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Radio Equipment and Systems (RES); Digital European Cordless Telecommunications (DECT) A Guide to DECT features that influence the traffic capacity and the maintenance of high radio link transmission quality, including the results of simulations

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Foreword

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This ETR has been produced by sub-technical committee RES3 (in charge of DECT) and approved by TCRES (Technical Committee Radio Equipment and Systems), a technical committee of the European Telecommunications Standards Institute (ETSI).

The present document aims to provide an overall description of the DECT features that influence the traffic capacity and the maintenance of high radio link transmission quality.

DECT: Digital European Cordless Telecommunications

ETSI: European Telecommunications Standards Institute

RES3: Radio Equipment and Systems, sub-technical committee 3, (in charge of DECT)

CEPT: Conférence Européenne des Postes et Télécommunications.

1 Introduction

CEPT has allocated for DECT the frequency band 1 880 - 1 900 MHz throughout Europe. This allocation has been reinforced by a directive from the European Commission, stating that the allocated frequency band has to be made available in each country from 1992 upon market demand.

There is a growing interest in comparing the traffic capacity and other related features of DECT with other digital (and analogue) systems. However, DECT introduces new unique features that make simple comparisons difficult. For instance, comparison of spectral utilisation for a DECT telephony service with other similar systems will not yield meaningful results unless these features are understood and are included in the analysis.

This report introduces these features. It gives some estimations to demonstrate their significance. The presentation is supported by a large number of simulations summarised in Annex D. The report also compares properties of systems using Fixed Channel Allocation (FCA), with the properties of DECT Dynamic Channel Selection (DCS). More information about DECT is found in the "Digital European Cordless Telecommunications Reference Document" ETSI Technical Report ETR 015 [1] and in the "Digital European Cordless Telecommunications Common Interface Specification" ETS 300 175 parts 1 to 9 [2] (see Annex F for references).

2 Summary of DECT features

DECT has four main features that are important for determining the traffic capacity:

a) DECT supports uncoordinated system installations co-existing on a common frequency resource (1 880 - 1 900 MHz) for all systems.

This feature avoids splitting the common frequency resource between different services or users and is in itself a capacity gain. Examples are private speech or data systems and multi-operator public 1- and 2-way Telepoint and PCN like systems.

b) DECT also provides a good means for sharing base stations between different operators. DECT has a powerful and flexible identity and addressing structure that provides for e.g. hosting private user groups in a large public system, hosting public access in private systems, and hosting public access from several service providers in a system owned by one of the public service providers. The same handset can be equipped with access rights to several public and private operators.

c) DECT supports telephony speech quality, in a quasi-stationary radio environment, by provision of the CCITT G.721 32 kbit/s ADPCM speech codec.

A DECT handset will in many cases serve as the only or the prime telephone instrument. Currently available codec candidates with lower bit rates than 32 kbit/s have been judged not to provide the needed speech quality.

d) DECT provides an <u>easily engineered</u> and <u>economic</u> installation of closer and closer cells, <u>whereby the efficiency of the Dynamic Channel Selection procedures (DCS) and the High Speech Quality is maintained</u>.

The use of small cells is the main key to high capacity. However, the real limit on how small the cells can be made depends on how well the following factors are maintained when the cells become smaller:

- easily planned (engineered);
- economic (base stations cost incl. installation);
- effective DCA;
- maintenance of High Speech Quality (no interruptions).

The key features of DECT are designed to allow high capacity, while maintaining high speech quality, by meeting the above mentioned requirements. Especially important is the unique DECT quick seamless (no interruption) decentralised intercell or intracell handover, which elegantly copes with changing local conditions, without need for central control.

And although Dynamic Channel Selection is not unique to DECT, the limitations of other known systems will not allow it to be realised in such an ideal manner.

Absolute capacity estimations for Dynamic Channel Selection can only be made by simulating the exact protocols and procedures as well as the base station characteristics used by the system and the effects of adjacent channel power and intermodulation.

Capacity has to be related to a wanted quality of the radio link including blocking, early call curtailments and interruptions.

In the following chapter it is shown that DECT, while maintaining the overall link quality and simple planning rules and economy, can go down to lower cell separation than other systems. If DECT can go down to half the cell size, that factor alone will give DECT 4 times higher traffic capacity than the other system.

The key parameter in assessing the traffic handling capacity of a system is the number of channels per MHz and km^2 (and floor), at a comparable quality and infrastructure volume, and not just channels per MHz,

DECT can <u>seem</u> inefficient in terms of channels per MHz, due to TDMA guard spaces, large signalling overhead and the 32 kbit/s codec. It is, however, the TDMA and the signalling that enables the very small cell design, with effective channel selection and high channel quality maintenance, and it is the 32 kbit/s codec that gives the required telephony speech quality.

3 Detailed description of features

3.1 Dynamic Channel Selection (DCS) and uncoordinated installations.

DECT supports a multi-system environment with uncoordinated installations co-existing on a common resource of spectrum.

DECT utilises a simple but efficient and robust Dynamic Channel Selection (DCS), procedure, that is decentralised to each Portable Part (PP) and its closest base station Radio Fixed Part (RFP).

For each call the portable chooses a channel that for the time being is best for the wanted local connection.

The most important advantage of this feature is that different systems and system operators and different types of services, in a self organising way, can utilise the same group of available channels without prior distribution of channels to specific services or base stations.

Mobile radio and mobile telephone systems with in principle fixed channel allocation, like NMT, TACS, AMPS, ADC, GSM and DCS 1 800 do not provide this important feature *Dynamic Channel Selection and Uncoordinated Installations.*

An additional important feature is that each service or equipment provider can, driven by the customer needs, increase their own capacity by increasing his base station density.

The Dynamic Channel Selection makes it possible for evolutionary services to use different slot lengths and even different bit rates or radio carrier bandwidths.

3.2 The DECT standard base station

DECT provides a cost effective standard base station concept.

This concept is described in Annex A.

This low cost standard base station can access all DECT traffic channels (common for all systems).

It consists of a single radio that can change carrier frequency from slot to slot. With the standard 12 duplex time slots, it offers over 5 E (Erlangs) average speech traffic, corresponding to 25 handsets with 0,2 E each.

This provides the major cost benefit offered by DECT, since the number of base radios needed per 12 offered speech traffic channels is reduced to 1 from the 12 required for analogue or digital FDMA systems.

3.3 System planning and installation cost

3.3.1 Frequency allocation

DECT provides simple system planning and cost effective installation.

There is no need for frequency (allocation) planning for DECT.

3.3.2 Number of channels per base station

There is no need to plan in detail how many channels are needed per base station. The system maintains a high grade of service even with local density variations.

Every standard DECT base station described in Clause 2 and Annex A, supports up to a maximum of 12 E 32 kbit/s duplex speech traffic. For further information see "Simple planning guide for DECT Base Station Locations in an Office environment" given in Annex C.

The DECT standard base station will thus have a large margin for automatic adjustment to foreseen and unforeseen local traffic variations. Careful planning of how many radios are needed per base, which gives a low grade of service at unforeseen local traffic variations, is thus avoided. If traffic increases in the system, the number of common central speech functions have to be increased, using the same base station infrastructure.

3.3.3 Adding base stations

When needed, new base stations can be added to increase capacity without special co-ordination with already installed base stations.

3.3.4 Base station installation costs

One single radio standard base station provides on average 5 E of speech traffic and can serve approximately 25-35 handsets in an office environment, see subclause 3.2. This leads to low installation costs.

(The connection to base stations can be two twisted pairs of wire, that operate at e.g. 2,048 Mbps (S_1) for up to 1 Km connections. This would support up to 30 simultaneous 32 kbit/s ADPCM calls, including signalling needs. Alternatively, 192 kbit/s (S_0) could be used providing 4 simultaneous duplex calls on one twisted pair up to 3 km.)

The allocated frequency band of 20 MHz also helps to keep the installation cost low. A system that accesses only 4-5 MHz, would have its traffic per base station reduced by a factor of 4 in an interference limited environment. This would require 4 times more base stations to be installed.

Limited frequency allocation has thus a considerable cost implication.

3.4 The distributed broadcast and control channel

DECT provides, without separate physical control channels, frequent system information and base station access rights identification that allows any portable, by receiving only, to identify any system or base station within reach, and, if wanted, to lock to it.

This is a unique DECT feature, provided by the fact that every DECT base station is always active on at least one channel, and that every active channel contains the above mentioned information. The access rights information lists the available services from different operators, that are accessible from the system within reach. The system information includes different types of synchronisation information, the capabilities of the system and lists the radio carriers that the system operates on.

An active channel may carry traffic or may be simplex down-link short-slot transmission called dummy bearer.

When a handset has recognised a wanted system, the receiver locks to it, by locking to any active channel on the strongest (nearest) base station. In this idle locked state the handset listens every 160 ms, (for about 100 microseconds), for a possible page from the system. (The theoretical power savings ratio is thus better than 1/1 000, while still achieving a very low average call set up delay of about 100 msec). When the handset wants to contact the system, it transmits on the "best" channel a 400 microseconds long burst, corresponding to a 10 ms speech packet.

Without this "beacon" concept with idle locked handsets, the system would have to make a rather lengthy blind transmission (up to 1 - 2 sec) to check if the portable is within reach of a system, or when trying to set up a call. The time cannot be much shorter for a good current saving duty cycle. Unsuccessful call set up attempts can lead to possible disturbances of up to 1 - 2 seconds of ongoing traffic. This must not lead to a handover request. Thus the system would have to accept interruptions of 1 - 2 seconds in the communication, before any handover procedure is started. Seamless handover as described in subclause 3.5 would not be possible. With the DECT "beacon" concept an unsuccessful call attempt only corresponds to a 10 ms (muted) interruption.

DECT has dynamic dummy bearer allocation procedures that in a rapidly changing environment can provide maintenance of a "beacon" on the least interfered channel.

3.5 The seamless handover

DECT provides, with a single radio per end point, a quick (50 ms) seamless handover that does not need central control or complicated procedures.

The key is TDMA in combination with the decentralised Dynamic Channel Selection (DCS) described in subclause 3.1; the old link is maintained on one slot in the portable, while the new link is set up on another time slot. When the new link is established, the (new) base station requests the central control to make a seamless switch from the old to the new radio link.

This is a unique TDMA feature.

3.6 Maintenance of the radio link

DECT provides call set up and handover to the closest (strongest) base station, providing stable Dynamic Channel Selection (DCS) high capacity and high link quality.

The distributed broadcast and control channel described in subclause 3.4, provides information to the portable to lock to any active channel on the closest base and if needed make a radio link set up to the closest base station.

The handover is portable controlled, while maintaining the original link it scans the other channels and records a ranking list of "free" channels and of own base stations that are stronger than the original one, and is thus prepared to perform a very quick handover (20 ms).

Handover is made as soon as another base station is, say 10 dB, stronger than the one of the current connection. Thus in a well engineered system handover is always performed before the link quality degrades.

The nature of DCS is such that a channel in use can (occasionally) be stolen, and therefore the quick DECT "seamless" intercell and intracell handover increases the capacity and cuts call curtailments drastically. DECT does not depend on the old channel to quickly set up the new.

If calls are not set up to and kept to the closest base stations through handover, the capacity of the system and the link quality decreases.

3.7 Influence of adjacent channel power and intermodulation

The DECT capacity is little affected by poor adjacent channel power attenuation or inter modulation, due to unique properties of the DECT standard base station concept. See subclause 3.2 and Annex A. This has been confirmed by recent simulations, see Annex D

While operating on different carriers, each call connected to the same base station always uses different time slots. Thus there is no intermodulation or adjacent channel interference between all (close by) handsets communicating with the same base station; this greatly reduces the in-system interference risk due to intermodulation or poor adjacent channel attenuation. It also gives freedom to deviate from the strict TDD up link and down link separation, which can be useful at data transfer. See results from simulations given in Annex D.

3.8 Flexible data services

DECT can, with one radio, set up multi-bearer connections to provide high data rates and ISDN services.

The quick channel set up procedures allow dynamic bandwidth allocation and packet switched data on the radio channel, which decreases the load on the radio channel.

3.9 Antenna base station diversity

DECT provides and combines different types of diversity; antenna diversity by changing the antenna radiation pattern, frequency diversity by intra-cell handover to another carrier and macro diversity by inter-cell handover. Diversity increases capacity, extends the range and copes with the time dispersion effects.

The simple antenna switch diversity is effective for stationary or quasi stationary applications. Antenna select diversity is effective for general applications. Diversity moves you out of a possible fading dip, and corresponds to up to 10 dB decrease of required C/I + N to maintain 1 % grade of service. *These 10 dB correspond to 2 - 3 times capacity increase.*

Application of antenna base station diversity is simple for the DECT standard base station (see subclause 3.2).

This antenna diversity is also an effective counter measure against bits corrupted by time dispersion, since this is highly correlated with the occurrence of fading dips. See Annex D.

The good system properties obtained by using Dynamic Channel Selection, may be further improved by proper use of fixed antennas with antenna gain. An example is a public DECT service intended to cover the streets. By directing the power along the street, rather than omnidirectionally, the range will increase in areas where the customers are and the interference will decrease to and from DECT systems in surrounding multifloor buildings. Antenna gain does not increase the total emitted power, but directs it were the users are, and normally decreases the time dispersion.

With the use of diversity (and when required suitable directive antennas) the radio coverage requirements for the different DECT services is intended to be met without the need for time dispersion equalisers. See Annex D.

3.10 Traffic capacity of DECT

3.10.1 The office environment

Traffic simulations and calculations for multi storey buildings conclude that with about 25 m base station separation, a 32 kbit/s speech traffic of 0,2 E per 20 m^2 and per floor requires 10 - 20 MHz depending on the interference situation from adjacent systems. See Annex D.

The range will be C/I limited for small close cells. There is no hard limit on the capacity or on the influence of adjacent systems. Decreasing your own system's base station separation will increase your own capacity and at the same time decrease the influence from nearby systems. *This does not mean that the total frequency allocation can be made very small.* As shown in subclause 3.4, a limited frequency band leads to high cost and for advanced data applications at least 5 - 10 simultaneous channels per base are needed, which require 20 MHz or more depending on the amount of data traffic. Substantial traffic in larger cells of evolutionary applications like local loop replacement and PCN could require increased spectrum. Increased use of ISDN services will also require increased spectrum.

3.10.2 Unsynchronised neighbour systems

Radio Fixed Points (RFPs) belonging to the same DECT fixed part are easily slot, frame and multiframe synchronised via the wired connections to the RFPs.

Dealing with the slow slot drift from unsynchronised neighbours does not introduce a new element for DECT, but is elegantly dealt with by the standard seamless (normally intra-cell) handover and channel selection procedures. It is in fact easier to make a seamless handover due to slot drift, than to cure the normal effect of a sudden channel (slot) theft, that occurs in all Dynamic Channel Selection systems, incl. other known cordless telephone systems. DECT has mechanisms to detect slot drift and make a handover before the user data is corrupted.

Also, all TDD systems suffer to some extent from unsynchronisation. However, DECT has 10 time slots with perfect isolation to escape to (besides escape to other carriers), and DECT provides quick and seamless handover to cope with interference or changed conditions. An optional intersystem synchronisation port is available for synchronising close by systems, if wanted.

For the general DECT applications, there is normally no significant difference between the average interference levels from RFPs or PPs from neighbour cells. RFPs and PPs are close to each other and their antennas are used at similar levels above the ground or floor. Therefore TDD has no drawback compared to Frequency Division Duplex (FDD) in this unsynchronised environment.

If for a specific public service omnidirectional base station antennas are installed high above the level where PPs normally are used, it is recommended to at least frame synchronise close by RFPs of this kind. Else these RFPs would cause much more interference to the up links than the PPs. A frame synchronisation with an accuracy of about 1 ms, will for this case make the interference performance (when using TDD) similar to the performance when using FDD. The need for synchronisation is much less critical for systems using, DCS, than for systems using FCA. See subclause 3.10.4. (It is possible that even for this worst case, a totally unsynchronised DCS system using TDD has no less capacity than a FCA system using FDD.) An attractive solution for this specific application is to derive the synchronisation reference from the Global Positioning System (GPS). No large antennas are required and GPS receiver boards are available for less than 1 000 ECUs.

3.10.3 The type of radio modulation

The chosen modulation GFSK, with deviation characteristics equivalent to GMSK with a nominal BT value of 0,5, gives good sensitivity and C/I performance. It allows for a low cost, robust, fast acting, limiter-discriminator detector, with 1-threshold bit-by-bit detection. It also allows low cost IF-filters and low radio frequency stability requirements. Simulations, Annex D, show that the performance of DECT is not degraded due to the adjacent channel power when using BT = 0,5.

It could be argued from a traffic capacity point of view that a more narrow modulation scheme is better, since the carrier spacing can be decreased. Studies show that with reasonable complexity of IF filters (max 6 poles) only in the order of 20 % increase in carrier spacing can be gained. Such a difference can, however, also be gained by installing base stations 10 % closer. A narrower band modulation technique could provide longer range (C/N) but would also give higher BER in C/I limited environment. e.g. GMSK BT = 0,3 with non-coherent demodulation would in this environment decrease the C/I performance by about 3 dB. Good C/I performance is important for robustness against time dispersion.

The use of linear modulation or GMSK with lower BT leads to more complexity and higher handset cost. This is considered to give more disadvantages than advantages in the DECT context. Instead of charging each handset with extra cost, the fixed infra structure will carry some extra cost only in cases where the highest capacity is needed.

3.10.4 Propagation characteristics for short range communications. Comparing Dynamic Channel Selection (DCS) with Fixed Channel Allocation (FCA).

Contributions on spectrum requirements for DECT have been made earlier using fixed channel allocation FCA methods. Also the capacity of DECT and GSM have been compared, using FCA in the analysis of both systems. These results have limited value when applied to systems with DCS and wrong conclusions are easily made.

As an example, we can compare the simulation results of a multi storey building referred to in subclause 3.10.1, with a fixed allocation scheme, using a 9 cell re-use pattern per floor and re-use every 3 floors. See Annex B.

The result is that for a stand alone building, DCS, is 6 -8 times more efficient. When surrounded by foreign base stations DCS is 3 - 4 times more efficient according to the example. This result can at first seem astonishing, but additional studies support this conclusion.

Firstly, DCS does not need any shadowing margins. It adjusts to the instant situation and the shadowing allows sometimes shorter and sometimes longer re-use distances, it averages out.

Secondly, FCA has a fixed and symmetric worse case re-use distance. DCS has a dynamic re-use distance. Portables close to the base station will have short re-use distance.

Thirdly, DCS gives a better trunking efficiency (especially for DECT). Any channel can be used by any base (typically up to 12 simultaneous channels per base). For DCS the average number of channels occupied per base equals the average traffic in Erlang per base: 2 - 5. For planning of a FCA system the maximum number of channels per base, 12, principally have to be regarded as occupied all the time. These gains have to be considered not only in two dimensions, but in three, and then the gain increases.

Another advantage of DCS which has been verified by measurements and simulation is that as the cells are made smaller, the average wanted signal increases leading to lower C/I (less noise) for constant Bit Error Rate (BER). This in conjunction with the decreased fading at shorter distances, leads to efficient DCS and short relative re-use distances also for very small cells.

When using the 9 cell cluster for FCA in the comparison above, we did not include the large shadowing margins needed for pico cells. The shadowing varies from building to building, is different in different parts of the building, is different in different directions and is different at different times (e.g. an open or closed metal door). The figure 1 following illustrates PP and RFP propagation patterns in one vertical plane of a multi storey building.

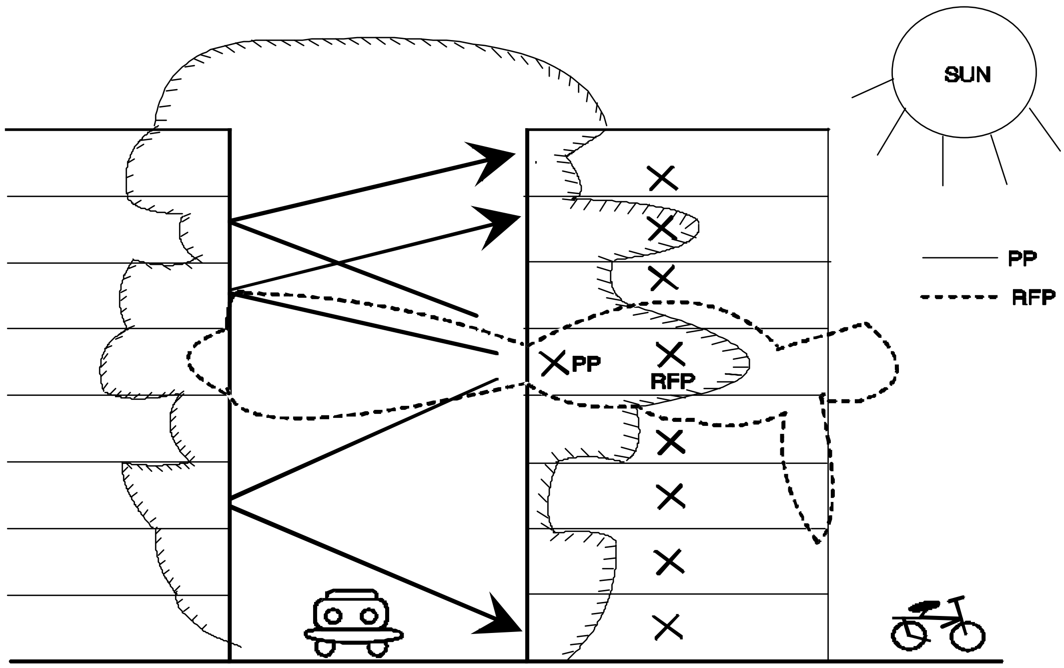


Figure 1: Example of irregular short range propagation patterns

These highly unpredictable, irregular and fast changing (in room and time) shadowing effects are characteristic for short range communications. For longer range communications, the propagation pattern is more predictable and the changes are slower.

The DECT Dynamic Channel Selection (DCS) in combination with its antenna diversity and seamless handover procedures elegantly deals with the above described irregular and fast changing conditions.

This type of shadowing effect will however make the engineering of a FCA system very difficult and will further reduce capacity due to the requirement of very large shadowing margins and if the engineering of an FCA system succeeds, it will be destroyed by reflections from a new building or when a neighbour sets up his independent system in an uncoordinated multi-system environment. See subclause 3.1.

NOTE: Comparisons of DECT and GSM capacities using FCA in the analysis of both systems, led to the expected result that GSM is about 5 times more frequency efficient than DECT. This difference only reflects the differences in modulation, detection and speech coding, but does not include the advantage of Dynamic Channel Selection (DCS) for DECT, when applying pico cells, nor the advantage in DECT of having a speech codec with a low number of quantisation distortion units (qdu's).

DCS is sometimes mentioned as a property of GSM, but that is a possibility to change the FCA, and it is not DCS in the DECT meaning.

Comparing DECT and GSM in simple capacity terms is hardly meaningful. The systems are rather complimentary to each other. They address different main services and are very different: DECT has DCS, GSM (DCS 1 800) has FCA. Due to the short range pico cells, DECT does not need to be so frequency efficient as GSM (DCS 1 800) in terms of channels per MHz. DECT provides telephony speech quality essential in an office, and GSM (DCS 1 800) provides interleaving with channel coding, which highly improves speech quality in fast fading etc.

DECT is very good for pico cells in a quasi-stationary radio environment including Telepoints. GSM (DCS 1 800) is superior in a mobile radio environment with fast fading, larger cell range requirements and slower changing and more predictable radio propagation patterns.

3.10.5 Conclusions

a) Fixed Channel Allocation (FCA) methods cannot be used to estimate capacity for Dynamic Channel Selection Systems (DCS). Simulations are needed, which use exact procedures and relevant radio characteristics.

b) In DECT the procedures for antenna diversity, seamless handover and DCS are designed to make quick adjustments in response to the rapid variations and unpredictable irregularities that are characteristic of a short range radio environment.

c) FCA is very difficult to use for three dimensional pico cell implementations and provides much less capacity per radio channel than DCS. In reality it is almost impossible.

d) FCA cannot be used at all in a multi-system multi-operator environment with uncoordinated installations, as required for the DECT service.

Annex A (informative): The DECT standard base station concept

The standard DECT base station Radio Fixed Part (RFP), consists of a single radio that can change frequency from slot to slot.

(This carrier change, during the guard time between two slots, 50 µs, can be provided by a fast synthesiser or e.g. by shift between two local oscillators, each having a simple slow synthesiser. In the latter case the duration of one slot, 0,4 ms, is available for a frequency shift.)

This simple, but powerful base station, can thus on each time frame operate on all 12 duplex time slots, each slot operating independently on any of the 10 DECT carriers.

This base station, with a complexity comparable to that of a DECT handset, has a capacity corresponding to 12 radios and a combiner in traditional land mobile radio systems.

It offers 5 E average speech traffic with a grade of service less than 0,5 %, corresponding to 25 hand sets with 0,2 E each in a PBX, or one base station per 1 000 sqm in a 5 000 E/km^2 telepoint service.

Annex B (informative): Dynamic Channel Selection (DCS) contra Fixed Channel Allocation (FCA)

Contributions or comparisons on spectrum requirements for DECT have earlier been made using fixed frequency allocation methods. These results have limited value when applied to systems with dynamic channel allocation, and wrong conclusions are easily made.

Absolute capacity estimations for Dynamic Channel Selection (DCS) can only be made by simulating the exact protocols and procedures and e.g. base station characteristics used by the system and effects of adjacent power and intermodulation.

As an example, we can compare the DCS simulation results for a multi-storey building with FCA with 3 floors re-use distance using Lee's formula:

n = 1/3(6 C/I) exp (2/b)

n is the number of cells in a cluster

b is the exponent in the propagation function

With C/I = 21 dB and b= 4, n is 9

The common parameters are:

- 1 % blocking;
- 9 bases per floor;
- 3 floor reuse distance;
- C/I limit for call set up 21 dB;
- d^{-4} propagation law with Rayleigh fading.

Table B.1: Simulated capacity with DCS

Average traffic per cell Erlang (E)	Total no of channels on 3 floors	
	Stand alone building	Surrounded by other systems
1,1	16	(30)
2,6	32	(60)
5,0	(60)	(120)

The values within parenthesis are estimations based on simulations and extrapolation of results from simulations. See Annex D.

The simulation shows how many E each base can carry in a three dimensional environment having a total of 16, 32 and 60 channels.

The FCA case is designed for the same traffic per cell. The second column below shows how many channels that have to be allocated to each cell to provide the traffic 1,1, 2,6 and 5,0 E. This number is multiplied with the total number of bases on three floors (9 x 3 = 27) to obtain the total number of channels required.

Table B.2: FCA with Lee's formula

Average. traffic per cell, Erlang (E)	No. of chan./cell 0,5% blocking	Total No. of channels 3 floors
1,1	5	135
2,6	8	216
5,0	12	314

The result is that for a stand alone house DCS is 6 - 8 times more efficient. This result can at first seem astonishing, but is reasonable after some deeper consideration.

One reason is that DCS does not need any shadowing margins. It adjusts to the instant situation and the shadowing allows sometimes shorter and sometimes longer re-use distances, it averages out.

Secondly, FCA has a fixed worse case re-use distance. DCS has a dynamic re-use distance. Portables close to the base station will have short re-use distance.

Thirdly, DCS gives a better trunking efficiency (especially for DECT). Any channel can be used by any base (typically up to 12 simultaneous channels per base). For DCS the average number of channels occupied per base equals the average traffic in Erlang per base: 2 - 5. For planning of a FCA system the maximum number of channels per base, 12, principally have to be regarded as occupied all the time. These gains have to be considered not only in two dimensions, but in three, and then the gain increases.

Another advantage of DCS is that as the cells are made smaller, the average wanted signal increases, leading to lower C/I (less noise) for constant Bit Error Rate (BER). This in conjunction with the decreased fading at shorter distances, leads to efficient DCS and short relative re-use distances also for very small cells.

When surrounded by other unsynchronised systems, DCS is 3 - 4 times more efficient according to the example.

This latter case will however by no means work with FCA since it will economically and practically impossible to coordinate frequency planning office pico cell with FCA between independent private users.

When using Lee's formula for FCA, we have not included the large shadowing margin needed for pico cells. The shadowing varies from building to building, is different in different parts of the building and different in different directions. This makes engineering of an FCA system very difficult and if you succeed, it will be destroyed, when the neighbour sets up his system. Also with only one operator FCA will be very sensitive to changes in the environment e.g. reflexions from new buildings.

Conclusion:

a) Fixed Channel Allocation (FCA) methods cannot be used to estimate capacity for dynamic channel allocation systems.

b) FCA is very difficult to use for three dimensional pico cell implementations and provides much less capacity per radio channel than DCS. In reality it is almost impossible.

c) FCA cannot be used at all in a multi-system multi-operator environment with uncoordinated installations, as required for the DECT service.

Annex C (informative): Simple planning guide for DECT base station locations in an office environment

C.1 Scope

The aim is to provide a few simple principles for choosing base station locations for DECT, especially in an office environment.

C.2 Introduction

DECT utilises an efficient and robust Dynamic Channel Selection (DCS) procedure, that is decentralized to each portable, PP, and its closest base station, RFP.

The primary advantage is that different systems and systems operators and different types of services, in a self organising way, can utilise the same group of available channels without prior distribution of channels to specific services or base stations.

Another very important aspect is that each service or equipment provider can, driven by the customer needs, increase the capacity by increasing his base station density.

These features in conjunction with the DECT standard base station concept greatly simplify planning for base station locations e.g. for office systems.

C.3 The DECT standard base station concept

The DECT standard base station concept is described in Annex A.

It consists of one single radio that can change carrier frequency from slot to slot. With the standard 12 duplex time slots, it offers up to 5 E (32 kbit/s speech) average traffic, corresponding to 25 PPs with 0,2 E each.

C.4 Needed spectrum, number of carriers

From simulations summarised in Annex D , the table below gives guidelines for a three dimensional office case (21 dB C/I limit for call set up). E(amax) is the maximum average speech traffic in Erlang for less than 1 % grade of service.

Table C.1: Guidelines for required number of duplex channels

CONDITION	E(amax)/RFP	N° of channels	N° of carriers
Natural extra isolation to RFPs from other systems	2,5	36	3
	5	60	5
No extra isolation to RFPs from other systems	2,5	72	6
	5	120	10

C.5 The planning procedure

a) Step 1

Estimate E(amax) from table C.1 in subclause C.4. Base it on information on "Condition" and "N° of carriers" (used by the system).

b) Step 2

Decide the range of an RFP in the specific building were the installation is to be made.

c) Step 3

Decide how much traffic (number of portables, E/PP) is to be generated in the different areas. (Take into account likely traffic increase from eventually added PPs).

d) Step 4

Place RFPs within maximum separation distance to meet the range condition.

e) Step 5

Check if the traffic generated within each RFP will be less than E(amax). If not, locate the RFP close enough to meet the E(amax) conditions.

NOTE 1: If it is known that the base station separation will be range limited, place the RFP's in stair ways, where the radio field easily spreads.

If it is known that the base station separation will be traffic limited, place the RFP's in corridors, where the radio field spreads less easily (beyond the wanted coverage).

NOTE 2: If it transpires that the traffic serviced in a part of the installation is too low, due to misjudgement or change in traffic requirements, extra base station(s) are easily added, with principally no need to review the planning criteria for the already installed RFPs.

NOTE 3: If the RFP network installation initially is made to cope with a traffic expected a few years from the installation date, the required gradual traffic increase will only need more resources at trunk level in the cordless central. These resources are speech processing and echo control circuits and trunks to the PABX.

Annex D (informative): Summary of simulation results

D.1 Introduction

This release mainly covers business and residential applications. More detailed results and conclusions for multi-bearer applications and public access applications will eventually become available as simulations and tests continue.

In the DECT reference document ETR 015 [1] (see Annex F) the main requirements on Grade of Service (GoS) and traffic density are given.

Validation of the DECT CI specifications [3] (see Annex F) on the Physical layer (part 2) and the MAC layer (part 3) is necessary to prove that these requirements can be met. Therefore RES3-R carried out simulations following a "Traffic and capacity simulation scenario for cordless PABX". See RES3-R(90)40 [4], RES3-R(90)40 [5], RES3-R(91)121 [15], RES3-R(PE)35 [16] (see Annex F). See Annex E for release 6,0 of the scenario. Release 6,0 is the same as release 5,0 except multi-bearers have been added.

In the following chapters a short overview is given of the main requirements from the DECT reference document, the main parameters defined in the simulation scenario and the most important simulation results obtained.

Results of simulations from different companies did agree very well. References given in this document is a representative minority of all contributions.

This summary annex also reports on simulation results for residential applications and on some relevant validation tests and simulations carried out earlier in the standardisation work.

D.2 Main requirements from the DECT reference document

D.2.1 Grade of service

Blocked call percentage ≥ 1 %

Interrupted call percentage ≥ 0,1 % (0,01 % preferred)

D.2.2 Busy hour traffic

The highest busy hour traffic figures are:

Residential systems:

- suburban houses: 150 E/km^2
- multi storey buildings: 250 E/km^2/floor

Telepoint systems: 5 500 E/km^2

PBX systems: 10 000 E/km^2/floor

Since the highest densities are for PBX systems in offices, the simulations mainly regard office systems.

10 000 E/km^2/floor corresponds to 0,2 E per 20 m^2/floor. An office telephone has 0,15 - 0,2 E busy hour traffic. DECT shall thus be able to provide 100 % cordless penetration in all office environments.

Measurements indicate that a DECT channel in average can be reused every third floor in multi-storey buildings. Therefore the simulations are made for a three storey building.

D.3 Simulation scenario

An overview is given of the main parameters defined in the scenario given in Annex E.

D.3.1 Office environment

The office is a square, 60 m x 60 m, 3 storey building without internal walls and zero floor thickness. The base stations are spaced regularly, e.g. 3 x 3, 4 x 4 etc. on each floor.

D.3.2 Traffic statistics

In this section the number of handsets in the building and the traffic generated by those handsets (call statistics) are described. The main points are:

- all users are static;
- all 120 full duplex channels are available;
- area per cordless terminal is 20 m^2;
- one cordless terminal generates 0,2E (0,15 in early simulations);
- the standard base station has 1 transceiver which can access all 120 channels by changing carrier frequency in the guardband between slots.

D.3.3 Radio propagation model

A simple propagation model is used containing mean power loss, signal shadowing statistics and multipath fading statistics. The necessary fade margin due to multipath fading is reduced by 10 dB if antenna diversity is applied. Also the receiver noise floor and the transmitted power level are defined here.

D.3.4 Call procedure

This section describes the method used for call set up and received signal strength (RSSI) measurement. The call set up threshold as well as the procedure is given and interrupted calls are defined. There are also included a handover procedure and a list of interference sources, co-channel interference, adjacent channel interference, receiver intermodulation and idle handset emissions.

D.3.5 Asymmetric channel allocation model

In this model it is assumed that 10 % of the cordless terminals are faxes. The faxes need channels with a 64 kbit/s bit rate instead of the 32 kbit/s for voice terminals. The number of voice terminals is therefore reduced by 20 % in order to keep the same overall traffic load.

D.3.6 Traffic density hot spots

On each floor 2 hot spots of 100 m^2 each are randomly positioned. Within the hot spots the traffic density is 2, 4 or 8 multiplied by the normal density. The total number of handsets within the building remains unchanged and there is no base station in the hot spots.

D.3.7 Results logging and presentation

A definition of the system Grade of Service (GoS) is given.

$$\text{GoS} = \frac{\text{blocked calls} + 10 \text{ interrupted calls}}{\text{all calls}}$$

The GoS shall be less than 1 %.

There is also described which results must be included in tables and/or graphs.

D.3.8 Residential environment

Simulations of GoS in a large area with densely installed non-synchronised residential systems. This is not included in the scenario.

D.4 Simulation results for the business environment

In this chapter results presented in RES3-R are discussed in brief.

D.4.1 Initial results

Several simulations have been carried out (see RES3-R(90)64 [6], RES3-R(90)78 [7], RES3-R(90)136 [9] (Annex F)) following a simplified version of the scenario (see RES3-R(90)40 [4], RES3-R(90)40 [5] (Annex F)) to get some first results and see if there were any ambiguities in the scenario. In the simplified scenario the influence of asymmetric channel allocation, handover and idle transmission is not included.

The main conclusion were:

- the results from different companies agreed very well;
- about 3 E average traffic could be generated per base station at 1 % GoS;
- the GoS is dominated by blocked calls, mainly due to "blind slot[1] blocking";
- the number of channels seems to be sufficient to serve the demanded amount of traffic.

Note that the performance will be influenced if all the interference sources are taken into account. See subclause D.4.3.

D.4.2 Effects of finite RSSI resolution at measurement of best base and quietest channel

One simulation with 100 % penetration is carried out with finite RSSI measurement resolution, see RES3-R(90)165 [10] (Annex F). The simulation includes handover, receiver adjacent channel selectivity and intermodulation.

See figure D.1a and D.1b. "RSSI" in the figures following mean non-ideal RSSI with 6 dB resolution. "Without" means ideal RSSI.

- The main conclusion is that the GoS is hardly influenced by non-ideal RSSI measurement.
- The number of handovers increases significantly, but still is a small portion of the total amount of calls.
- Another interesting result is that the average traffic per base station increased to 5 E for 1 % GoS. This is because limited adjacent channel selectivity reduces the blocking due to blind slots and that handover reduces the number of interrupted calls to virtually 0.

---

1) A blind slot is a physical channel which is in use for transmission from a handset to the base station and therefore cannot be used by another handset to communicate with the same base station. This channel occupancy cannot always be directly detected at channel selection due to large adjacent channel selectivity.

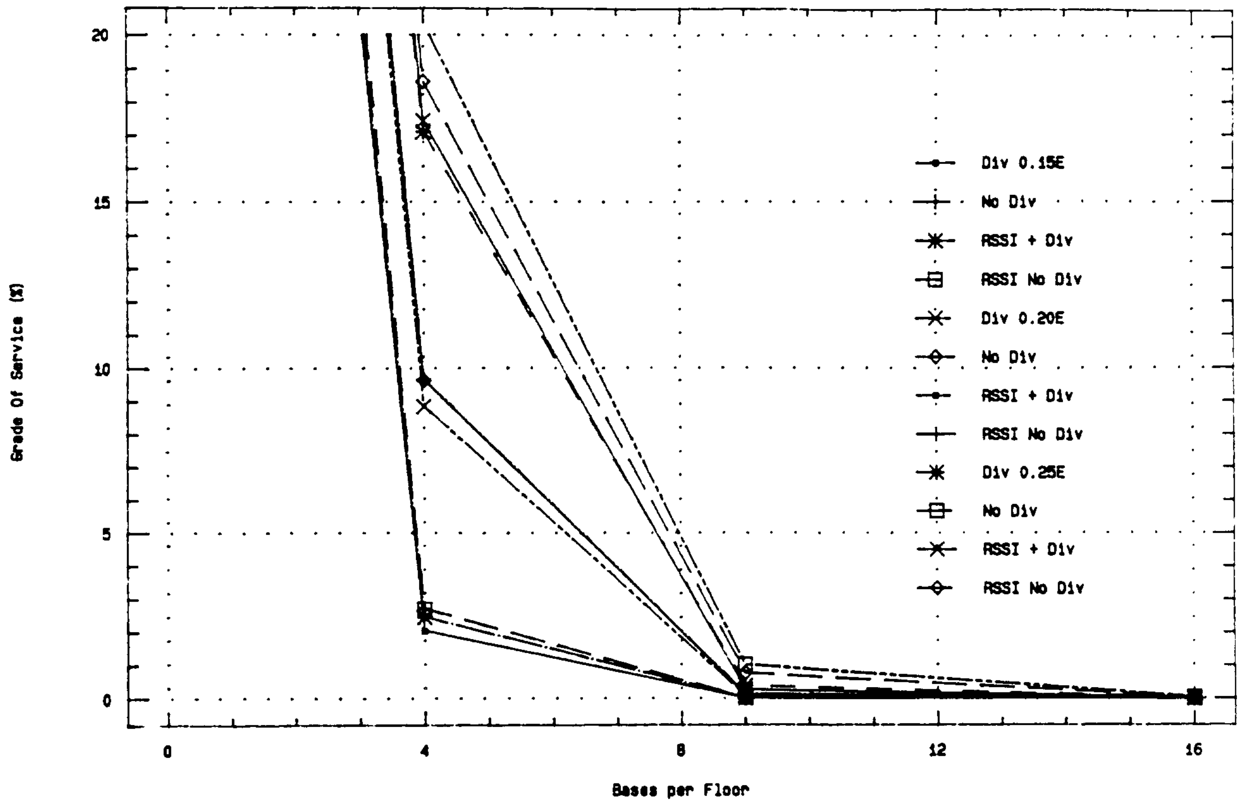


Figure D.1a: GoS with and without and with non-ideal RSSI including handover, adjacent channel and intermodulation interference for 0,15, 0,20 and 0,25 E per handset

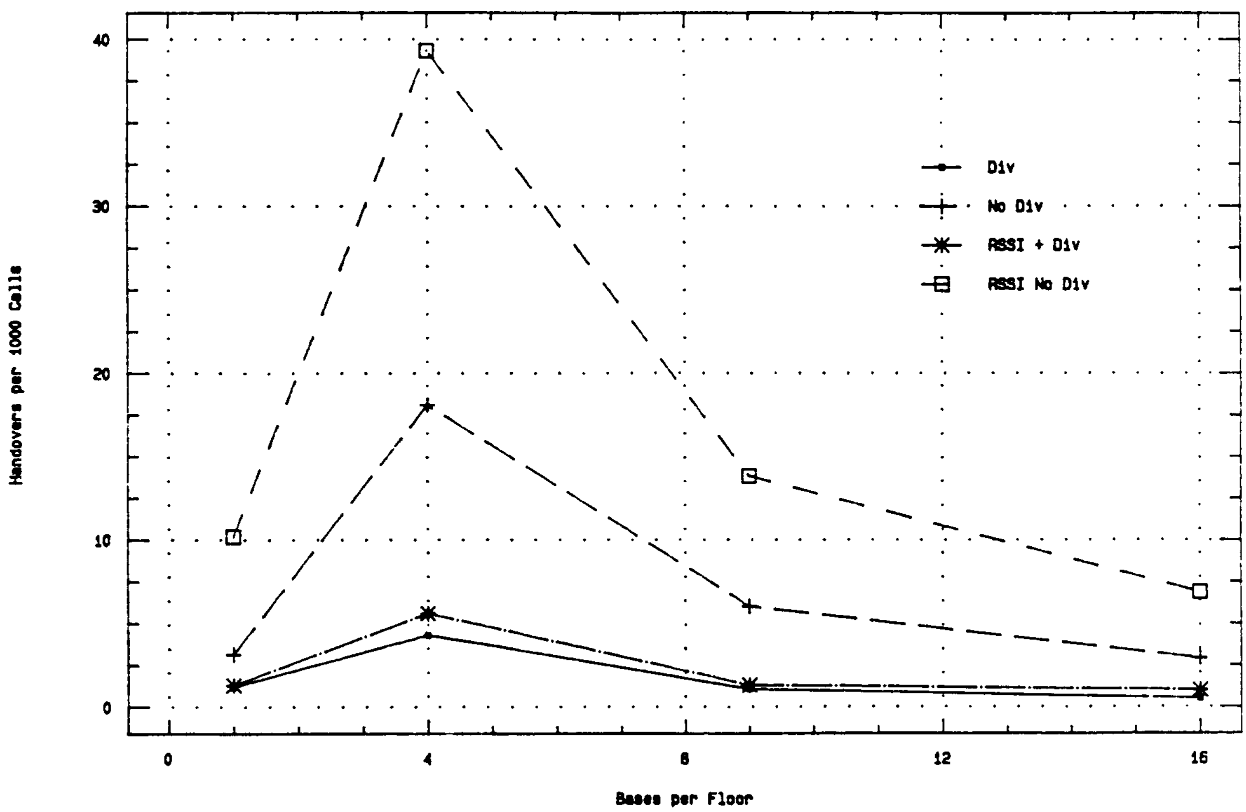


Figure D.1b: Handover statistics with and without non-ideal RSSI for 0,2 E per handset

D.4.3 The sensitivity to receive selectivity and intermodulation

In RES3-R(90)135 [8] (see Annex F) simulations conforming to release 2.1 of the scenario (RES3-R(90)133 [14] see Annex F) have been carried out. In RES3-R(90)135 [8] the influence of intermodulation adjacent and co-channel interference as well as some receiver specifications are separately considered.

Again the GoS as a function of the number of base stations per floor.

The main conclusions from RES3-R(90)135 [8] are:

- antenna diversity improves the GoS (See table D.1 following):

Table D.1: Examples of advantages of diversity and handover including interference from co-channel; adjacent channel and intermodulation.

Hand-over	Diver-ersity	Bases/ floor	Interrup-ted (%)	Blocked (%)	GoS (%)	Mean E /base	Handovers/ 1000 calls
No	No	9	0,14	0,008	1,48	2,99	-
	Yes	9	0,02	0,04	0,24	3,01	-
Yes	No	9	0,03	0,03	0,33	3,01	1,8
	Yes	9	0,0	0,05	0,05	3,04	0,9

- handover improves the GoS, although the number of handovers is small (See table D.1);

- the receiver specifications on third order intercept point and first and second channel selectivity does not limit the performance (RES3-R(90)135 [8]). See figures D.2a, D.2b and D.2c;

- analysis in RES3-R(90)135 [8] shows that the adjacent channel and intermodulation interference of fig. D.2a, D.2b and D.2c only affected the number of interrupted calls and not the number of blocked calls. As shown in Table D.1 adding handover to a diversity case will also mainly reduce the number of interrupted calls. Thus, for a system with handover the significance of adjacent channel and intermodulation interference will be even less than indicated in figures D.2a, D.2b and D.2c;

- it is clear that the capacity (GoS) was limited by blocked calls at set up, mainly due to blind spots.

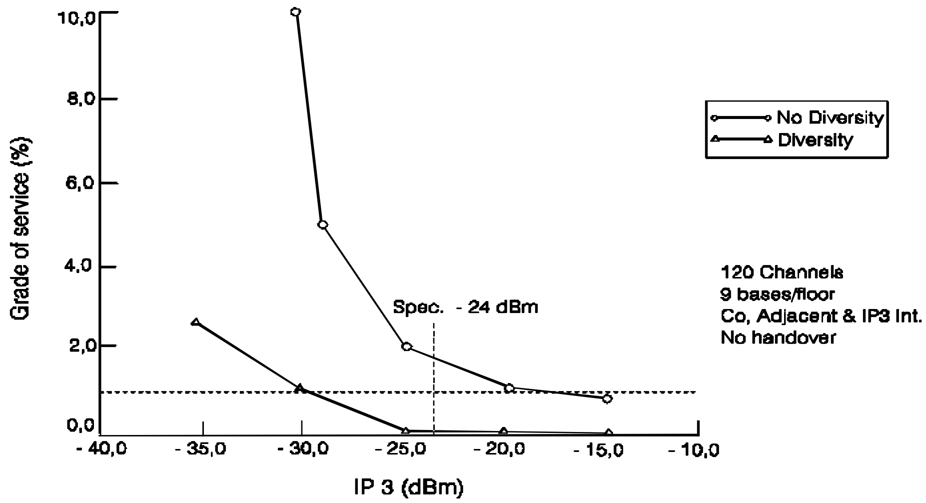


Figure D.2a: Effect of IP3 on GOS

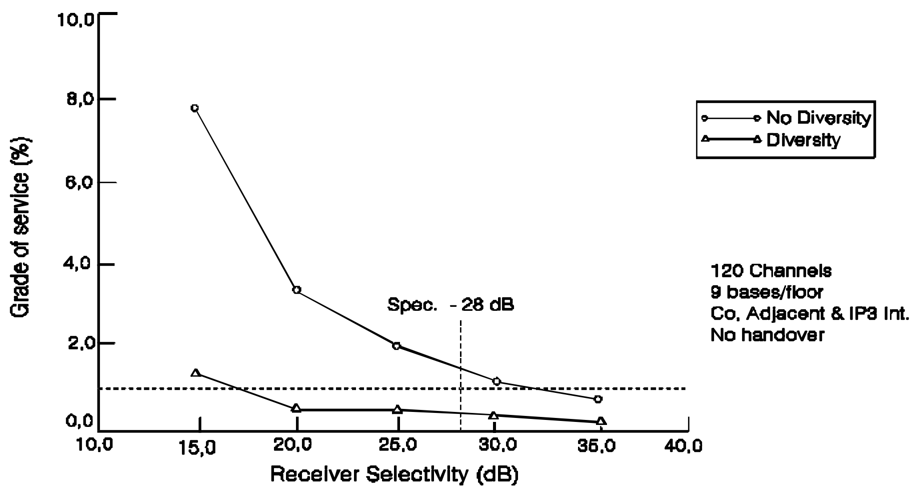


Figure D.2b: Performance with 1st channel RX selectivity

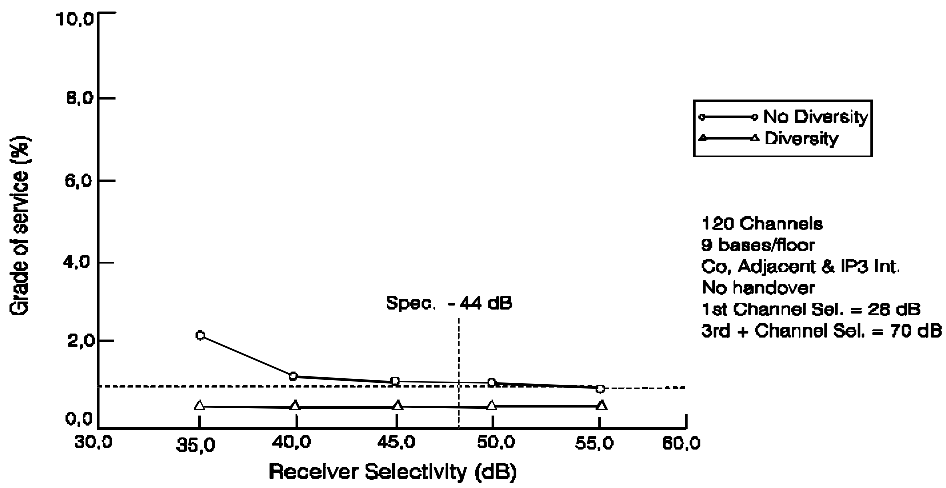


Figure D.2c: Performance with 2nd channel RX selectivity

D.4.4 Alternative call set up procedures that reduce the number of blocked calls due to blind slots

In RES3-R(90)181 [12] (see Annex F) the effects of several call set up methods are simulated for the case with handover and antenna diversity. The five curves 1 - 5 of figures D.3a and D.3b. relate to the following:

1: Try 5 channels on the strongest base.
2: Try 10 channels on the strongest base.
3: Blind slots known in handset while using the first standard method (time slots known).
4: Try 5 channels on the second strongest base if access fails on the five quietest channels of the strongest base (2 bases).
5: For comparison the traffic according to the Erlang-B formula for 12 trunks.

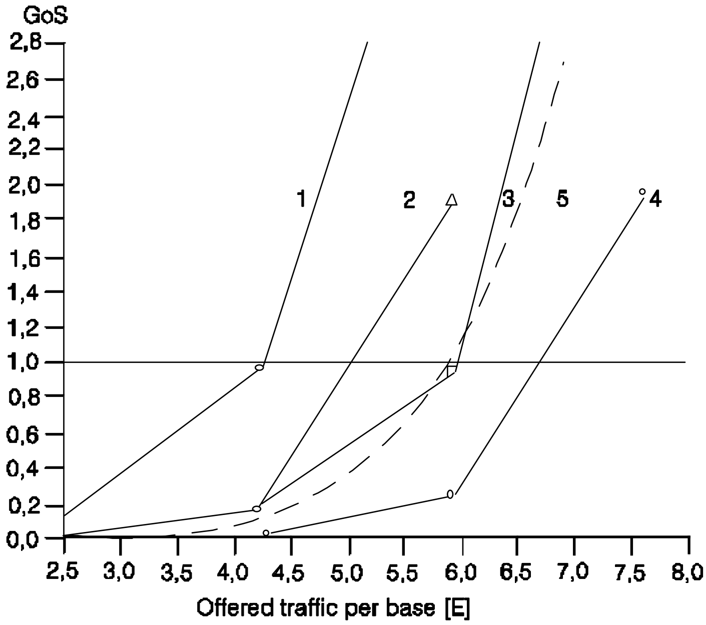


Figure D.3a: Effect of alternative call set up methods; 4 bases per floor

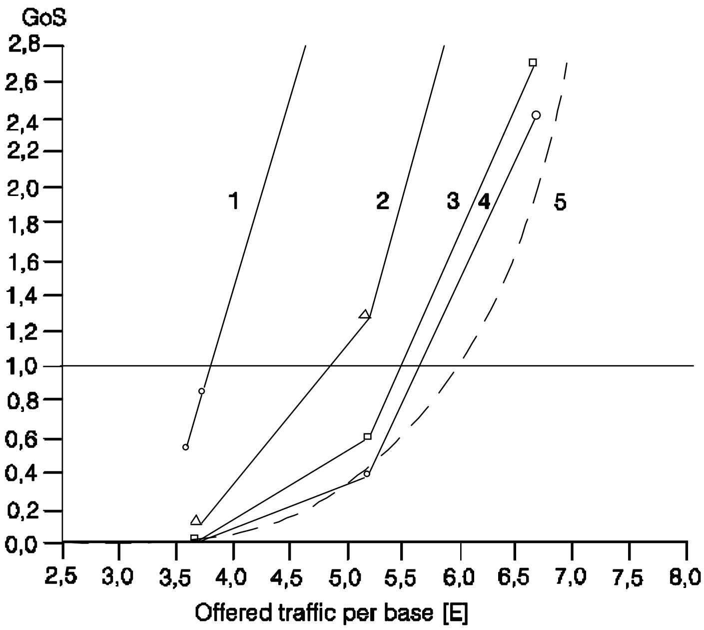


Figure D.3b: Effect of alternative call set up methods; 9 bases per floor

In RES3-R(91)(PE)12 [18] comparison between 5 attempts only on the strongest base and the case with 5 additional attempts on the second base confirms the results of RES3-R(90)181 [12] (see Annex F for reference).

Conclusions:

- the system capacity increases by 50 % for 1 % GoS compared with the first set up method if set up on the second strongest base is allowed; for lower GoS the capacity almost doubles;

- none of the alternative setup methods increase the number of interrupted calls;

- 5 E average traffic per standard DECT base station gives 0,1-1 % GoS.

NOTE 1: RES3-R(90)181 [12] (see Annex F) deviates from scenario release 5.0 in that sense that 11 carriers were used instead of 10, no adjacent channel or intermodulation interference was taken into account, but 30 % of the hand sets were randomly moving around during the simulation.

However, RES3-R(91)(PE)12 [18] (see Annex F) that closely follows scenario release 5.0 except for intermodulation confirm a 50-60 % improvement with the new call set up procedure. Traffic up to 7E per base station was generated at less than 1 % GoS.

The DECT specification allows the set up attempts to more than one base station. This improved set up procedure has been included in release 5,0 RES3-R(PE)35 [16] (see Annex F) and 6,0 of the Scenario.

D.4.5 Mixture of voice and asymetric data connections (10 % faxes)

In RES3-(90)178 [11] and RES3-R(90)185 [13] (see Annex F) asymmetric channel allocation is simulated.

The most important conclusions from figure D.4a of RES3-(90)178 [11] are (with a fixed number of base stations per floor):

- the voice GoS nearly equals the voice only GoS;

- the DownLink (DL) data GoS is approximately two times worse than the voice GoS, which could be expected;

- the UpLink data (UL) GoS is much worse than the voice GoS.

The poor GoS figures for data services are caused by bad channel selection and base station-to-base station interference. The first problem can be solved by measuring for double simplex transmission the received signal strength of the best channels in both halves of a frame, and provide this information from the handset to the base station in case of a data downlink, and from the base station to the handset in case of a data uplink. The second problem can be solved by alternative base station positioning schemes, e.g. 4 regularly spaced bases at the 1st and 3rd floor and 9 regularly spaced bases at the 2nd floor. See figure D.4b for the results.

Analysis of the results in RES3-(90)178 [11] shows that with advanced channel selection and non-aligned base position, voice data-DL and data-UL will have about the same GoS (0,4 - 0,75 % for 3,6 E per base). This coincides with results with handover but without diversity for voice only from table D.1.

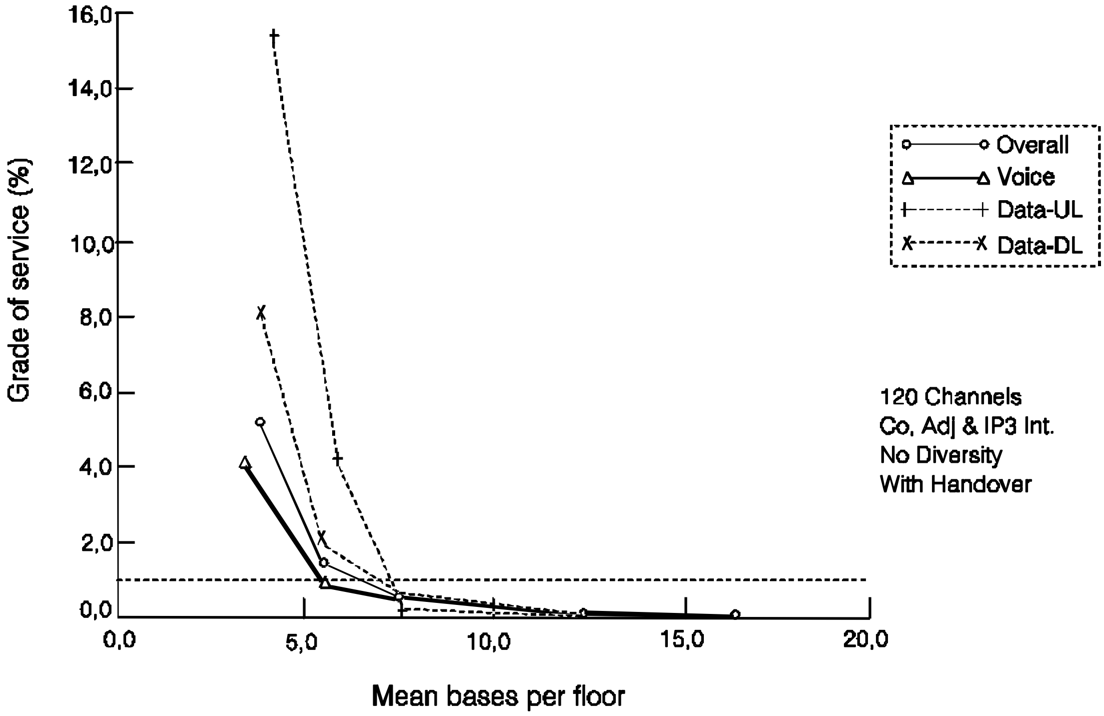


Figure D.4a: GoS with 10 % asymmetric channel use

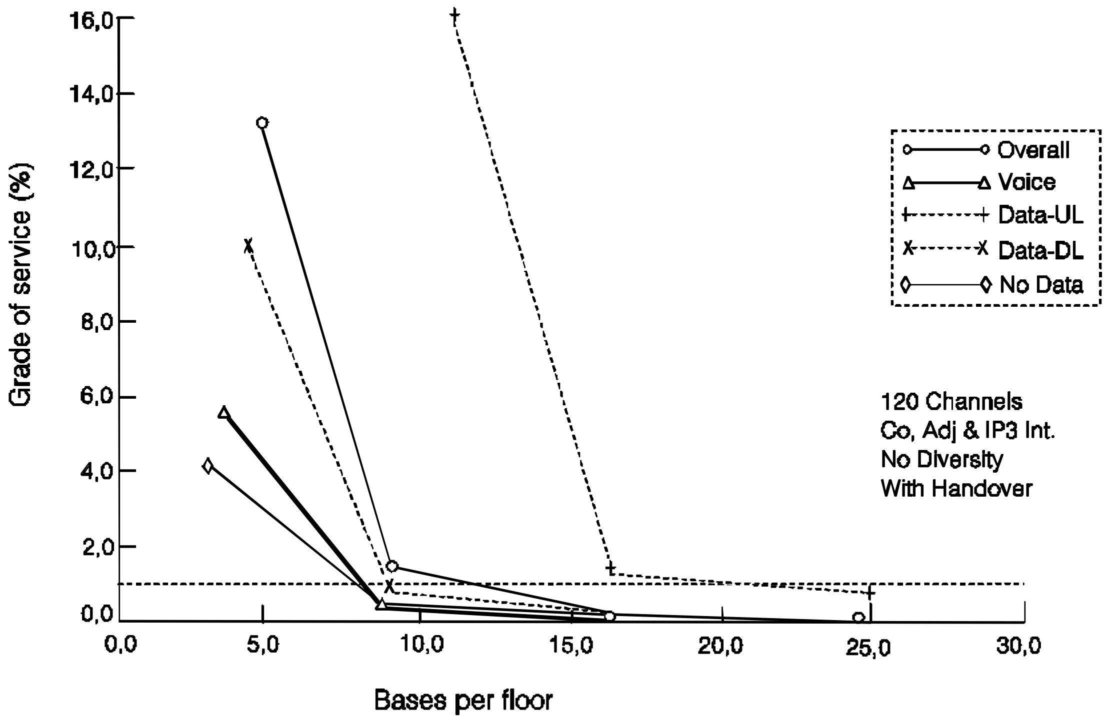
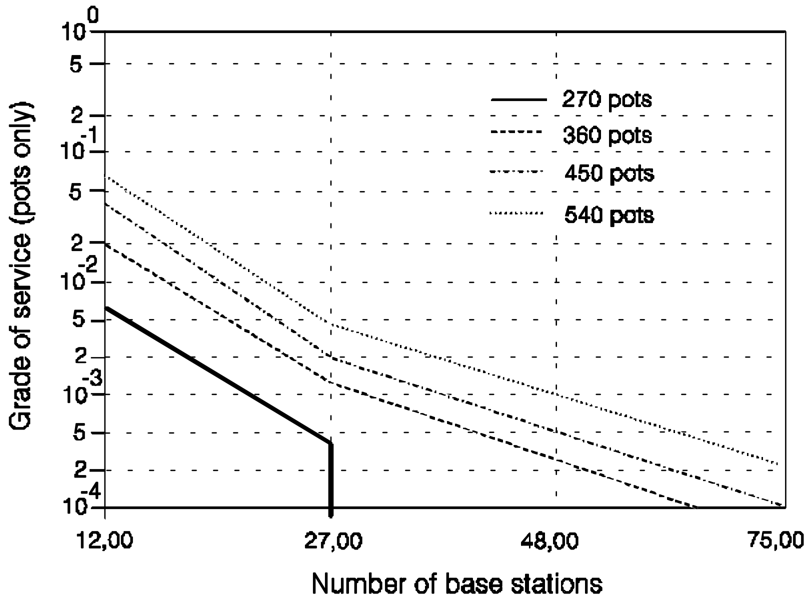


Figure D.4b: Performance with advanced channel selection and non-aligned base station positioning

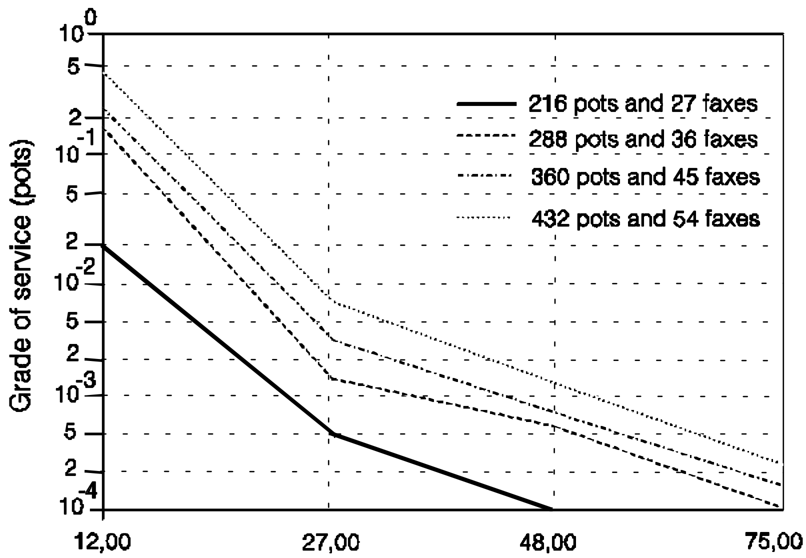
With diversity and set up attempts also to a second base as described in subclause A.4.4, we can expect to have 5 E per base station (as for voice only systems) for voice systems with 10 % asymmetric connections.

The simulations in RES3-R(90)185 [13] were made with advanced channel selection, with diversity, but without handover. See figures D.5a, D.5b and D.5c. The total number of 27 (9 per floor) base stations corresponds to 3 E per base station. The result for voice only agrees well with table 1. The results from RES3-R(90)185 [13] confirms the 2 result from RES3-(90)178 [11], that 10 % asymmetric connections will have very little effect on the GoS.



Number of pots:	270 - 540
Number of faxes:	0
Number of base stations:	12 - 75
Number of carriers:	10
Generated traffic per handset:	0,15
Average call length (s):	100
Number of calls:	20 000
Call setup threshold:	20 dB

Figure D.5a: Voice GoS without data terminals



Number of pots:	218 - 432
Number of faxes:	27 - 54
Number of base stations:	12 - 75
Number of carriers:	10
Generated traffic per handset:	0,15
Average call length (s):	100
Number of calls:	20 000
Call setup threshold:	20 dB

Figure D.5b: Effect of asymetric channels on voice GoS

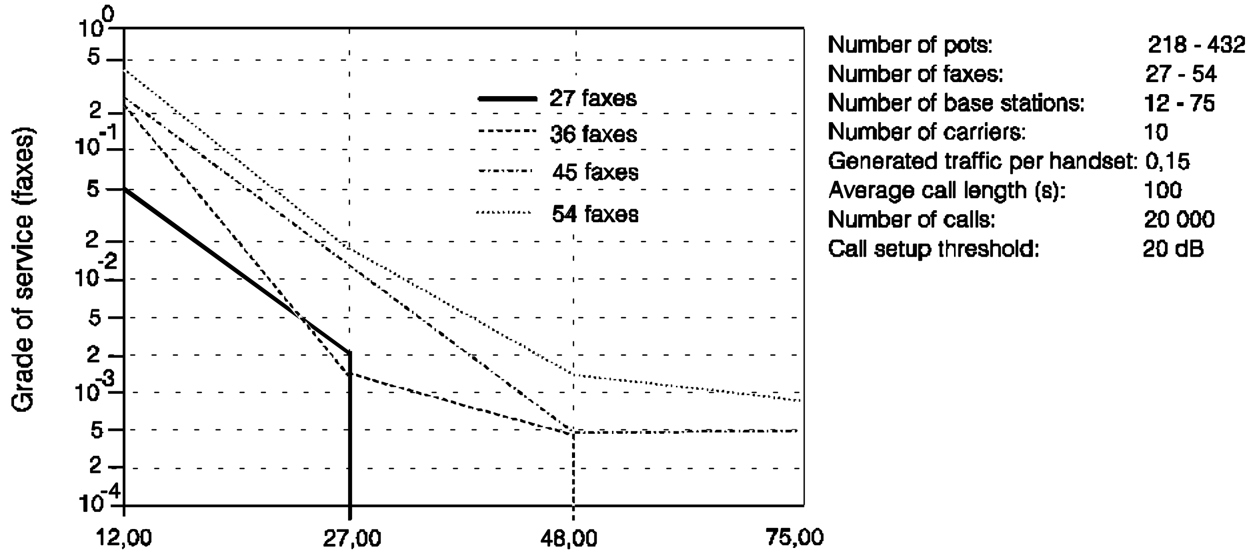


Figure D.5c: Effect of asymetric channels on data GoS

D.4.6 The sensitivity to hot spots

Hot spots are simulated in RES3-R(90)185 [13] (see Annex F). These hot spots were three 9 m^2 areas on each floor with relative densities ranging 1 - 64 (see figure D.6). Relative density 32 corresponds to 32 x 0,15 x 9/20 = 2,16 E. This corresponds to 3 data terminals per floor, continuously active on two duplex bearers each. This data traffic equals 24 % of the total traffic.

- The overall GoS was hardly influenced at all.

- The results however, did not separate GoS for terminals in or close to the hot spots, from the GoS from all other terminals.

This simulation differs from the scenario release 6.0. It simulates hot spots due to continuously operating data terminals, while the scenario specifies a situation typical for hot spots by closer positioning of handsets.

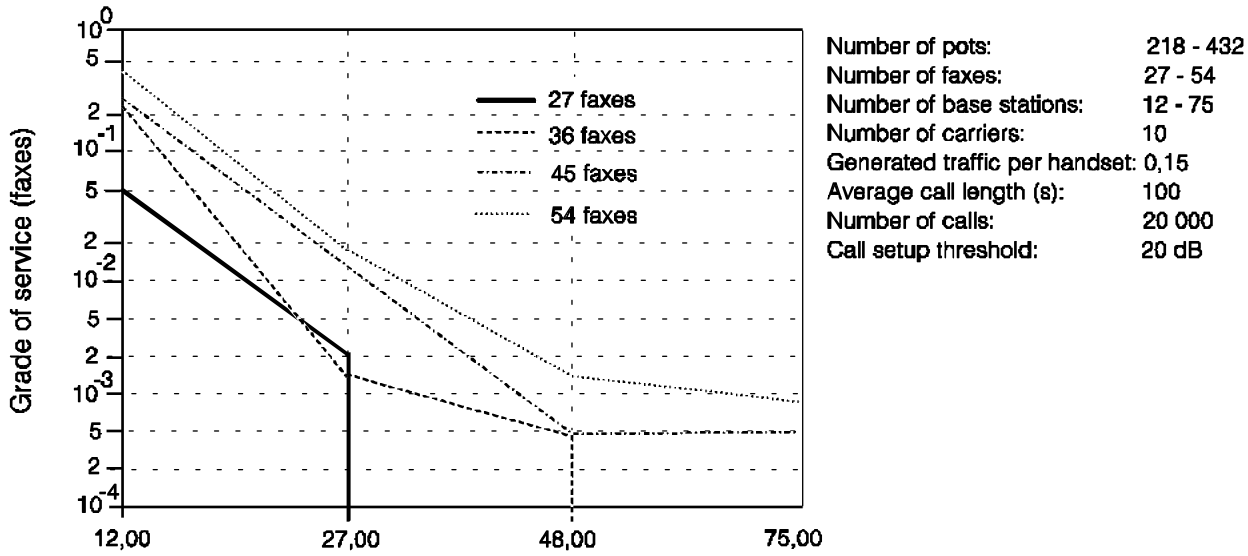


Figure D.6: Effect of "hot of spots" on system GoS

D.4.7 Effects of in-band spurious handset emissions

The effect of idle handset emissions, 2 nW on any carrier, and emissions between transmit bursts of handsets in call, 20 nW on any carrier, are simulated for 100 % cordless penetration in RES3-R(91)122 [17] (see Annex F). The distance to an idle handset is never less than 0,5 m and the distance to an active handset is never less than 1 m.

The simulation (handover, but no diversity) showed considerable degradation due to spurious. However, if the spurious was emitted on only one (random) carrier, the degradation was very small, also when the spurious from idle handsets was increased to 20 nW and for handsets in call to 500 nW. These exceptional increases are allowed on one DECT carrier according to the DECT specification, ETS 300 175-1 to -9 [2] (see Annex F). See figure D.7a.

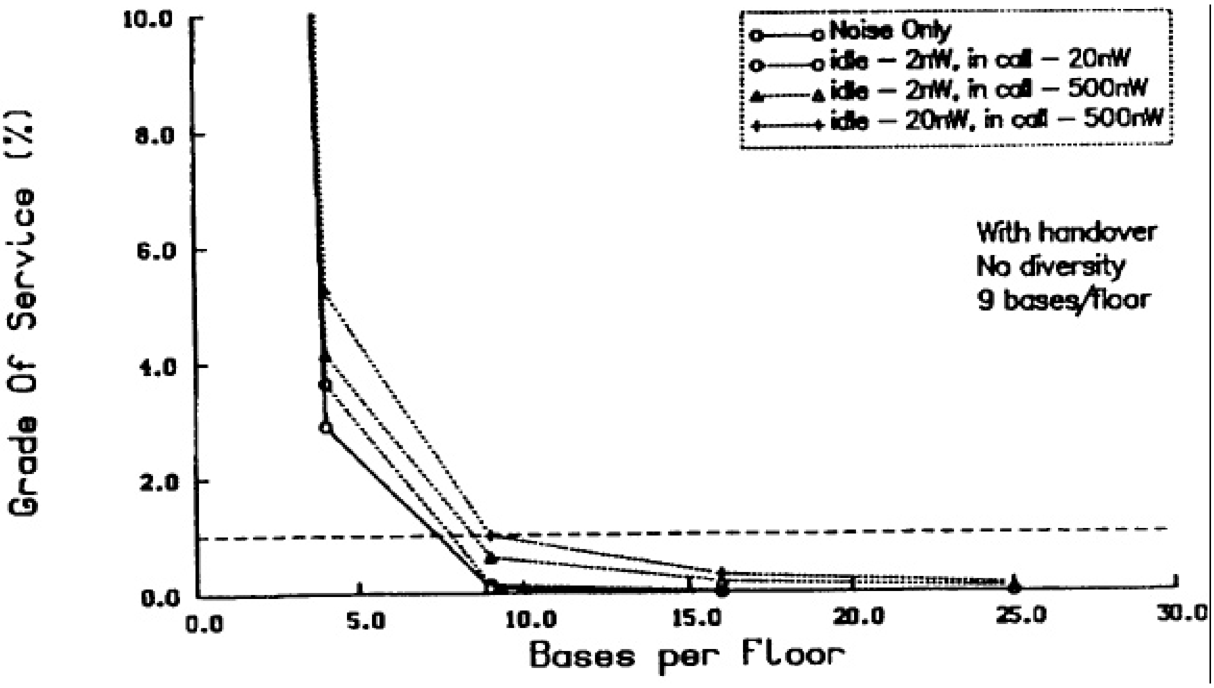


Figure D.7a: Spurious emissions on 1 carrier only

The propagation law from the scenario Annex E was used. 2 nW emissions 0,5 m away from a handset corresponds to - 77 dBm, and 20 nW 1 m away also to - 77 dBm.

The standard propagation law for short line of sight distances is more realistic for these handset emissions:

Power Loss (dB) = 38 + 20 log d.

Using this more realistic power law, 2 nW emissions 0,5 m away corresponds to - 89 dBm, and 20 nW 1 m away to - 85 dBm.

Thus according to figure D.7b, there will be no degradation even if every handset in call has an idle or in call handset at minimum distance, emitting on all carriers as in the scenario (handover but no diversity).

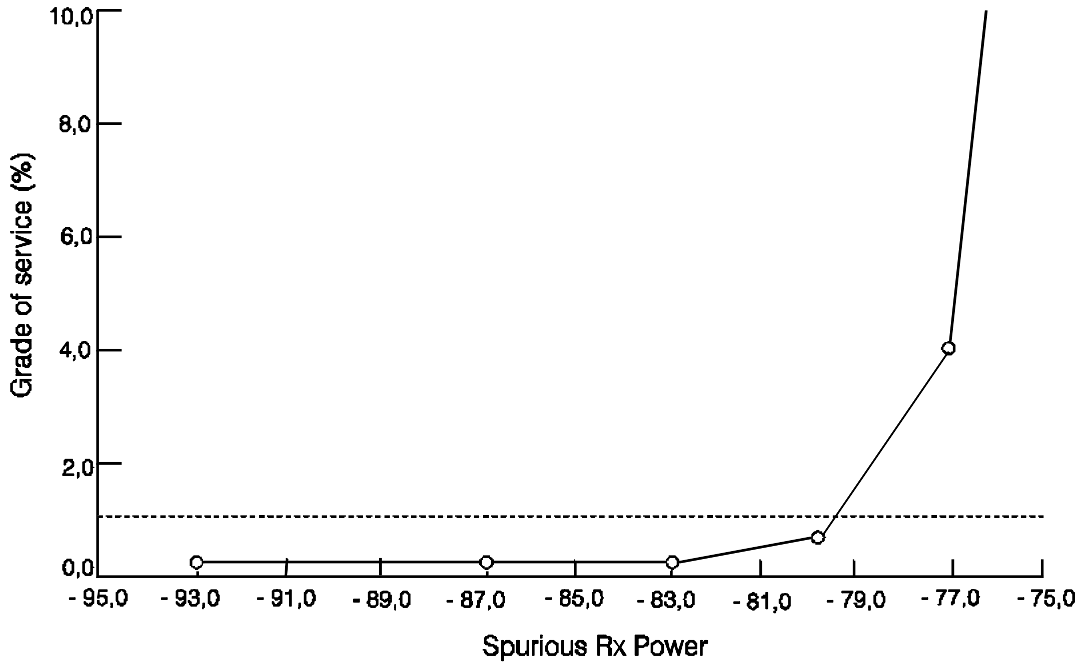


Figure D.7b: Varied received spurious emission level

With antenna diversity the results from figures D.7a and D.7b will further improve.

In RES3-R(91)(PE)12 [18] (see Annex F) the power law from the scenario Annex E is used. These results also show degradation when spurious are emitted on all carriers and very little effect when they are emitted on one carrier.

The conclusion is:

- hand set spurious are only influencing the GoS at the high hand set density cases;

- the effect is very dependent on the propagation model used for short range;

- with a realistic propagation model (and a realistic model for how many carriers a handset is able to emit spurious on), the spurious emissions for hand sets specified for DECT in ETS 300 175-1 to -9 [2] (see Annex F) will not degrade the system performance.

D.4.8 Guide lines for expected traffic capacity in normal office environments

The simulations discussed so far, have verified the relevance of chosen radio design parameters for DECT. However, the influence of normal open air spaces between bodies of office buildings is also important.

In document reference [20] (see Annex F) the traffic capacity for speech is simulated for a real 6 stories building shown in figure D.8. About half the area is open air between the bodies of the houses. The simulation was made for 3 floors with 9 (the crosses) and 14 (the circles) bases per floor, totalling 27 and 42 bases.

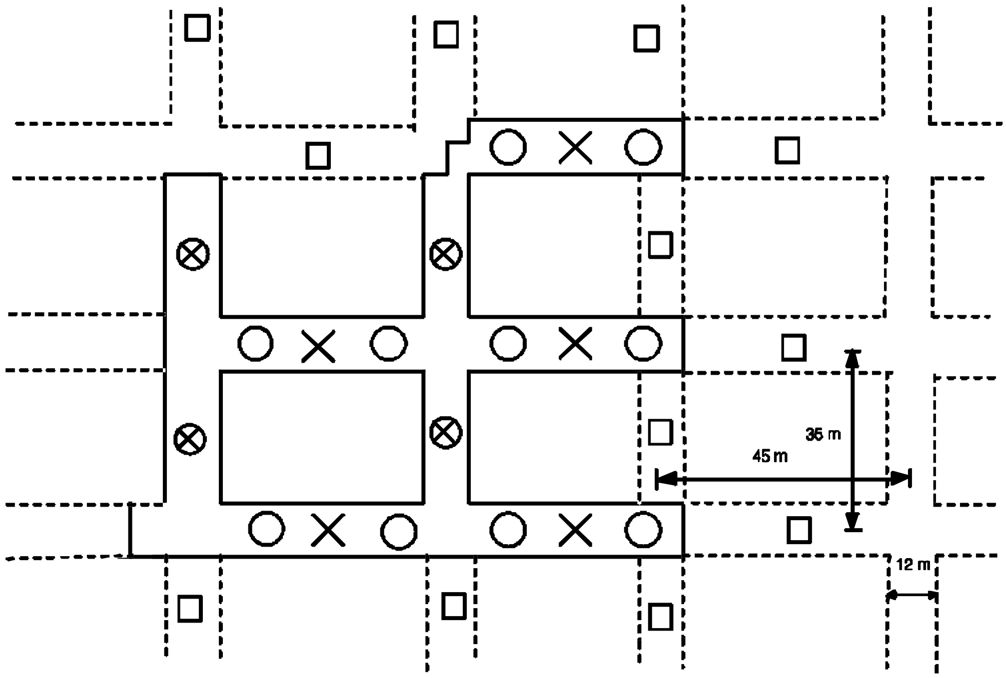


Figure D.8: Floor plan of modern building with 6 stories.

The propagation model was based on measurements in the building used for the simulations, and agrees well up to 40 m with the model from the scenario. The call set up and channel selection was made as in scenario release 5.0, with set up also to the second strongest base. Diversity and handover is implemented. The simulation was made for up to 32 duplex radio channels and with different numbers of TDMA/TDD slots in a frame.

For 32 duplex radio channels and 14 bases per floor a traffic of 2,4 E per standard base station is reported to give 0,1 % GoS with 16 duplex slots, and 0,6 % GoS with 8 duplex slots. DECT uses 12.

This result is very interesting, since from this result it can be estimated that a DECT system in the same typical building can offer about 5 E per base station using 60 duplex channels, with about 22 m average base station separation.

In simulations RES3-R(90)181 [12] and RES3-R(91)(PE)12 [18] (see Annex F) 6 E to 7 E was offered per base on an office floor without open spaces using the 120 duplex channels available for DECT. The dominant reason for this difference is that the majority of blocked calls occur in the intersection areas between cells (without any dominant closest base), and most of these areas in [20] (see Annex F) are in the open space where there are no hand sets.

This margin in capacity is needed for interference from unsynchronised neighbour systems. The theoretical maximum capacity decrease due to slot unsynchronisation is 50 %. In reality the degradation is less because the traffic is not always co-channel interference limited, and many cells have neighbour cells (synchronised) to their own system and there is often some natural separation between adjacent systems. A TDMA simulation from Japan uses 4 base stations per floor for three floors, as in our scenario. The capacity decrease was about 30 % for GoS around 0,5 %, when all 12 base stations were unsynchronised. Subclause D.6 following, includes unsynchronised systems in an suburban environment.

Although the capacity depends heavily upon the base station separation the following guideline is concluded:

- a DECT system using standard base stations offers 5 E average 32 kbit/s (speech) traffic per base with 0,1 to 1 % GoS. This requires 60 to 120 duplex channels (5 to 10 DECT RF carriers) or 10 to 20 MHz, depending on the building structure and the interference situation from adjacent systems. With 24 m hexagonal base station separation, 5 E per base corresponds to 10 000 E per km^2 per floor, or one handset with 0,2 E per 20 m^2 floor.

D.4.9 On range limitations

The ETSI Technical Report ETR 043 [3] (see Annex F) requires, excluding evolutionary services, a range of up to 200 m for business applications.

The nominal available path loss is 107 dB assuming a 10 dB noise figure and 21 dB C/N (antenna diversity) (see RES3-R(91)(PE)19) [21] (Annex F). A path loss proportional to the third power of the distance will support a 200 m range. The range will be 77 m with the in-door propagation model and 21 dB noise figure used in the scenario given in Annex E. It should be noted that the range may vary considerably depending on the environment and the use of antenna gain.

An even less predictable factor is co-channel symbol interference due to time dispersion. Dispersion equalisers are not intended to be needed in the DECT receivers.

Before the agreement in CEPT/ETSI to make the DECT standard, test systems similar to DECT working at 900 MHz using MSK with a bit rate of 1,3 Mb/s, were used to demonstrate and check performance and critical parameters. The test systems had 32 kbit/s 2-way speech and seamless handover and PABX connection facilities. The practical tests with 2-way speech indicated a surprisingly low influence of time dispersions see documents CEPT R22 adhoc ETC-8 [22], RES-3(88)23 [23] (Annex F). In document [22] the tests were made in a larger modern office building, in a large metal workshop and open yards surrounding the office building. Performance limitations due to time dispersion could not be detected. The system was reported to behave like a narrowband system.

In order to follow up the indications from document [22], further tests given in RES-3(88)23 [23] (see Annex F) were conducted by the radio working group (at that time organised by ECTEL/TCS). The tests were made in areas with relatively high field strength and with known RMS delay spread of 100 ns and 200 ns. No objectionable effect of time dispersion could be detected during the subjective speech test carried out. The system had no speech muting and the antenna diversity was disabled. The measurements showed that the spots with effects from time dispersion were very small and highly correlated with fading amplitude dips. Therefore, well designed antenna diversity can improve performance in time dispersive, quasi stationary environments typical for DECT.

How well do these results agree with results from proper simulations?

The very limited comparison that could be made between the results in RES3-(88)23 [23] and a recent simulation given in RES-3(PE)75 [24] (see Annex F) shows for high field strength, 100 ns RMS delay spread and no antenna diversity, that the number of slots with errors measured in the test in RES3-(88)23 [23] and those indicated by the simulation in RES-3(PE)75 [24], were almost the same. That is not a bad agreement, and thus there is no reason to question the model used in the simulations.

In document [28] (see Annex F) is stated that recent indoor measurements suggest typical delay spread values of 50 ns and maximum delay spread values of 100 ns, and that DECT will meet the requirement for a worst case indoor estimate of 200 ns with a carefully designed antenna diversity. The limit for acceptable performance was in [28,24] a bit error rate of 10^{-3} or a slot error rate of 10^{-2}.

However, the users in RES-3(88)23 [23] did not recognise any degradation in a 200 ns RMS delay spread environment, even without antenna diversity. This result suggests that in an indoor environment the subjective perception of occasional losses of 10 ms speech frames while the vast majority of frames are error free, is less critical than anticipated in the conclusions of RES-3(PE)75 [24] and document [28] (see Annex F).

The performance of the test system given in RES-3(88)23 [23] could be the performance limit expected from a well designed DECT radio link for the following reasons:

- time dispersion characteristics at 900 MHz and 1 800 MHz are similar (see COST 231TD(91) [27]) (see Annex F);

- an ADPCM codec with a well designed muting function could have as good performance as a delta modulated codec without muting;

- the chosen DECT modulation, GFSK, with deviation characteristics equivalent to GMSK with a nominal BT value of 0,5, has sensitivity and C/I performance very close to MSK used in the test, *provided that the receiver IF filters are as wide as allowed by the DECT specification. BbT may be about 1,5 according to subclause 3,1 of [24]. A wide IF filter is thus important to optimise against time dispersion;*

- the test system given in RES-3(88)23 [23] had a C/I performance similar to figure 8 of [24], that is BER less than 10^{-3} for C/I = 4 dB at high field strength. *The bit and word synchronisation circuitry thus has to be well designed.*

The simulations indicate that DECT with well designed antenna diversity meets the indoor range requirements without the need for receiver equalisers. Furthermore, the practical test suggests that for a well designed system, e.g. with proper speech muting, the subjective perception of time dispersion effects is less critical than anticipated.

D.4.10 Multi bearer connections

Simulations of multibearer connections is an ongoing activity.

Early results given in RES-3(PE)79 [25] (see Annex F) report that for systems with only one type of connection, the average number of simultaneous connections per DECT standard RFP for 1 % GoS are (1 E_C relates to 1 connection independently of how many bearers are used for this connection):

- for 3 symmetric linked full slot bearers per connection 0,82 E_C;

- for 2 symmetric linked full slot bearers per connection 1,9 E_C;

- for 1 symmetric full slot bearer per connection (speech) 5,8 E_C.

This aligns very well with the GoS obtained when applying the Erlang B equation for 4, 6 and 12 trunks. This could be expected from earlier experience.

The case with 10 % symmetric full slot multibearer connections and 90 % symmetric full slot single bearer connections (speech) given in RES-3(PE)92 [26] (see Annex F) gave the following results with 1 % GoS for the multibearer connections:

- with 3 multibearers 0,28 E_C (2,5 E_C and 0,1 % GoS for the speech);

- with 2 multibearers 0,39 E_C (3,5 E_C and 0,25 % GoS for the speech).

Three multibearers may be used for a 1B + D ISDN service. For the conditions used, the speech capacity per RFP is halved (5,8 to 2,5 E) when each telephone user (0,2 E per user) utilises the 1B + D service 2 % of the time. To maintain the speech capacity, the number of RFPs have to be doubled or the number of full slot channels per RFP have to be increased beyond 12. If the ISDN service can afford more than 1 % GoS, then the decrease in speech capacity will be less.

D.5 Simulation results for the public access profile

As a result of the complex and varied nature of the public access propagation environment, from open rural to highly cluttered cities, definitive conclusions on DECT's performance cannot yet be drawn by ETSI RES3.

Key issues in this regard are signal level variations and time dispersion characteristics in a non-stationary environment.

D.6 Simulation results for the residential environment

Document RES3-R(91)(PE)35 [19] (see Annex F) gives results for a residential suburban environment with 200 E/km^2 traffic. The following scenario is used:

- residential suburban environment - 4 000 users/km^2;
- the environment is a regular pattern of houses;
- each house is 10 m square;
- each house is situated centrally in a garden 15,81 m square;
- a total area of 490 x 490 m is analysed (961 houses);
- one base is positioned randomly in each house;
- one terminal per base;
- bases operate asynchronously;
- each beacon has an individual frame and multiframe reference;
- bases have a constant slot drift between + 10 ppm to - 10 ppm;
- each base operates a Dummy Bearer, which is an idle short beacon. In RES3-R(91)(PE)35 [19] this short beacon is referred to as an A field only transmission.

As idle bases transmit only an A field, traffic due to calls becomes significant. Therefore traffic has been introduced as follows:

- mean call duration = 100 secs;
- mean inter call arrival time per handset = 2 000 secs.

This equates to a mean of 0,05 Erlangs offered by each handset and to 200 E/km^2 with 4 000 handsets/km^2.

- normal handover and PP initiated change of Dummy Bearer channel allocation is implemented.
- if the C/I of the received Dummy Bearer decreases below 25 dB, the handset selects a "free" channel and sends a "Change Dummy Bearer Request" to its base, see [3] in Annex F. The base shall respond by changing the dummy bearer to this "free" channel, if the received C/I is at least 25 dB.

The following results were obtained:

- a residential user can use his handset over the area of 20 neighbour properties (of 250 m^2 each) surrounding his own house, with 1 % GoS at the most distant locations. Each of the surrounding neighbours also has a DECT residential system;
- DECT will give an adequately good coverage for residential suburban users also when each neighbour has an own unsynchronised DECT system;
- the key for good coverage beyond the own property is the short A field only Beacon Carrier combined with Beacon Carrier Change Requests when required by the handset;
- influence of different propagation models was small, since the coverage area was traffic limited rather than noise limited.

D.7 Conclusions

D.7.1 Base station traffic capacity

A standard DECT base station can offer at least 5 E average speech (1 duplex 32 kbit/s bearer) traffic with 0,1 - 1,0 % GoS in an office environment. This is also the case when 10 % of the calls use asymmetric bearers.

D.7.2 System traffic capacity

5 E per base corresponds to 10 000 E/km^2/floor if the base stations are separated by 24 m. 10 000 E/km^2/floor corresponds to one 0,2 E user 20 m^2.

D.7.3 Resistance to interference

Due to the Dynamic Channel Selection (DCS), the C/I limited range, and the fast (seamless) handover the capacity can always be increased, or the influence of interfering sources decreased by moving the base stations closer.

D.7.4 Importance of bearer setup procedures

A good set up procedure is critical in order to avoid blocking due to "blind slots" at the base station. Poor adjacent channel receiver selectivity helps, and allowing another 5 attempts on a second base gives as good result as knowing the blind slots.

D.7.5 Asymmetric connections

Asymmetric bearers do not degrade the GoS for symmetric bearers. A correct channel selection procedure is critical not to degrade the GoS for asymmetric bearers.

D.7.6 Importance of RF characteristics

The relatively low DECT requirements on:

- receiver selectivity;
- transmitter modulation power in adjacent channels;
- intermodulation;
- and receiver in-band spurious;

are not critical or limiting the performance of DECT.

D.7.7 Accuracy of the RSSI measurements

A resolution of 6 dB in RSSI measurements is not critical.

D.7.8 Effects of 'hot spots'

Including "hot spots" did not indicate any dramatic changes.

D.7.9 Receiver influences on the range of DECT

For DECT systems without receiver equalisers, time dispersion is not expected to limit the possible range for the ranges required for essentially indoor business applications in the DECT Services and Facilities Document ETR 043 [3] (see Annex F). Further tests are required to conclude on range limits and performance for public access and evolutionary applications.

D.7.10 Effects of antenna diversity and handover

Antenna diversity and handover (intra and inter-cell) are key features in reaching the reported results (in combination with the relatively large number of TDMA slots, and the standard DECT base station that communicates on one time slot at a time).

D.7.11 Performance in the residential environment

DECT meets with a high margin coverage and GoS requirements in a suburban residential environment where each villa has an unsynchronised residential DECT system.

Annex E (informative): Cordless PABX simulation scenario

Status

Release 6.0.

Release 6.0 follows 5.0 and includes the following:

- modified set up algorithm as in 5.0;
- multi-bearers.

Parameters for the simulation are divided up under the following headings:

E.1. Office environment

E.2. Traffic statistics

E.3. Radio propagation model

E.4. Call procedure

E.5. Multi-bearer channel allocation model

E.6. Results logging and presentation

E.1 Office environment

This section specifies the parameters necessary to describe the office environment in which the system will operate.

E.1.1 Office building dimensions

Square three storey building 60 m x 60 m x 9 m. 3 m between floors, zero floor thickness. No internal walls. A uniform density is assumed with the effect of objects causing possible radio shadowing included in the radio propagation model.

E.1.2 Base station positioning

Base stations are spaced regularly on each storey e.g. 3 x 3, 4 x 4, 5 x 5, etc., and are attached to the ceiling.

E.2 Traffic statistics

The traffic characteristics within the building are described below.

E.2.1 Number of handsets

One telephone per 20 m^2 of floor area equates to a total of 540 telephones within the building.

- for 10 % cordless penetration = 54 handsets within the building;
- for 30 % cordless penetration = 162 handsets within the building;
- for 70 % cordless penetration = 378 handsets within the building;
- for 100 % cordless penetration = 540 handsets within the building.

E.2.2 Call statistics

E.2.2.1 Call length

Negative exponential distribution with a mean of 100 seconds.

E.2.2.2 Single handset inter call arrival time

Negative exponential distribution with a mean of 500 seconds.

The two previous parameters define a Poisson distribution call arrival rate with each handset offering 0,2 Erlang. If the Poisson statistics generate a call, event when all cordless handsets are conducting a call the event is ignored.

E.2.2.3 User mobility

All users are static throughout the duration of a call. Later more advanced scenarios will introduce mobility.

E.2.2.4 System spectrum allocation

Full 120 duplex physical channels available. 10 radio channels. 12 duplex pair time slots per radio channel.

E.2.2.5 Base station implementation

Standard single transceiver base station capable of switching between any radio channel within the interslot guard space and operating on the adjacent time slot.

E.3 Radio propagation model

This clause describes the radio propagation model to be used in the simulation. It assumes static radio propagation conditions during a call. (Linked to the assumption that handsets are static whilst in a call.)

E.3.1 Mean power loss model

Power Loss = - Unit Loss + 10 (n) log (Range) + k(Floor loss)

Unit Loss = 30 dB
Power decay index n = 3,5
Floor loss = 15 dB
Range = 2 dimensional horizontal x - y range
k = Number of floors

E.3.2 Signal shadowing statistics

An even distribution random factor between - 10 dB and + 10 dB is to be added to the mean power loss figure derived above. The shadow factor from point A to point B is equivalent to that from B to A. Each individual signal and interference link between a handset and the base station has an associated shadow factor that is created and used whilst channel sounding and remains constant for the duration of the handset's call.

E.3.3 Multipath fading statistics

Rayleigh statistics are assumed and a fade margin is included to compensate for the potential outage. For 1 % outage with antenna diversity the margin is 10 dB and without antenna diversity the margin is 20 dB.

E.3.4 Receiver noise floor

The receiver noise floor, N, is - 93 dBm, allowing for a 1 MHz noise bandwidth and 21 dB noise figure.

E.3.5 Transmitted power level

The transmitter power level is 250 mW.

E.4 Call procedure

This section describes the method used for call set up and signal strength measurement. The call set up threshold is given and blocked and interrupted calls are defined. Interference sources to be included are listed.

E.4.1 Call set up threshold

The call set up threshold is 30 dB without antenna diversity corresponding to 10 dB C/(I + N) plus a 20 dB Rayleigh fade margin or 20 dB corresponding to 10 dB C/(I + N) plus a 10 dB Rayleigh fade margin with antenna diversity.

E.4.2 Interference sources

Sources of interference and their description are listed below. All separate interference sources are added linearly to give a final combined interference value at a base station or handset.

E.4.2.1 Co-channel interference

Interference from neighbouring users on the same channel.

E.4.2.2 Adjacent channel interference

Interference comprising both receiver selectivity and modulated emissions. The final adjacent channel interference level is obtained by adding all the contributions linearly.

Receiver selectivity:

- First radio channel = - 28 dB;
- Second radio channel = - 44 dB;
- Any other radio channel = - 50 dB.

Modulated emissions:

- First radio channel = 160 µW;
- Second radio channel = 1 µW;
- Any other radio channel = 20 nW.

Second and higher order combinations of receiver selectivity and modulated emissions are considered negligible.

E.4.2.3 Receiver intermodulation

Only third order intermodulation products are included. Intermodulation is related to the non linear front end element by:

$$P_{out} = a_1 P_{in} + a_3 P_{in}^3$$

This provides intermodulation interference products of the form:

$$a_3 \frac{3}{2} ABC \sin(a + ß - y)$$

$$\text{and } a_3 \frac{3}{4} A^2 B \sin(2a - ß)$$

The third order Intercept Point IP3 can be derived from a_1 and this should be varied between - 15 dBm and - 25 dBm. Activity on all other carriers within the DECT band should be considered when calculating intermodulation products. All intermodulation products are added linearly to arrive at a final figure for a handset or base.

E.4.2.4 In-band spurious handset emissions

The aim of this section is to simulate an average level of background interference across the whole DECT band due to idle handset spurious emissions.

It is not envisaged that every simulation run would include idle handset spurious emissions but when they are included the method detailed below should be used.

At the beginning of the simulation run all handsets are assigned a random position within the building. All handsets continuously generate 2 nW on every DECT radio channel except when transmitting (then the emissions are as per the modulated emissions detailed above) or when in-call but idling between transmissions (20 nW emission on all radio channels).

Handsets are selected for call set up and randomly positioned as detailed in subclause 4.5 following. After the call the handset remains in this position generating idle emissions until next selected for a call.

E.4.3 Call initiation

All calls are assumed to be to external recipients and are initiated by handsets. Initiation by handsets will make no difference to the results at this level of simulation.

E.4.4 Signal strength measurement

Perfect RSSI measurement resolution is assumed.

E.4.5 Call set up procedure

a) When a call set is scheduled an active handset is created which is randomly positioned within the building. If placement is horizontally within 1 metre of a base station then it is repositioned by a second random process. Height is irrelevant if horizontal range is used in the propagation model.

b) The handset measures received signal strength levels, C, from all base stations. In reality this is done using the base stations' ongoing calls or idle beacons.

c) The handset selects the strongest suitable base for a call set up attempt. Suitable means that at least one bearer from that base is received with C/(I + N) larger than the Call Set Up Threshold.

d) The I + N value for all channels not used by the selected base is recorded, where I is other base station co-channel interference.

e) The channel with the smallest (I + N) at the handset is selected if C/(I + N) is greater than the Call Set Up Threshold at both the handset and the base station. Then the call is established.

f) Up to 4 further channels may be attempted, in order of decreasing C/(I + N) at the handset, to try to obtain C/(I + N) greater than the Call Set Up Threshold at both the handset and the base station. After another 5 unsuccessful attempts on the second strongest base the call is recorded as blocked.

g) No additional call set up attempts are permitted on new base stations.

Although many different call set up strategies are possible, the above has been chosen to provide a base for comparison.

E.4.5.1 Call set up collisions

If two or more call set ups are scheduled to occur simultaneously to separate base stations then all interference from ongoing calls and attempted call set ups is included in the C/(I + N) calculations that determine if call set up attempts are successful.

If two or more call set ups are scheduled to occur simultaneously and the handsets are positioned so that they will attempt access to the same base stations then a random decision determines which handset is selected for the call set up attempt. (No concept of receiver scanning order is included.) Interference from all ongoing calls as well as that resulting from attempted call set up is included in C/(I + N) calculations.

E.4.6 Interrupted call

A call is defined as having been interrupted if C/(I + N) is less than the Call Set Up Threshold for $t > 10$ seconds at either the base station or handset at any time during a call.

E.4.7 Handover procedure

When the C/I falls below the Call Set Up Threshold then the handover procedure begins. Handover channel selection proceeds identically to set up with the restriction that no channel can be selected on the current channel's timeslot because of receiver blindness. The following rules apply:

a) Handover is attempted whenever C/I goes below 21 dB, or when the signed strength of another base is more than 10 dB stronger then of the current base.

b) No mobility is included.

c) 15 handover attempts per 3 seconds are permitted.

d) Handover may not be initiated less then three seconds after the last successful handover.

e) If there has been no successful handover and C/I remains below the Call Set Up Threshold for 10 seconds then the call is logged as interrupted.

f) Handover is initially attempted to the strongest base station and then may be attempted to other base stations.

E.4.8 Traffic density hotspots

The normal average handset density for 100 % cordless penetration is 1 per 20 sq. metres. The hot spot scenario is as follows:

a) Create two randomly positioned 10 m x 10 m areas on each floor. These areas should not include a base station.

b) Within these areas are created two, four or eight times the normal density of handsets. i.e. 10, 20 or 40 handsets per hotspot.

c) All handsets within the building offer equivalent traffic and the total number of handsets within the building remains unchanged.

d) Results should show the grade of service separately for the handsets in the hot spot areas. Care should be taken if multiple simulation runs are averaged. Vertical alignment of hot spot regions over more than one floor should be considered.

E.5 Multi-bearer channel allocation model

In this section a simple model for the allocation of symmetric and asymmetric multi-bearer connections is described; it includes as a particular case the asymmetric channel allocation model issued in the previous revisions of this document.

The number of terminals in the reference building is still 540 as in subclause E.2.1, but in this case includes handsets, data terminals and fax machines. It is suggested that comparisons of results are made on the basis of the mean traffic per base, for the same number of bases per floor. Each terminal activates a different kind of call:

- a handset activates a duplex bearer connection;

- fax machines and data terminals generate multi-bearer asymmetric connections, in one of the two directions, chosen at random;

- an ISDN terminal generates a multi-bearer symmetric connection with the same number of simplex bearers in both transmission directions.

Each multi-bearer connection, which includes one duplex bearer, is defined by the two following parameters:

- the target number of bearers needed by the connection;

- the minimum number of bearers that the connection can accept.

Each kind of terminal generates a call with different parameters:

- a fax machine requires 1 normal duplex channel and 2 double simplex channels in the transmitting direction;

- a data terminal requires 1 normal duplex channel and 4 double simplex channels in the transmitting direction;

- an ISDN terminal requires 3 duplex channel;

All the above numbers are intended as target number of bearers; the minimum number can be changed in order to test the performance of the system.

Each data terminal has call statistics as given in subclause E.5.2, but the call length is defined as the duration of the call, supposing one channel is used; the actual length of the call can change according to the number of channels in use during the connection.

> (For example, if the call length is 100 seconds and three channels are obtained, the actual duration of the call becomes 33 seconds (100/3). Note that during the connection the number of channels in use may vary, therefore the call duration must be changed accordingly. With this assumption the traffic at the base should remain constant).

E.5.1 Call procedures

E.5.1.1 Set up procedure

The set up procedure is as follows:

a) The terminal starts the set up of a duplex channel using the voice call set up procedure given in subclause E.4.5.

b) If the set up is successful, in case of a voice call the connection is established; instead for a multi-bearer connection, the set up of the target number of bearers is tried, not only to the strongest base, but to any base belonging to the same cluster.

c) The duplex channel is used to pass information about channels to be attempted:

- for symmetric calls, the terminal can start immediately the set up procedure without waiting for the list of best channels;

- for downlink double simplex transmission the terminal analysis received interferer signal strength on both halves of the frame and sends a list of best (quietest) channels to the base station, taking into account base station blindspots;

- for uplink double simplex transmission, the terminal receives a similar list of channels from the base station.

d) The terminal attempts a parallel set up on the target number of channels, using an unconfirmed request; if the C/(I + N) is greater than the call set up threshold at the receiving parts in all the channels, the call is established, otherwise the procedure is as follows.

e) The terminal may try the procedure of set up until the maximum number of attempts is reached; this is calculated from the table E.1 following, where the number of required bearers is the difference between the target number and the number of already established bearers.

Table E.1

Number of required bearers	Maximum number of attempts
1	1 * 10
2 - 3	2 * 10
4 - 7	3 * 10
8 - 15	4 * 10
> 15	5 * 10

If the maximum number of attempts is reached and the number of already established bearers is less than the minimum acceptable number, the call is blocked, otherwise it is considered to be established even if the number of obtained bearers is less than the target number. In the latter case, the terminal may try to reach the target number any time during the call.

E.5.1.2 Interrupted calls

The events that can cause the interruption of an established connection are:

a) the interruption of the pilot duplex bearer of the call, when it is the only duplex bearer of the connection;

b) the decreasing of the number of used bearers under the minimum threshold, as a result of one or more bearer interruptions.

A single bearer is considered to be interrupted if the C/(I + N) is less than the call set up threshold for more than 10 seconds at either the base station or the terminal at any time during the call.

E.5.1.3 Handover procedure

When the C/(I + N) of a bearer becomes less than the call set up threshold, or if terminal mobility is included, the signal strength of another base is more than 10 dB stronger than that of the current base, the procedure of handover begins. There are two different procedures according to the kind of bearer.

a) If the bearer is a duplex bearer, the procedure described in subclause E.4.7 is used.

b) If the bearer is a double simplex, the receiving endpoint may request a bearer handover to the transmitting side, that starts the procedure of set up following the rules c), d) and e) of the set up procedure (given in subclause E.5.1.1). The handover must conform to the rules (a - f) of subclause E.4.7.

E.5.2 Asymmetric channel allocation model

It is possible to define the traffic for a simulation that includes only fax machines, assuming that the 10 % of cordless terminals are group 4 fax machines generating traffic of 0,2 E each and requiring a continuous 64 kbits/s protected connection, that is 1 normal duplex channel and 1 double simplex channel in a direction chosen at random.

The call procedures are the same as described previously (see subclause E.5.1) for the general case, with the exception that the two bearers of one connection should be to the same base station.

E.6 Results logging and presentation

E.6.1 Voice calls

Many different output parameters can be examined from this simulation but to obtain some form of comparison the results should include a graph of "System Grade of Service", plotted on the vertical axis, against "Number of Base Stations per Floor" on the horizontal. This should be available for cordless handset penetration levels of 10 %, 30 % and 70 %.

System Grade of Service is defined as follows:

$$\text{System Grade of Services (GOS)} = \frac{\sum \text{Blocked Calls} + 10 \sum \text{Interrupted Calls}}{\sum \text{All calls}}$$

This equation weights the interrupted calls by a factor of 10 in their contribution to the System GoS. This is thought to be reasonable as being cut off is subjectively more annoying than failing to get through at initial call set up.

Tables should include the following:

- average of the mean traffic per base station;
- standard deviation of the above average;
- logarithmic average of the C/(I + N) value at call set up over all base stations;
- percentage of interrupted calls;
- percentage of blocked calls; splitting those blocked due to receiver blind spots and those blocked due to insufficient C/I ratio.

E.6.2 Multi-bearer connections

When multi-bearer connections are considered, it would be useful to calculate the system Grade of Service (GoS) described in subclause E.6.1 separate for voice calls and data calls, and analyse the effects of different penetrations of data terminals and fax machines on the system performance.

Besides the output parameters shown in subclause E.6.1, the tables could include:

- average number of channels used for data calls (asymmetric/symmetric);
- average number of handovers per 1 000 calls for each kind of terminal;
- percentage of interrupted calls and blocked calls with the indication of the causes of blocking and the kind of terminal.

Annex F (informative): References

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[6] RES3-R(90)64: "Cordless PBX Simulation Results. Philips Research, UK".

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[21] RES3-R(91) (PE) 19: "On range of the DECT Radio Link. ETSI PT10".

[22] CEPT R22 adhoc ETC-8: "Practical tests of speech quality versus range per cell for a digital cordless telephone system without use of time dispersion equalizers. Ericsson".

[23] RES-3(88)23: "Test of speech quality versus RMS delay spread for a digital TDMA cordless telephone system without use of time dispersion equalizers, Ericsson".

[24] RES-3(PE)75: "The performance of DECT in the outdoor 1.8 GHz radio channel. The University of LEEDS and BT laboratories, UK. IEE Sixth Conference on Mobile Radio and Personal Communications, Warwick, UK, 9-11 Dec. 1991".

[25] RES-3(PE)79: "Figures concerning capacity in multi bearer environment. Ericsson".

[26] RES-3(PE)92: "Multi-bearer simulation results. Ericsson".

[27] COST 231TD(91): "Radio propagation channel modelling for the DECT test bed. Wilkinson. The University of Leeds".

[28] "Channel modelling and link simulation studies for the DECT test bed program. Wilkinson. The University of Leeds, UK. IEE Sixth Conference on Mobile Radio and Personal Communications, Warwick, UK" 9-11 Dec. 1991.

The above references are available at the following addresses:

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