenarios is still related to the old description. It is always assumed an operating frequency of 400 MHz.

The simulation results reported on this ETR, related to the protocol and service performance, have been evaluated for one of the following scenarios.

Starting from a reference scenario and based on radio coverage calculations, precise cell topologies can be established.

A.2 Scenarios

The following clauses report a detailed description of some reference traffic scenarios and applications for TETRA network. After the description of the propagation environment where the network is placed, the traffic profile (the set of required services, with their statistical description) of network subscribers is illustrated with the information about their position and speed on the territory.

The position of subscribers is described in terms of probability to be located in a particular point on the covered area. Two kind of distribution are considered: uniform (same probability to be in any point of the area) and Gaussian (higher probability to be in the centre of the area).

The Gaussian distribution is a mathematical abstraction for the description of subscriber concentrations. Supposing a circular area with radius R, the Gaussian distribution is intended to be centred in the centre of the area, with standard deviation $\sigma = R/3$.

Voice conversations after the call set-up can be modelled as a sequence of time segments called "over". During an "over" one of the subscribers involved in the call is speaking and all the others (the other for individual calls) are listening. When the speaker ends, one of the other subscribers can gain control of the call beginning a new "over". In the proposed scenarios, typical voice conversations consist of 5 "over" with same duration during the lifetime of the call.

The on/off hook signalling is required for the set-up of individual voice calls. The delay of the answer from the called party is modelled as a uniform distribution between 0,5 and 10 s. It is also supposed that 25 % of calls are not answered.

For all examined scenarios, the mobility of subscribers during a call can be considered negligible. Even if the subscriber is moving, the area that he covers during a call is considered very small in respect to the dimension of the radio cell.

In scenarios description, voice and circuit data calls between fixed and mobile terminal are described in the only direction from mobile to fixed. In the reverse direction it is perfectly symmetric.

Voice and circuit data calls can be set-up according to different priorities for the resource allocation. Three levels are given for voice calls (pre-emptive, high and low) and two for circuit data calls (high and low). Depending on the particular scenario, different distributions of priorities are considered.

Depending on the particular scenario, group calls can be set-up according two policies:

- no check of the presence of called group members:
    - the network broadcasts the call set-up message and the reached users immediately enter the call;
- check of the presence and notification to the call originator:
    - after the call set-up message transmission, the network checks the presence of group members. A notification is then sent back to the call originator, and finally the conversation can start.

A Dispatcher is sometimes present in the network. It is modelled as a fixed user that generates group calls.

A.2.1 Scenario n. 1: Urban & sub-urban public network on a medium density European city

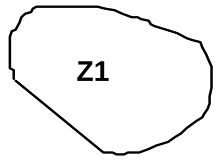

Figure A.1: Example of covered area for scenario n. 1

Propagation environment: TU on the whole area;

Covered area: 1 500 km^2

Network subscribers present homogeneous traffic characteristics throughout the network. These characteristics are described in the following:

Subscriber position: Gaussian distribution

Average density 5 subs/km^2

Subscriber speed: uniform distribution between 3 and 80 km/h

Power class of mobile terminals: 50 % class A, 50 % class D;

Requested services are described in table A.1.

Subscribers belong to three different groups at the same time for voice calls.

Voice and circuit data group calls do not require the presence checking of the called group members.

No priorities are allocated for voice calls.

50 % high priority and 50 % low priority for circuit data calls.

Table A.1: Scenario 1 requested services and statistical description

Service	Parameter	Value
M-M individual voice call	Frequency of requests	0,3 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
M-F individual voice call	Frequency of requests	0,9 calls/h (POISSON)
	Call duration	20 s to- 40 s (UNIF)
M-M group #1 voice call	Frequency of requests	0,045 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
	Group size	10
M-M group #2 voice call	Frequency of requests	0,045 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
	Group size	20
M-M group #3 voice call	Frequency of requests	0,21 calls/h (POISSON)
	Call duration	20 s to 40 s (UNIF)
	Group size	20
M-F individual circuit data call	Frequency of requests	0,4 calls/h (POISSON)
	Call duration	10 Kbytes (FIXED)
M-M group circuit data call	Frequency of requests	0,1 calls/h (POISSON)
	Call duration	10 Kbytes (FIXED)
	Group size	20
Short Data transmission	Frequency of requests	20 trasm/h (POISSON)
	Call duration	100 bytes (FIXED)

A.2.2 Scenario n. 2: Urban & sub-urban public network on a high density European city, with ring motorways and peripheric conglomerations

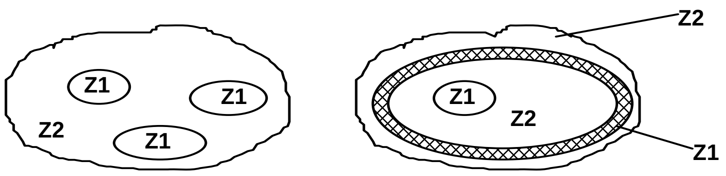

Figure A.2: Example of covered area for scenario n. 2

Propagation environment: BU on Z1 areas TU on Z2 areas;

Covered area: 1 000 km^2 for Z1 6 500 km^2 for Z2

Network subscribers are distributed on the territory depending on the area type(Z1 or Z2). Nevertheless traffic characteristics are homogeneous throughout the network. All the characteristics are described in the following:

Subscriber position distribution: Uniform on Z1 Gaussian on Z2

Average density 10 subs/km^2 in Z1 1 subs/km^2 in Z2

Subscriber speed: uniform distribution between 3 and 80 km/h

Power class of mobile terminals: 50 % class A in Z1 30 % class A in Z2

50 % class D in Z1 70 % class B in Z2

Requested services are described in table A.2.

Subscribers belong to three different groups at the same time for voice calls.

Voice and circuit data group calls do not require the presence checking of the called group members.

No priorities are allocated for voice calls.

50 % high priority and 50 % low priority for circuit data calls.

Table A.2: Scenario 2 requested services and statistical description

Service	Parameter	Value
M-M individual voice call	Frequency of requests	0,3 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
M-F individual voice call	Frequency of requests	0,9 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
M-M group #1 voice call	Frequency of requests	0,045 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
	Group size	10
M-M group #2 voice call	Frequency of requests	0,045 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
	Group size	20
M-M group #3 voice call	Frequency of requests	0,21 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
	Group size	20
M-F individual circuit data call	Frequency of requests	0,4 calls/h (POISSON)
	Call duration	10 Kbytes (FIXED)
M-M group circuit data call	Frequency of requests	0,1 calls/h (POISSON)
	Call duration	10 Kbytes (FIXED)
	Group size	20
Short Data transmission	Frequency of requests	20 trasm/h (POISSON)
	Call duration	100 bytes (FIXED)

A.2.3 Scenario n. 6: Urban & sub-urban private network on a medium density European city for utility services

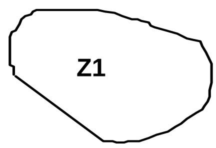

Figure A.3: Example of covered area for scenario n. 6

Propagation environment: TU on the whole area;

Covered area: 1 500 km^2

Network subscribers present homogeneous traffic characteristics throughout the network. These characteristics are described in the following:

Subscriber position: Gaussian distribution

Average density = 5 subs/km^2

Subscriber speed: uniform distribution between 3 and 80 km/h

Power class of mobile terminals: 50 % class A, 50 % class D;

Requested services are described in table A.3.

Subscribers belong to three different groups at the same time for both circuit data and voice calls.

5 % of voice and circuit data group calls require the presence checking of the called group members.

1 % pre-emptive priority, 10 % high priority and 89 % low priority for voice calls.

10 % high priority and 90 % low priority for circuit data calls.

A Dispatcher is present: it generates calls toward all groups.

Table A.3: Scenario 6 requested services and statistical description

Service	Parameter	Value
M-M individual voice call	Frequency of requests	0,108 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
M-F individual voice call	Frequency of requests	0,252 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
M-M group #1 voice call	Frequency of requests	0,144 calls/h (POISSON)
	Dispatcher to group #1	0,547 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
	Group size	10
M-M group #2 voice call	Frequency of requests	0,072 calls/h (POISSON)
	Dispatcher to group #2	0,274 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
	Group size	20
M-M group #3 voice call	Frequency of requests	0,144 calls/h (POISSON)
	Dispatcher to group #3	0,547 calls/h (POISSON)
	Call duration	20_s to 40 s (UNIF)
	Group size	20
M-M individual circuit data call	Frequency of requests	0,1 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
M-F individual circuit data call	Frequency of requests	0,25 calls/h (POISSON)
	Call duration	10 Kbytes (FIXED)
M-M group #1 circuit data call	Frequency of requests	0,006 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	20
M-M group #2 circuit data call	Frequency of requests	0,003 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	20
M-M group #3 circuit data call	Frequency of requests	0,006 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	20
Short Data transmission	Frequency of requests	5 trasm/h (POISSON)
	Call duration	100 bytes (FIXED)

A.2.4 Scenario n. 8: Urban and sub-urban private network on a high density European city, with peripheric conglomerations, for emergency services

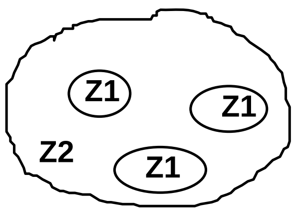

Figure A.4: Example of covered area for scenario n. 8

Propagation environment: BU on both Z1 and Z2 areas;

Covered area: 500 km^2 for Z1 2 000 km^2 for Z2

Network subscribers are distributed on the territory depending on the area type(Z1 or Z2). Nevertheless traffic characteristics are homogeneous throughout the network. All the characteristics are described in the following:

Subscriber position distribution: Uniform on Z1 Uniform on Z2

Average density	2 subs/km^2 in Z1	0,5 subs/km^2 in Z2
Subscriber speed:	uniform distribution between 3 and 80 km/h	
Power class of mobile terminals:	80 % class A in Z1	30 % class A in Z2
	20 % class D in Z1	70 % class B in Z2

Requested services are described in table A.4.

Subscribers belong to four different groups at the same time for voice and data calls.

5 % of voice and circuit data group calls require the presence checking of the called group members.

1 % pre-emptive priority, 10 % high priority and 89 % low priority for voice calls.

10 % high priority and 90 % low priority for circuit data calls.

A Dispatcher is present: it generates calls toward all groups.

Table A.4: Scenario 8 requested services and statistical description

Service	Parameter	Reference Scenario 8
M-M individual voice call	Frequency of requests	0,324 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
M-F individual voice call	Frequency of requests	0,756 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
F-M individual voice call	Frequency of requests	0,756 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
M-M group #1 voice call	Frequency of requests	0,108 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	10
Dispatcher-M group #1 voice call	Frequency of requests	0,108 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	10
M-M group #2 voice call	Frequency of requests	0,054 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	15
Dispatcher-M group #2 voice call	Frequency of requests	0,054 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	15
M-M group #3 voice call	Frequency of requests	0,054 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	20
Dispatcher-M group #3 voice call	Frequency of requests	0,054 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	20
M-M group #4 voice call	Frequency of requests	0,054 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	100
Dispatcher-M group #4 voice call	Frequency of requests	0,054 calls/h (POISSON)
	Call duration	10 s to 30 s (UNIF)
	Group size	100
M-M individual circuit data call	Frequency of requests	0,2 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
M-F individual circuit data call	Frequency of requests	0,5 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
F-M individual circuit data call	Frequency of requests	0,5 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
M-M group #1 circuit data call	Frequency of requests	0,06 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	10
Dispatcher-M group #1 circuit data call	Frequency of requests	0,06 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	10
M-M group #2 circuit data call	Frequency of requests	0,03 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	15
Dispatcher-M group #2 circuit data call	Frequency of requests	0,03 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	15
M-M group #3 circuit data call	Frequency of requests	0,03 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	20
Dispatcher-M group #3 circuit data call	Frequency of requests	0,03 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	20
M-M group #4 circuit data call	Frequency of requests	0,03 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	100
Dispatcher-M group #4 circuit data call	Frequency of requests	0,03 calls/h (POISSON)
	Call duration	2 Kbytes (FIXED)
	Group size	100

Service	Parameter	Reference Scenario 8
Short Data transmission	Frequency of requests	10 trasm/h (POISSON)
	Call duration	100 bytes (FIXED)

Annex B: Message Sequence Charts (MSCs) of the simulated procedures

B.1 Individual voice or circuit data call

The model of the individual circuit (voice and circuit data) call set-up procedure in a TETRA V+D network is described in the following clauses by means of MSC diagrams. The represented procedures show the successful set-up of a voice or circuit data individual M-M call. The calling MS and the SwMI protocol stack directly related to it are represented separately in respect of the called MS and the SwMI protocol stack related to the called MS. The procedure is based on EN 300 392-2 [i.2], annex D. Paging procedure, CONNECT message transmission and CONNECT-ACK message transmission are modelled as basic link acknowledged transmissions.

B.1.1 Calling MS and SwMI protocol stack related to the calling part

Figure B.1 reports the MSC diagram of the individual circuit M-M call set-up procedure looking to the calling MS and the SwMI protocol stack related to the calling side.

B.1.2 Called MS and SwMI protocol stack related to the called part

Figure B.2 reports the MSC diagram of the individual circuit M-M call set-up procedure looking to the called MS and the SwMI protocol stack related to the called side.

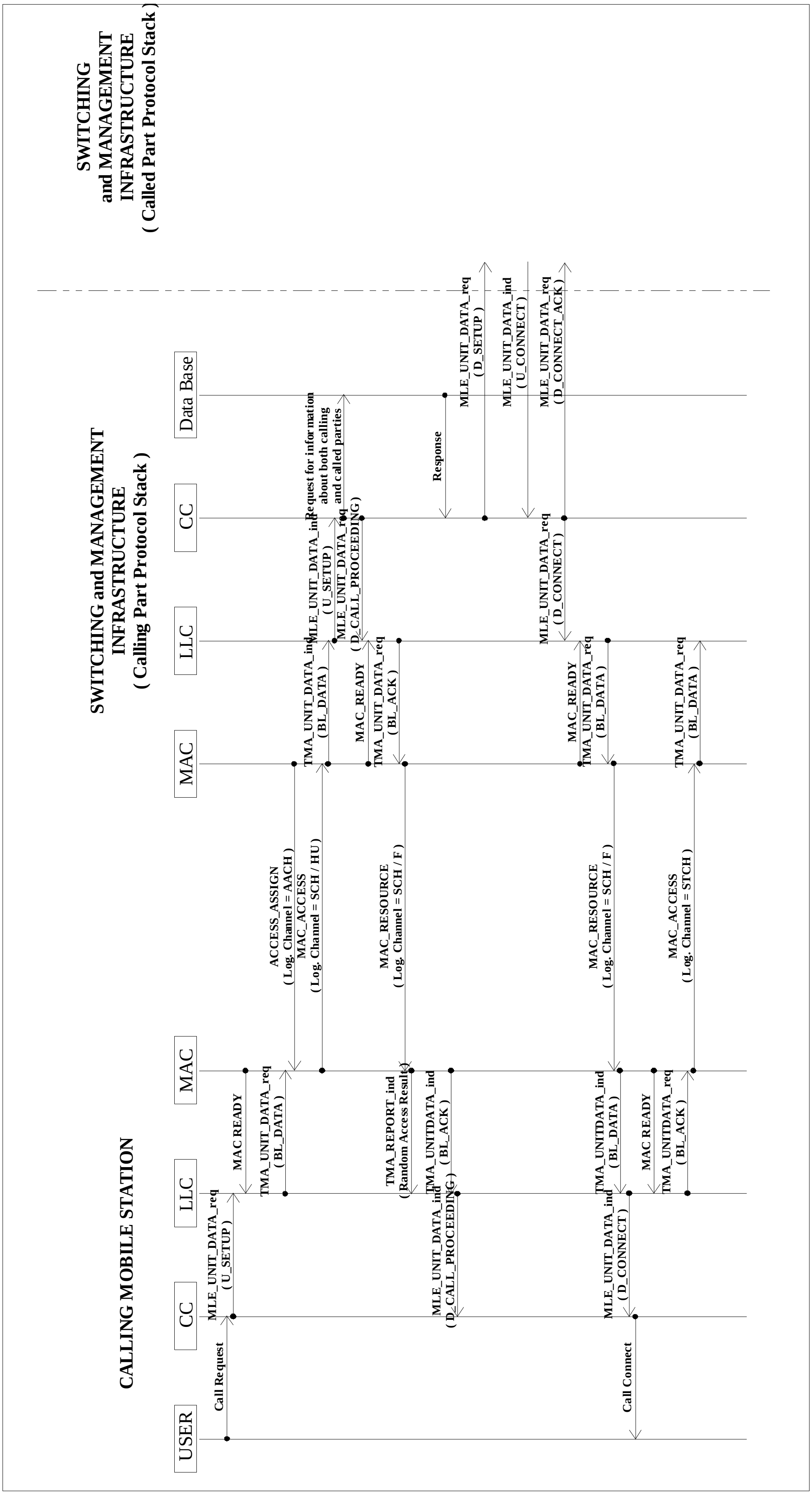

Figure B.1: MSC for the individual call (mobile and fixed calling side)

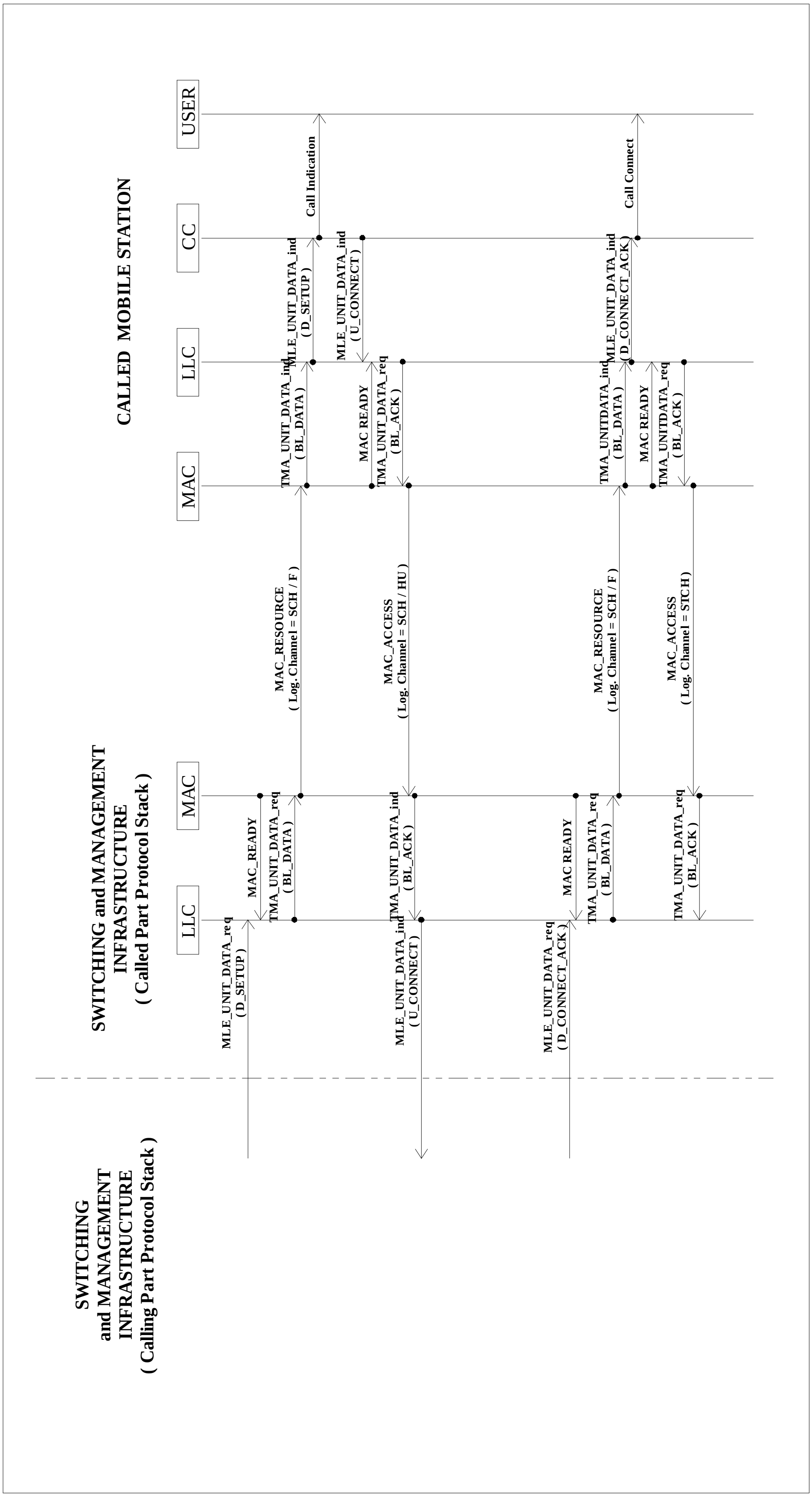

Figure B.2: MSC for the individual call set-up (mobile and fixed called side)

B.2 Group voice and circuit data call

The model of the circuit (voice and circuit data) group call set-up procedure in a TETRA V+D network is described in the following clauses by means of MSC diagrams. The represented procedures show the successful set-up of a voice or circuit data group call. The calling MS and the SwMI protocol stack directly related to it are represented separately in respect of the called MS and the SwMI protocol stack related to the called MS. The procedure is based on EN 300 392-2 [i.2], annex D. The Paging procedure is realized with an un-acknowledged basic link transmission, while CONNECT message transmission is modelled with basic link acknowledged transmission.

B.2.1 Calling mobile and SwMI in the calling side

Figure B.3 reports the MSC diagram of the group M-M call set-up procedure looking to the calling MS and the SwMI protocol stack related to the calling side.

B.2.2 SwMI at called side and called mobile

Figure B.4 reports the MSC diagram of the call group M-M set-up procedure looking to one of the called MS and the SwMI protocol stack related to the cell where the called MS is located.

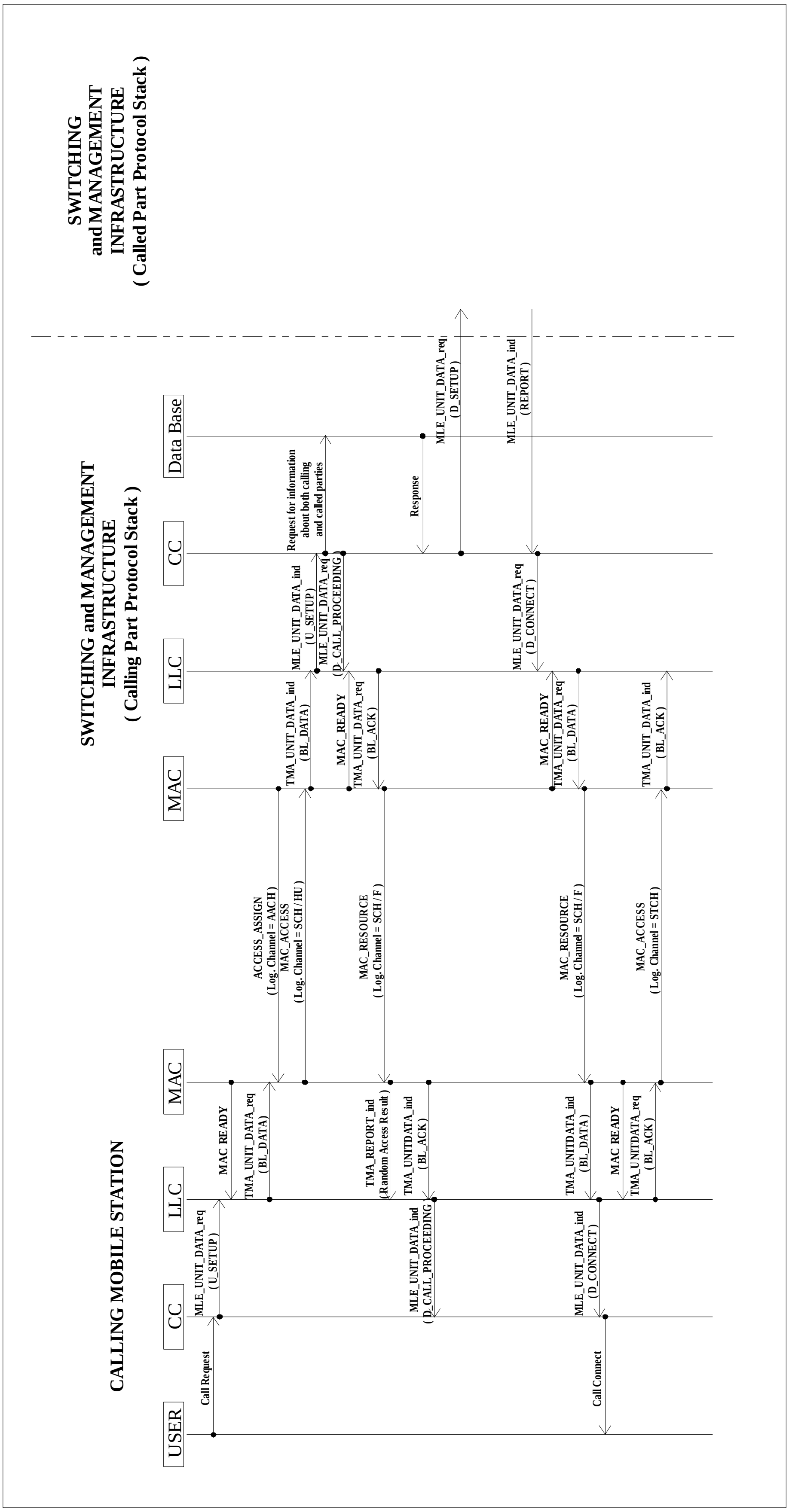

Figure B.3: MSC diagram for the successful call set-up of a voice or circuit data group call (Calling MS - BS signalling)

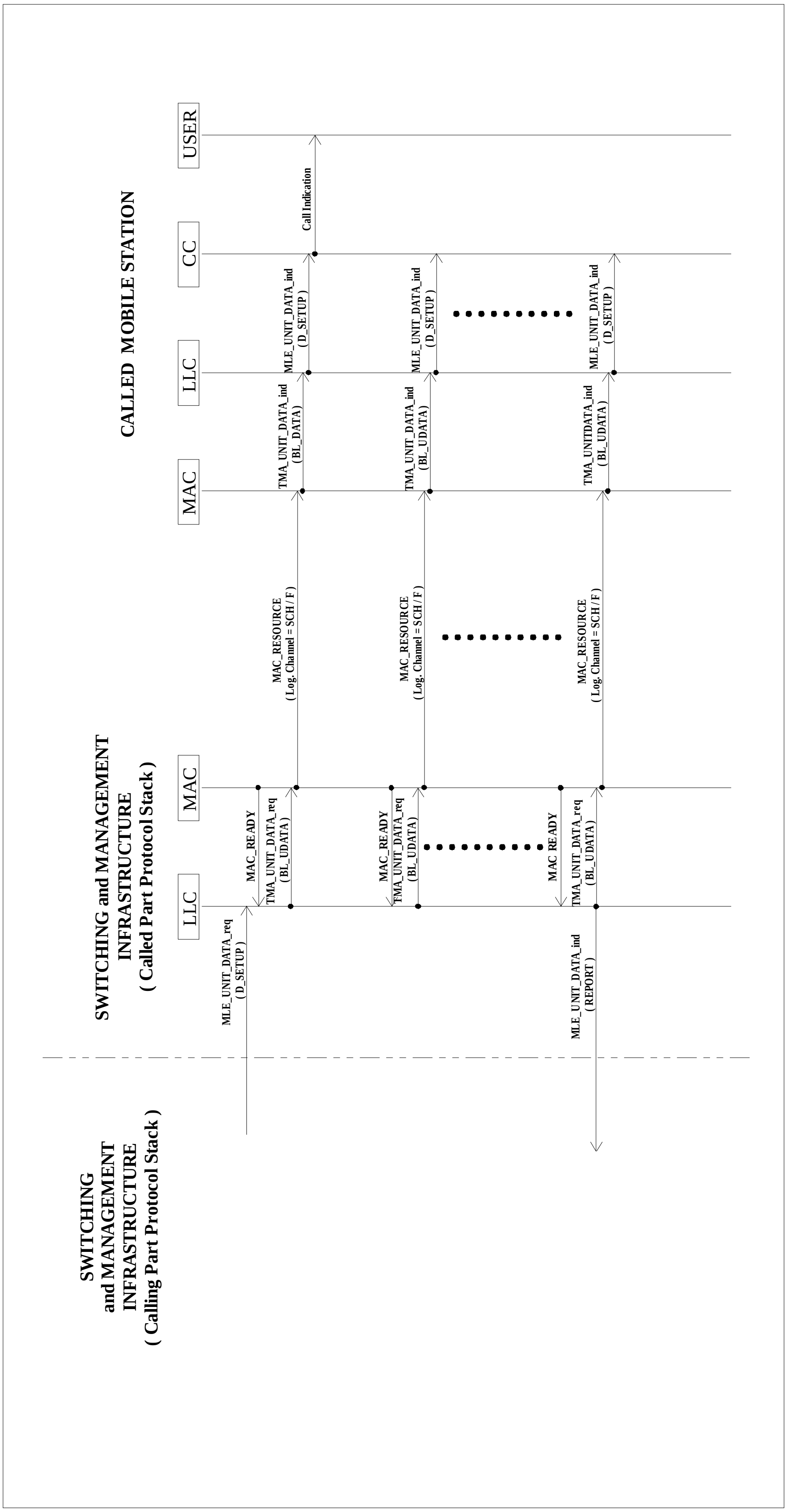

Figure B.4: MSC diagram for the successful call set-up of a voice or circuit data group call (Called MS - BS signalling)

B.3 Individual M-F short data transmission

The model of a short data transmission procedure in a TETRA V+D network is described in the following clauses by means of MSC diagrams. The represented procedures show the successful transmission of a short packet. This procedure can directly represent a connection-less data transmission (SCLNP or SDS) or a connection-oriented data transfer (CONP) after that a virtual call is already set-up. The calling MS and the SwMI protocol stack directly related to it are represented separately in respect of the called MS and the SwMI protocol stack related to the called MS. The procedure is based on EN 300 392-2 [i.2], annex D. The data transmission is modelled by an acknowledged LLC basic link data transmission. In case of MS originated transmission, after the random access, a suitable amount of uplink timeslots are reserved for the remaining bytes. The acknowledgement is sent back by the SwMI at the end of the last transmitted slot. In case of MS terminated transmission the SwMI pages the MS and waits the MS acknowledgement; then, a sequence of downlink slots are reserved for the remaining part of transmission. After the last slot, the MS sends the acknowledgement of the whole packet.

B.3.1 Mobile to network data transmission

Figure B.5 reports the MSC diagram of the short data transmission procedure related to a MS originated transmission, representing the calling MS and the SwMI protocol stack related to it.

B.3.2 Network to Mobile data transmission

Figure B.6 reports the MSC diagram of the short data transmission procedure related to a MS terminated call, representing the called MS and the SwMI protocol stack related to it.

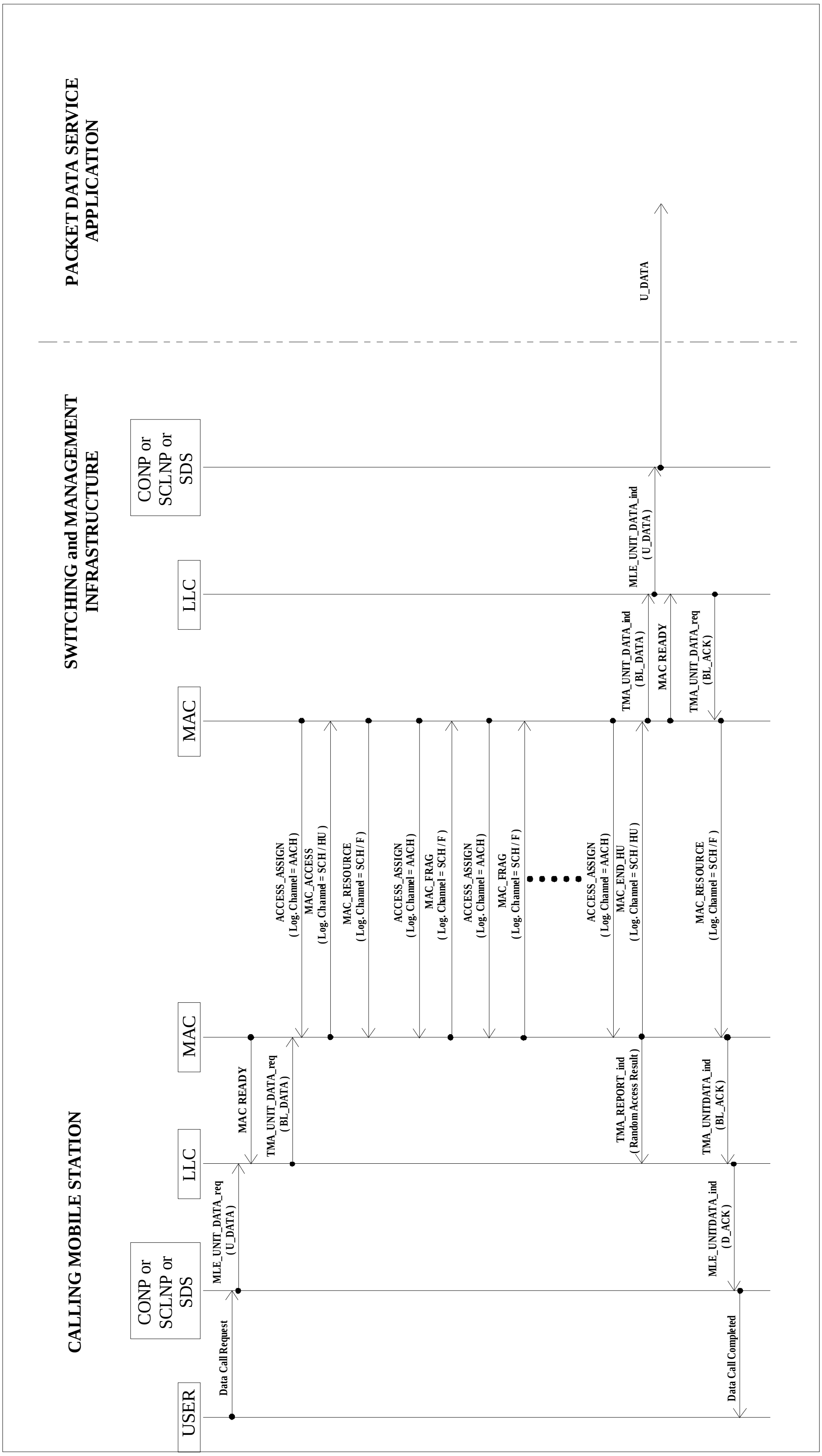

Figure B.5: MSC for the individual packet data transmission (MS to network)

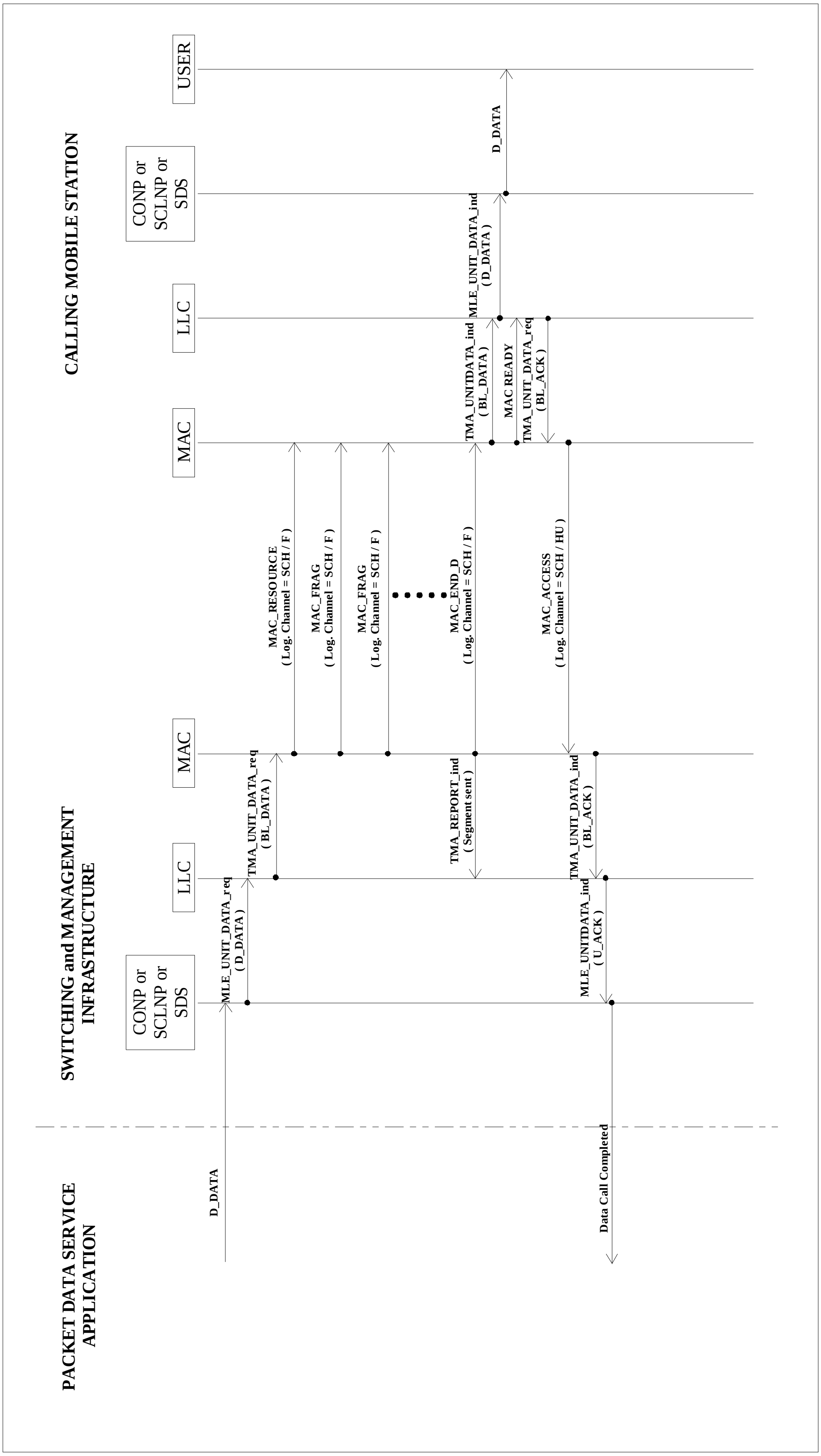

Figure B.6: MSC of the individual packet data transmission (network to MS)

Annex C: Service Diagrams related to the model of Mobile user

C.1 General description of the model of the TETRA user

The SDL diagram of the model of a TETRA user (human being and service applications) is represented in figure C.1. The parts with grey background are related to the evolution of a mobile terminated call. The others to the mobile originated. In the dashed rectangle it is shown the behaviour of the user in case of data transmission requests. When the user is busy of other services, data transmissions are queued, while voice services are discarded. The meaning of the parameters is explained in clause 5.3.2.

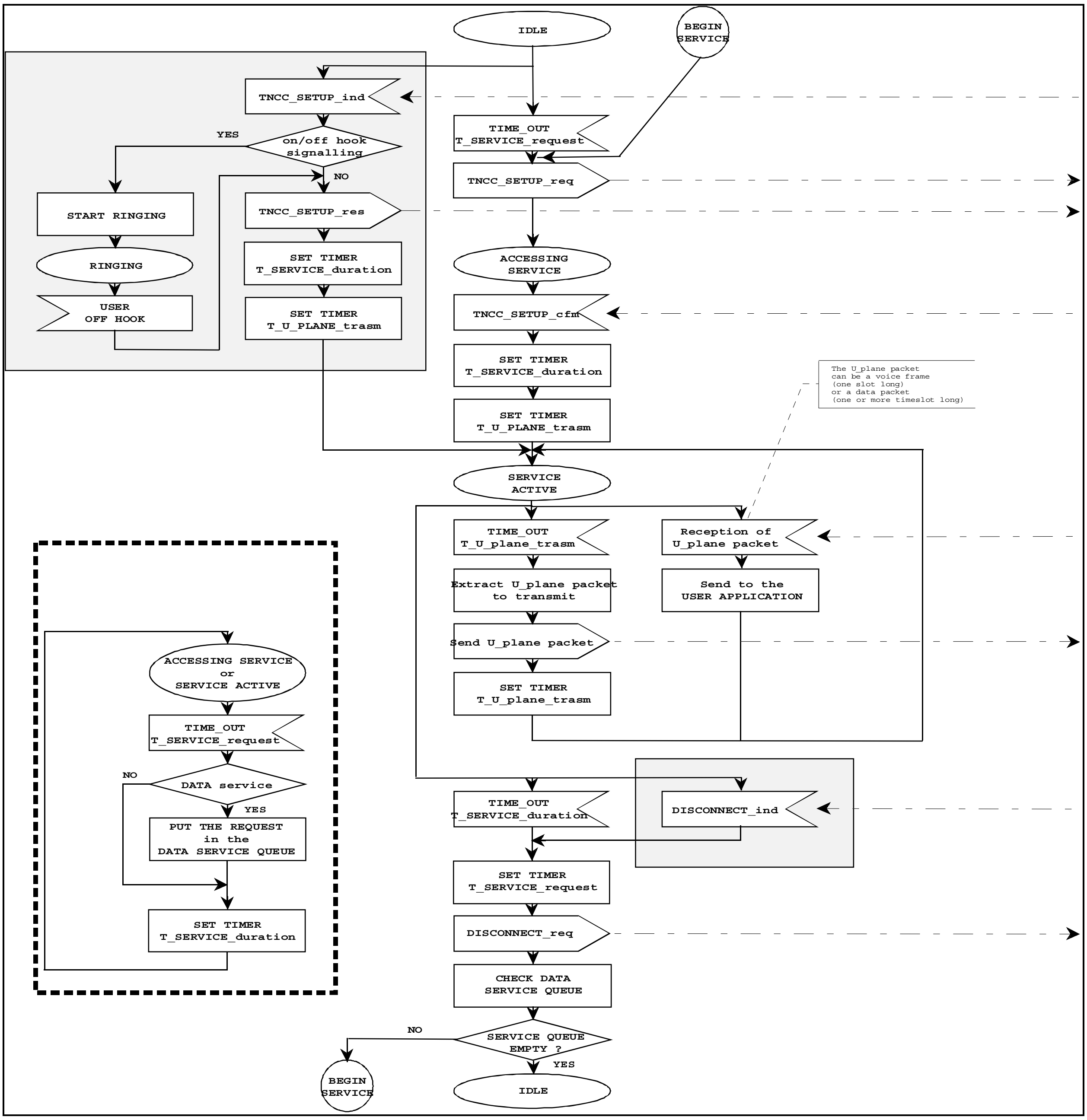

Figure C.1: SDL diagram of the user model

Annex D: Service Diagrams related to the MS

D.1 Random access procedure.

All service set-up procedures originated by a MS are initiated by the random access procedure. Figure D.1 reports the SDL diagram of the random access procedure that is realized on the calling MS. It is based on the MSC diagrams reported in annex B and gives the behaviour for all possible events. This detailed description is based on EN 300 392-2 [i.2], clause 23.5.

All MS originated procedures report a block called RANDOM ACCESS, that is a short description of figure D.1.

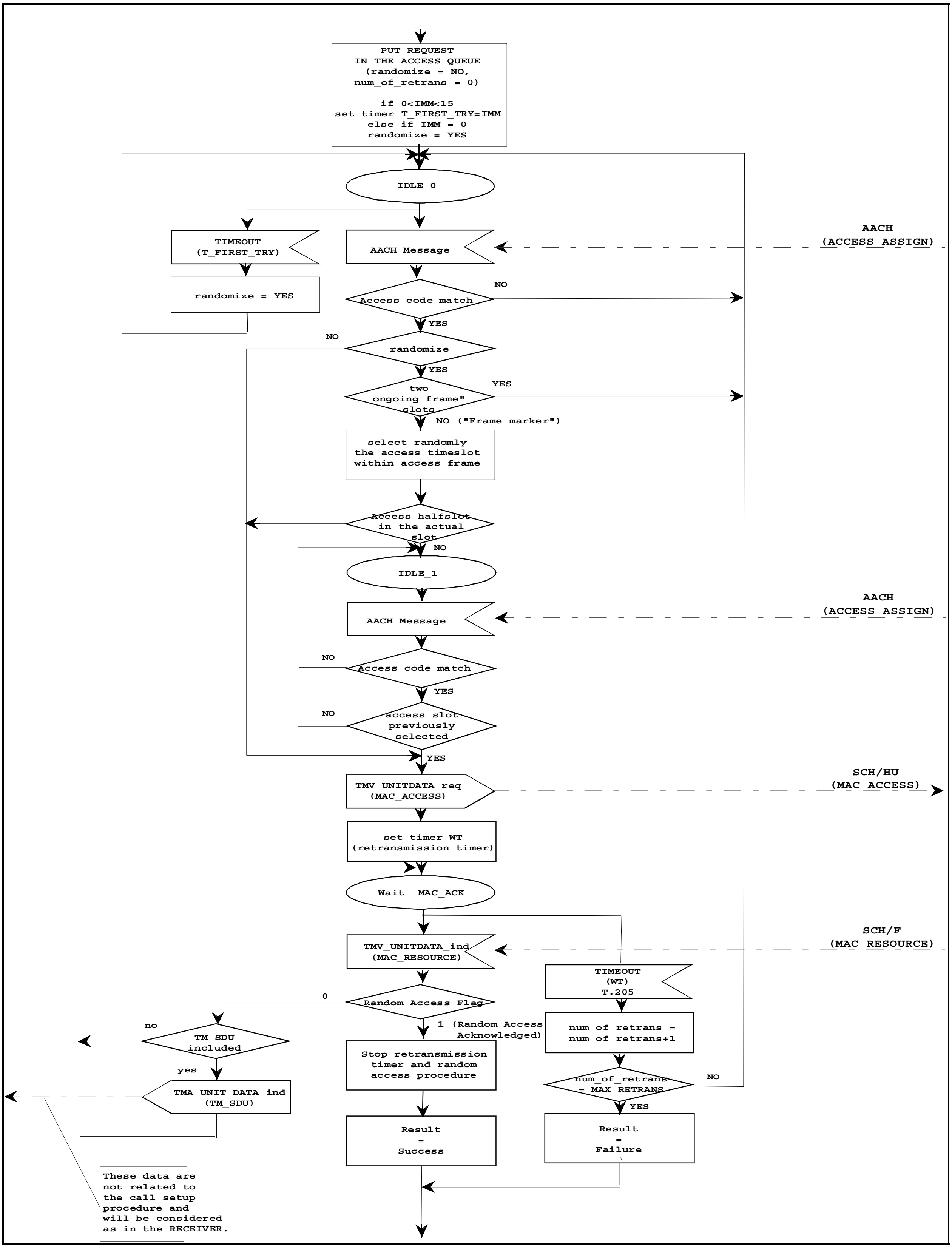

Figure D.1: SDL diagram of random access procedure (MS side)

D.2 Individual voice and circuit data call

D.2.1 Originating mobile side

Figure D.2 reports the SDL diagram related to the individual voice and circuit data call procedure inside the calling MS. It is based on the MSC diagram of figure B.1 and gives the detailed behaviour that takes into account all possible events in the procedure.

D.2.2 Terminating mobile side

Figure D.3 reports the SDL diagram related to the individual voice and circuit data call procedure inside the called MS. It is based on the MSC diagram of figure B.2 and gives the detailed behaviour that takes into account all possible events in the procedure.

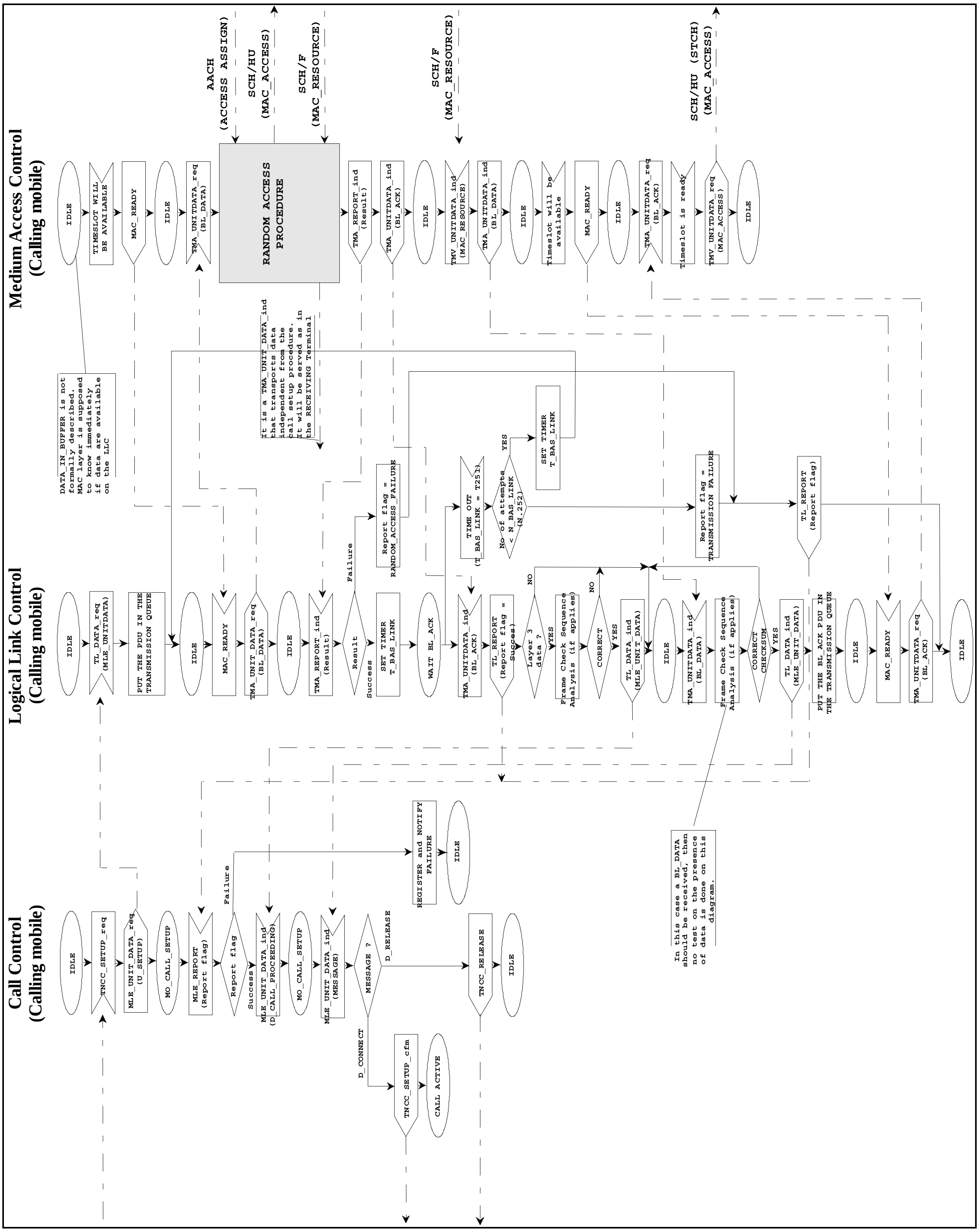

Figure D.2: SDL diagram of the MS that requires access to the network for an individual voice or circuit data call

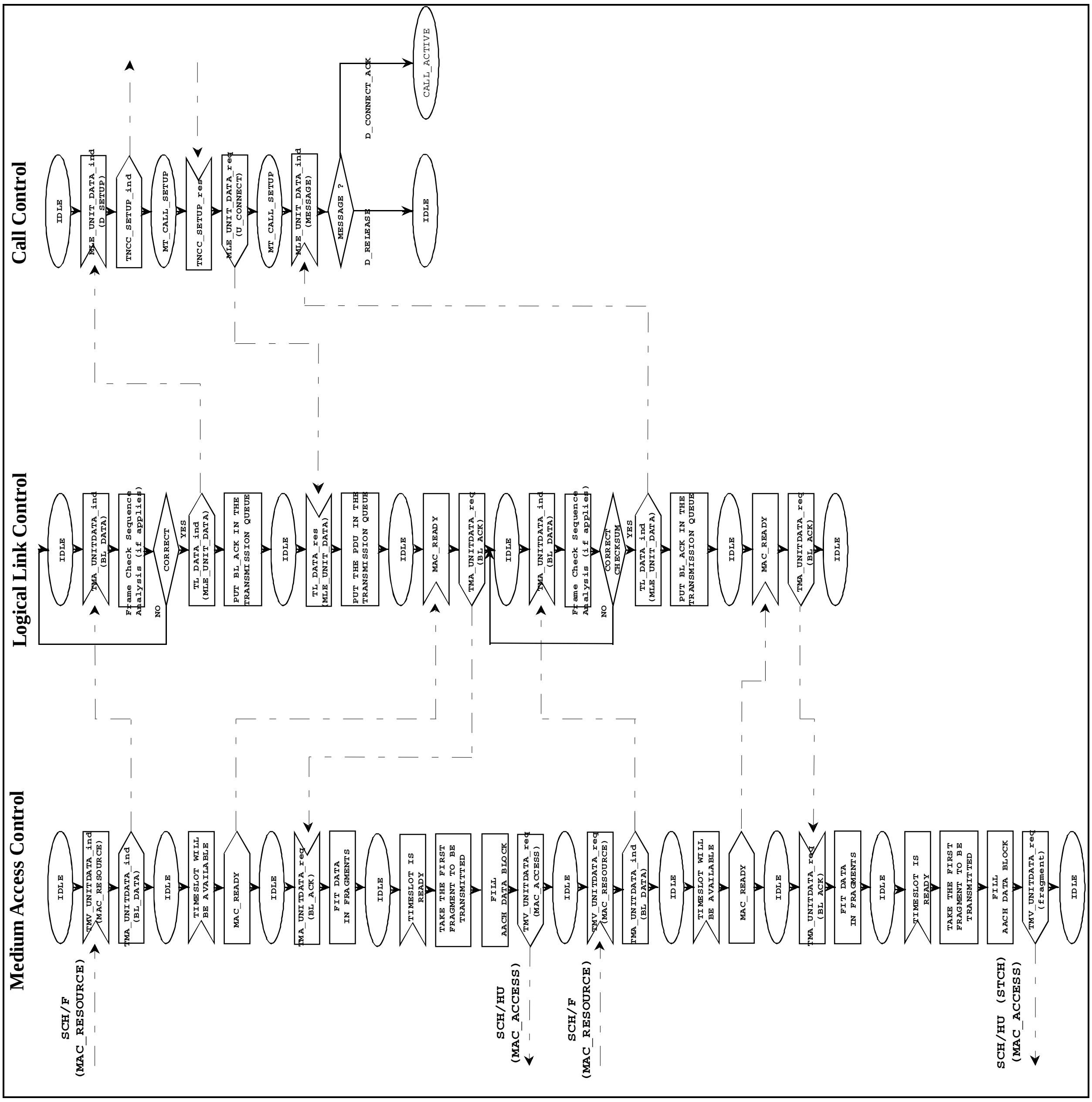

Figure D.3: SDL diagram of the MS that is paged by the network for an individual voice or circuit data call

D.3 Group voice and circuit data call

D.3.1 Originating mobile side

Figure D.4 reports the SDL diagram related to the group voice and circuit data call procedure inside the calling MS. It is based on the MSC diagram of figure B.3 and gives the detailed behaviour that takes into account all possible events in the procedure.

D.3.2 Terminating mobile side

Figure D.5 reports the SDL diagram related to the group voice and circuit data call procedure inside one of the called MSs. It is based on the MSC diagram of figure B.4 and gives the detailed behaviour that takes into account all possible events in the procedure.

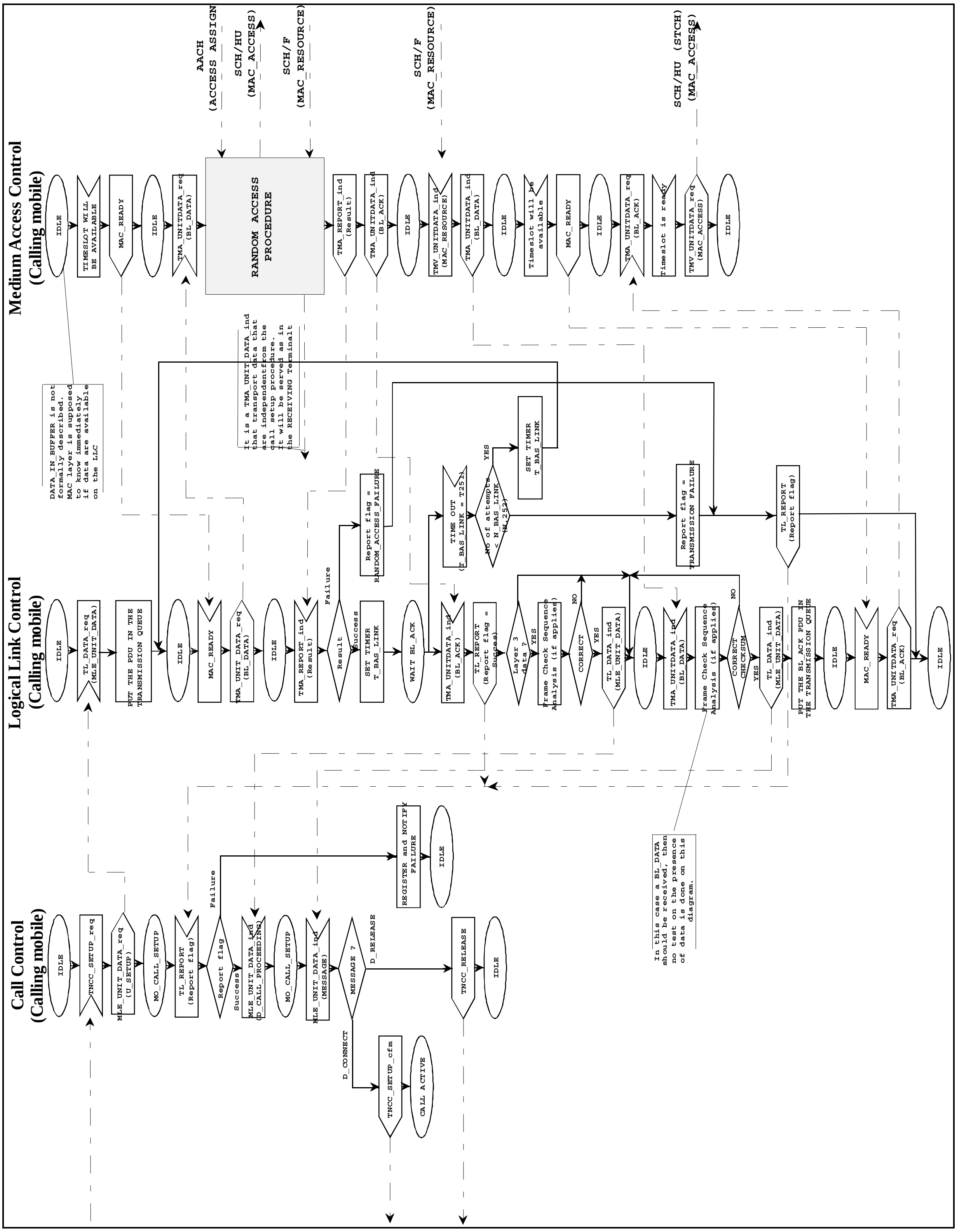

Figure D.4: SDL diagram of the MS that requires access to the network for a group voice or circuit data call

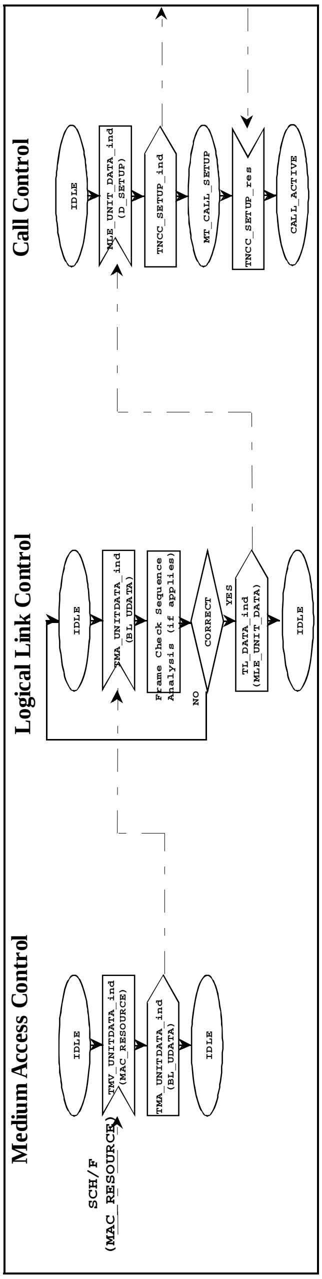

Figure D.5: SDL diagram of the MS that is paged by the network for a group voice or circuit data call

D.4 Packet data call

D.4.1 Originating mobile side

Figure D.6 reports the SDL diagram related to the short data transmission procedure inside the calling MS. It is based on the MSC diagram of figure B.5 and gives the detailed behaviour that takes into account all possible events in the procedure.

D.4.2 Terminating mobile side

Figure D.7 reports the SDL diagram related to the short data transmission procedure inside the called MS. It is based on the MSC diagram of figure B.6 and gives the detailed behaviour that takes into account all possible events in the procedure.

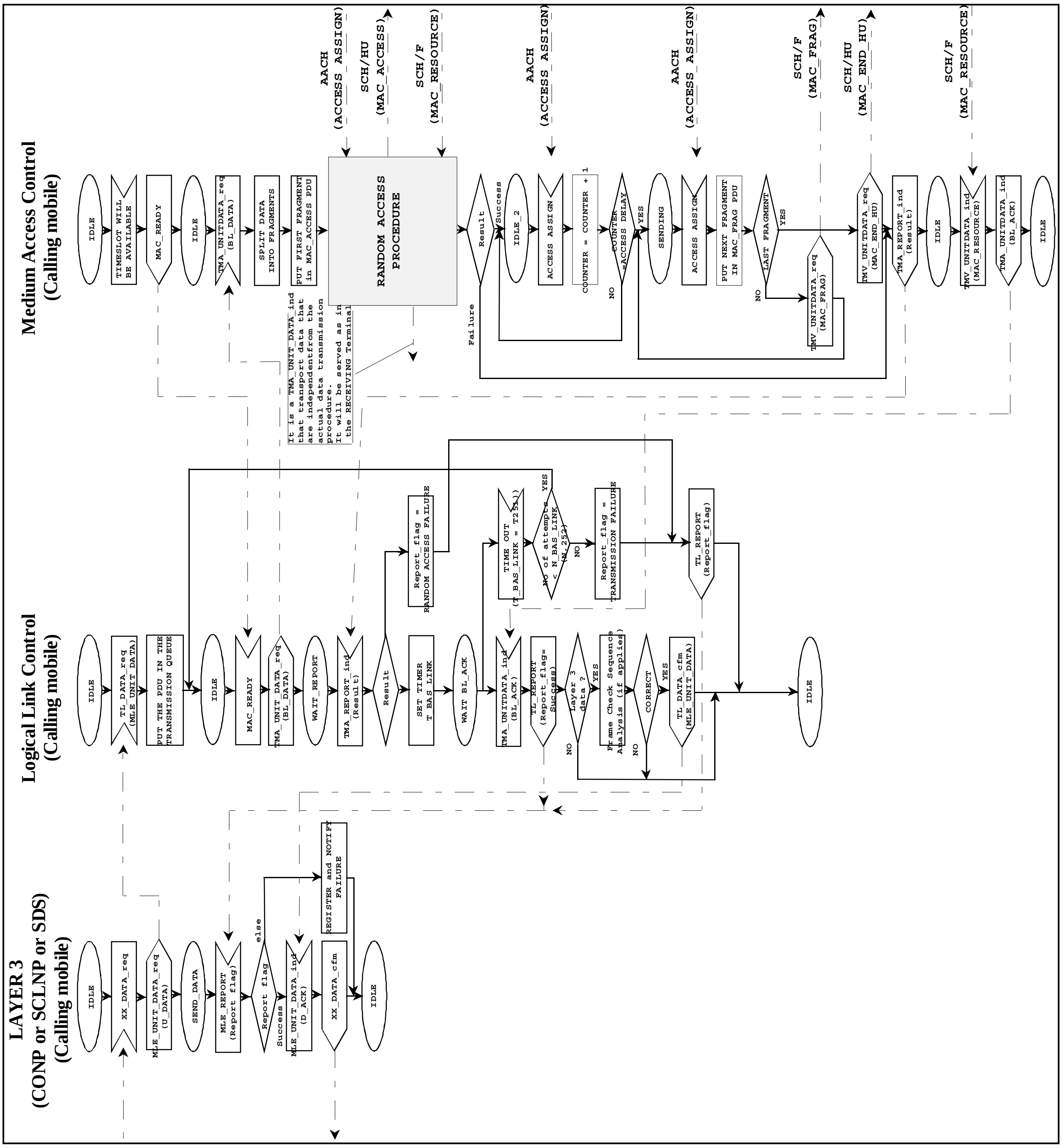

Figure D.6: SDL diagram of the MS that requires access to the network for an individual short data transmission to the network

Figure D.7: SDL diagram of the MS that receives an individual short data transmission from the network

Annex E: Service diagrams related to the SwMI

E.1 Individual voice and circuit data call

E.1.1 Calling side SwMI

Figure E.1 reports the SDL diagram related to the individual voice and circuit data call procedure inside the SwMI on the protocol stack related to the calling MS. It is based on the MSC diagram of figure B.1 and gives the detailed behaviour that takes into account all possible events in the procedure. LSs and external systems call requests are taken into account in this diagram. Depending on the call management policy, the behaviour of SwMI can change. In case of queuing strategy, a queuing policy based on call priority is described. In all cases, a late channel assignment is performed: after paging procedure the availability of channels is checked, then the Connection procedure is performed or delayed depending on the call management strategy.

E.1.2 Called side SwMI

Figure E.2 reports the SDL diagram related to the individual voice and circuit data call procedure inside the SwMI on the protocol stack related to the called MS. It is based on the MSC diagram of figure B.2 and gives the detailed behaviour that takes into account all possible events in the procedure. LSs and external systems call requests are taken into account in this diagram. Depending on the call management policy, the behaviour of SwMI can change. In case of queuing strategy, a queuing policy based on call priority is described. In all cases, a late channel assignment is performed: after paging procedure the availability of channels is checked, then the Connection procedure is performed or delayed depending on the call management strategy.

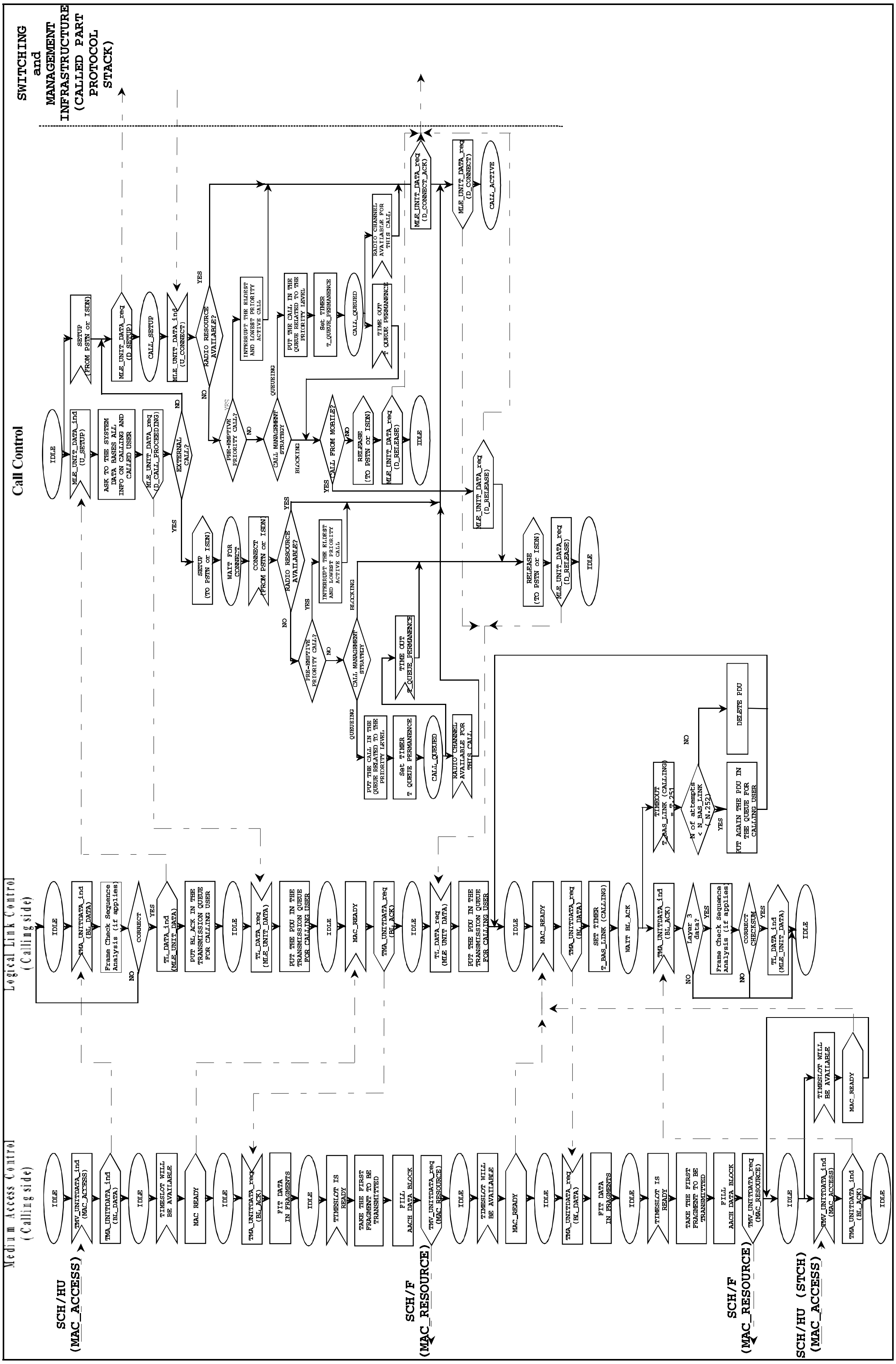

Figure E.1: SDL diagram of the BS when it receives an access request from a MS for an individual M-M, M-F voice or circuit data call

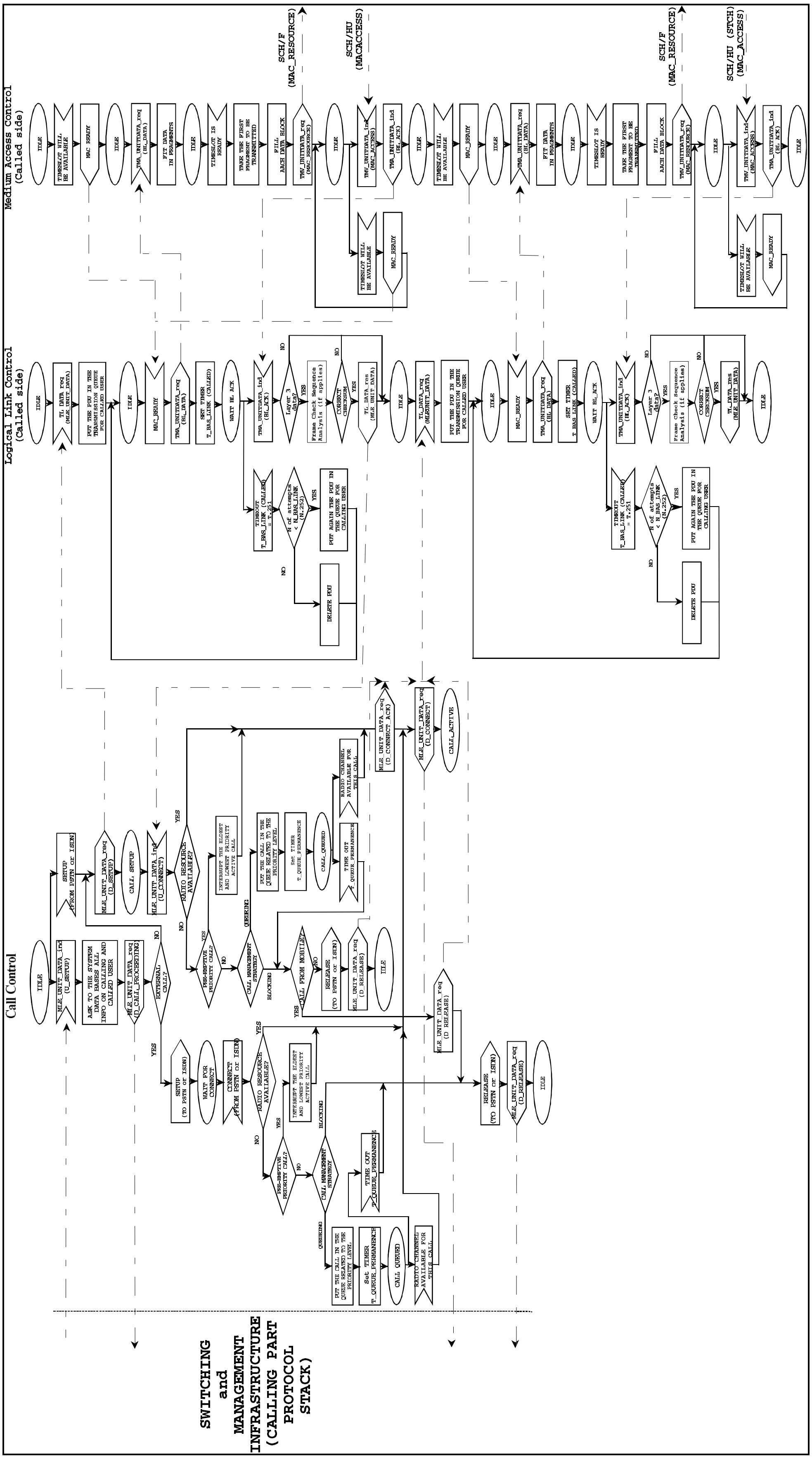

Figure E.2: SDL diagram of the BS when pages a MS for an individual M-M or F-M voice or circuit data call

E.2 Group voice and circuit data call

E.2.1 Calling side SwMI

Figure E.3 reports the SDL diagram related to the group voice and circuit data call procedure inside the SwMI on the protocol stack related to the calling MS. It is based on the MSC diagram of figure B.3 and gives the detailed behaviour that takes into account all possible events in the procedure. LSs and Dispatcher group calls are taken into account in this diagram. Depending on the call management policy, the behaviour of SwMI can change. In case of queuing strategy, a queuing policy based on call priority is described.

E.2.2 Called part SwMI

Figure E.3 reports the SDL diagram related to the group voice and circuit data call procedure inside the SwMI on the protocol stack related to one of the called MSs. It is based on the MSC diagram of figure B.4 and gives the detailed behaviour that takes into account all possible events in the procedure. LSs and Dispatcher group calls are taken into account in this diagram. Depending on the call management policy, the behaviour of SwMI can change. In case of queuing strategy, a queuing policy based on call priority is described.

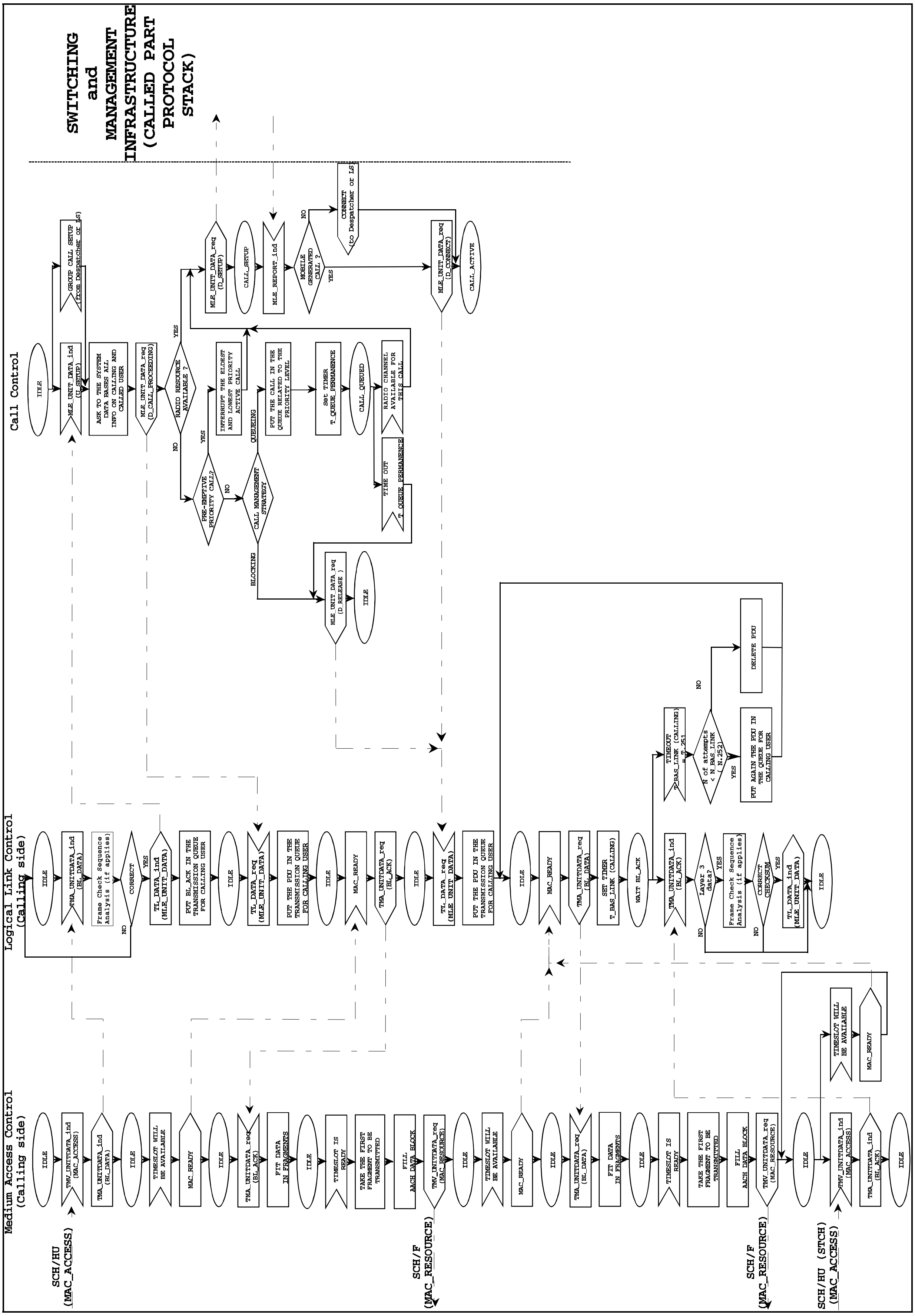

Figure E.3: SDL diagram of the BS when it receives an access request from a MS for a group M-M voice or circuit data call

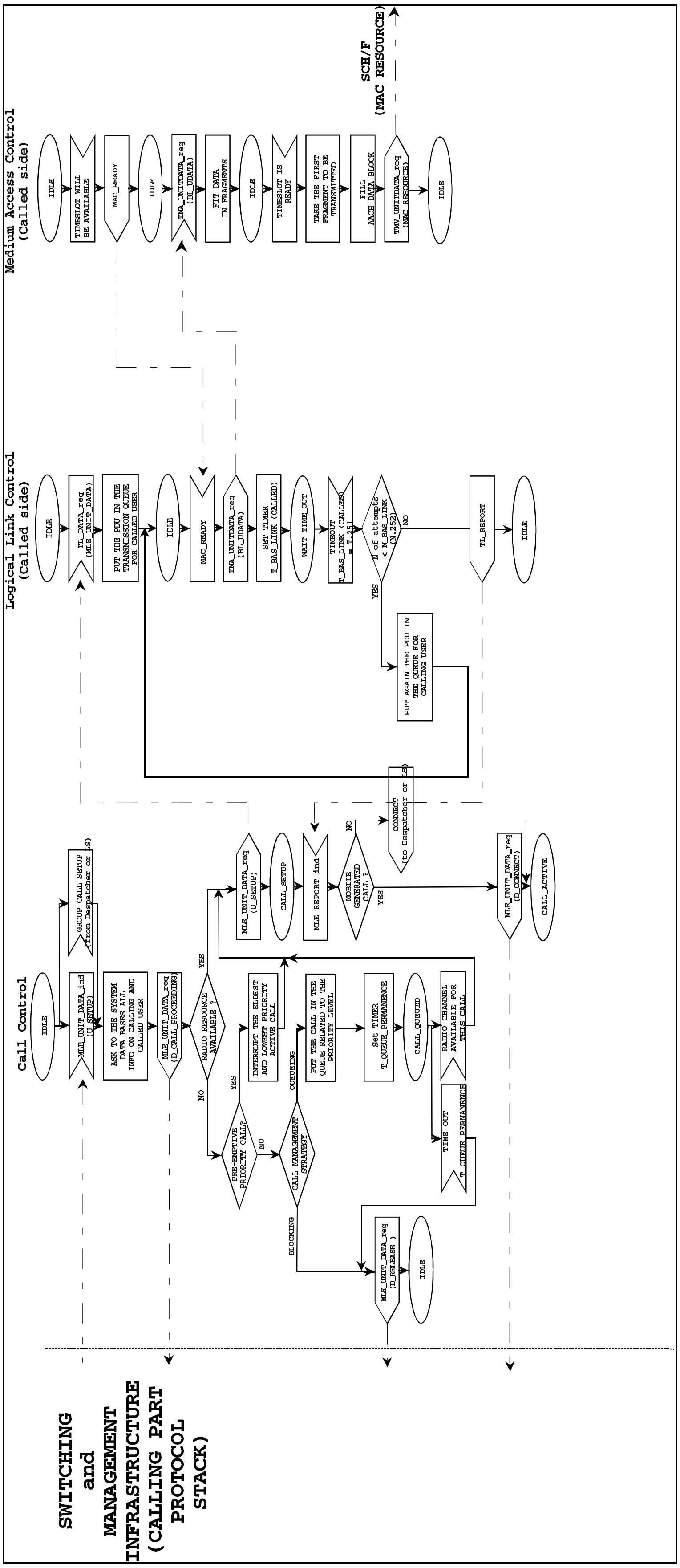

Figure E.4: SDL diagram of the BS when it pages a MS for a group M-M voice or circuit data call

E.3 Packet data call

E.3.1 Calling side SwMI

Figure E.5 reports the SDL diagram related to the short data transmission procedure inside the SwMI on the protocol stack related to the calling MS. It is based on the MSC diagram of figure B.5 and gives the detailed behaviour that takes into account all possible events in the procedure.

E.3.2 Called side SwMI

Figure E.6 reports the SDL diagram related to the short data transmission procedure inside the SwMI on the protocol stack related to the called MS. It is based on the MSC diagram of figure B.6 and gives the detailed behaviour that takes into account all possible events in the procedure.

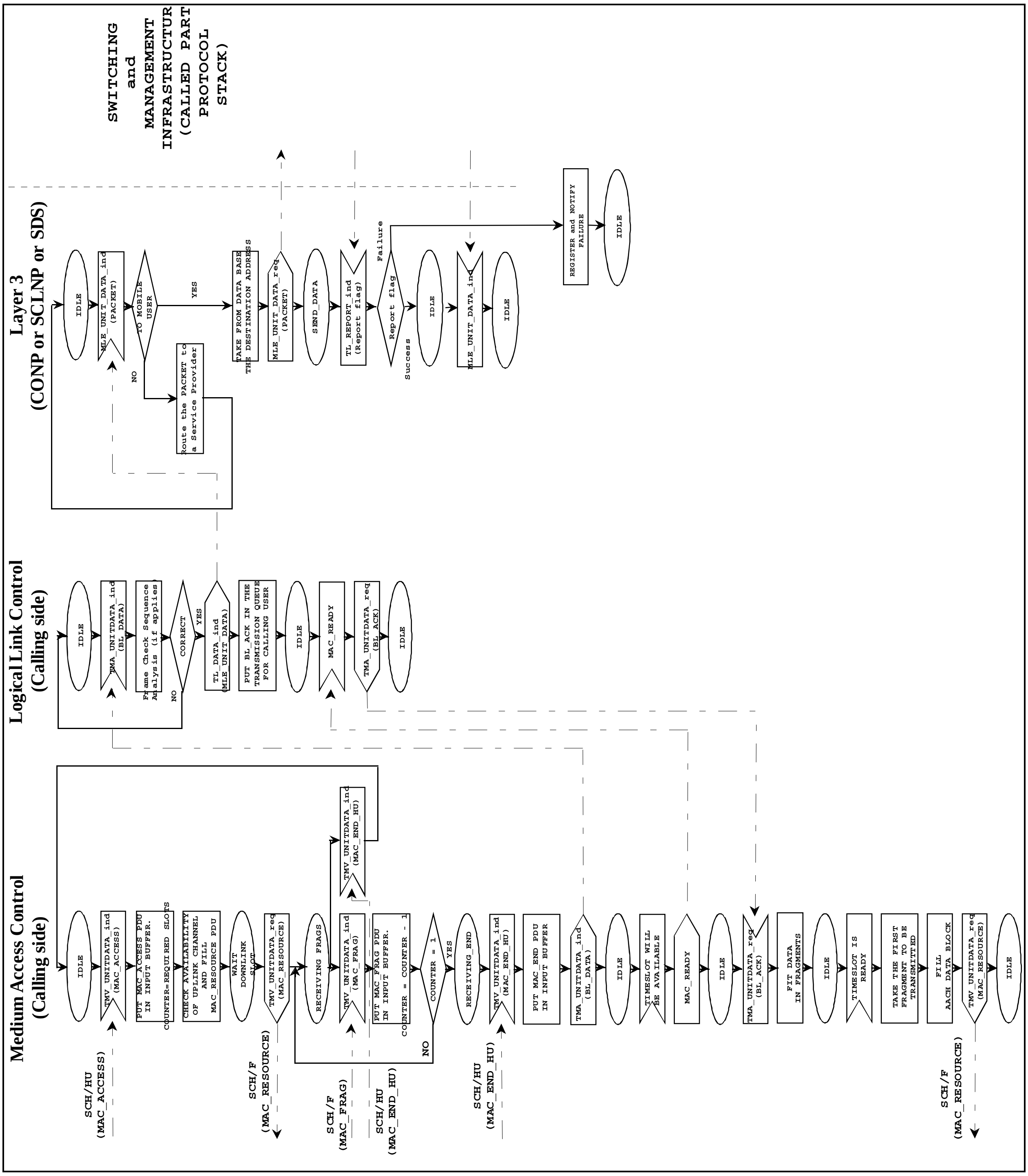

Figure E.5: SDL diagram of the BS when it receives an access request from a MS for an individual M-F short data transmission

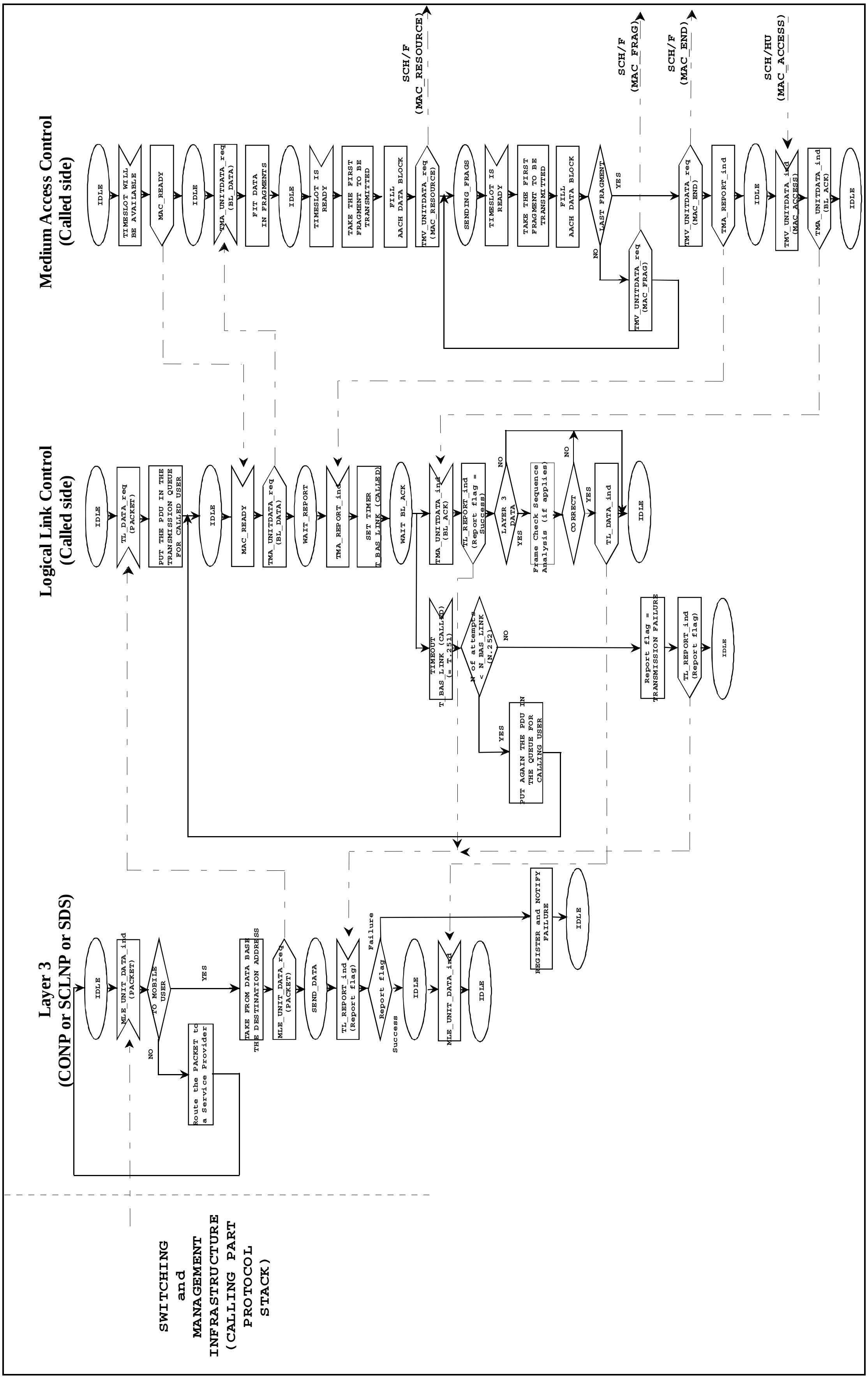

Figure E.6: SDL diagram of the BS when it pages a MS for an individual F-M short data transmission

Annex F: Simulations for performance at 138 MHz to 300 MHz

F.1 Introduction

This annex shows the results of the simulation to analyse the performance of TETRA with regard to π/4-DQPSK modulation at 138 MHz. The present TETRA standard EN 300 392-2 [i.2] addresses the frequencies between 300 MHz to 1 GHz. TETRA Protocol stack design and simulation results for π/4-DQPSK shown in EN 300 392-2 [i.2] and in clause 4 respectively are conducted for 400 MHz. The purpose of this annex is to extend the results for π/4-DQPSK down to 138 MHz. Clause F.2 explains the system design and results obtained from the simulation.

F.2 Simulation results

F.2.1 General observations

The figures in clauses F.2.2 and F.2.3 are simulation results based on the simulation model discussed in annex G clause G.2. Table 1 in mentioned document shows the Simulation parameters while figure 1 illustrates the simulation design.

Clause 4.3 of the present document is referred for the evaluation and comparison of simulated results for 430 MHz frequency for the respective channels, also by confirming the simulations matches with the standard results. Comparison of simulated results with the standard results as presented in clause 4.3 are based on the simulation set-up guidelines discussed in annex G. However introduction of different filter parameters like filter order, up-sampling or any other technique at receiver may impact the simulation results. Simulation parameters and receiver characteristics are configured based on the recommendation in the clause 4.2 while implementation for specific logical channels are based on the clause 8 of EN 300 392-2 [i.2].

Performance of logical channels over TU50 propagation channel is presented in clause F.2.2 while performance of logical channels over HT200 propagation channel is presented in clause F.2.3. Difference in Doppler shift value for 430 MHz and 138 MHz is major simulation difference between the performance presented in the annex G and results presented in clauses F.2.2 and F.2.3. Doppler Shift at 430 MHz is 20 Hz for TU50 and 80 Hz for HT200 propagation channel. Doppler shift at 138 MHz is calculated it to be around 6,38 Hz for TU50 and 25,6 Hz for HT200 propagation channel. Although there is not direct relation in the Doppler shift of TU5 and TU50 at 430 MHz and TU50 and HT200 at 138 MHz, for comparison and analysis we can relate the performance of logical channels over TU50 and HT200 at 138 MHz. Symbol duration for TETRA is 14,167 ms while maximum relative delay for TU50 channel is 5 µs and 15 µs for HT200 propagation channel. Key characteristics due to change in Doppler shift as a results of change in frequency band are given in figure F.1. We can see the Doppler shift for TU50 at 430 MHz and HT200 at 138 MHz effects comparable number of slots in contrast to other channels, but due to difference in relative path delays for both channels, results behave differently. The clause 4.3 shows the performance of TU50 channel at 430 MHz which have comparable Doppler shift as HT200 at 138 MHz. Results presented in the present document follows widely the same performance pattern.

Table F.1: Doppler shift on different frequency bands

	Doppler Shift (Hz)	Time Period (ms)	Number of Slots
TU50 at 430 MHz	20	50	3,52
TU50 at 138 MHz	6,38	156,5	11,0
HT200 at 430 MHz	80	12,5	0,88
HT200 at 138 MHz	25,5	39,13	2,76

For TU50 channel Doppler spread effects 12 slots in 138 MHz as compared to 4 slots for TU50 at 430 MHz, while for HT200 channel Doppler spread is 3 slots as compared to 1 slot. Interleaving across 4 and 8 slots as in case of BER performance of TCH/2,4 and TCH/4,8 logical channels, it does improves the performance but due to larger Doppler spread in case of 138 MHz there is a performance loss.

Performance characteristics given as message error rate (MER) for AACH, BSCH, SCH/F and SCH/HU logical channel while BER plots for TCH/7,2, TCH/2,4, TCH/2,4 N=4, TCH/2,4 N=8, TCH/4,8, TCH/4,8 N=4, TCH/4,8 N=8 logical channels over TU50 and HT200 propagation environments.

Figures F.1 to F.4 the Doppler spread for differ propagation conditions and frequencies.

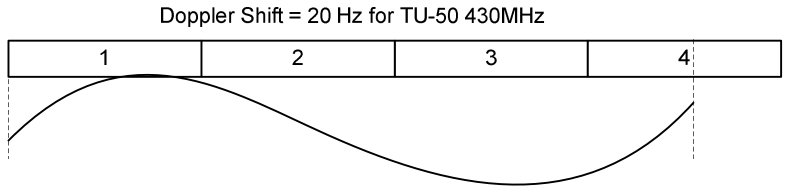

Figure F.1: Doppler Shift = 20 Hz for TU50 430 MHz

Figure F.1 shows the Doppler spread number of slots effected by the Doppler shift at 430 MHz at TU50 propagation channel.

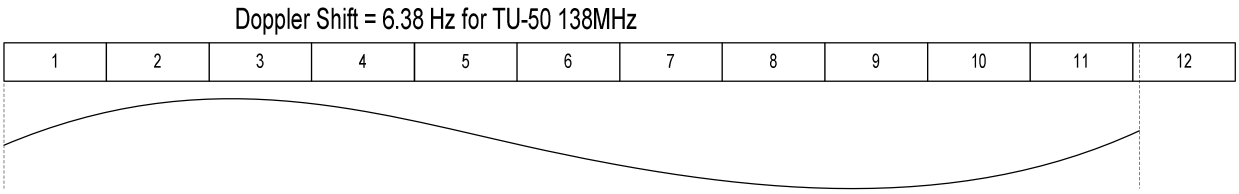

Figure F.2: Doppler Shift = 6,38 Hz for TU50 138 MHz

Figure F.2 shows the Doppler spread number of slots effected by the Doppler shift at 138 MHz at TU50 propagation channel.

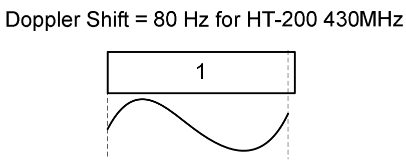

Figure F.3: Doppler Shift = 80 Hz for HT200 430 MHz

Figure F.3 shows the Doppler spread number of slots effected by the Doppler shift at 430 MHz at HT200 propagation channel.

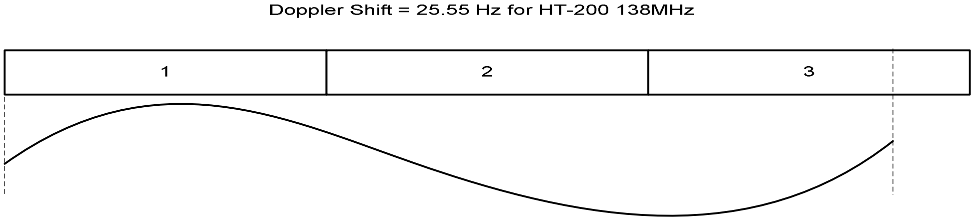

Figure F.4: Doppler Shift = 25,5 Hz for HT200 138 MHz

Figure F.4 shows the Doppler spread number of slots effected by the Doppler shift at 138 MHz at HT200 propagation channel.

F.2.2 Simulator at 138 MHz for TU50 Channel against clause 4.3

Message Error Rate of AACH channel as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.5, compared to the standard plots generated at 430 MHz in clause 4.3.

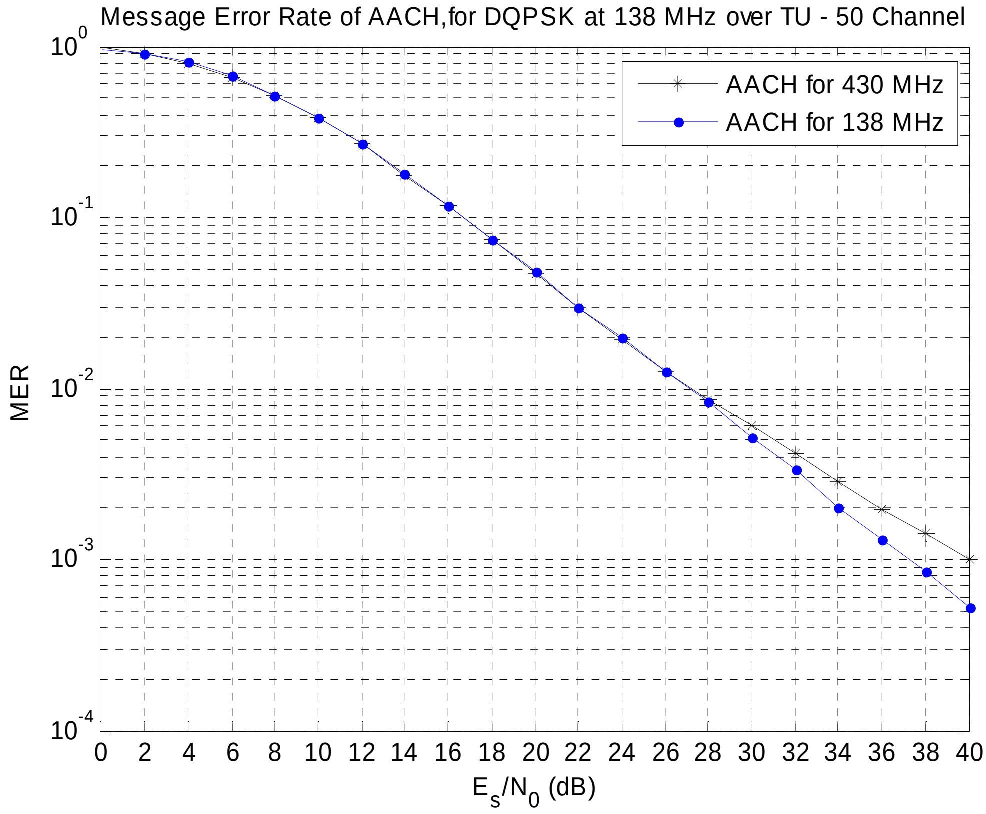

Figure F.5: Message Error Rate of AACH over TU50 Propagation Channel for 138 MHz

Table F.2: Parameters for figure F.5

Channel Parameters	
Logical Channel	AACH
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	14/30 Reed - Muller code
Type-1 bits	14 bits

AACH is Reed Muller encoded channel with only 14 type-1 bits. Relating the performance of AACH in figure F.5 with figure 3 in clause 4.3. Performance of AACH over TU5 channel at 430 MHz and presented performance of AACH over TU50 channel at 138 MHz shows a similar performance characteristics. Doppler shift for TU5 at 430 MHz and for TU50 at 138 MHz is less than Doppler for TU50 at 430 MHz.

Message Error Rate of BSCH channel as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.6, compared to the standard plots generated at 430 MHz clause 4.3.

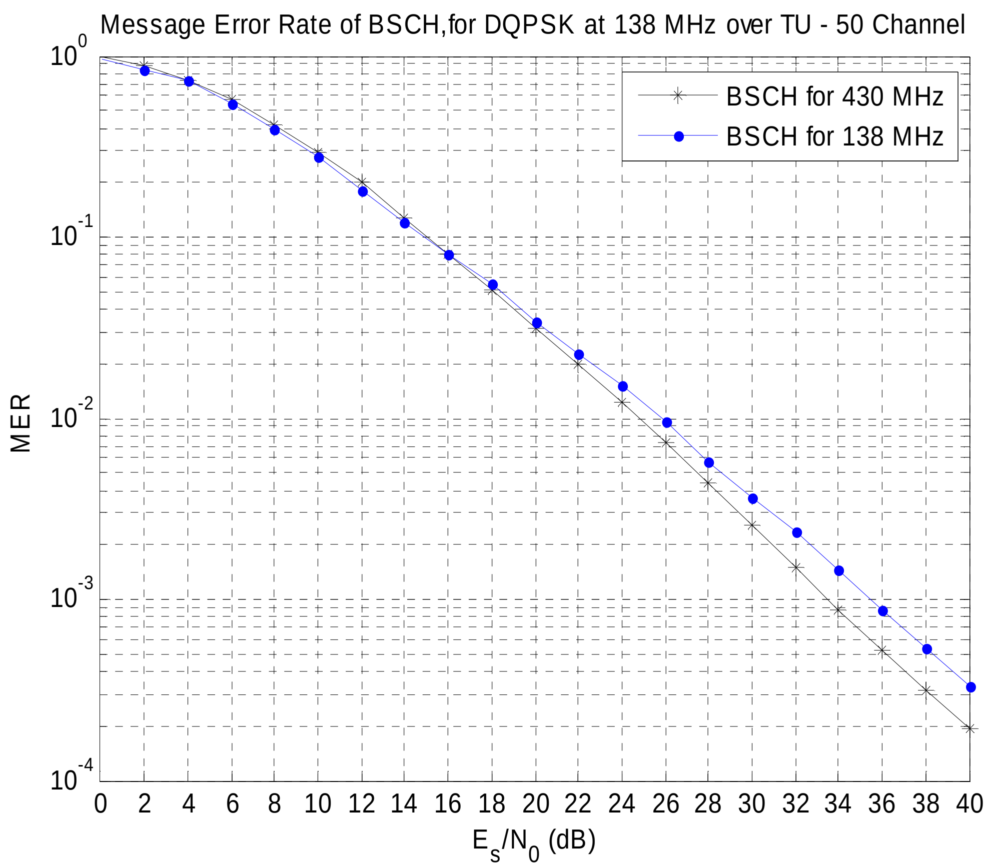

Figure F.6: Message Error Rate of BSCH over TU50 Propagation Channel for 138 MHz

Table F.3: Parameters for figure F.6

Channel Parameters	
Logical Channel	BSCH
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 2/3
Type-1 bits	60 bits

BSCH is design on RCPC encoder, rate = 2/3 with 60 type-1 bits. Performance of BSCH over TU5 channel at 430 MHz and presented performance of BSCH over TU50 channel at 138 MHz can be related in figure F.6 and figure 21 in clause 4.3. Doppler shift for TU5 at 430 MHz and for TU50 at 138 MHz is less than the Doppler for TU50 at 430 MHz, values of which are mentioned in clause G.3.1, table G.1.

Message Error Rate of SCH/F channel as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.7, compared to the standard plots generated at 430 MHz clause 4.3.

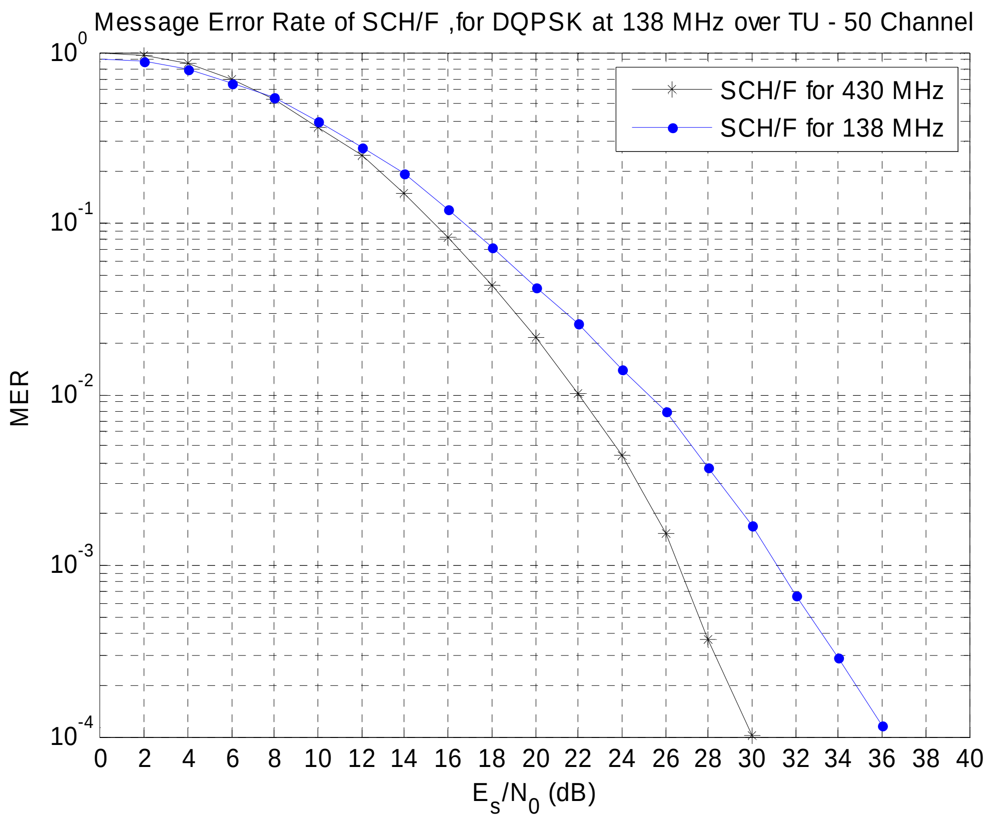

Figure F.7: Message Error Rate of SCH/F over TU50 Propagation Channel for 138 MHz

Table F.4: Parameters for figure F.7

Channel Parameters	
Logical Channel	SCH/F
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 2/3
Type-1 bits	268 bits

SCH/F is design as RCPC encoded, rate = 2/3 with 268 type-1 bits. Relating the performance of SCH/F in figure F.7 with figure 15 in clause 4.3. Performance of SCH/F over TU5 channel at 430 MHz is worst due to less Doppler shift which resultantly effects more slots, resultantly MER. performance of SCH/F over TU50 channel at 138 MHz is about 4 dB worst than the performance of same system over 430 MHz at $10e^{-3}$.

Message Error Rate of SCH/HU channel as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.8, compared to the standard plots generated at 430 MHz clause 4.3.

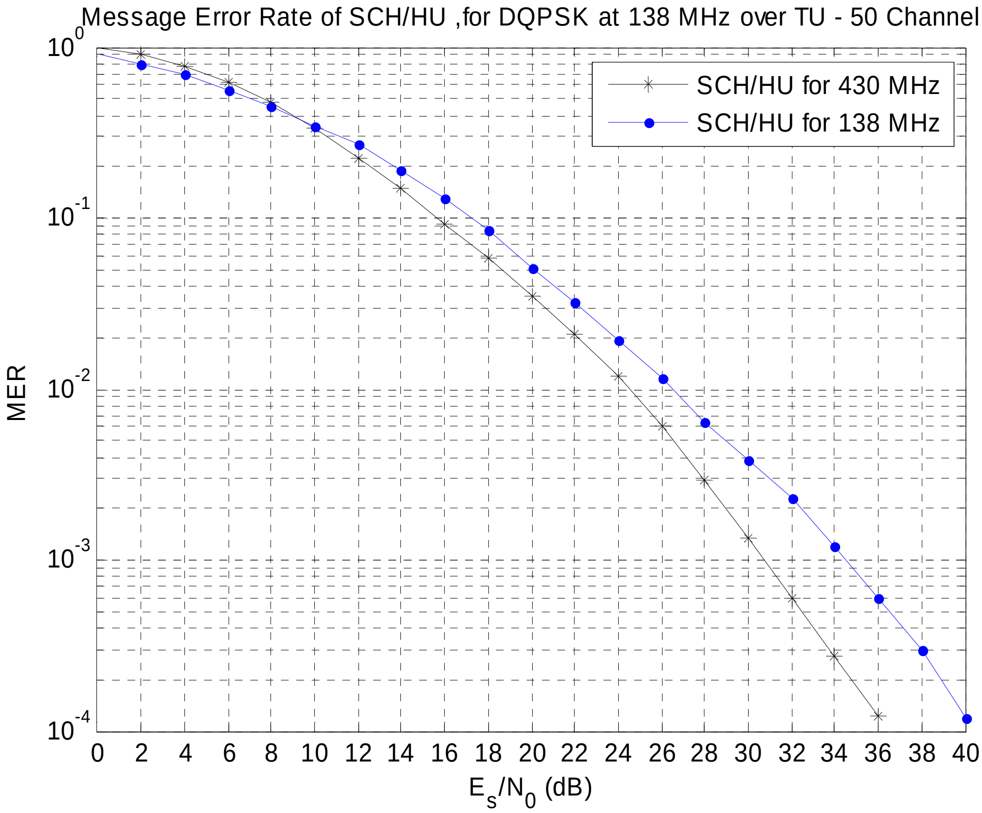

Figure F.8: Message Error Rate of SCH/HU over TU50 Propagation Channel for 138 MHz

Table F.5: Parameters for figure F.8

Channel Parameters	
Logical Channel	SCH/HU
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 2/3
Type-1 bits	92 bits

SCH/HU logical channel is design as RCPC encoded, rate = 2/3 with 92 type-1 bits. Performance of SCH/HU over TU50 at 138 MHz is about 4 dB worse than the performance at 430 MHz. Performance of SCH/HU over TU5 channel at 430 MHz in figure 9 in clause 4.3 is worst due to less Doppler shift which resultantly effects more slots, resultantly MER. As a results performance of SCH/HU at TU5 at 430 MHz is 6 dB to 7 dB worse. Similarly performance of SCH/HU over TU50 channel at 138 MHz can be related in figure F.8 and figure 9 in clause 4.3.

Bit Error Rate of TCH/7,2 channel as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.9, compared to the standard plots generated at 430 MHz clause 4.3.

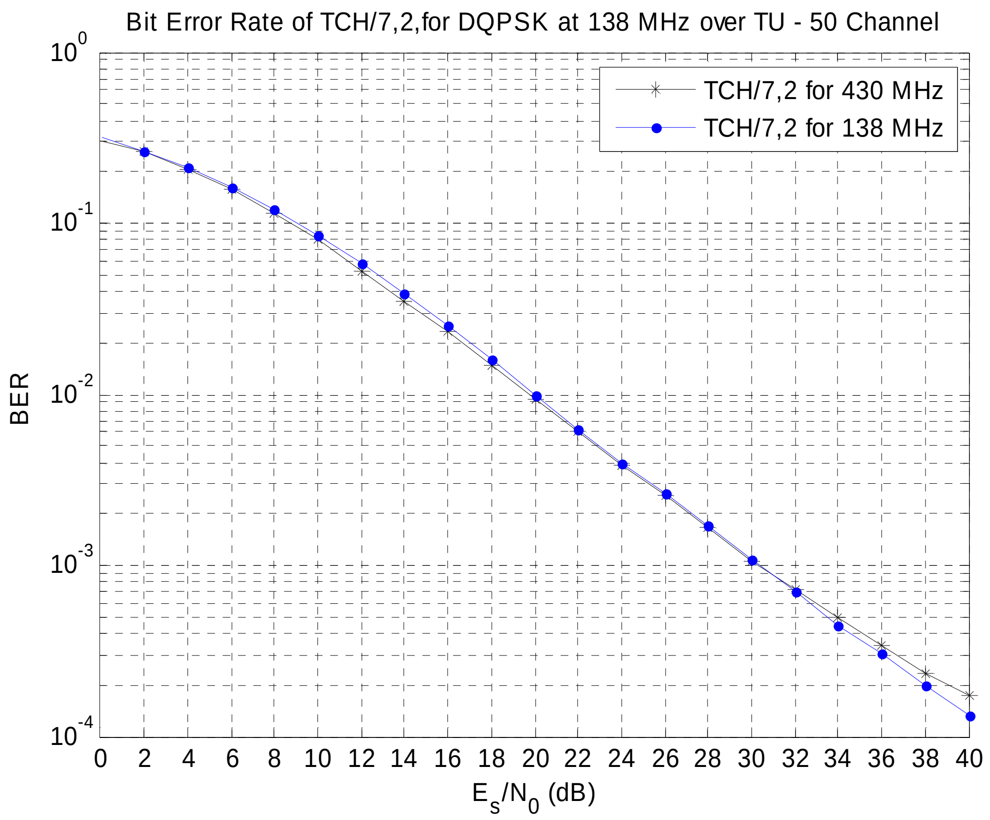

Figure F.9: Bit Error Rate of TCH/7,2 over TU50 Propagation Channel for 138 MHz

Table F.6: Parameters for figure F.9

Channel Parameters	
Logical Channel	TCH
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	Un-coded channel
Type-1 bits	432 bits

BER performance of TCH/7,2 for TU50 channel over 138 MHz exhibits a similar performance behaviour as TCH/7,2 for TU5 over 430 MHz. TCH/7,2 is un-coded channel with 432 type-1 bits. Relating the performance of TCH/7,2 in figure F.9 with figure 26 in clause 4.3. Performance of TCH/7,2 over TU5 channel at 430 MHz is somewhat similar to the performance of TCH/7,2 over TU50 channel at 430 MHz. Performance of TCH/7,2 over TU50 channel at 138 MHz is performing slightly better in terms of BER due to reduced Doppler shift over un-coded channel.

Bit Error Rate of TCH/2,4 channel as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.10, compared to the standard plots generated at 430 MHz clause 4.3.

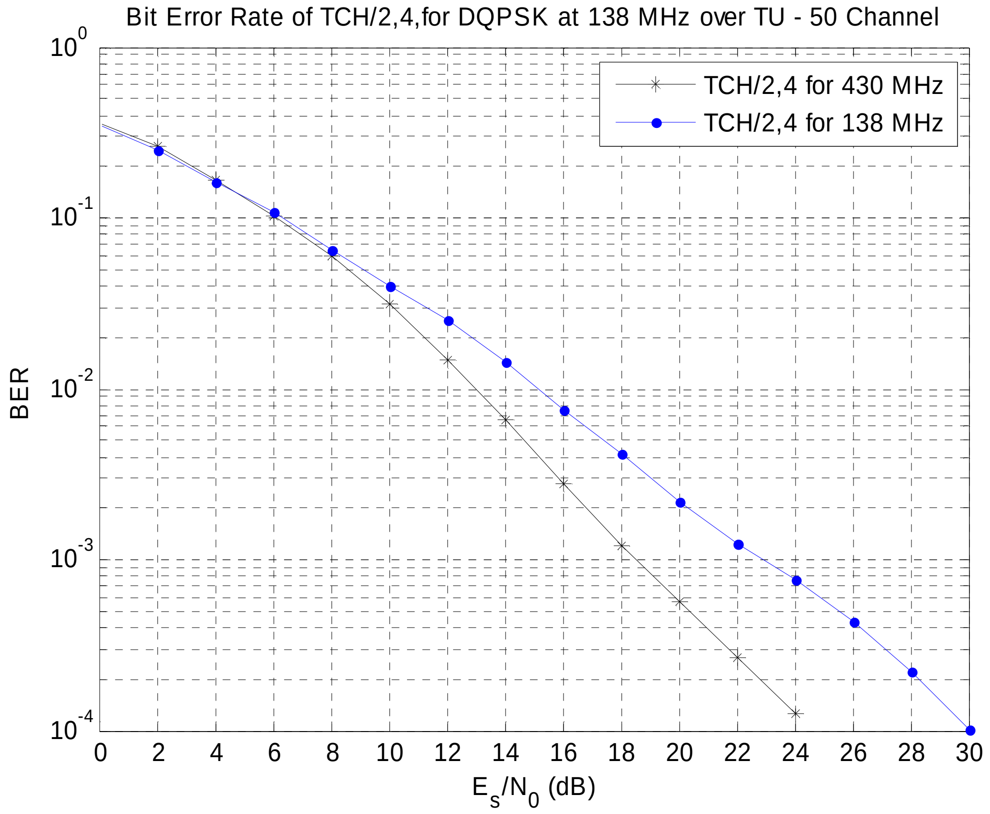

Figure F.10: Bit Error Rate of TCH/2,4 over TU50 Propagation Channel for 138 MHz

Table F.7: Parameters for figure F.10

Channel Parameters	
Logical Channel	TCH/2,4
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 148/432
Type-1 bits	144 bits

BER performance of TCH/2,4 for TU50 channel over 138 MHz exhibits a similar performance behaviour as TCH/2,4 for TU5 over 430 MHz as compared to over TU50. TCH/2,4 is RCPC encoded channel, rate = 148/432 with 144 type-1 bits. Relating the performance of TCH/2,4 in figure F.10 with figure 50 in clause 4.3. Performance of TCH/2,4 over TU5 channel at 430 MHz is worse than the at TU50 by around 10 dB at $10e^{-3}$, while performance of the logical channel over TU50 at 138 MHz is out by 4 dB at $10e^{-3}$. Doppler shift for TU5 at 430 MHz is about 10 times less while Doppler shift at TU50 at 138 MHz is about 3 times less.

Bit Error Rate of TCH/2,4 channel with interleaving over 4 blocks as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.11, compared to the standard plots generated at 430 MHz clause 4.3.

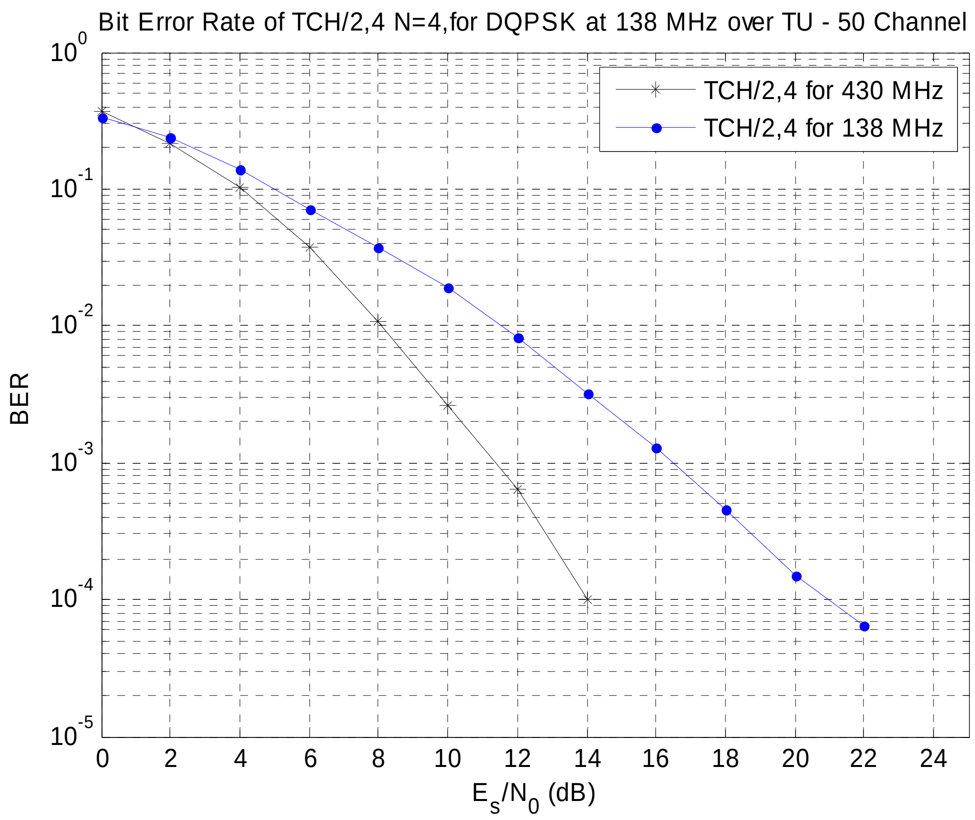

Figure F.11: Bit Error Rate of TCH/2,4 N=4 over TU50 Propagation Channel for 138 MHz

Table F.8: Parameters for figure F.11

Channel Parameters	
Logical Channel	TCH/2,4
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 148/432
Interleaving Length	4
Type-1 bits	144 bits

BER performance of TCH/2,4 with interleaving over 4 blocks for TU50 channel over 138 MHz exhibits a similar performance behaviour as TCH/2,4 N=4 for TU5 over 430 MHz as compared to over TU50. TCH/2,4 is RCPC encoded channel, rate = 148/432 with 144 type-1 bits. Interleaving over 4 blocks improves the system performance, while Doppler over 138 MHz at TU50 channel is spread over 11 timeslots, resulting in loss of performance compare with similar operating environment over 430 MHz. Performance of TCH/2,4 in figure F.11 can be related with figure 56 in clause 4.3. Performance of TCH/2,4 N=4 over TU5 channel at 430 MHz is worse than the at TU50 by around 16 dB at $10e^{-3}$, while performance of the logical channel over TU50 at 138 MHz is out by 5 dB at $10e^{-3}$. Doppler shift for TU5 at 430 MHz is about 10 times less while Doppler shift at TU50 at 138 MHz is about 3 times less.

Bit Error Rate of TCH/2,4 channel with interleaving over 8 blocks as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.12, compared to the standard plots generated at 430 MHz clause 4.3.

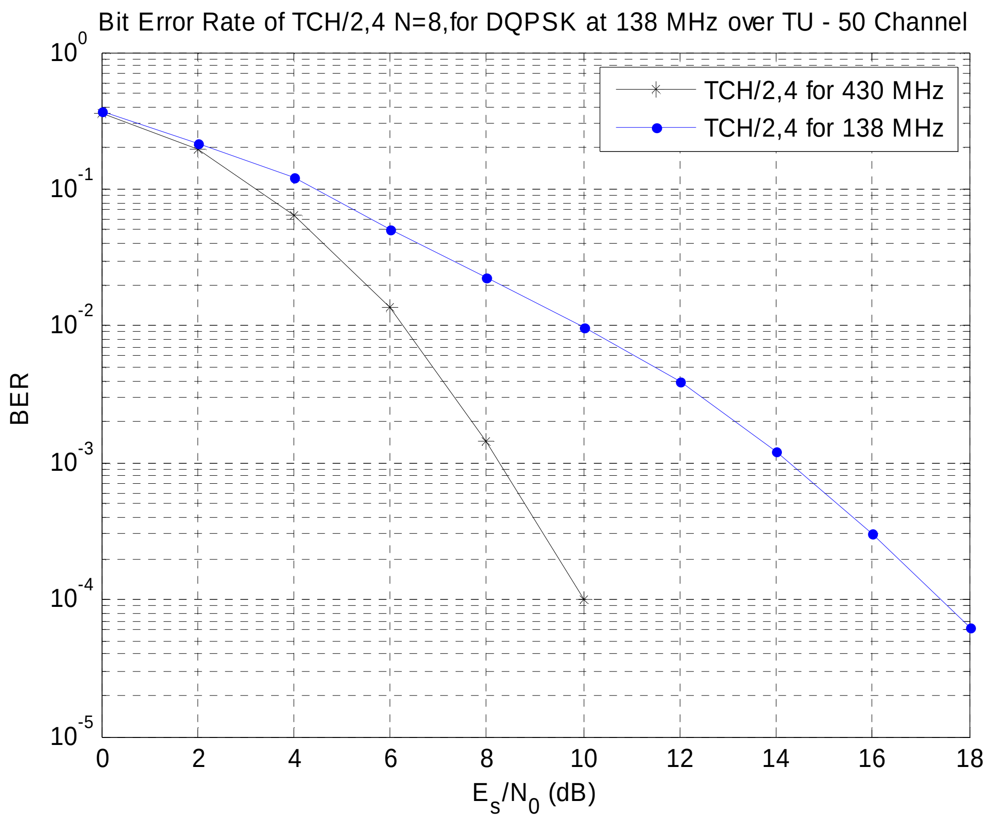

Figure F.12: Bit Error Rate of TCH/2,4 N=8 over TU50 Propagation Channel for 138 MHz

Table F.9: Parameters for figure F.12

Channel Parameters	
Logical Channel	TCH/2,4
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 148/432
Interleaving Length	8
Type-1 bits	144 bits

BER performance of TCH/2,4 with interleaving over 8 blocks for TU50 channel over 138 MHz is reduced by 6 dB at $10e^{-3}$. TCH/2,4 is RCPC encoded channel, rate = 148/432 with 144 type-1 bits. Interleaving over 8 blocks improves the 0system performance, while Doppler shift over 138 MHz at TU50 channel is spread over 11 timeslots, resulting in loss of performance compare with similar operating environment over 430 MHz. Performance of TCH/2,4 in figure F.12 can be related with figure 62 in clause 4.3. Performance of TCH/2,4 N=8 over TU5 channel at 430 MHz is worse than the at TU50 by around 22 dB at $10e^{-3}$, while performance of the logical channel over TU50 at 138 MHz is out by 6 dB at $10e^{-3}$.

Bit Error Rate of TCH/4,8 channel as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.13, compared to the standard plots generated at 430 MHz clause 4.3.

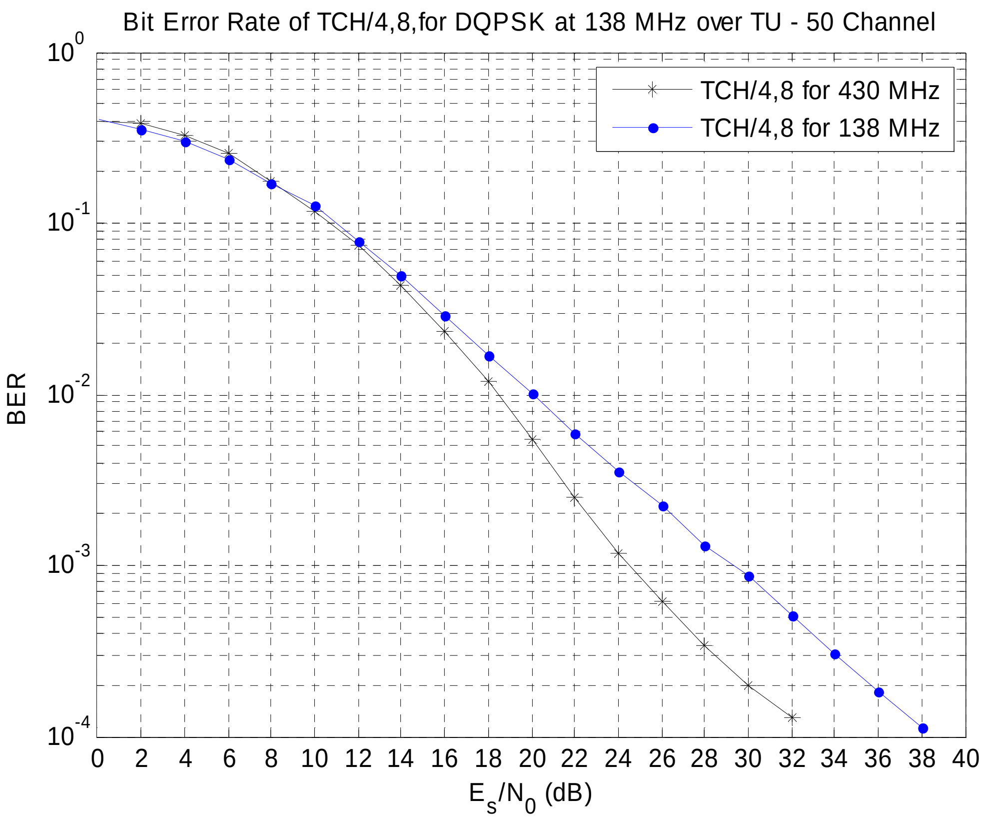

Figure F.13: Bit Error Rate of TCH/4,8 over TU50 Propagation Channel for 138 MHz

Table F.10: Parameters for figure F.13

Channel Parameters	
Logical Channel	TCH/4,8
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 292/432
Type-1 bits	288 bits

BER performance of TCH/4,8 for TU50 channel over 138 MHz exhibits a similar performance behaviour as TCH/4,8 for TU5 over 430 MHz as compared to over TU50. TCH/4,8 is RCPC encoded channel, rate = 292/432 with 288 type-1 bits. Relating the performance of TCH/2,4 in figure F.13 with figure 32 in clause 4.3. Performance of TCH/4,8 over TU5 channel at 430 MHz is worse than the at TU50 by around 7 dB at $10e^{-3}$, while performance of the logical channel over TU50 at 138 MHz is out by 5 dB at $10e^{-3}$. Doppler shift for TU5 at 430 MHz is about 10 times less while Doppler shift at TU50 at 138 MHz is about 3 times less.

Bit Error Rate of TCH/4,8 channel with interleaving over 4 blocks as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.14, compared to the standard plots generated at 430 MHz clause 4.3.

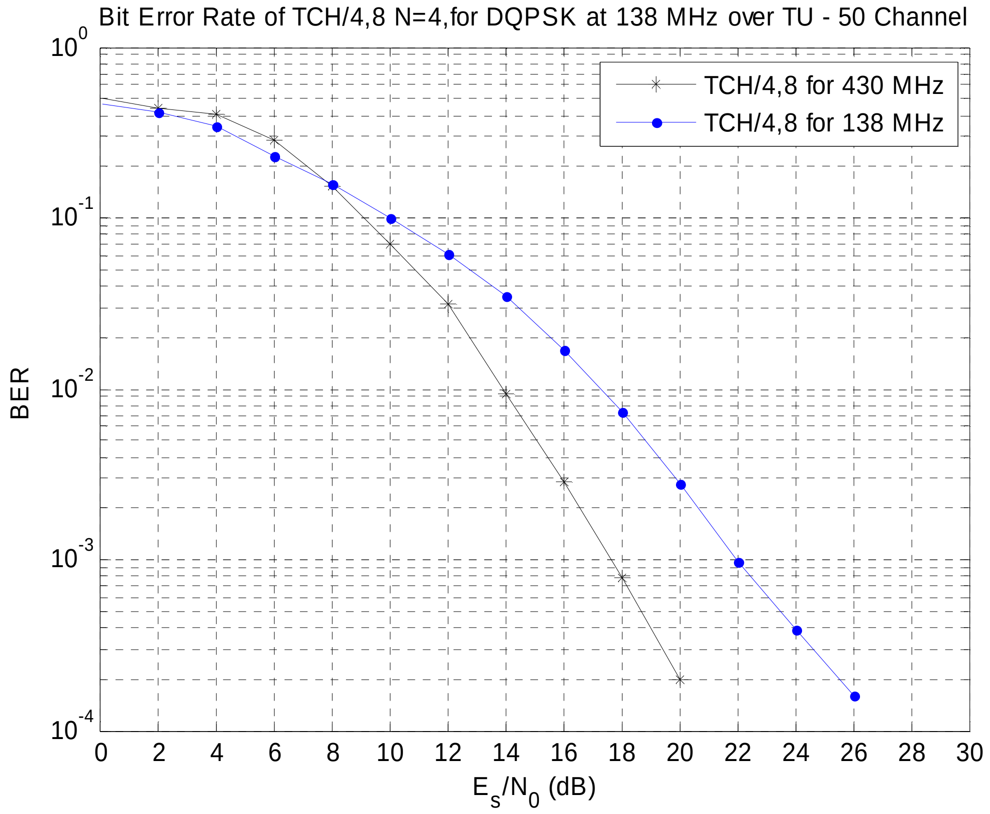

Figure F.14: Bit Error Rate of TCH/4,8 N=4 over TU50 Propagation Channel for 138 MHz

Table F.11: Parameters for figure F.14

Channel Parameters	
Logical Channel	TCH/2,4
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 292/432
Interleaving Length	4
Type-1 bits	288 bits

BER performance of TCH/4,8 with interleaving over 4 blocks for TU50 channel over 138 MHz is 4 to 5 dB worse at $10e^{-3}$ as compare to the performance at TU50 channel over 430 MHz. TCH/4,8 is RCPC encoded channel, rate = 292/432 with 288 type-1 bits. Interleaving over 4 blocks improves the system performance, while Doppler over 138 MHz at TU50 channel is spread over 11 timeslots, resulting in loss of performance compare with similar operating environment over 430 MHz. Performance of TCH/4,8 in figure F.14 can be related with figure 38 in clause 4.3. Performance of TCH/4,8 N=4 over TU5 channel at 430 MHz is worse than the at TU50 by around 12 dB at $10e^{-3}$. Doppler shift for TU5 at 430 MHz is about 10 times less while Doppler shift at TU50 at 138 MHz is about 3 times less.

Bit Error Rate of TCH/4,8 channel with interleaving over 8 blocks as function of E_s/N_0 in TU50 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.15, compared to the standard plots generated at 430 MHz clause 4.3.

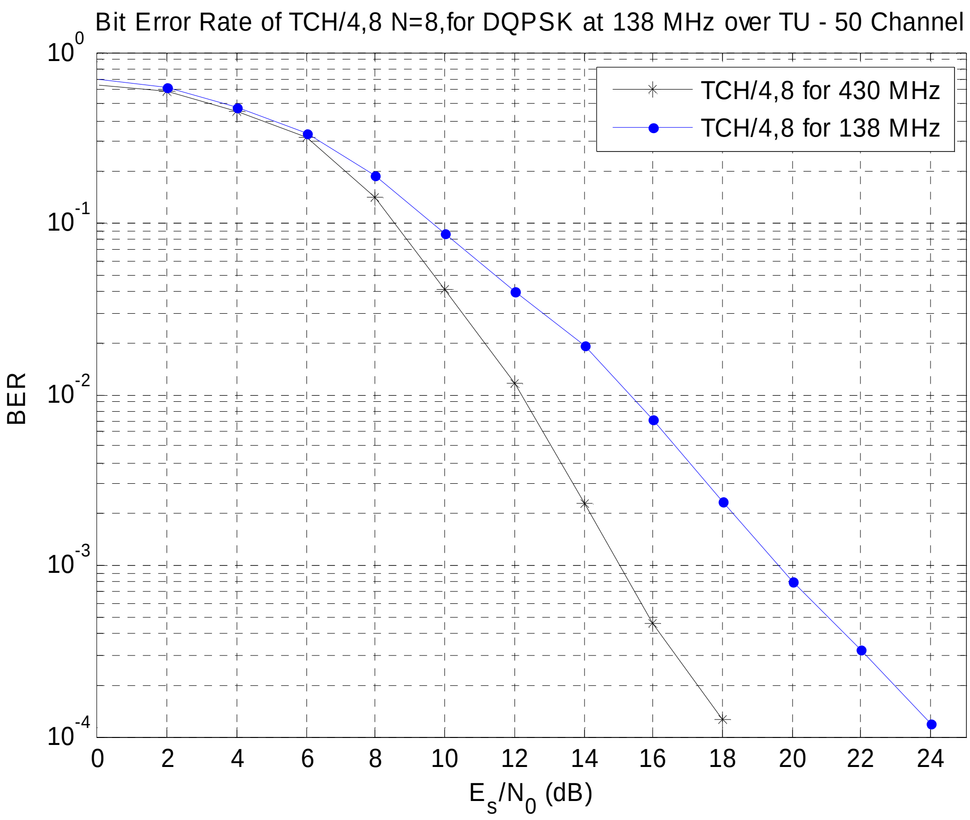

Figure F.15: Bit Error Rate of TCH/4,8 N=8 over TU50 Propagation Channel for 138 MHz

Table F.12: Parameters for figure F.15

Channel Parameters	
Logical Channel	TCH/2,4
Propagation Channel	TU50
Doppler Shift	6,38
Channel Encoding	RCPC code with rate 292/432
Interleaving Length	8
Type-1 bits	288 bits

BER performance of TCH/4,8 with interleaving over 8 blocks for TU50 channel over 138 MHz is 4 to 5 dB worse at $10e^{-3}$ as compare to the performance at TU50 channel over 430 MHz. TCH/4,8 is RCPC encoded channel, rate = 292/432 with 288 type-1 bits. Interleaving over 8 blocks improves the system performance, while Doppler over 138 MHz at TU50 channel is spread over 11 timeslots, resulting in loss of performance compare with similar operating environment over 430 MHz. Performance of TCH/4,8 in figure F.15 can be related with figure 44 in clause 4.3. Performance of TCH/4,8 N=4 over TU5 channel at 430 MHz is worse than the at TU50 by around 14 dB at $10e^{-3}$. Doppler shift for TU5 at 430 MHz is about 10 times less while Doppler shift at TU50 at 138 MHz is about 3 times less.

F.2.3 Simulator at 138 MHz for HT200 Channel against clause 4.3

Message Error Rate of AACH channel as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.16, compared to the standard plots at 430 MHz as in clause 4.3.

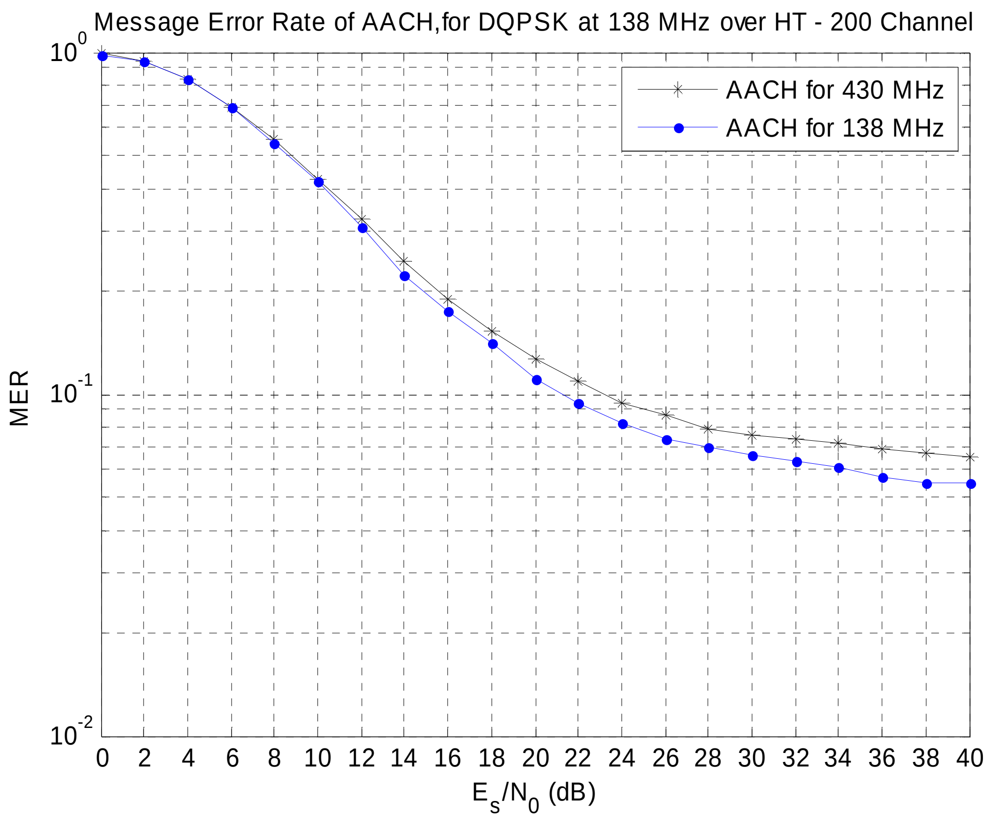

Figure F.16: Message Error Rate of AACH over HT200 Propagation Channel for 138 MHz

Table F.13: Parameters for figure F.16

Channel Parameters	
Logical Channel	AACH
Propagation Channel	TU200
Doppler Shift	25,55
Channel Encoding	14/30 Reed - Muller code
Type-1 bits	14 bits

AACH is Reed Muller encoded channel with only 14 type-1 bits. Relating the performance of AACH in figure F.16 with figure 6 in clause 4.3. Performance of AACH over TU50 channel at 430 MHz and presented performance of AACH over HT200 channel at 138 MHz shows a similar performance characteristics. Doppler shift for HT50 at 430 MHz and for HT200 at 138 MHz is less than Doppler for HT200 at 430 MHz.

Message Error Rate of BSCH channel as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.17, compared to the standard plots at 430 MHz as in clause 4.3.

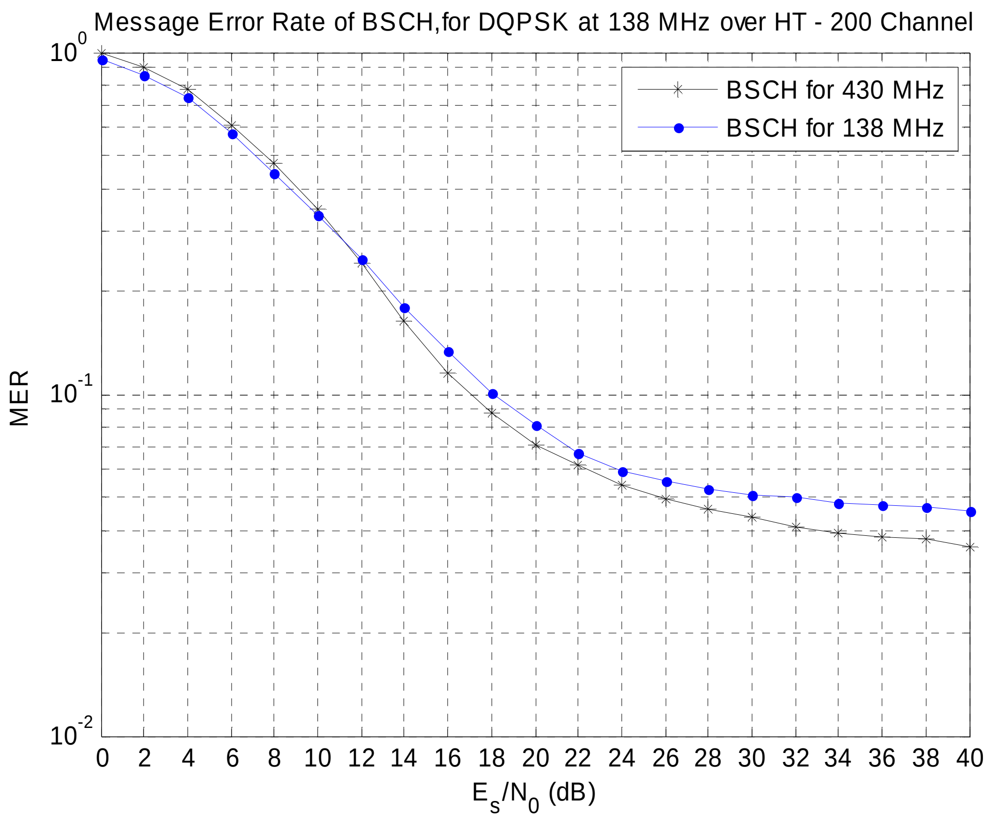

Figure F.17: Message Error Rate of BSCH over HT200 Propagation Channel for 138 MHz

Table F.14: Parameters for figure F.17

Channel Parameters	
Logical Channel	BSCH
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 2/3
Type-1 bits	60 bits

BSCH is design on RCPC encoder, rate = 2/3 with 60 type-1 bits. Performance of BSCH over HT50 channel at 430 MHz and presented performance of BSCH over HT200 channel at 138 MHz can be related in figure F.17 and figure 24 in clause 4.3. Doppler shift for HT50 at 430 MHz and for HT200 at 138 MHz are less than the Doppler for HT200 at 430 MHz.

Message Error Rate of SCH/F channel as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.18, compared to the standard plots at 430 MHz as in clause 4.3.

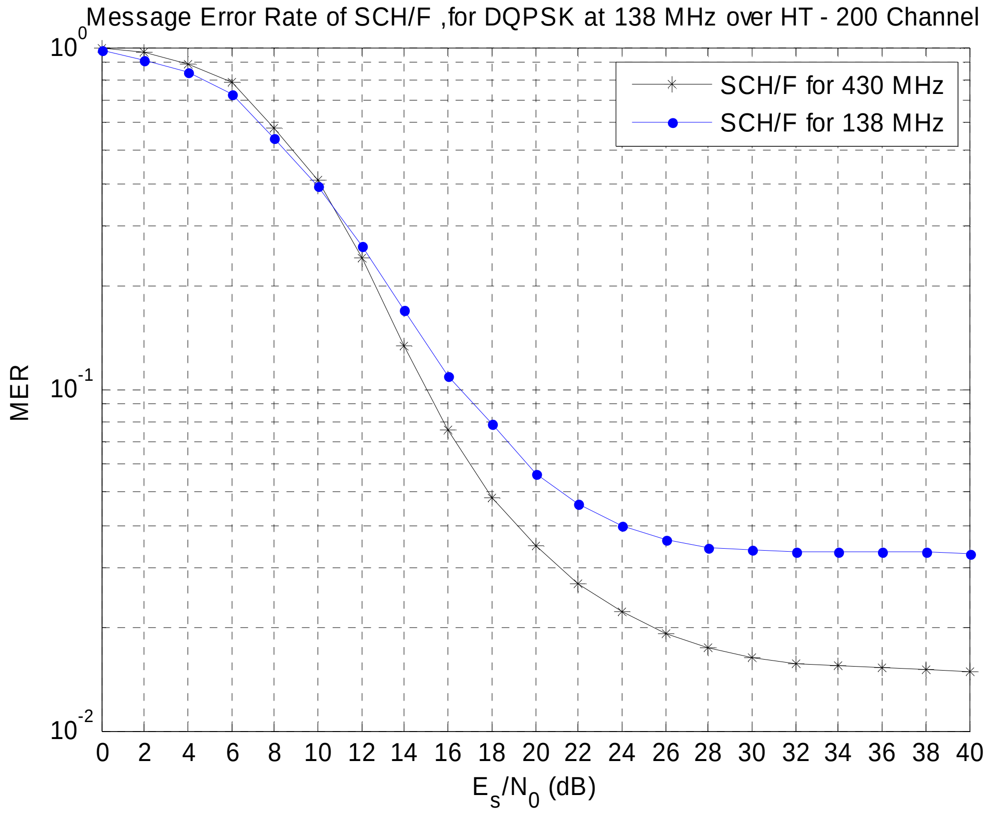

Figure F.18: Message Error Rate of SCH/F over HT200 Propagation Channel for 138 MHz

Table F.15: Parameters for figure F.18

Channel Parameters	
Logical Channel	SCH/F
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 2/3
Type-1 bits	268 bits

SCH/F is design as RCPC encoded, rate = 2/3 with 268 type-1 bits. Relating the performance of SCH/F in figure F.18 with figure 18 in clause 4.3. Performance of SCH/F over HT50 channel at 430 MHz is worst due to less Doppler shift which resultantly effects more slots, resultantly MER. Similarly performance of SCH/F over HT200 channel at 138 MHz can be related with other HT channels in figure F.18 and figure 18 in clause 4.3.

Message Error Rate of SCH/HU channel as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.19, compared to the standard plots at 430 MHz as in clause 4.3.

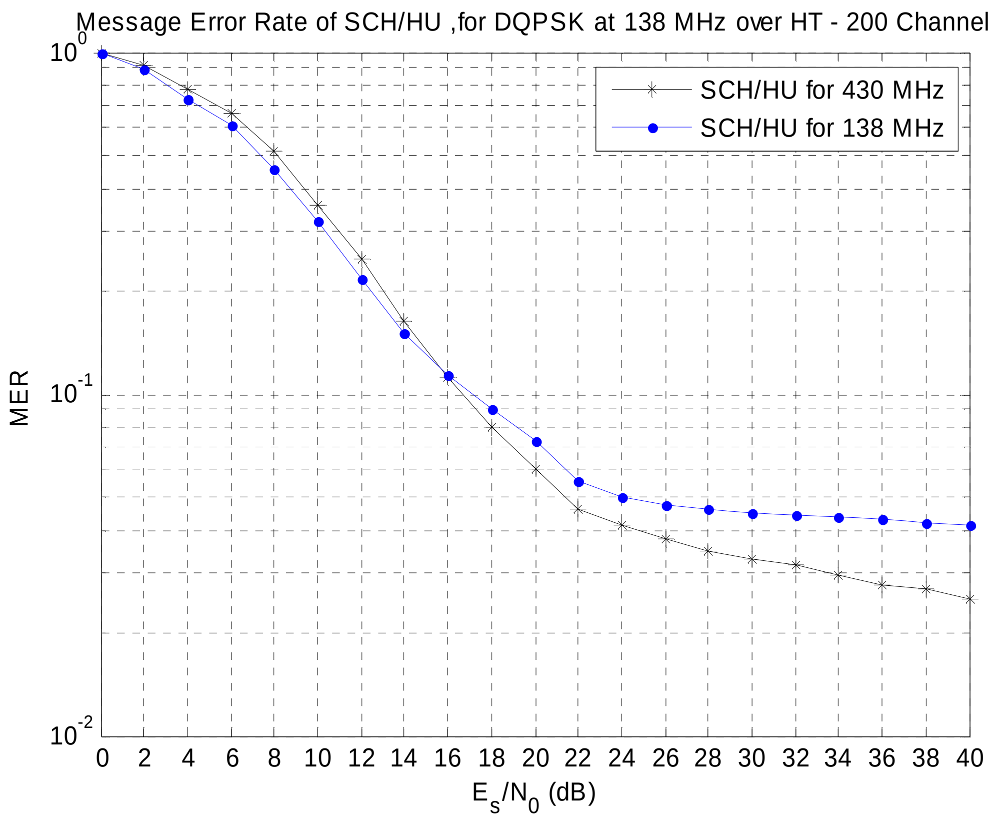

Figure F.19: Message Error Rate of SCH/HU over HT200 Propagation Channel for 138 MHz

Table F.16: Parameters for figure F.19

Channel Parameters	
Logical Channel	SCH/HU
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 2/3
Type-1 bits	92 bits

SCH/HU logical channel is design as RCPC encoded, rate = 2/3 with 92 type-1 bits. Performance of SCH/HU over HT200 at 138 MHz is worse than the performance at 430 MHz. Performance of SCH/HU over HT50 channel at 430 MHz in figure 12 in clause 4.3 is worst due to less Doppler shift which resultantly effects more slots, resultantly MER. Similarly performance of SCH/HU over HT50 channel at 138 MHz can be related in figure F.19 and figure 12 in clause 4.3.

Bit Error Rate of TCH/7,2 channel as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.20, compared to the standard plots at 430 MHz as in clause 4.3.

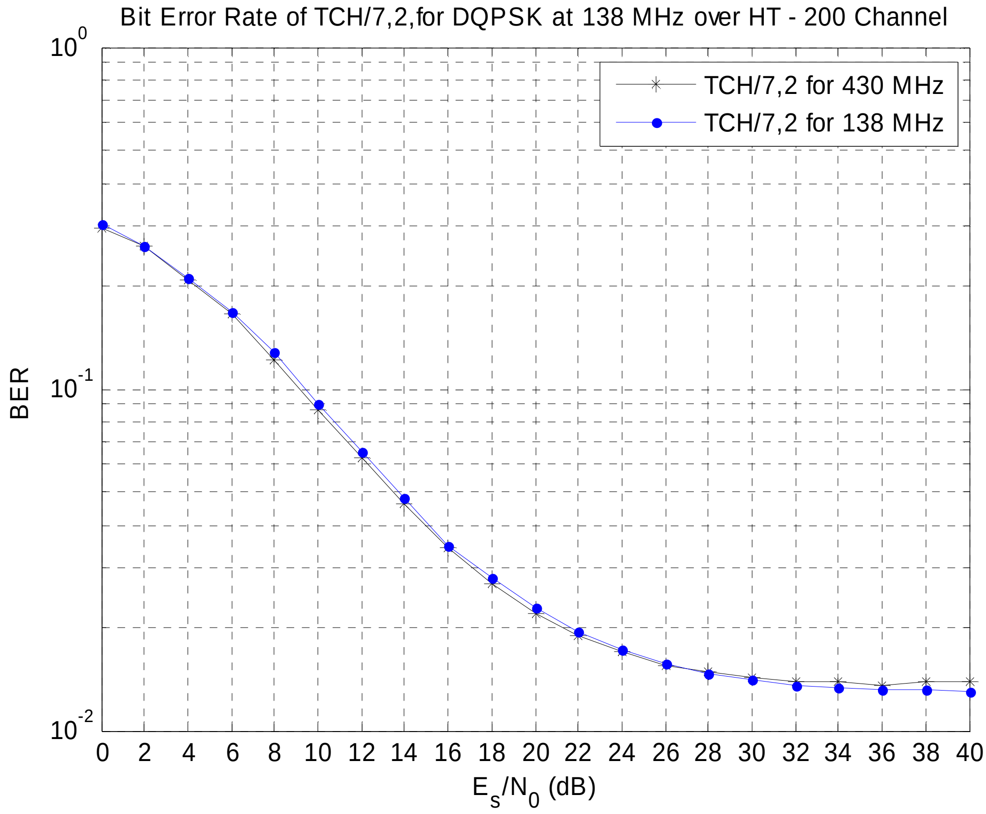

Figure F.20: Bit Error Rate of TCH/7,2 over HT200 Propagation Channel for 138 MHz

Table F.17: Parameters for figure F.20

Channel Parameters	
Logical Channel	TCH
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	Un-coded channel
Type-1 bits	432 bits

BER performance of TCH/7,2 for HT200 channel over 138 MHz exhibits a similar performance behaviour as TCH/7,2 for TU50 over 138 MHz. There is slight improvement in the performance of the system. TCH/7,2 is un-coded channel with 432 type-1 bits. We can observe the performance of TCH/7,2 logical channel over HT propagation channel in figure 29. Performance of TCH/7,2 over HT200 channel at 138 MHz is performing slightly better in terms of BER due to reduced Doppler shift over un-coded channel.

Bit Error Rate of TCH/2,4 channel as function of E_s/N_0 in HT - 200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.21, compared to the standard plots at 430 MHz as in clause 4.3.

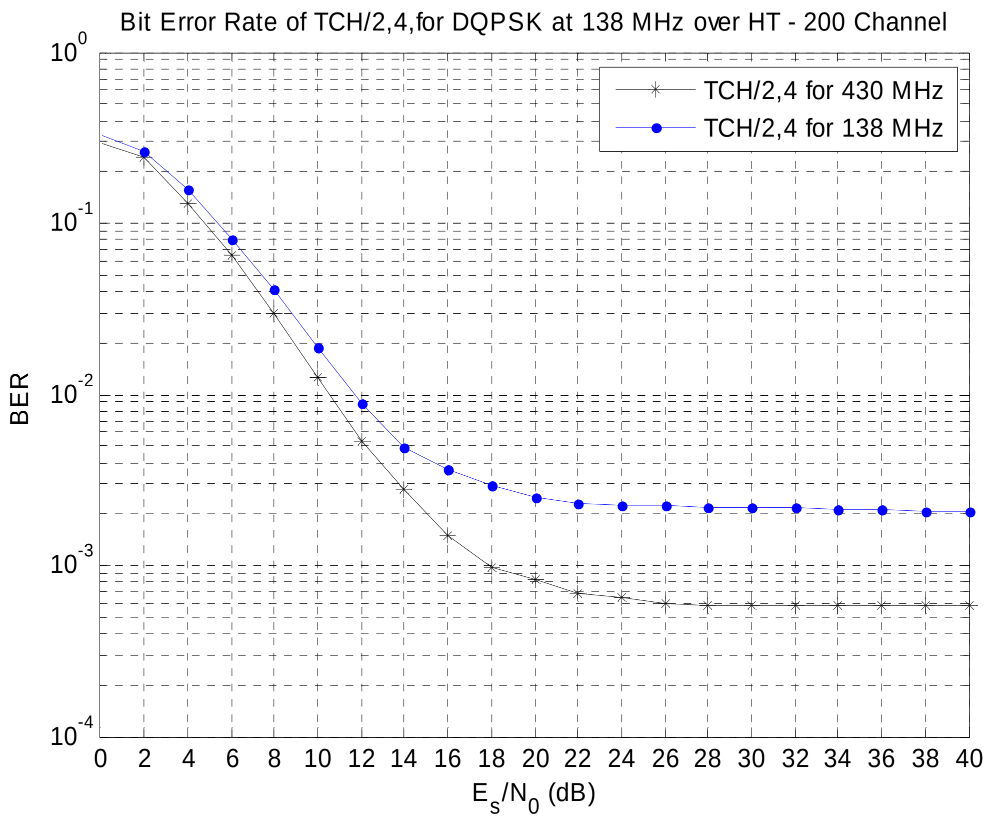

Figure F.21: Bit Error Rate of TCH/2,4 over HT200 Propagation Channel for 138 MHz

Table F.18: Parameters for figure F.21

Channel Parameters	
Logical Channel	TCH/2,4
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 148/432
Type-1 bits	144 bits

BER performance of TCH/2,4 for HT200 channel over 138 MHz exhibits a similar performance behaviour as TCH/2,4 for HT50 over 430 MHz. TCH/2,4 is RCPC encoded channel, rate = 148/432 with 144 type-1 bits. Relating the performance of TCH/2,4 in figure F.21 with figure 53 in clause 4.3. Performance of TCH/2,4 over HT50 channel at 430 MHz is worse than the at HT200 and have a above the $10e^{-3}$, while performance of the logical channel over HT200 at 138 MHz have an error floor above $10e^{-3}$ with reduced Doppler. Reason for which is reduce Doppler effects more slots resultantly MER.

Bit Error Rate of TCH/2,4 channel with interleaving over 4 blocks as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.22, compared to the standard plots at 430 MHz as in clause 4.3.

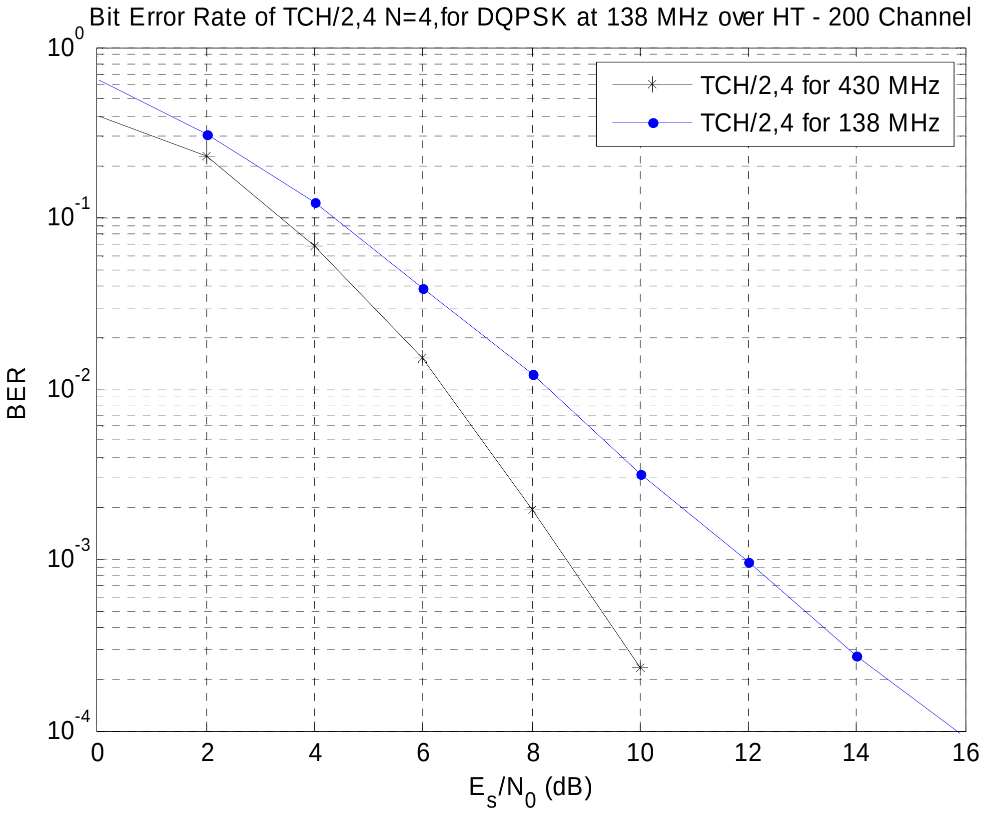

Figure F.22: Bit Error Rate of TCH/2,4 N=4 over HT200 Propagation Channel for 138 MHz

Table F.19: Parameters for figure F.22

Channel Parameters	
Logical Channel	TCH/2,4
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 148/432
Interleaving Length	4
Type-1 bits	144 bits

BER performance of TCH/2,4 with interleaving over 4 blocks for HT200 channel over 138 MHz is shown in figure F.22. TCH/2,4 is RCPC encoded channel, rate = 148/432 with 144 type-1 bits. Interleaving over 4 blocks improves the system performance, while Doppler over 138 MHz at HT200 channel is spread over 3 timeslots, resulting in loss of performance compare with similar operating environment over 430 MHz. Performance of TCH/2,4 in figure F.22 can be related with figure 59 in clause 4.3 with other HT channel at 430 MHz.

Bit Error Rate of TCH/2,4 channel with interleaving over 8 blocks as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.23, compared to the standard plots at 430 MHz as in clause 4.3.

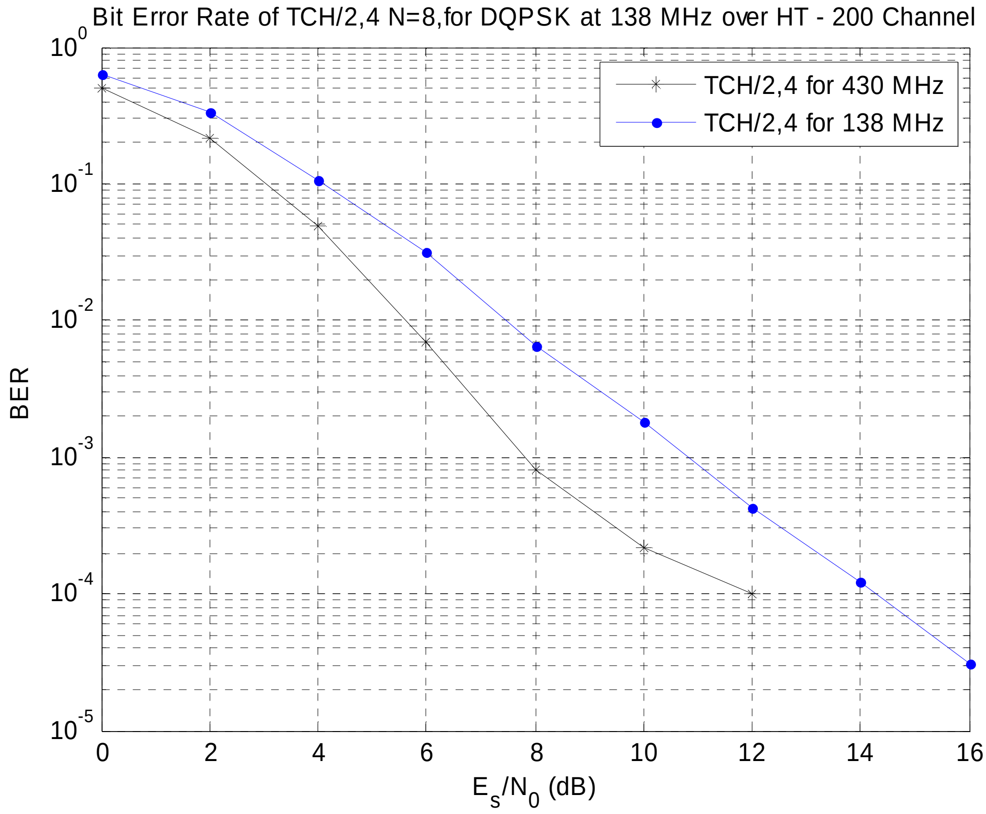

Figure F.23: Bit Error Rate of TCH/2,4 N=8 over HT200 Propagation Channel for 138 MHz

Table F.20: Parameters for figure F.23

Channel Parameters	
Logical Channel	TCH/2,4
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 148/432
Interleaving Length	8
Type-1 bits	144 bits

BER performance of TCH/2,4 with interleaving over 8 blocks for HT200 channel over 138 MHz is worse by 2 dB at 10e-4. TCH/2,4 is RCPC encoded channel, rate = 148/432 with 144 type-1 bits. Interleaving over 8 blocks improves the system performance, while Doppler shift over 138 MHz at HT200 channel is spread over 3 timeslots, resulting in loss of performance compare with similar operating environment over 430 MHz. Performance of TCH/2,4 in figure F.23 can be related with figure 65 in clause 4.3.

Bit Error Rate of TCH/4,8 channel as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.24, compared to the standard plots at 430 MHz as in clause 4.3.

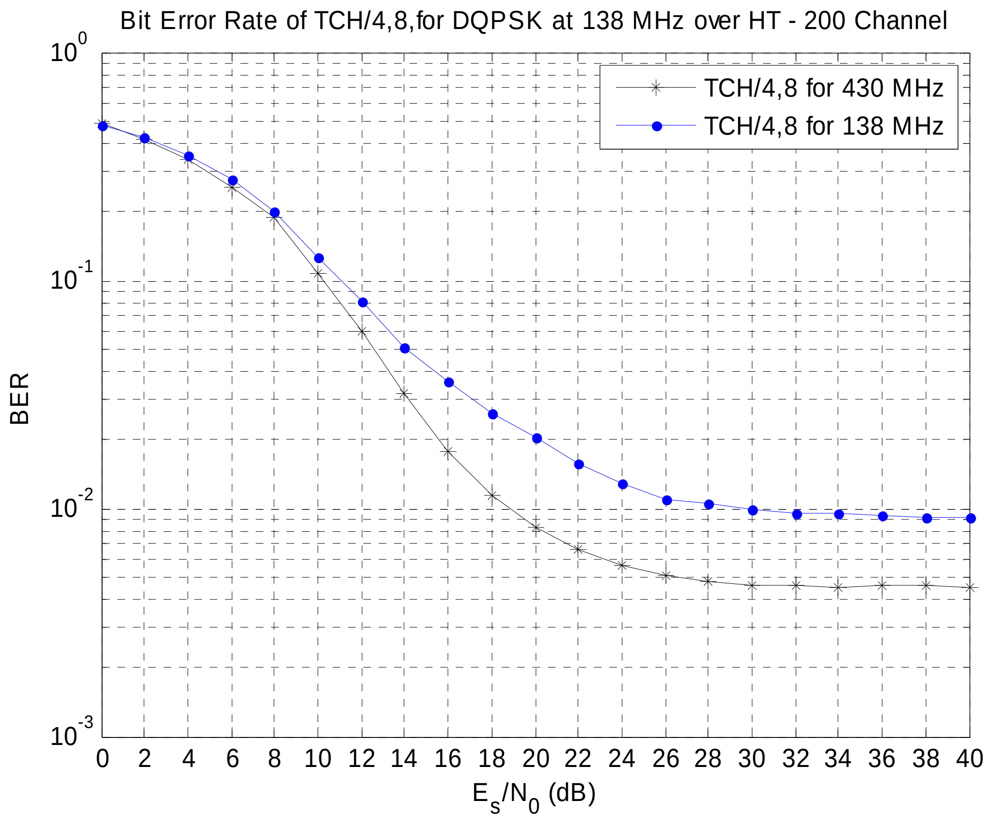

Figure F.24: Bit Error Rate of TCH/4,8 over HT200 Propagation Channel for 138 MHz

Table F.21: Parameters for figure F.24

Channel Parameters	
Logical Channel	TCH/4,8
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 292/432
Type-1 bits	288 bits

BER performance of TCH/4,8 for HT200 channel over 138 MHz exhibits a similar performance behaviour as TCH/4,8 for HT50 over 430 MHz. TCH/4,8 is RCPC encoded channel, rate = 292/432 with 288 type-1 bits. Relating the performance of TCH/2,4 in figure F.24 with figure 35 in clause 4.3. Performance of TCH/4,8 over HT200 channel at 138 MHz is worse than the at HT200 at 430 MHz.

Bit Error Rate of TCH/4,8 channel with interleaving over 4 blocks as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.25, compared to the standard plots at 430 MHz as in clause 4.3.

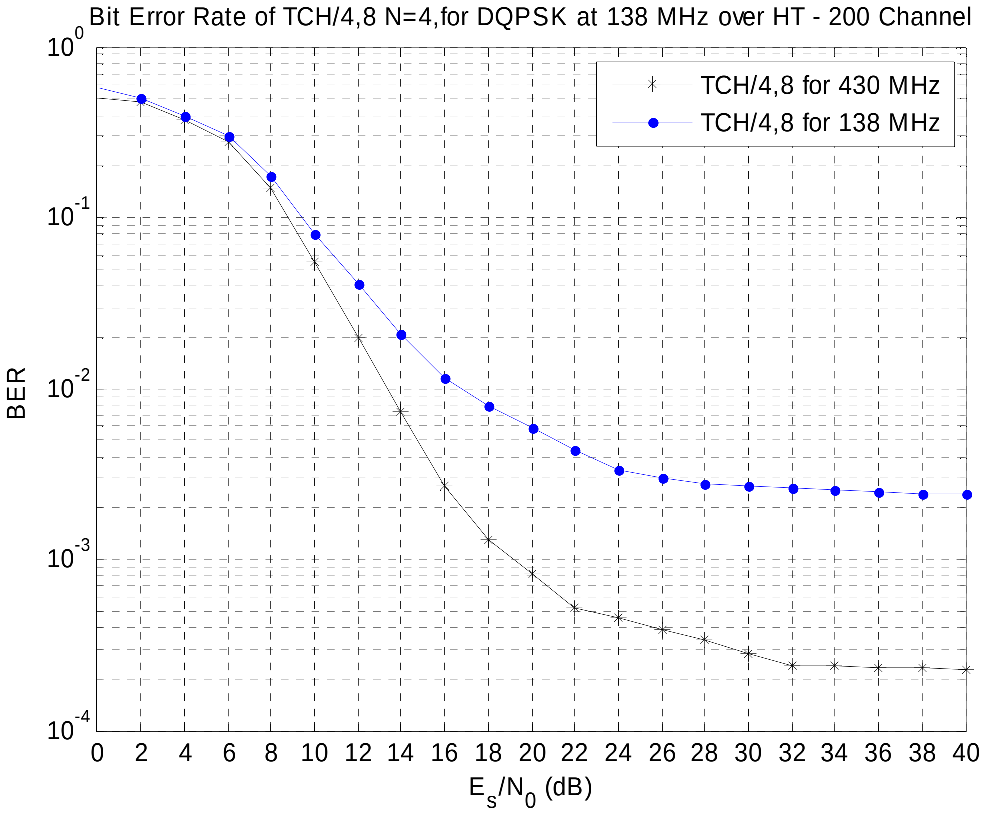

Figure F.25: Bit Error Rate of TCH/4,8 N=4 over HT200 Propagation Channel for 138 MHz

Table F.22: Parameters for figure F.25

Channel Parameters	
Logical Channel	TCH/4,8
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 292/432
Interleaving Length	4
Type-1 bits	288 bits

BER performance of TCH/4,8 with interleaving over 4 blocks for HT200 channel over 138 MHz is presented in figure F.25 against the performance at HT200 channel over 430 MHz. TCH/4,8 is RCPC encoded channel, rate = 292/432 with 288 type-1 bits. Interleaving over 4 blocks improves the system performance, while Doppler over 138 MHz at HT200 channel is spread over 3 timeslots, resulting in loss of performance compare with similar operating environment over 430 MHz. Performance of TCH/4,8 in figure F.25 can be related with figure 41 in clause 4.3.

Bit Error Rate of TCH/4,8 channel with interleaving over 8 blocks as function of E_s/N_0 in HT200 propagation environments with ideal synchronization technique over 138 MHz is shown in figure F.26, compared to the standard plots at 430 MHz as in clause 4.3.

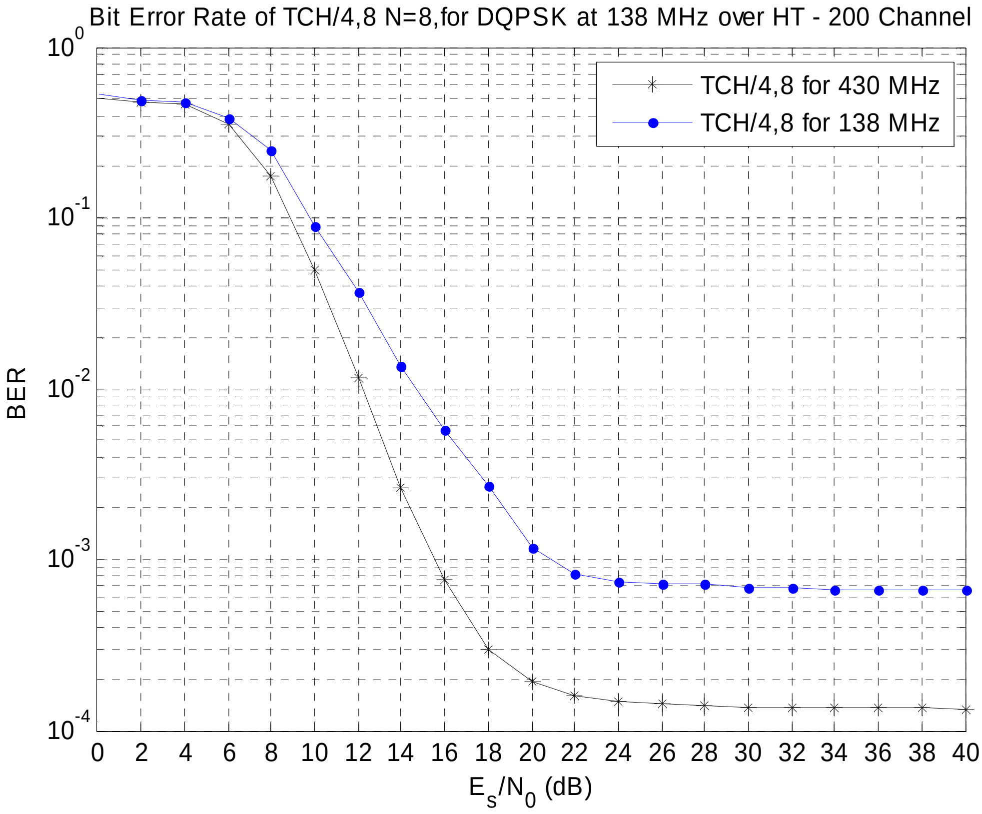

Figure F.26: Bit Error Rate of TCH/4,8 N=8 over HT200 Propagation Channel for 138 MHz

Table F.23: Parameters for figure F.26

Channel Parameters	
Logical Channel	TCH/4,8
Propagation Channel	HT200
Doppler Shift	25,55
Channel Encoding	RCPC code with rate 292/432
Interleaving Length	8
Type-1 bits	288 bits

BER performance of TCH/4,8 with interleaving over 8 blocks for HT200 channel over 138 MHz have error floor below $10e^{-3}$. TCH/4,8 is RCPC encoded channel, rate = 292/432 with 288 type-1 bits. Interleaving over 8 blocks improves the system performance, while Doppler over 138 MHz at HT200 channel is spread over 3 timeslots, resulting in loss of performance compare with similar operating environment over 430 MHz. Performance of TCH/4,8 in figure F.26 can be related with figure 47 in clause 4.3.

Annex G: Simulator validation

G.1 Introduction

This annex shows the results of the simulation to validate the performance of the simulator at 430 MHz. Validation of performance of TETRA with regard to π/4-DQPSK modulation at 430 MHz is done to establish a test bed for 138 MHz simulations. The present TETRA standard EN 300 392-2 [i.2] addresses the frequencies between 300 MHz to 1 GHz. EN 300 392-2 [i.2] illustrates the TETRA Protocol stack design and the clause 4 of the present document presents the simulation results for π/4-DQPSK at 400 MHz. Standard refers the simulation at 400 MHz frequency while the actually value of the Doppler shift is calculated based on 430 MHz frequency, for this reason we will refer all the standard simulation presented in EN 300 392-2 [i.2] and in the clause 4 as at 430 MHz. This annex presents the results for the verification simulation environment for π/4-DQPSK for TETRA at 430 MHz, while annex F presents the results at 138 MHz. Results presented in both the annexes follow the same protocol stack design as explained by EN 300 392-2 [i.2].

G.2 System Design

Transmission design characteristic for simulation results presented in the present document are based on the parameters discussed in EN 300 392-2 [i.2] where as receiver design characteristics are based on the transmission parameters and general system outline given in clause 4.3 of EN 300 392-2 [i.2]. Error control coding for logical channels based on Rate-Compatible Punctured Convolutional Codes (RCPC) and Reed-Muller codes (RM) are based on the clause 8.2 of EN 300 392-2 [i.2], while error control flow of logical channel is based on the figures in clause 8.3.1 of EN 300 392-2 [i.2]. Simulation system environment is based on the outline discussed in clause 4.2 of EN 300 392-2 [i.2]. Channel model and characteristics is based on the clause 6.6.3 of EN 300 392-2 [i.2]. Over all system for simulation of logical channels is given below in figure G.1. Modulation symbol and filter definition is based on the clause 5 of EN 300 392-2 [i.2].

Burst structure and burst format for "Normal Downlink Burst", "Normal Continuous Down-link Burst", "Synchronization Continuous Down-link Burst" and "Control Up-link Burst" for respective logical channels. Logical channels simulated are AACH, BSCH, SCH/F, SCH/HU, TCH/7,2, TCH/4,8 and TCH/2,4 for 430 MHz and 138 MHz Summary of logical channels is given in table G.1. TCH /4,8 and TCH/2,4 are also simulated with 2 special cases for each. In TCH/2,4 and TCH/4,8 N=4 case interleaving is carried over the 4 blocks n than within the block while In TCH/2,4 and TCH/4,8 N=8 case interleaving is carried over the 8 blocks and also within the block based on the description given in clause 8.2.4 in EN 300 392-2 [i.2].

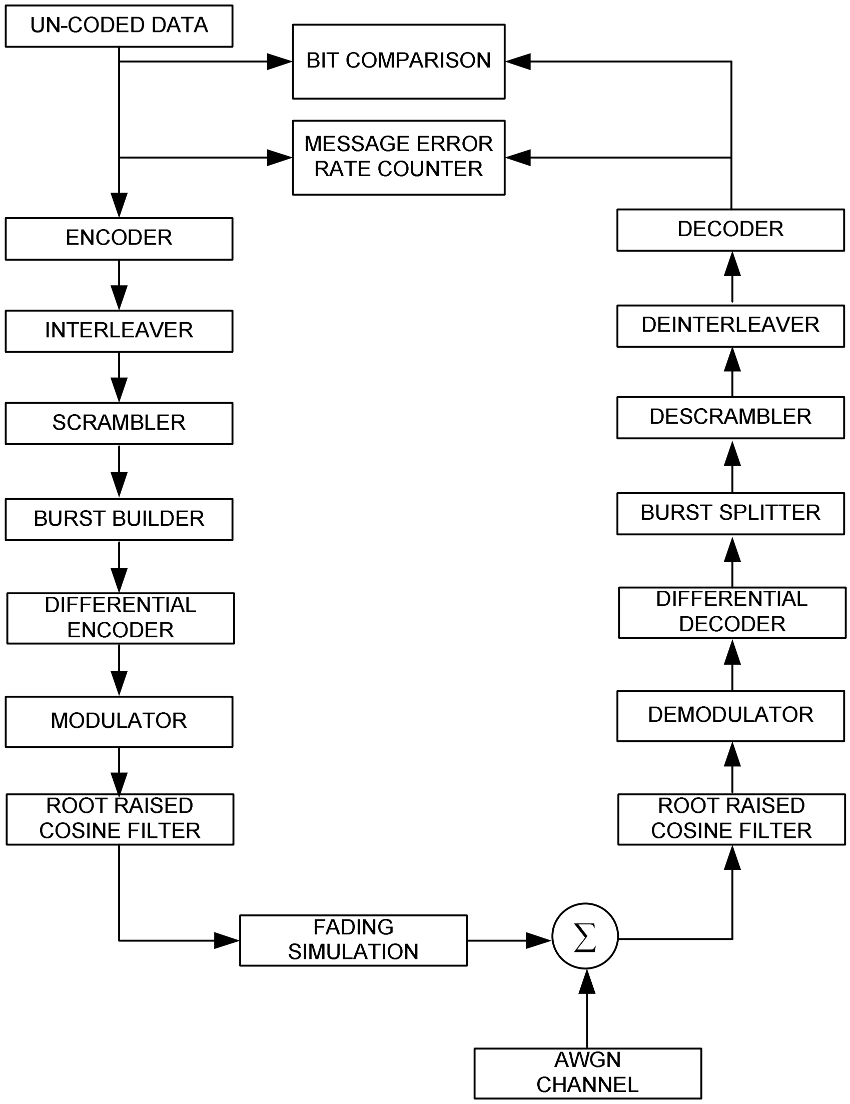

Figure G.1: Simulation System Design

G.3 Simulation Results

G.3.1 Simulation plan

The following figures are simulation results based on the simulation model discussed in clause G.2. Logical channel specifications are based on the EN 300 392-2 [i.2] clauses 8 and 9.

Clause 4.3 is referred for the evaluation and comparison of simulated results for 430 MHz frequency for the respective channels, also by confirming the simulations matches with the standard result.

Comparison of simulated results with the standard results as presented in clause 4.3 are based on the simulation set-up guidelines discussed in clause 4.2, However introduction of different filter parameters like filter order, higher sampling rate or any other technique at receiver may impact the simulation results slightly. Doppler shift for TU50 channel for 430 MHz frequency is 20 Hz as specified in clause 6.8.3 of EN 300 392-2 [i.2]. While Doppler shift for 138 MHz is calculated 6,38 Hz for TU50 channel. Doppler shift for HT200 channel is 80 Hz for 430 MHz and 25,6 Hz for 138 MHz. Simulation parameters and receiver characteristics are configured based on the recommendation in the clause 4.2 while implementation for specific logical channels are based on the clause 8 of EN 300 392-2 [i.2].

This annex presents the 430 MHz results for conditions listed in table G.1. The 138 MHz result are presented in annex F.

Table G.1: Summary of simulation plan along with simulation parameters

No.	Parameters	Logical Channel	Doppler Shift	Results	Remarks
1	430 MHz, TU50	TCH/7,2	20	BER	Done
2		TCH/4,8 N=1	20	BER	Done
3		TCH/4,8 N=4	20	BER	Done
4		TCH/4,8 N=8	20	BER	Done
5		TCH/2,4	20	BER	Done
6		TCH/2,4 N=4	20	BER	Done
7		TCH/2,4 N=8	20	BER	Done
8		SCH/F	20	MER	Done
9		SCH/HU	20	MER	Done
10		STCH	20	MER	Done
11		AACH	20	MER	Done
12		BSCH	20	MER	Done
13	430 MHz, HT200	TCH/7,2	80	BER	Done
14		TCH/4,8 N=1	80	BER	Done
15		TCH/4,8 N=4	80	BER	Done
16		TCH/4,8 N=8	80	BER	Done
17		TCH/2,4	80	BER	Done
18		TCH/2,4 N=4	80	BER	Done
19		TCH/2,4 N=8	80	BER	Done
20		SCH/F	80	MER	Done
21		SCH/HU	80	MER	Done
22		STCH	80	MER	Done
23		AACH	80	MER	Done
24		BSCH	80	MER	Done
25	138 MHz, TU50	TCH/7,2	6,38	BER	Done
26		TCH/4,8 N=1	6,38	BER	Done
27		TCH/4,8 N=4	6,38	BER	Done
28		TCH/4,8 N=8	6,38	BER	Done
29		TCH/2,4	6,38	BER	Done
30		TCH/2,4 N=4	6,38	BER	Done
31		TCH/2,4 N=8	6,38	BER	Done
32		SCH/F	6,38	MER	Done
33		SCH/HU	6,38	MER	Done
34		STCH	6,38	MER	Done
35		AACH	6,38	MER	Done
36		BSCH	6,38	MER	Done
37	138 MHz, HT200	TCH/7,2	25,55	BER	Done
38		TCH/4,8 N=1	25,55	BER	Done
39		TCH/4,8 N=4	25,55	BER	Done
40		TCH/4,8 N=8	25,55	BER	Done
41		TCH/2,4	25,55	BER	Done
42		TCH/2,4 N=4	25,55	BER	Done
43		TCH/2,4 N=8	25,55	BER	Done
44		SCH/F	25,55	MER	Done
45		SCH/HU	25,55	MER	Done
46		STCH	25,55	MER	Done
47		AACH	25,55	MER	Done
48		BSCH	25,55	MER	Done

Performance characteristics given as message error rate (MER) for AACH, BSCH, SCH/F and SCH/HU logical channel while BER plots for TCH/7,2, TCH/2,4, TCH/2,4 N=4, TCH/2,4 N=8, TCH/4,8, TCH/4,8 N=4, TCH/4,8 N=8 logical channels over TU50 and HT200 propagation environments.

G.3.2 Validation of the simulator against clause 4.3 for TU channel

MER of AACH channel as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.2, compared to those of clause 4.3.

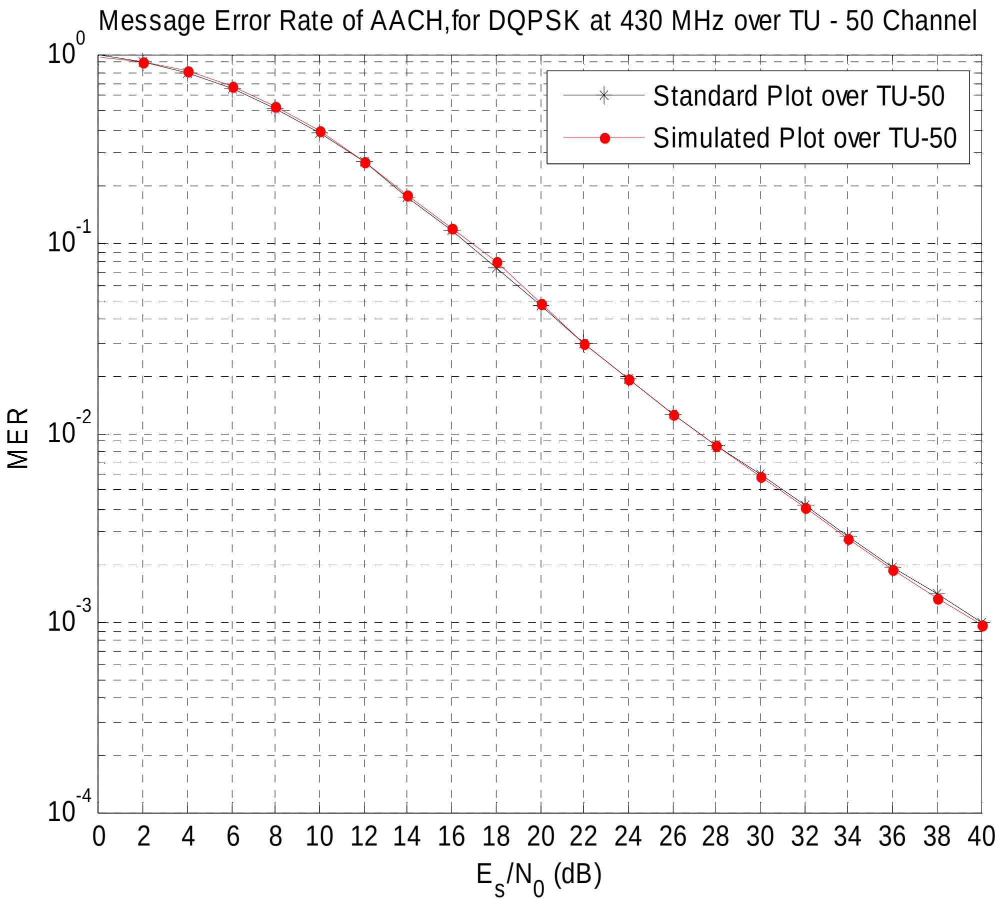

Figure G.2: Message Error Rate of AACH over TU-50 propagation channel for 430 MHz, results corresponds to figure 3 of clause 4.3

MER of BSCH channel as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.3, compared to those of clause 4.3.

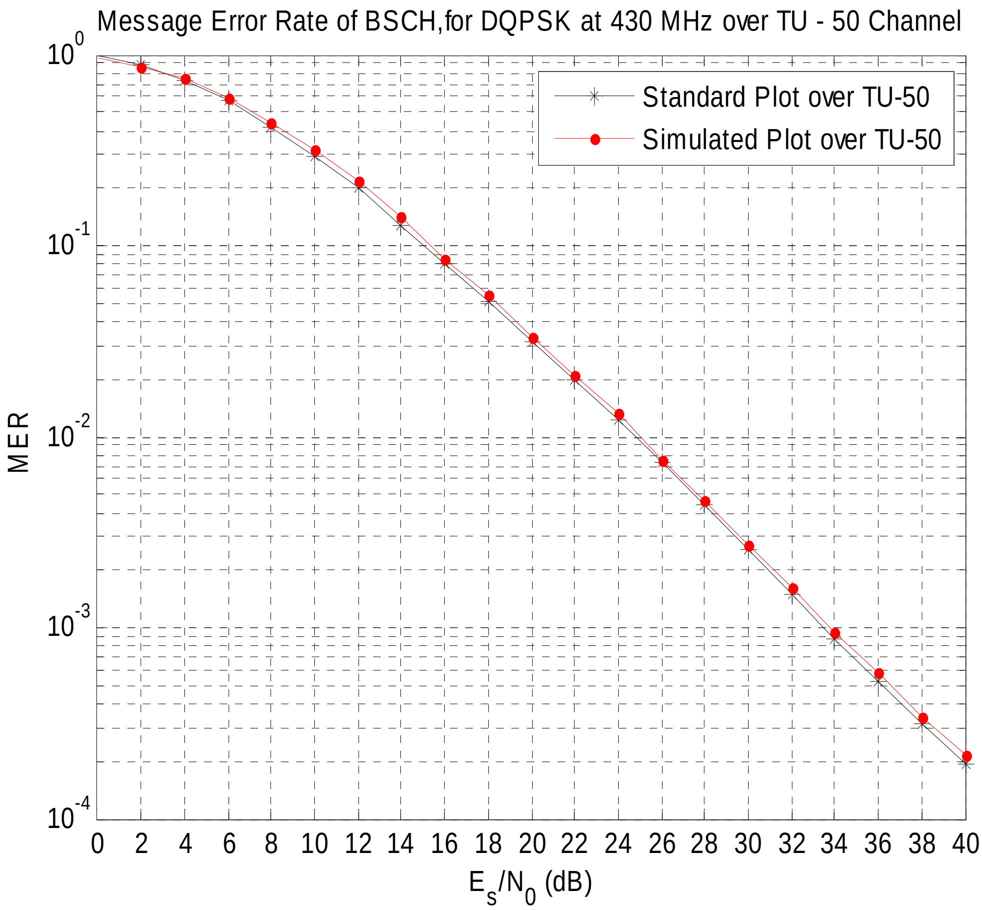

Figure G.3: Message Error Rate of BSCH over TU-50 propagation channel for 430 MHz, results corresponds to figure 21 of clause 4.3

MER of SCH/F channel as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.4, compared to those of clause 4.3.

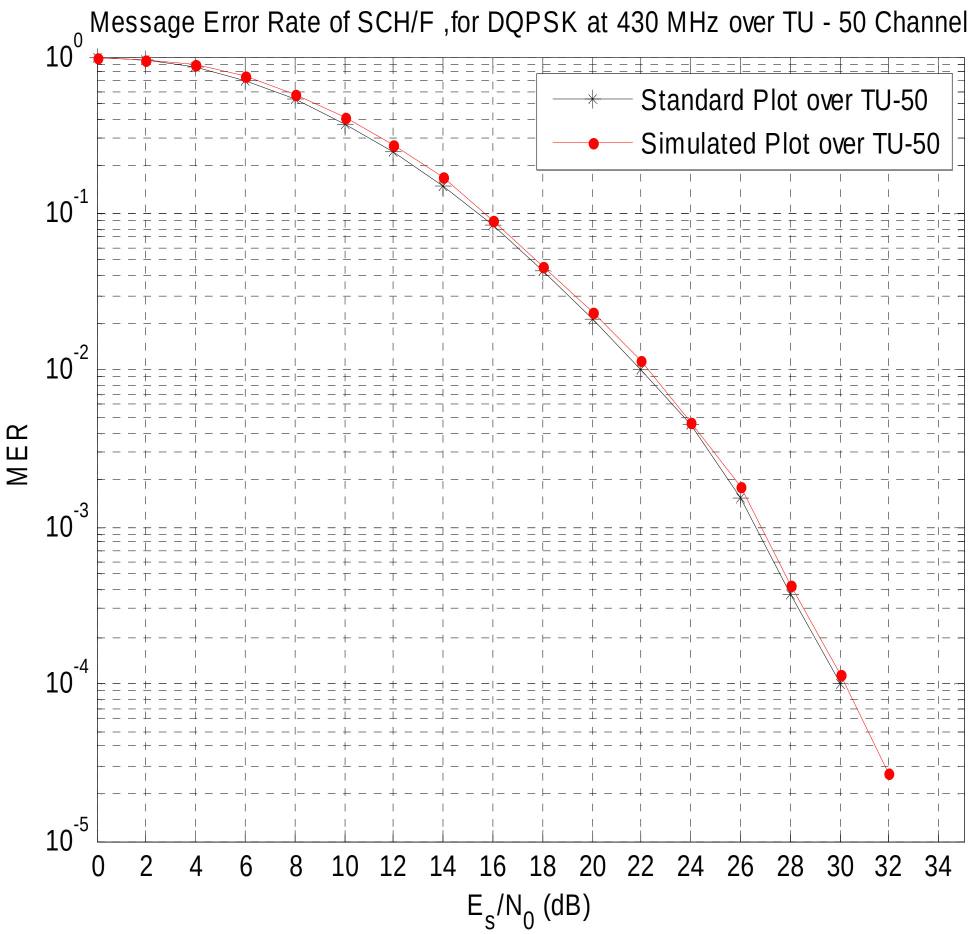

Figure G.4: Message Error Rate of SCH/F over TU-50 propagation channel for 430 MHz, results corresponds to figure 15 of clause 4.3

MER of SCH/HU channel as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.5, compared to those of clause 4.3.

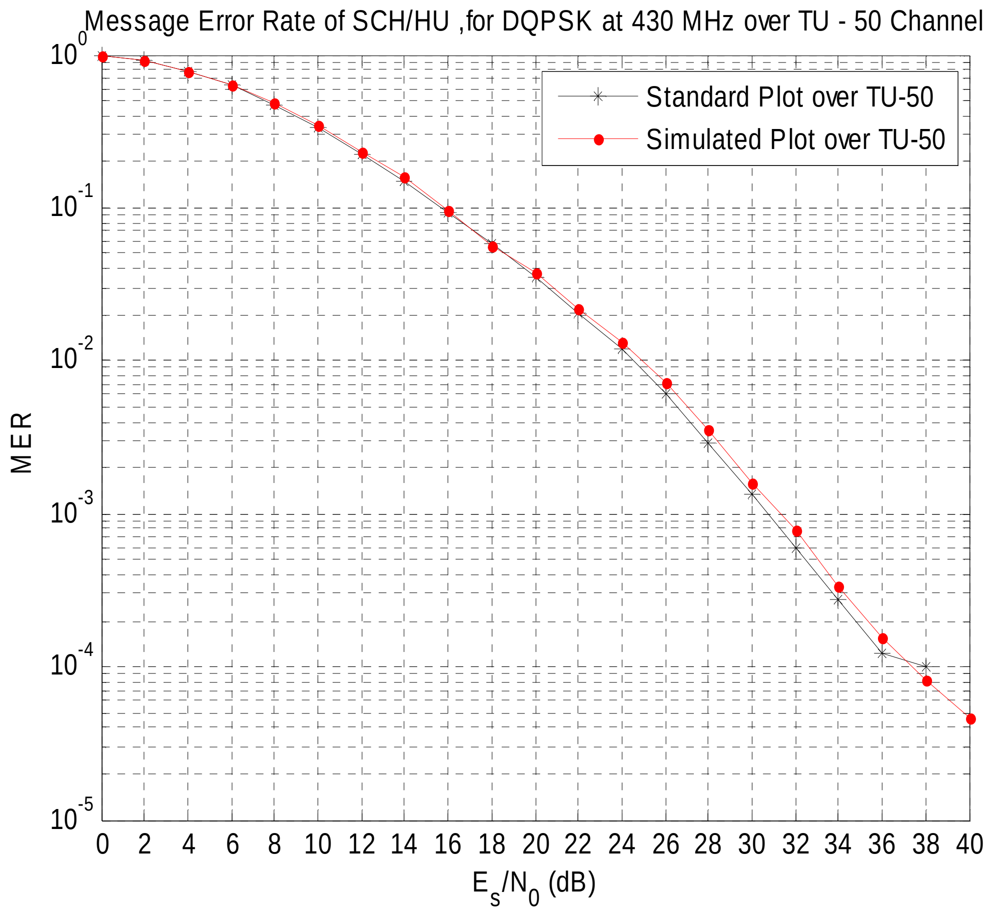

Figure G.5: Message Error Rate of SCH/HU over TU-50 propagation channel for 430 MHz, results corresponds to figure 9 of clause 4.3

BER of TCH/7,2 channel as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.6, compared to those of clause 4.3.

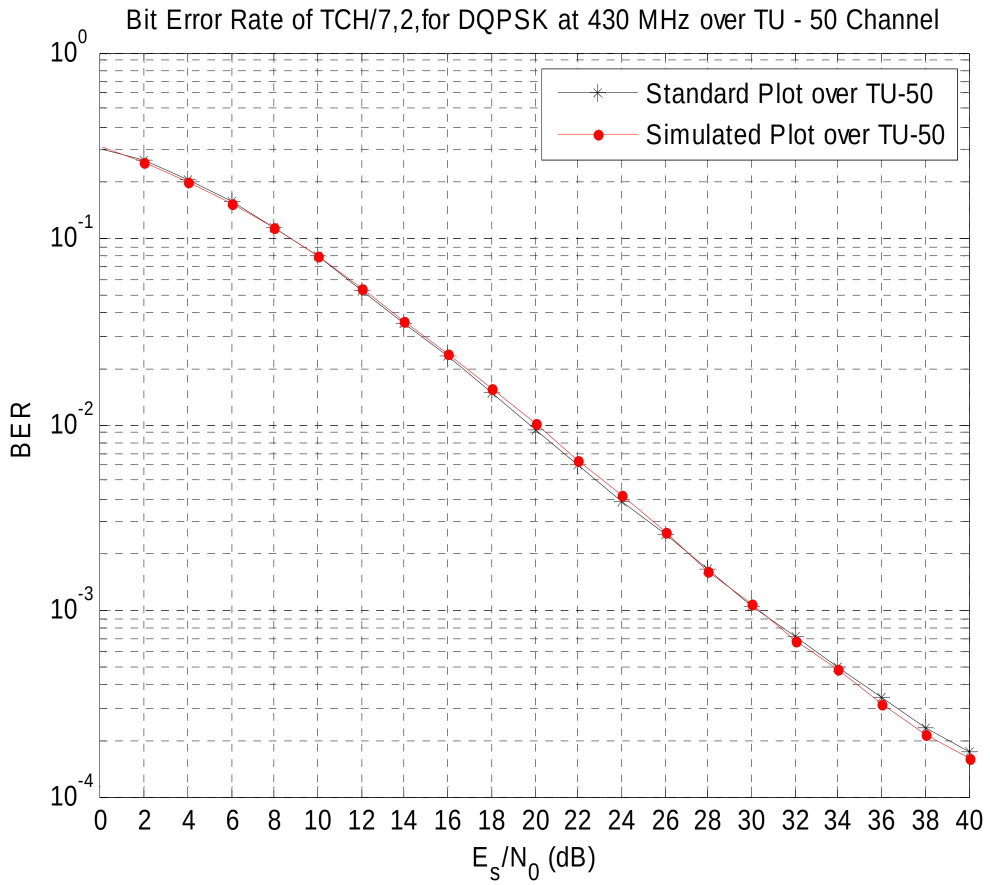

Figure G.6: Bit Error Rate of TCH/7,2 over TU-50 propagation channel for 430 MHz, results corresponds to figure 26 of clause 4.4

BER of TCH/2,4 channel as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.7, compared to those of clause 4.4.

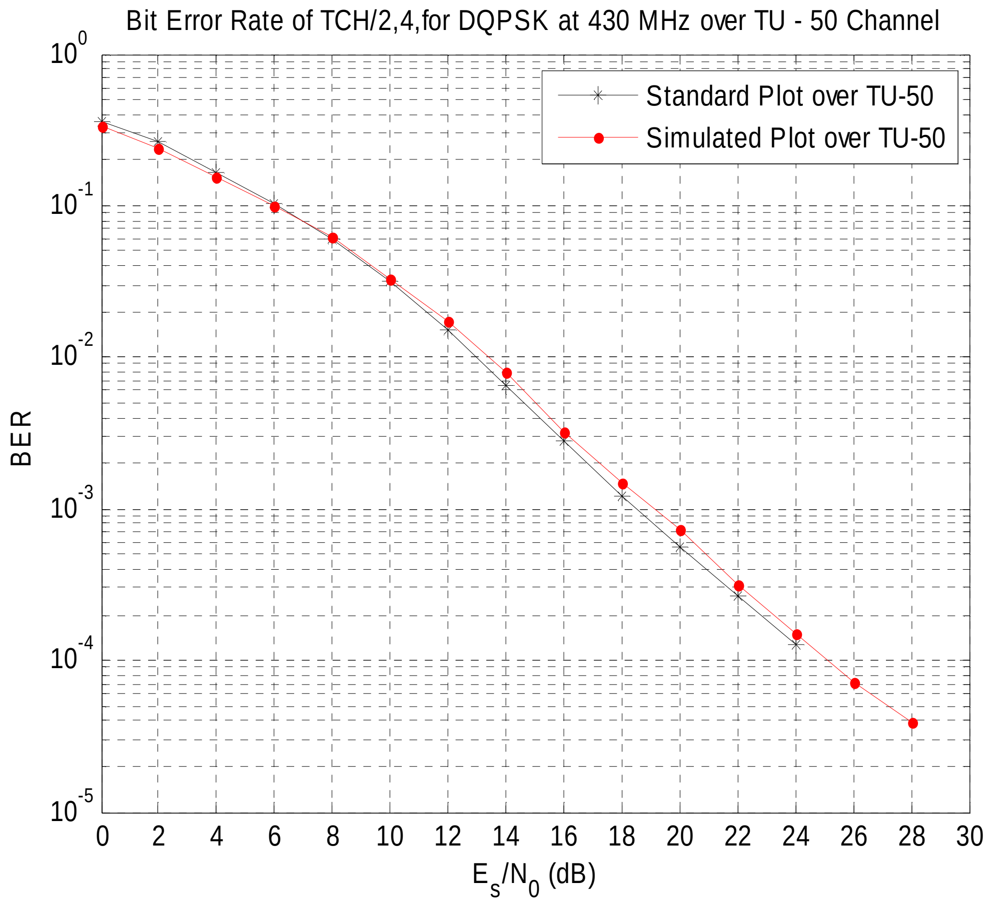

Figure G.7: Bit Error Rate of TCH/2,4 over TU50 propagation channel for 430 MHz, results corresponds to figure 50 of clause 4.4

BER of TCH/2,4 channel with interleaving over 4 blocks as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.8, compared to those of clause 4.4.

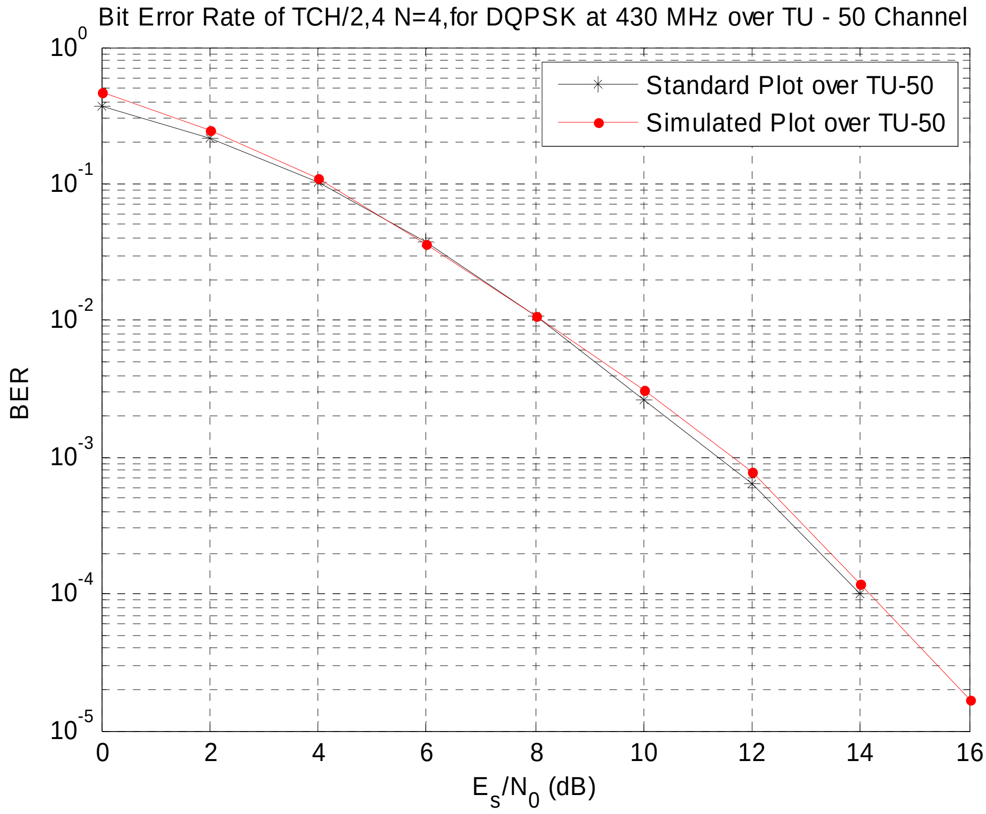

Figure G.8: Bit Error Rate of TCH/2,4 N=4 over TU50 propagation channel for 430 MHz, results corresponds to figure 56 of clause 4.4

BER of TCH/2,4 channel with interleaving over 8 blocks as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.9, compared to those of clause 4.4.

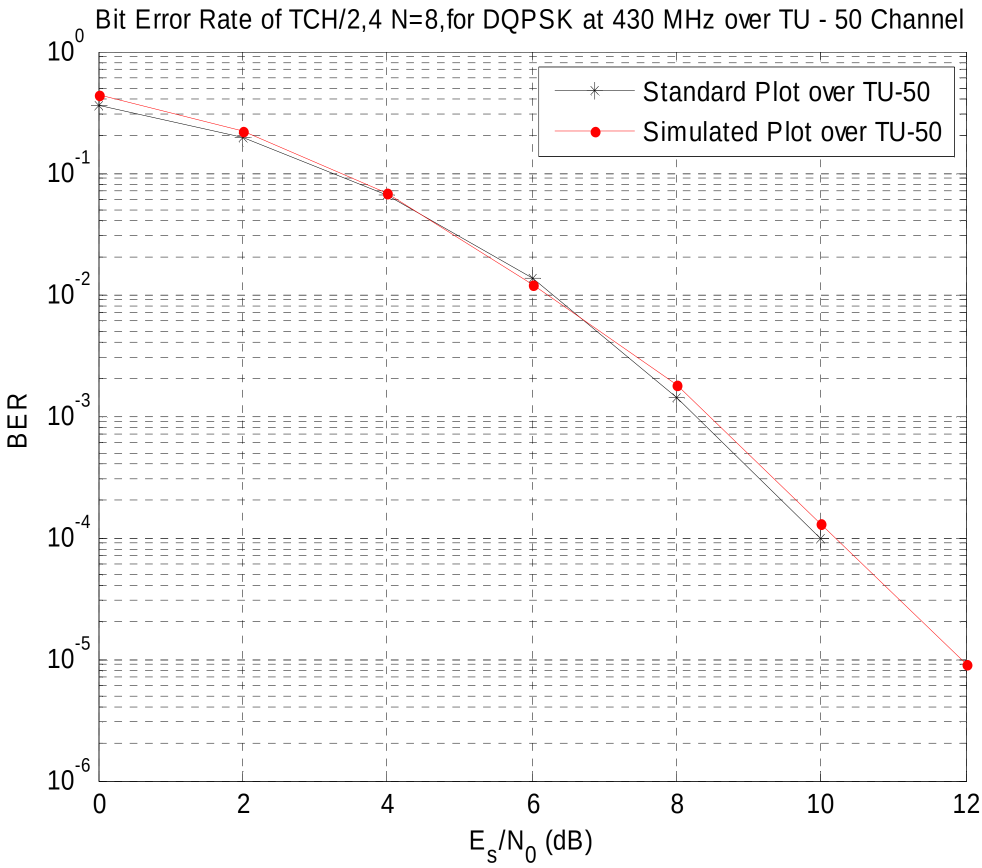

Figure G.9: Bit Error Rate of TCH/2,4 N=8 over TU50 propagation channel for 430 MHz, results corresponds to figure 62 of clause 4.4

BER of TCH/4,8 channel as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.10, compared to those of clause 4.4.

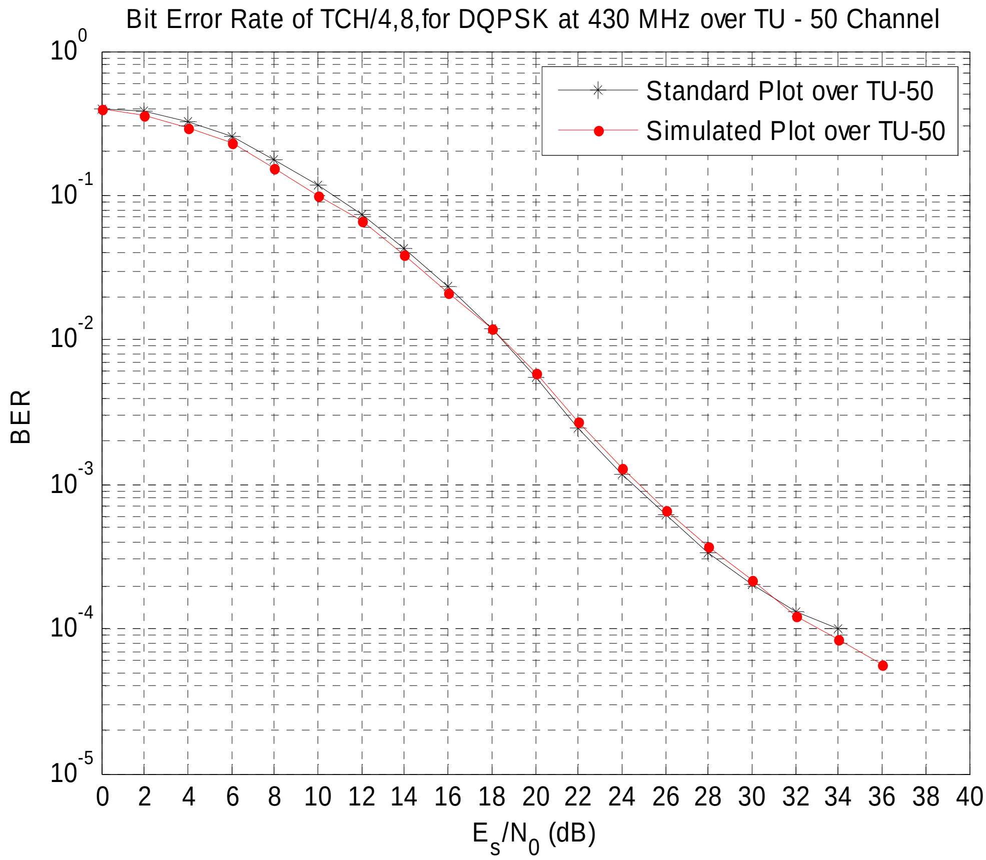

Figure G.10: Bit Error Rate of TCH/4,8 over TU50 propagation channel for 430 MHz, results corresponds to figure 32 of clause 4.4

BER of TCH/4,8 channel with interleaving over 4 blocks as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.11, compared to those of clause 4.4.

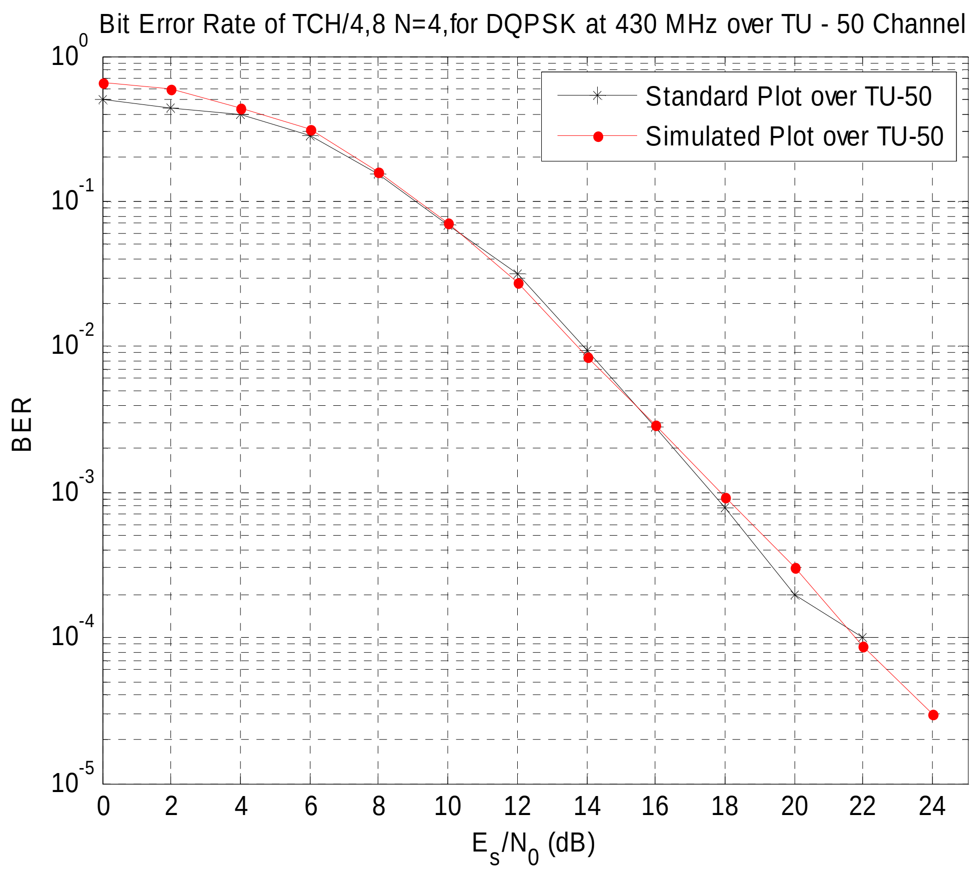

Figure G.11: Bit Error Rate of TCH/4,8 N=4 over TU50 propagation channel for 430 MHz, results corresponds to figure 38 of clause 4.4

BER of TCH/4,8 channel with interleaving over 8 blocks as function of Es/N0 in TU50 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.12, compared to those of clause 4.4.

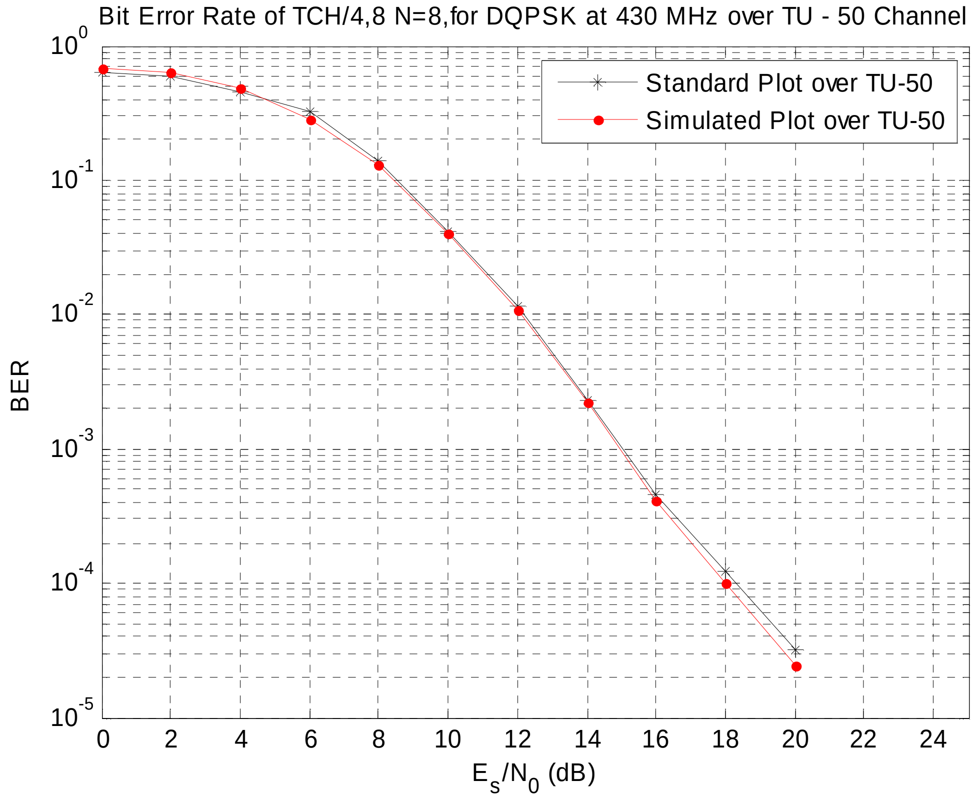

Figure G.12: Bit Error Rate of TCH/4,8 N=8 over TU50 Propagation Channel for 430 MHz, results corresponds to figure 44 of clause 4.4

G.3.3 Validation of the simulator against clause 4.3 for HT channel

MER of AACH channel as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.13, compared to those of clause 4.3.

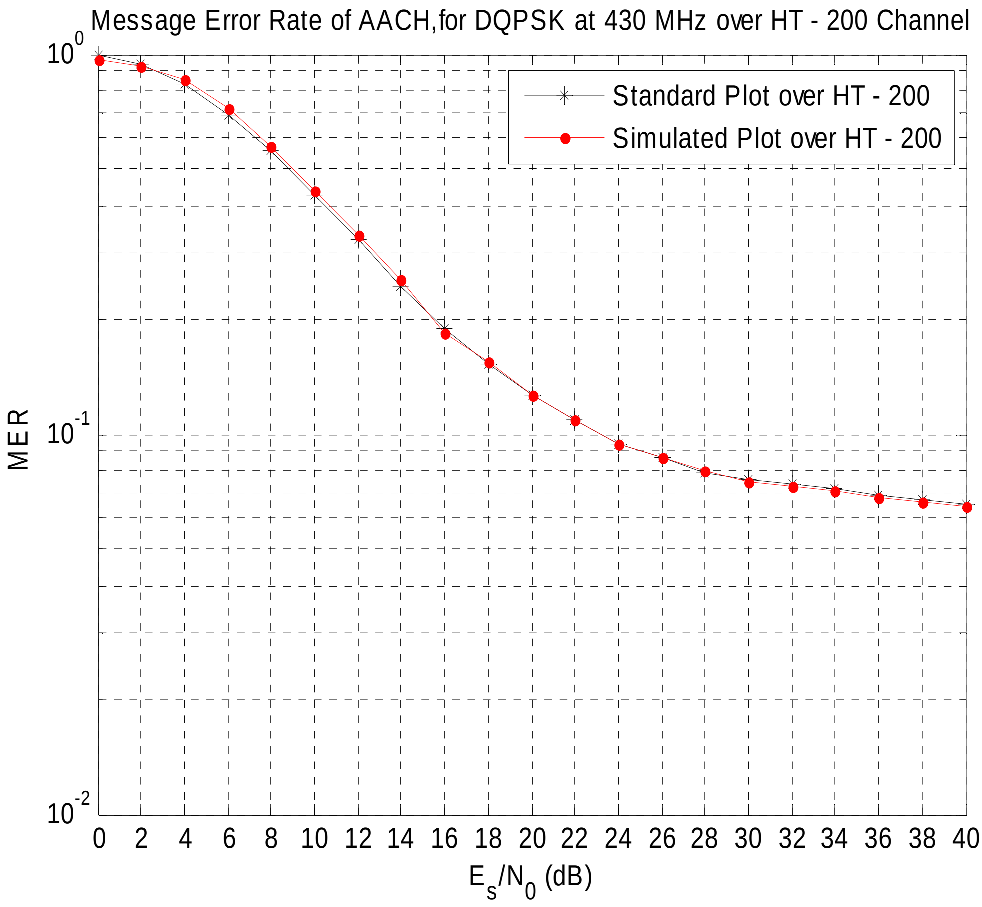

Figure G.13: Message Error Rate of AACH Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 6 of clause 4.3

MER of BSCH channel as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.14, compared to those of clause 4.3.

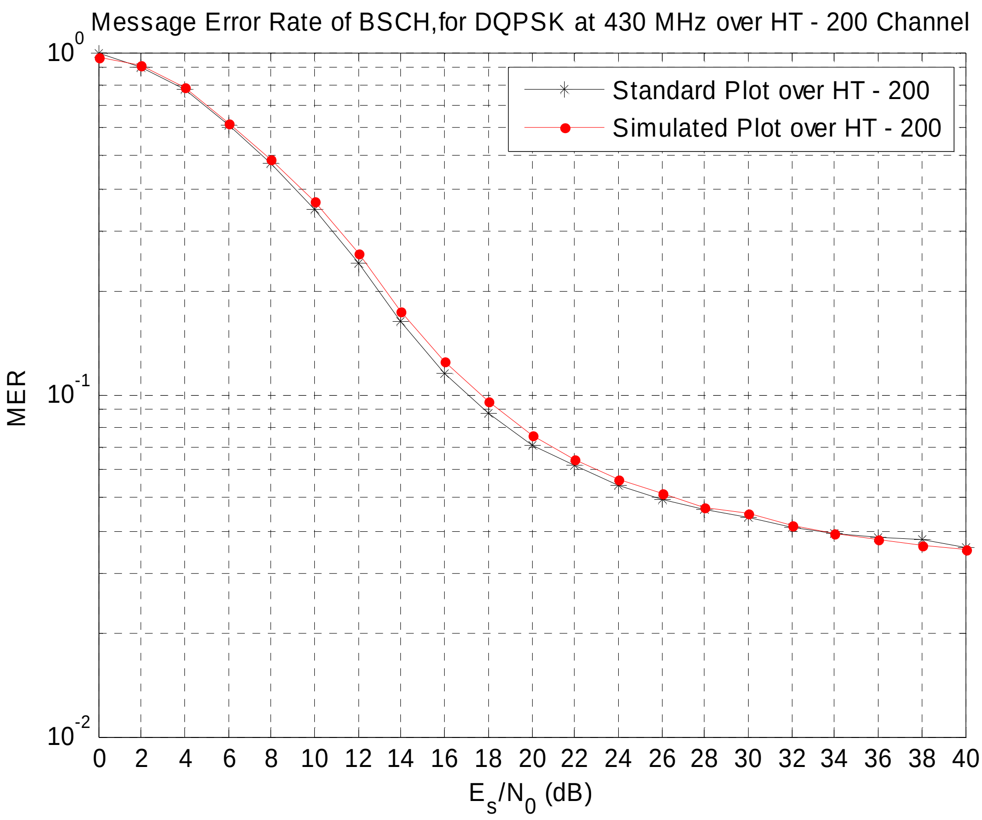

Figure G.14: Message Error Rate of BSCH Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 24 of clause 4.3

MER of SCH/F channel as function of Es/N0 in HT - 200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.15, compared to those of clause 4.3.

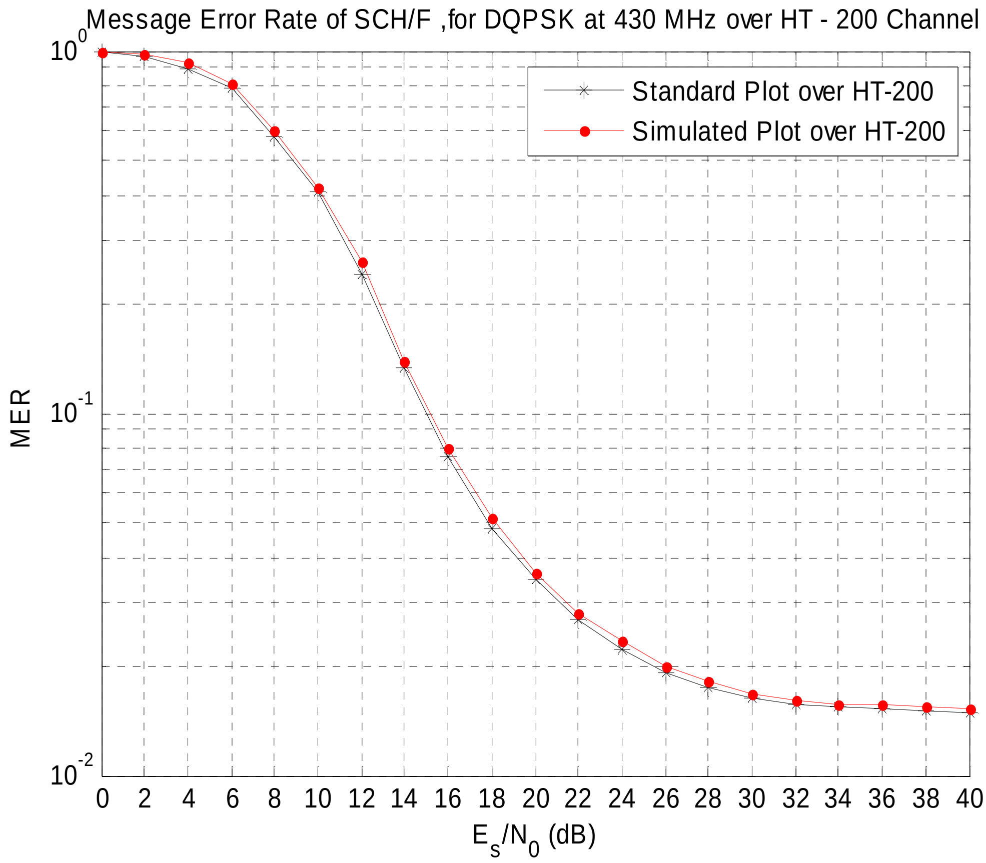

Figure G.15: Message Error Rate of SCH/F Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 18 of clause 4.3

MER of SCH/HU channel as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.16, compared to those of clause 4.3.

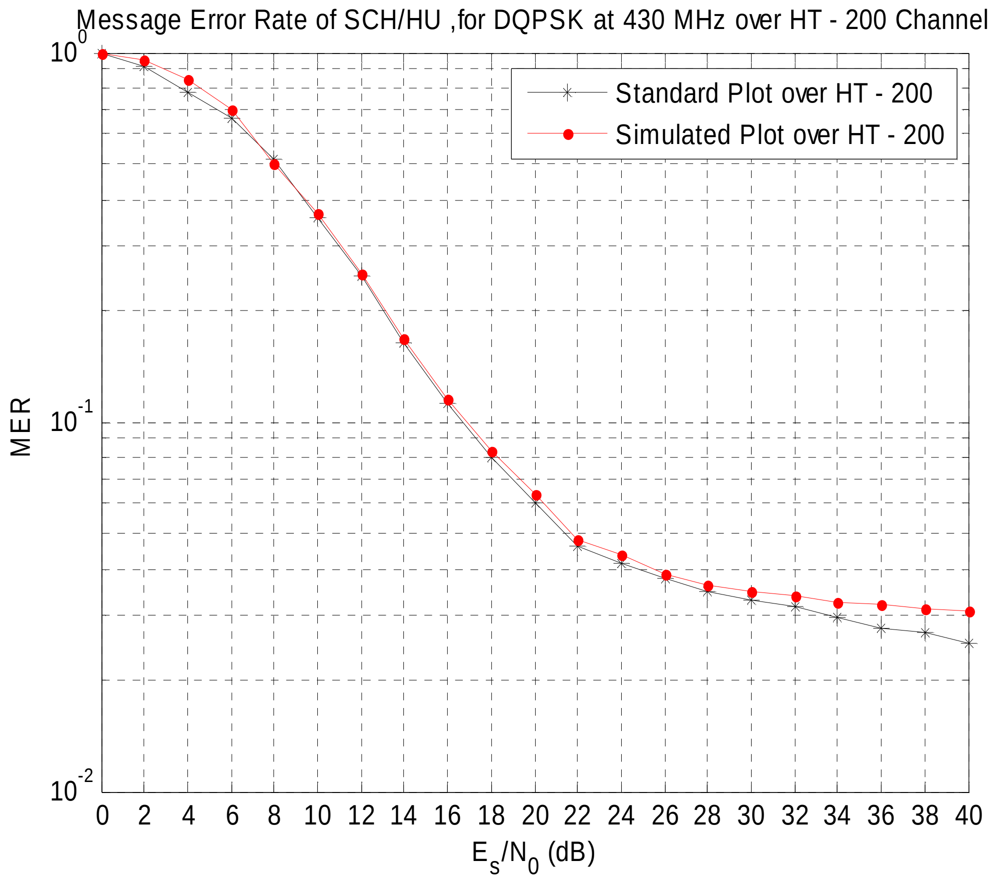

Figure G.16: Message Error Rate of SCH/HU Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 12 of clause 4.3

BER of TCH/7,2 channel as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.17, compared to those of clause 4.3.

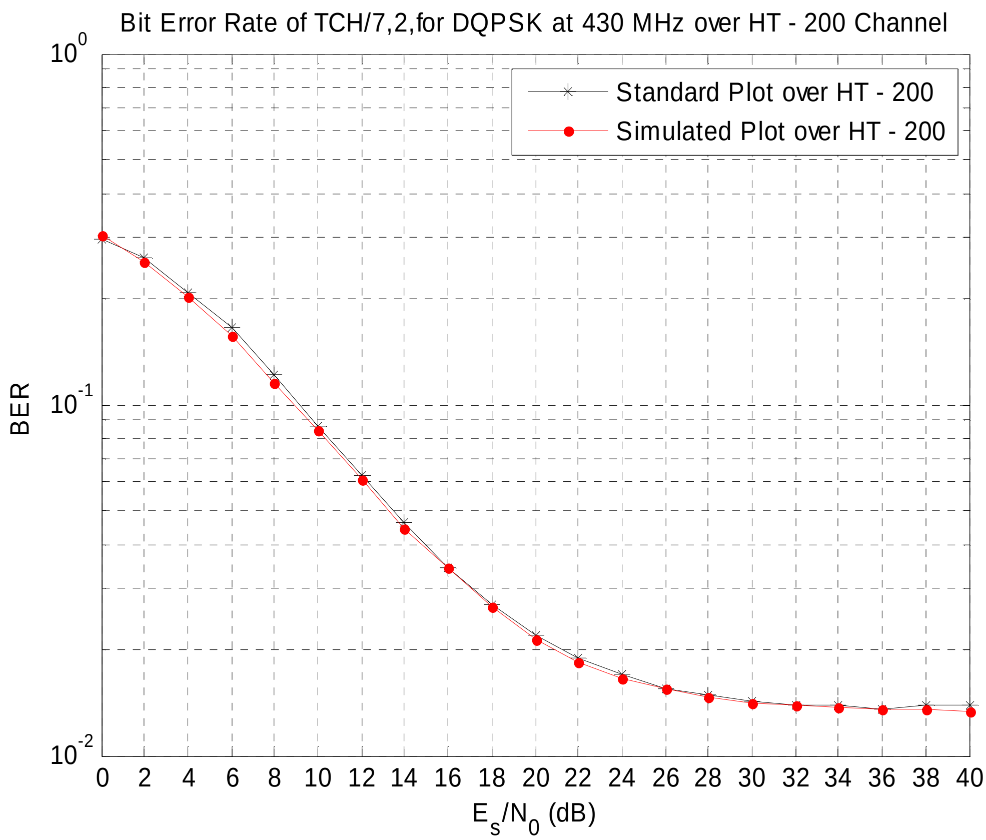

Figure G.17: Bit Error Rate of TCH/7,2 Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 29 of clause 4.4

BER of TCH/2,4 channel as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.18, compared to those of clause 4.4.

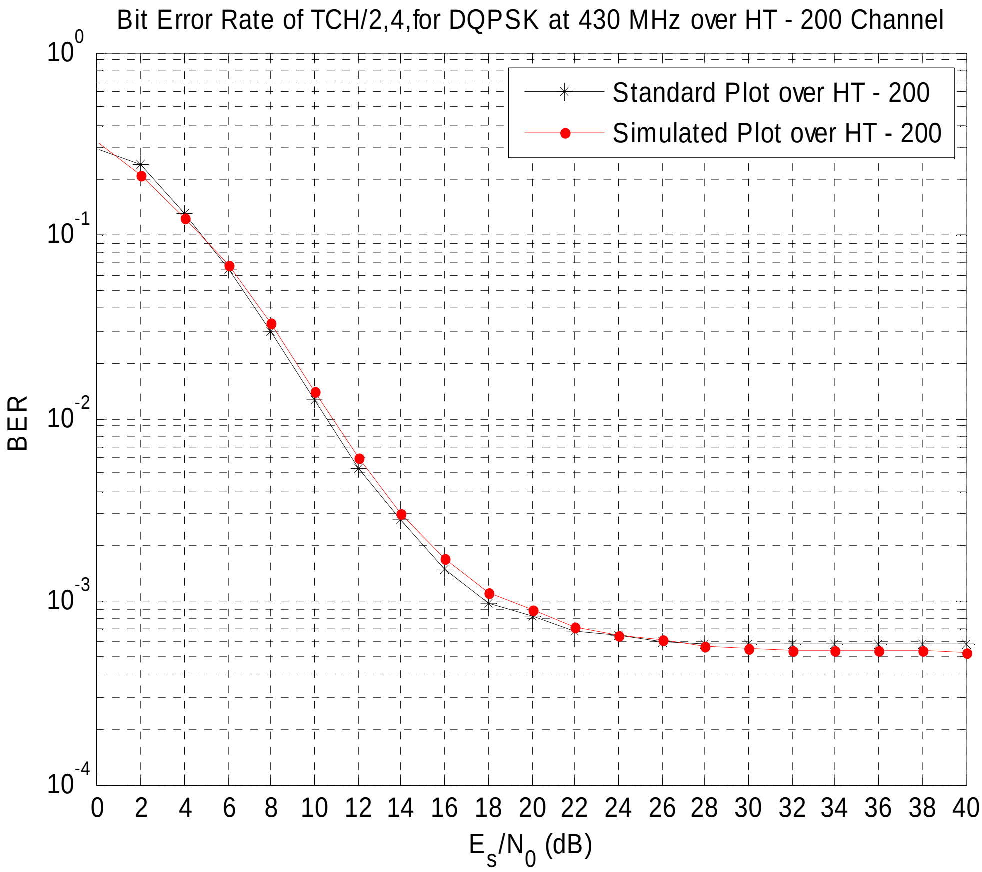

Figure G.18: Bit Error Rate of TCH/2,4 Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 53 of clause 4.4

BER of TCH/2,4 channel with interleaving over 4 blocks as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.19, compared to those of clause 4.4.

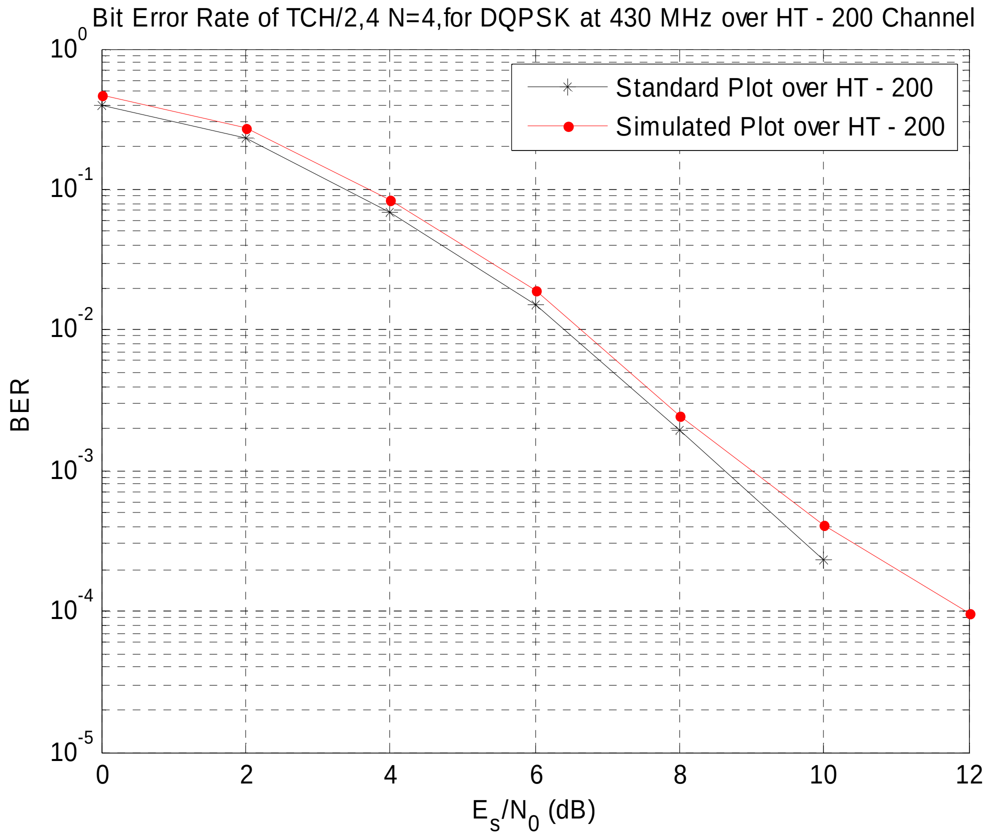

Figure G.19: Bit Error Rate of TCH/2,4 N=4 Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 59 of clause 4.4

BER of TCH/2,4 channel with interleaving over 8 blocks as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.20, compared to those of clause 4.4.

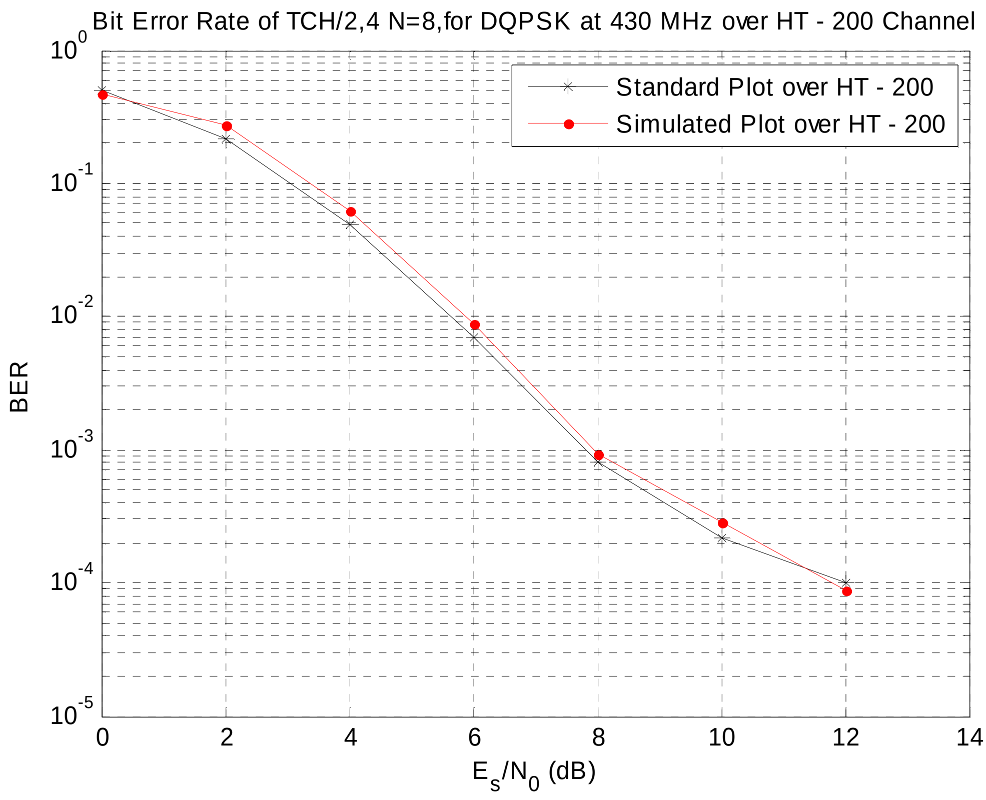

Figure G.20: Bit Error Rate of TCH/2,4 N=8 Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 65 of clause 4.4

BER of TCH/4,8 channel as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.21, compared to those of clause 4.4.

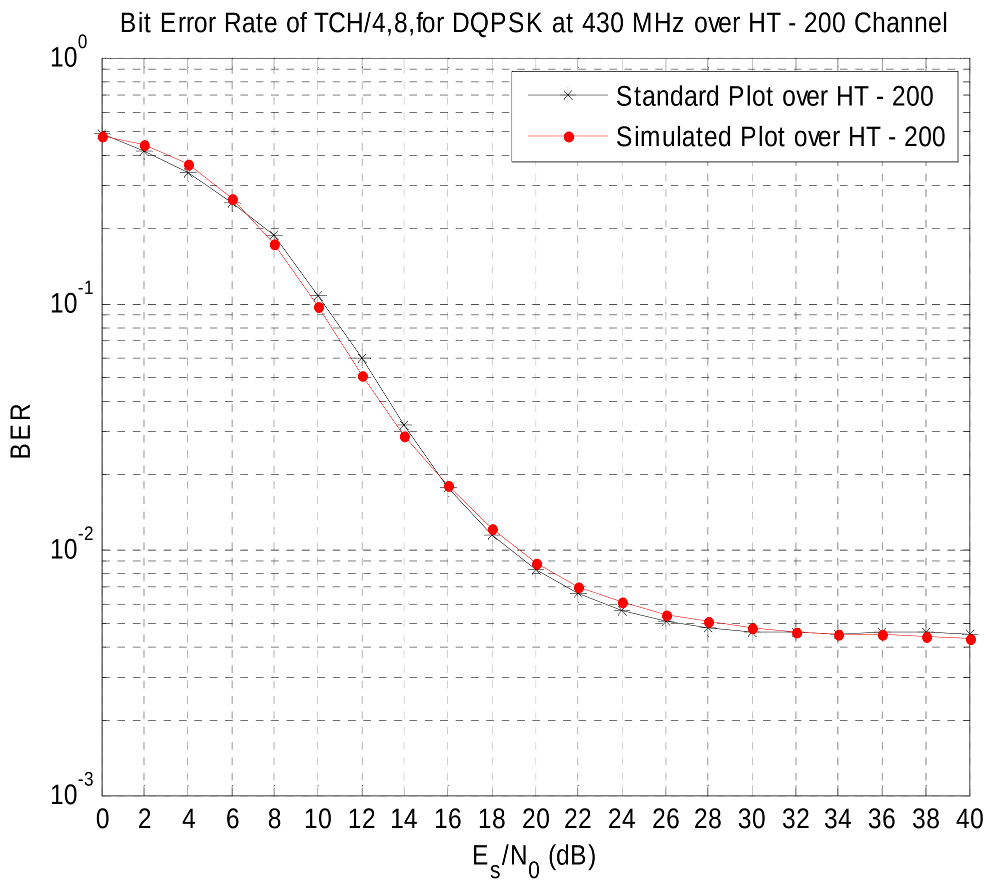

Figure G.21: Bit Error Rate of TCH/4,8 Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 35 of clause 4.4

BER of TCH/4,8 channel with interleaving over 4 blocks as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.22, compared to those of clause 4.4.

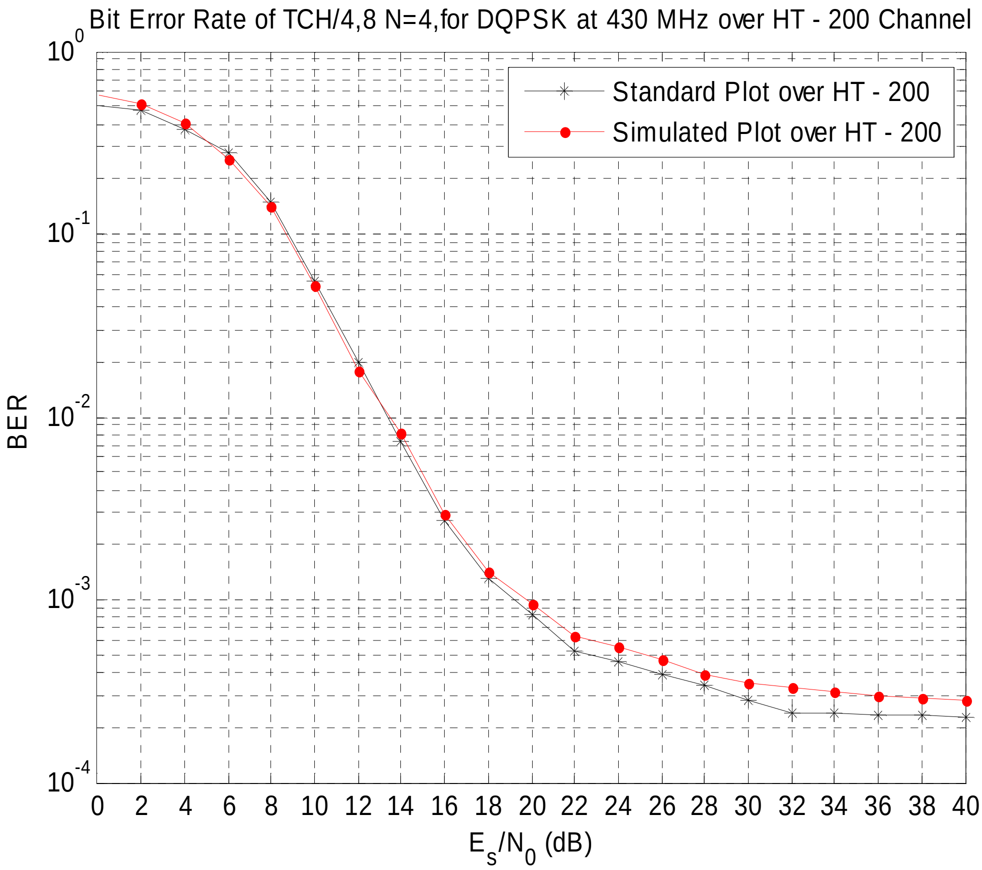

Figure G.27: Bit Error Rate of TCH/4,8 N=4 Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 41 of clause 4.4

BER of TCH/4,8 channel with interleaving over 4 blocks as function of Es/N0 in HT200 propagation environments with ideal synchronization technique over 430 MHz are shown in figure G.23, compared to those of clause 4.4.

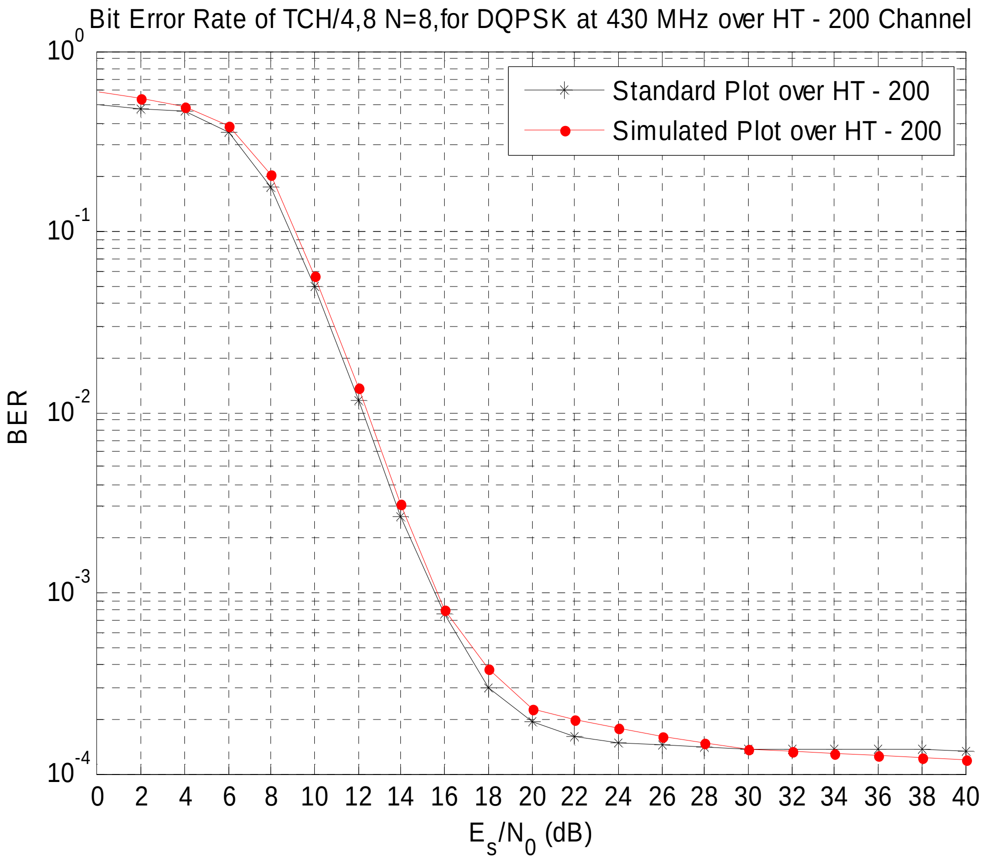

Figure G.22: Bit Error Rate of TCH/4,8 N=8 Channel over HT200 propagation channel for 430 MHz, results corresponds to figure 47 of clause 4.4

History

Document history		
Edition 1	May 1997	Publication as ETR 300-2
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