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# Radio Equipment and Systems (RES); Radio in the Local Loop (RLL)

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## Foreword

This ETSI Technical Report (ETR) has been produced by the Radio Equipment and Systems (RES) Technical Committee of the European Telecommunications Standards Institute (ETSI).

## Introduction

This ETR reports the work of STC-RES 03 working party on Radio in the Local Loop (RLL).

Working party RLL was formed in ETSI RES 3 in January 1993. It started its work in February 1993, with the aim of preparing the first draft of its ETR by September and preparing its final report by the end of 1993.

This ETR has been produced according to schedule. This ETR is the product of contributions from the RLL group, comprising more than 35 people from some 20 organisations, both telecommunication network operators and equipment manufacturers. The group conducted eight meetings during 1993 in: France, (18/1), France (11-12/2), the UK (31/3-1/4), Finland (11-12/5), Israel (22-23/6), Germany (31/8-2/9), the UK (19-21/10 and 22/11).

In this ETR "Radio Local Loop" covers the diversity of techniques and applications where the connection of customers' fixed telephone terminal equipment to the local exchange is achieved wholly or partially by radio means. The RLL concept is defined more precisely in subclause 4.2.

Subsequent clauses of this ETR develop the following topics:

Clause 5: describes representative, but not exhaustive examples of typical RLL deployments to be used as basis for technology assessment;

Clause 6: describes the range of services envisaged for RLL;

Clause 7: describes radio and regulatory constraints;

Clause 8: analyses DECT and CT2 technologies for RLL;

Clause 9: analyses analogue and digital cellular technologies for RLL;

Clause 10: reviews the application of Microwave Point to Multi-Point (MPMP) systems for RLL;

Clause 11: reviews spread spectrum techniques for RLL;

Clause 12: draws the main conclusions of the report;

Clause 13: sets out the recommendations of the working party to ETSI.

The majority of the work has focused on the areas outlined above. However, the true extent and complexity of RLL, as described in this ETR, has made it evident that further work could usefully be carried out, especially in the following specialist areas:

- cost analysis;
- network interfaces;
- data capacity;
- spectrum issues;
- service levels;
- network management.

During the work of the group two different approaches have been adopted.

The first approach has been to state that "RLL is an alternative to other access technologies and, therefore, should support most, or all, of existing and future services that are provided by a fixed network".

This view is supported by the fact that the fixed network operator cannot control the type of customer terminal which is connected to its network. This approach leads to major technical challenges when using existing mobile radio technologies and these are presented in the later clauses of this ETR.

The second approach has been to state that "existing mobile radio technologies might have advantages which make them superior to other access technologies in certain applications".

Examples of such advantages could be flexibility and range. Such advantages might compensate for some of the disadvantages inherent in radio systems, such as limitations in bandwidth or bit rate.

An example supporting this approach is the provision of ordinary voice telephony to fixed customers by a mobile operator. Mobile operators might have the flexibility to base their charges to fixed customers on the marginal cost of the customer's terminal connection and usage whilst at the same time increasing the utilisation of the mobile network.

Development of cordless and mobile equipment standards might improve the position of the mobile technologies when utilised for fixed applications and these possibilities are presented in later clauses of this ETR.

# 1 Scope

The European Telecommunications Standards Institute (ETSI) 4th Strategic Review Committee (SRC) recommended that TC RES should prepare an ETSI Technical Report (ETR) to examine technologies in use, or under development, in Europe for Radio in the Local Loop (RLL) and to make recommendations on any standardisation action required by ETSI.

Following this recommendation TC-RES delegated RES 3 to established terms of reference for a RLL working party as follows:

- define the relevant applications and services appropriate to radio access in the local loop network;
- consider existing and recognised standards and technologies in Europe suitable for radio access in the local loop;
- liaise with relevant Technical Committees in ETSI;
- produce an assessment of the operational and regulatory issues within Europe, including those associated with radio spectrum;
- prepare an ETR which examines various radio access technologies in use or under development in Europe for radio in the local loop, i.e. with the Public Switched Telephone Network (PSTN) and the Integrated Services Digital Network (ISDN);
- make recommendations for possible standardisation action by ETSI.

This ETR is the result of those deliberations.

# 2 References

For the purposes of this ETR the following references apply.

[1] ITU-R Recommendation 697-1 (1992): "Error performance and availability objectives for the local grade portion at each end of an ISDN connection utilising radio relay systems".

[2] ITU-R Recommendation 757 (1992): "Basic system requirements and performance objectives for cellular type mobile systems used as fixed systems".

[3] ITU-R Recommendation 755 (1992): "Point-to-multipoint systems used in the fixed service".

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[17] Björn Gudmundson, "A comparison of CDMA and TDMA Systems", IEEE VTC 42nd VTS conference, Denver, pp 732-735.

[18] S. C. Swales et al, "A comparison of CDMA Techniques for Third Generation Mobile Radio Systems", 43rd IEEE VTC, New Jersey, USA, May 1993, pp 424-427.

[19] ITU-T Recommendation Q.552: "Transmission characteristics at 2-wire analogue interfaces of digital exchanges".

[20] NET 4: "Attachments to Public Switched Telephone Network (PSTN); General technical requirements for equipment to be connected to an analogue subscriber interface in the PSTN".

[21] Draft prETS 300 448: "Business TeleCommunications (BTC); Ordinary quality voice bandwidth 2-wire analogue leased line (A2O) Connection characteristics and network interface presentation".

[22] Draft prETS 300 449: "Business TeleCommunications (BTC); Special quality voice bandwidth 2-wire analogue leased line (A2S) Connection characteristics and network interface presentation".

[23] Draft prETS 300 451: "Business TeleCommunications (BTC); Ordinary quality voice bandwidth 4-wire analogue leased line (A4O) Connection characteristics and network interface presentation".

[24] Draft prETS 300 452: "Business TeleCommunications (BTC); Special quality voice bandwidth 4-wire analogue leased line (A4S) Connection characteristics and network interface presentation".

[25] ITU-T Recommendation G.114: "One-way transmission time".

[26] ITU-T Recommendation G.113: "Transmission impairments".

[27] ITU-T Recommendation G.721: See ITU-T Recommendation G.726 [28].

[28] ITU-T Recommendation G.726: "40, 32, 24, 16 kbit/s adaptive differential pulse code modulation (ADPCM)".

[29] 89/336/EEC: "Council Directive on the approximation of the laws of the Member States relating to electromagnetic compatibility".

[30] ETS 300 175-1 to -9: "Radio Equipment and Systems (RES); Digital European Cordless Telecommunications (DECT) Common interface".

[31] ETR 056: "Radio Equipment and Systems (RES); Digital European Cordless Telecommunications (DECT) System description document".

[32] ETR 043: "Radio Equipment and Systems (RES); Digital European Cordless Telecommunications (DECT) Common interface Services and Facilities requirements specification".

[33] ETR 042: "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".

[34] ETS 300 329: "Radio Equipment and Systems (RES); Electro-Magnetic Compatibility (EMC) for Digital European Cordless Telecommunications (DECT) equipment".

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[36] I-ETS 300 131, Edition 2: "Radio Equipment and Systems (RES); Common Air Interface specification to be used for the interworking between cordless telephone apparatus in the frequency band 864,1 MHz to 868,1 MHz, including public access services".

[37] ITU-R Recommendation 370-5: "VHF and UHF propagation curves for the frequency range from 30 MHz to 1 000 MHz. Broadcasting services".

[38] ETS 300 530: "European digital cellular telecommunications system (Phase 2); Location registration procedures (GSM 03.12)".

[39] Final draft prETS 300 599: "European digital cellular telecommunications system (Phase 2); Mobile Application Part (MAP) specification (GSM 09.02)".

[40] ITU-R Recommendation 701: "Radio-frequency channel arrangements for analogue and digital point-to-multipoint radio systems operating in frequency bands in the range 1,427 to 2,690 GHz (1,5, 1,8, 2,0, 2,2, 2,4 and 2,6 GHz)".

[41] ITU-T Recommendation G.703: "Physical/electrical characteristics of hierarchical digital interfaces".

[42] ETR 103: "European digital cellular telecommunications system (Phase 2); Radio network planning aspects (GSM 03.30)".

[43] ITU-T Recommendation E.164: "Numbering plan for the ISDN era".

## 3 Abbreviations

For the purposes of this ETR the following abbreviations apply:

| | |
|---|---|
| AC | Authentication Centre |
| ADPCM | Adaptive Differential Pulse Code Modulation |
| BER | Bit Error Ratio |
| BRA | Basic Rate Access |
| BS | Base Station |
| BSS | Base Station System |
| BSC | Base Station Controller |
| BTS | Base Transceiver Station |
| CAI | Common Air Interface |
| CCITT | (The) International Telegraph and Telephone Consultative Committee |
| CDMA | Code Division Multiple Access |
| CEPT | European Conference of Postal and Telecommunications Administrations |
| CFP | Cordless Fixed Part |
| C/I | Carrier to Interference |
| CM | Connection Management |
| CODIT | Code Division Testbed |
| CPP | Cordless Portable Part |
| CRC | Cyclic Redundancy Check |
| CT2 | Second generation Cordless Telephone |
| DCS | Dynamic Channel Selection |
| DCS1800 | Digital Communication System 1800 |
| DECT | Digital European Cordless Telecommunications |
| DS-CDMA | Direct Sequence-CDMA |
| DTI | Department of Trade and Industry |
| DTMF | Dual Tone Multi Frequency |
| EIR | Equipment Identification Register |
| EMC | Electro-Magnetic Compatibility |
| ETR | ETSI Technical Report |
| ETS | European Telecommunication Standard |
| ETSI | European Telecommunications Standards Institute |
| FDD | Frequency Division Duplex |
| FDMA | Frequency Division Multiple Access |
| FFHSS | Fast Frequency Hopping Spread Spectrum |
| FHSS | Frequency Hopping Spread Spectrum |
| GFSK | Gaussian Frequency Shift Keying |
| GoS | Grade of Service |
| GSM | Global System for Mobile communication |
| HLR | Home Location Register |
| IPUI | International Portable User Identity |
| ISDN | Integrated Services Digital Network |
| LAN | Local Area Network |
| LE | Local Exchange |
| LOS | Line-Of-Sight |
| MM | Mobility Management |
| MPMP | Microwave Point-to-Multi-Point |
| MS | Mobile Station |
| MSC | Mobile Switching Centre |
| MT | Mobile Terminal |
| NDC | National Destination Code |
| NLOS | Not Line Of Sight |
| NMA | Network Management Agent |
| NMT | Nordic Mobile Telephone |
| O&M | Operation and Maintenance |
| ONP | Open Network Provision |
| PABX | Private Automatic Branch Exchange |
| PBX | Private Branch Exchange |
| PCM | Pulse Code Modulation |
| PLMN | Public Land Mobile Network |
| POTS | Plain Old Telephone System |

| | |
|---|---|
| PSTN | Public Switched Telephone Network |
| PTN | Private Telecommunication Network |
| QPSK | Quadrature Phase Shift Keying |
| QDU | Quantization Distortion Unit |
| RACE | Research and Development in Advanced Communication in Europe |
| RES | Radio Equipment and Systems |
| RFP | Radio Fixed Part |
| RLL | Radio in the Local Loop |
| RR | Radio Resource Management |
| RT | Radio Termination |
| RX | Receiver |
| SFH | Slow Frequency Hopping |
| SN | Subscriber Number |
| SNR | Signal to Noise Ratio |
| SMG | Special Mobile Group |
| ST | Subscriber Terminal |
| STC | Sub-Technical Committees |
| TACS | Total Access Communication System |
| TBR | Technical Basis for Regulations |
| TDD | Time Division Duplex |
| TDM | Time Division Multiplex |
| TDMA | Time Division Multiple Access |
| TE | Terminal Equipment |
| TPUI | Temporary Portable User Identity |
| TX | Transmitter |
| UMTS | Universal Mobile Telecommunications System |
| VB Data | Voice Band Data |
| VLR | Visitor Location Register |

# 4 Summary of RLL service requirements

Clauses 6 and 7 define RLL service characteristics, operational characteristics and regulatory requirements. The services which are characterised in this clause including basic services, (i.e. voice band telephony, voice band data, and facsimile), analogue leased lines and digital services (i.e. ISDN 2B+D, digital leased lines). These are based on the comparisons with wire-line access. RLL technologies which fulfil these characteristics would be a technical alternative to wire line access technologies and would allow the use of any terminal equipment available in a de-regulated market. Services requiring bandwidths greater than 4 kHz or with bit rates higher than ISDN basic access have not been considered.

## 4.1 Technology overview

In this ETR it is not the intention to define a "best" technology, or even to identify those which might be the right ones for specific applications in the local loop. This issue will be the focus of market developments. However, in line with the terms of reference set for the working party by RES 3 most of the effort has been directed towards an examination of the most advanced European cellular and cordless radio technologies, with a secondary task to examine both existing analogue technologies and potentially promising future technologies. Additionally, MPMP radio systems have been examined to determine their suitability for RLL applications.

## 4.2 The RLL reference model

A reference model for RLL systems is presented in figure 1. It is the view of the working party that the reference model serves the purpose of a common definition of such systems without differentiating between technologies being applied for their implementation.

The reference model is to clarify:

- which interfaces need to be identified in the RLL system;

- which interfaces needed in the RLL system can be based on existing standards, or standards in preparation.

By defining the different elements and interfaces it is not suggested that specific parts of the system should necessarily be subject to standardisation. However, it may be useful to adjust the external interfaces of the system to existing standards. Such external interfaces include interfaces to the customer terminal, to the local exchange, and to the operational and maintenance centre. Also included are the air interface and possibly the interface between the controller and the (remote) base stations.

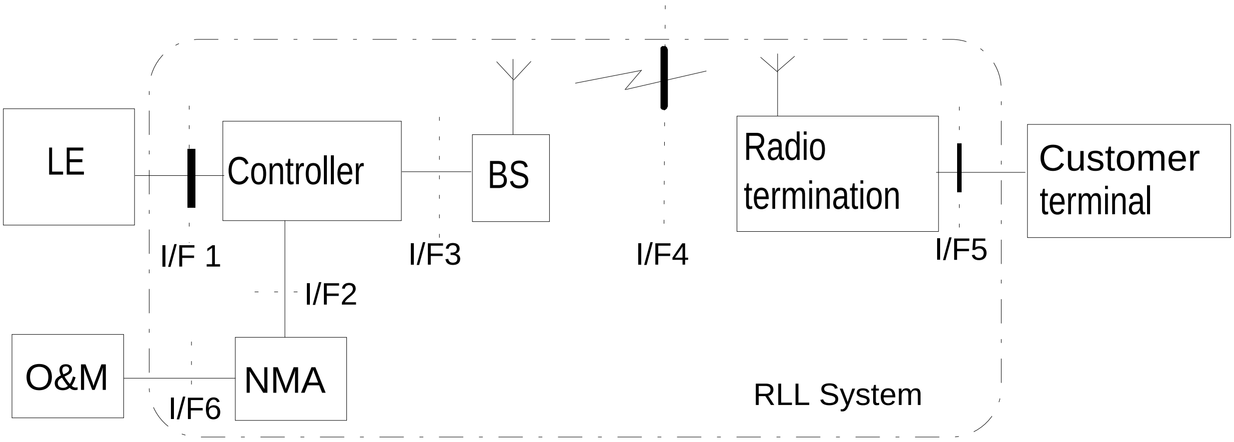
The reference model demonstrates the role of a radio local loop has in a telecommunications network as an access system for transmission of telecommunication information between the local exchange and the customer terminal, both being external to such a system.

The importance of the Network Management Agent (NMA) is recognised. The RLL is considered to be a relatively complex system and should be supported by dedicated specialised equipment which comprises an integral part of such a system.

The RLL system may consist of the elements and interfaces listed below:

- interface between controller and local exchange of the public network (I/F1);
- base station controller;
- interface between controller and Base Station (I/F3);
- a number of base stations;
- interface between controller and operational, NMA element (I/F2);
- radio interface (I/F4);
- radio termination;
- customer terminals connected to the radio termination;
- interface between radio termination and user's terminal (I/F5);
- interface between Operational and Maintenance (O&M) centre and the NMA (I/F6).

NOTE: These elements may not necessarily represent physical blocks in any particular implementation, and that an interface, in the context of this ETR, may only exist as a conceptual reference point.




LE - Local Exchange
BS - Base Station
NMA -Network Management Agent

I/F1 - Local Exchange to Controller Interface
I/F2 - NMA to Base Station Interface
I/F3 - Controller to Base Station Interface
I/F4 - Air Interface
I/F5 - Radio Termination to Terminal Interface
I/F6 - Operational & Maintenance Interface

NOTE: There may be several BS and Radio Termination elements associated with a single system.

**Figure 1: The reference model**

### 4.2.1 Reference model elements

**Local Exchange (LE):** in this model "local exchange" is intended to represent a number of different elements of the fixed network, according to operator requirements. These include the telephony network, leased line network and data network.

**Controller:** connects the RLL system into the local exchange/fixed network, controls the BSs, and interfaces to the NMA element.

**Base Station (BS):** a BS has all the necessary radio parts to receive and transmit information and signalling from/to customer terminals, and has the ability to maintain and measure the radio path.

**Radio termination:** has the ability to access the air interface (I/F4). It should be possible to support standard ISDN, PSTN or leased line terminals via the radio termination. The radio termination may be provided by more than one physical implementation, depending on the application. Not all supported services may necessarily be provided at the same time by a single unit.

**Customer terminal:** a standard ISDN or PSTN terminal.

**Network Management Agent (NMA):** network management is needed e.g. to handle configuration data, customer, system and radio parameters. NMA for the RLL system may require functions in the RLL access network. The RLL access network can be considered as a managed entity.

### 4.2.2 Reference model interfaces

**Local Exchange to Controller Interface (I/F1):** this interface is used to connect the RLL access network to the public fixed network. This interface is used to carry information between the controller and local exchange of the public network related to the services accessed by the RLL users. In this model the local exchange represents both the fixed voice network and private data networks where appropriate.

**NMA Interface (I/F2):** an interface between the NMA and the controller.

**Controller to BS Interface (I/F3):** this interface is used to connect a BS or a number of BSs to the controller of the RLL access network. This interface is used to carry information between the controller and BS related to the call handling, radio resource management, O&M messages, and mobility management specific to RLL.

**Radio interface (I/F4):** this interface is used to connect a radio termination or a number of radio terminations to one BS or to a number of BSs of the RLL access network. The radio interface is used to carry information between radio termination and BS related to call handling, radio resource management, operational & maintenance messages, and mobility management specific to RLL. The radio interface may be used to carry supervisory messages to the radio termination.

**Radio termination to customer terminal interface (I/F5):** this interface is used to connect a customer terminal to the radio termination. This interface is used to carry information between the radio termination and a customer terminal related to the services accessed by a user or an application.

**O&M interface (I/F6):** this interface is used to connect the RLL system to the operational and maintenance (O&M) centre. This interface is used to carry between the O&M centre and the NMA, information related to the configuration, performance and fault management of the RLL system.

### 4.3 Economic aspects

RLL systems are of interest to operators for a number of reasons related to network economics. A large proportion of the cost of connecting a customer can be deferred until nearly the moment that customer subscribes, and from that point the connection generates revenue for the operator. This fact can have a major impact on the maximum amount of cash an operator should devote to deploying a network in a given area.

Many faults in a conventional wired network occur in the "final drop"; for a radio system the final drop is a radio link and therefore maintenance costs can be significantly reduced.

This ETR does not consider extensively "network economics".

## 5 RLL deployment examples

This clause describes typical examples of the deployment of RLL networks.

The examples yield typical requirements for possible technologies for RLL applications.

It is expected that other occurring cases can be derived by a combination of those described.

### 5.1 Deployment example 1: existing operators, new area

#### 5.1.1 New housing area near existing town

At the peripheral of a new town a new housing area (radius 0,5 km) is being constructed (see figure 2). An operator with an existing network infrastructure in the town has to serve that area. The next local exchange is 1 to 5 km apart from the centre of the new housing area. The connection density ranges between 500 to 2 000 connections per $km^2$. At peak hour the traffic amounts to 0,07 Erl/connection (mixture of residential and business users). The completion of the service provision takes one year (time between first house complete and last house complete).

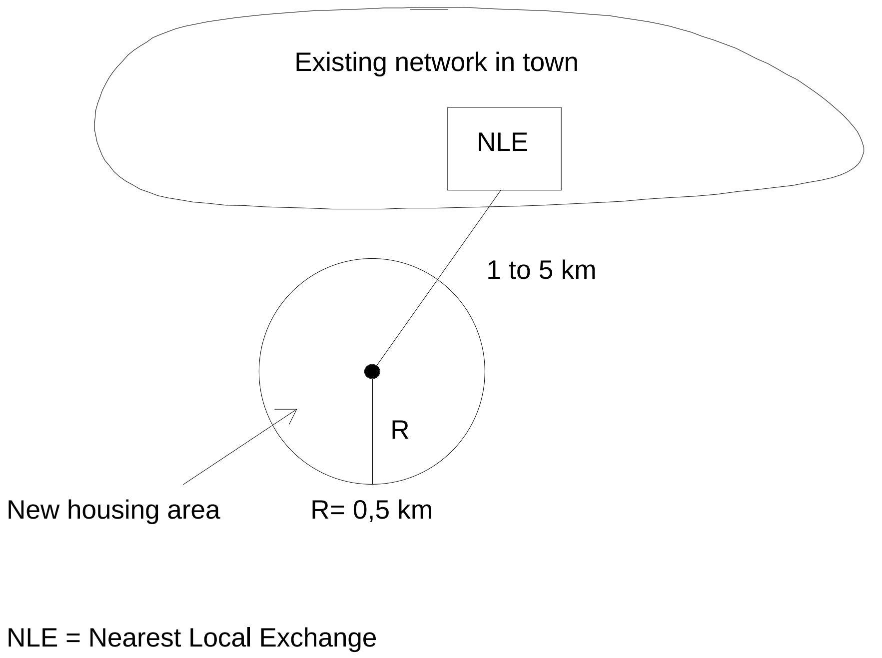



**Figure 2: New housing area near existing town**

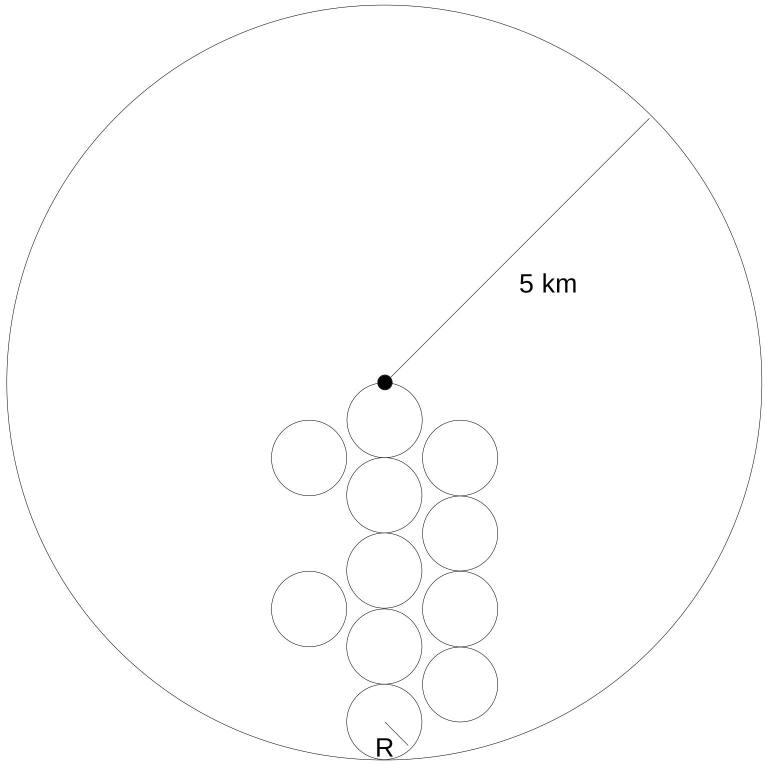
The services required are:

- Plain Old Telephone System (POTS) as specified in subclauses 6.1.1.1 and 6.1.1.2;
- capability for 64 kbit/s and/or ISDN BA (as in subclause 6.1.3) for up to 5 % of the customers;
- analogue leased lines (as in subclause 6.1.2).

### 5.1.2 New town

A new town is being developed, the size of the town amounts to 5 km in radius (see figure 3). The actual development consists of developing sub-areas (radius 0,5 km) over a period of time of 10 years. Each sub-area can be described by subclause 5.1.1.

This case may also be applicable for the deployment of a network in a town with almost no existing telecommunication infrastructure (e.g. Eastern Europe). The deployment time period may be shorter than 10 years in that case.




R = 0,5 km

**Figure 3: A new town**

## 5.2 Deployment example 2: replacement of obsolete copper lines in rural areas

### 5.2.1 Introduction

This subclause describes one example of a rural area with its different kinds of parameters, e.g. range, capacity, area of coverage, subscriber densities, etc. Renewing the area is mainly considered because of high maintenance cost and poor quality. The penetration is high and very fast roll out of the system is required, practically full coverage on day 1.

### 5.2.2 Rural area description

A typical rural area is often hilly and forested. The local exchange is placed in the centre of the area and about 90 % of all subscribers are within the range of 4 km from the switch. Normally the remaining 10 % of subscribers are situated in clusters with up to 10 premises together. These clusters are often spread out over a large area and their relative distance between each other of 5 -10 km, (see figure 4).

### 5.2.3 Services

The main part of the subscribers are private and have no extra requirements but old telephony services. There are often some small businesses (home and office) in the area with some need of fax and data transmission. The following basic service requirements (see subclauses 6.1.1.1 and 6.1.1.2) are assumed:

- POTS i.e. basic telephony with good speech quality, similarly to fixed telephony;

- value added services like forward calling etc. This requires transparency of Dual Tone Multiple Frequency (DTMF) signalling and "R-button" (register recall);

- facsimile group 3 up to 9,6 kbit/s;

- voice band modems for data transmission up to 9,6 kbit/s.

There is no basic need of ISDN within a time period of 10 years.

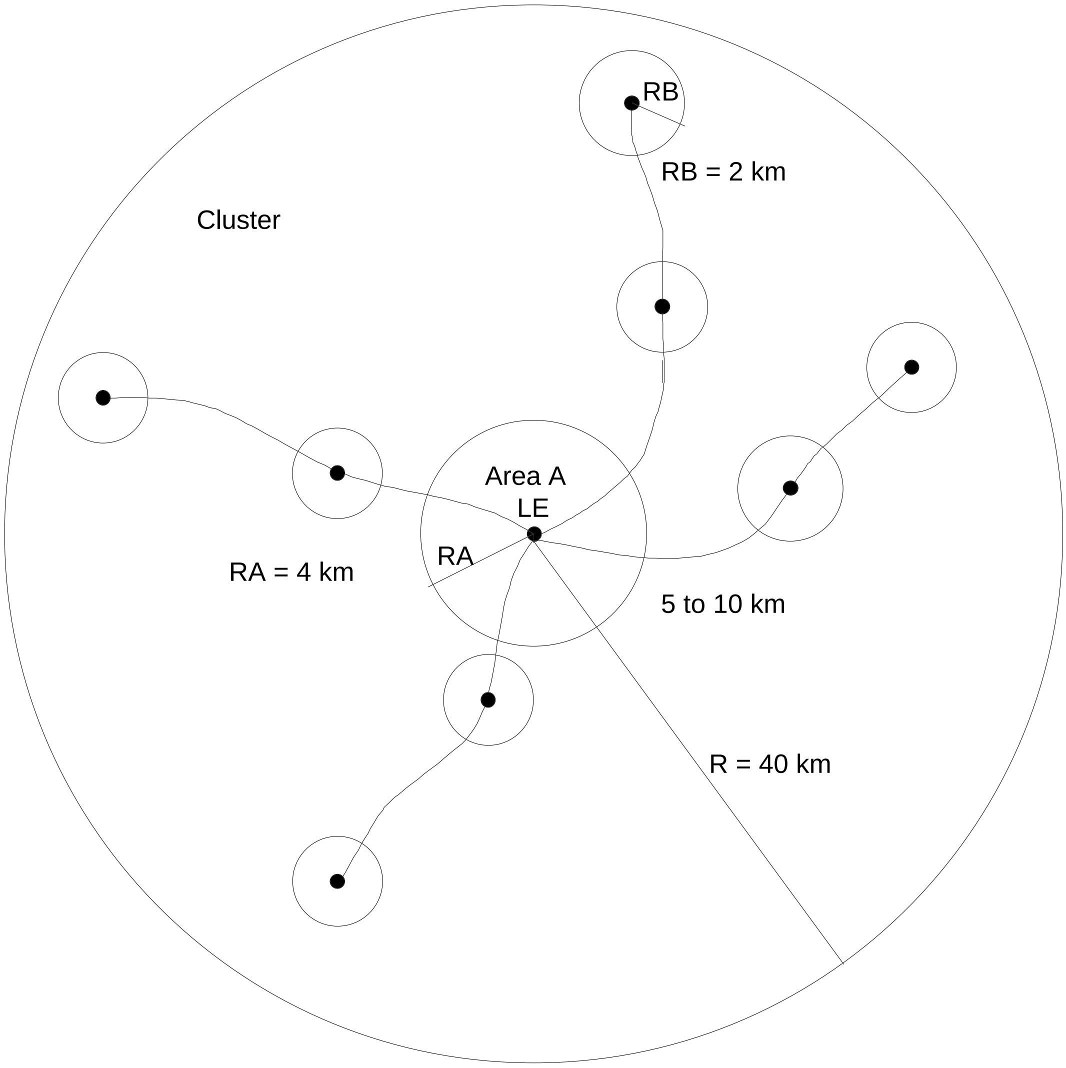



**Figure 4: A typical rural access network**

### 5.2.4 Traffic

The typical subscriber density within the area is 5 to 50 subscribers per km$^2$. The higher density is within 4 km range (area A) and the lower density is the other 10 % of subscribers (area B). Traffic per subscriber is 70 mErl in busy hour. Typical figure for blocking is 1 %.

### 5.2.5 Summary

**Table 1: Figures for deployment example 2**

| Area | A | Cluster |
|---|---|---|
| Customer density | 5 to 50/km$^2$ | - |
| Traffic requirement | 70 mErl | 70 mErl |
| Population | 90 % | 3 to 10 customers |
| Radius | 4 km | 2 km |

## 5.3 Deployment example 3: capacity increase of existing network

An existing cable network has reached its capacity limits and an easy expansion is not possible (new ducts and feeders). The expansion shall be realised by RLL.

The example describes a typical 10 000 to 30 000 customer local exchange area covering typically suburban areas, with a radius extending to 15 km. The local exchange area is divided into several distribution areas, each being served by 2 000 telephone line feed cable. Figure 5 shows the typical dimensions and line amounts in one such segment. The last drop cable to the customer is some 100 m long being served from the passive cable tap serving 5 to 20 customer lines. A cable segment of 100 to 600 lines serves a chain of 20 to 100 of these 5 to 20 customer taps. The 2 000 line feed cable from the local exchange serves 2 to 20 of these cable segments.

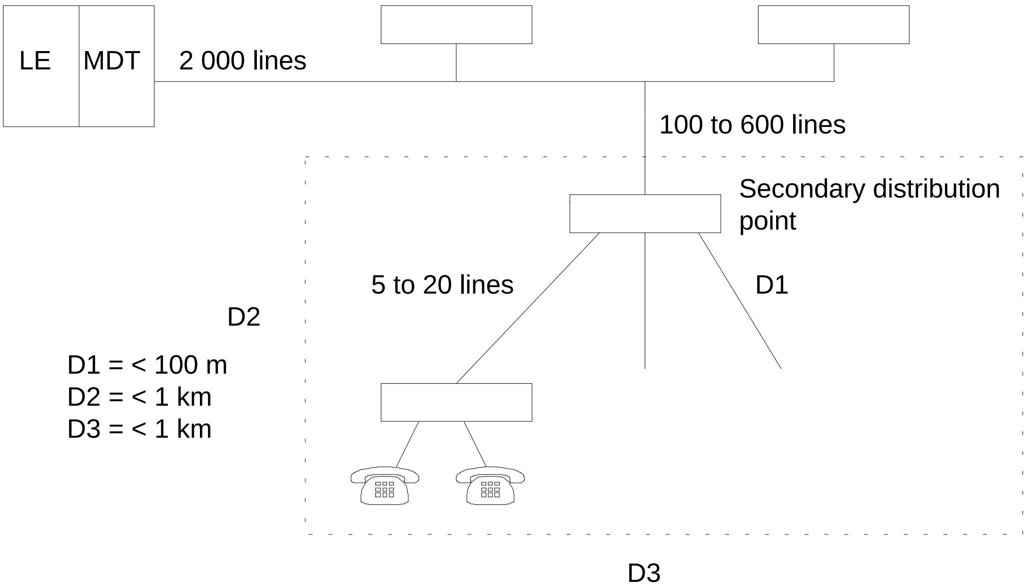



**Figure 5: The typical dimensions and line amounts of a segment**

The capacity restriction occurs in a peripheral part of the cable network area between the secondary distribution point and the customer (i.e. within the dotted line). The distance between the local exchange and the secondary distribution point is at maximum 15 km. Typical average values are between 1,7 km and 2,5 km.

Traffic is 70 mErl and services required are as in subclause 5.1.

It is assumed that congestion will occur in 10 % of the feed cables and a 3 % of yearly growth in telephone lines in these areas. This would mean a yearly growth of some 60 new lines in the 1 to 4 $km^2$ distribution areas. It may be assumed that it is not cost effective to replace the existing copper plant by a radio solution, but try to handle new growth by a radio solution. It may be assumed, however, that the operator could replace for some of the existing wired POTS customers a RLL solution instead and thus free copper pairs for customers who need extended services like leased lines or ISDN. Thus the RLL solution for new growth could support only POTS customers, who need voice and low speed data services. It is very doubtful that the operator could re-arrange the copper pair lines in the copper plant to isolate the possible new RLL solution to a smaller area and thus free copper lines for new growth in the rest of the area.

A scenario to extend the exhausted copper plant by 10 years with the radio solution is to be provided.

### 5.4 Deployment example 4: new operator in competitive environment

The main factors influencing such an operator are:

- requirement to cover customers in a variety of areas: urban, suburban and rural;
- needs to achieve coverage quickly over the maximum possible area;
- no existing infrastructure in place;
- the existing, operator, (probably a monopoly), will have a high market penetration (nearly 100% of customer premises), so growth in customer numbers is likely to be slow;

- the service offered must be technically equivalent to that provided by the existing operator, probably using a wired network.

Three distinct types of area are defined. These do not represent the full range of situations which will be encountered, but at least illustrate the extremes of customer density, and perhaps a more typical case. The elements of the example are:

- rural area with low average population density, e.g. small villages with significantly higher density but still a relatively small total number of connections;

- a small town with 50 000 lines (in the residential and small business sector), equivalent to a population at 10 000 to 150 000;

- a city with 500 000 lines (in the residential and a small business sector), equivalent to a population of 1 to 1,5 million.

In the latter two cases, most of the users are located in the "suburban ring" of lower density. For the city, it is assumed that the user density in the centre is significantly higher than in the town centre reflecting the higher level of building development typical of larger cities.

Nevertheless, much higher peak densities than those assumed as an average may be met in both towns and cities.

The traffic levels per line are assumed to be 70 mErl. This is thought to be a reasonable average for residential and small business lines. It is assumed that an alternative access means would be used for business premises with a larger number of lines, where the traffic will be pre-concentrated by a Private Business Exchange (PBX).

Two key issues concern the operator assessing technologies for this purpose.

First, the economics of the system should match the economic requirements of the business. This is partly a matter of the cost of the actual equipment, but also a strong function of its deployment characteristics, in particular maximum service range.

Secondly, as mentioned above, the service must be technically equivalent to that provided by an existing operator through a wired network. In particular, any telecommunications terminal which will operate when connected to the wired network should operate equivalently when connected to the radio network.

Figure 6 and table 2 define the parameters of this example.

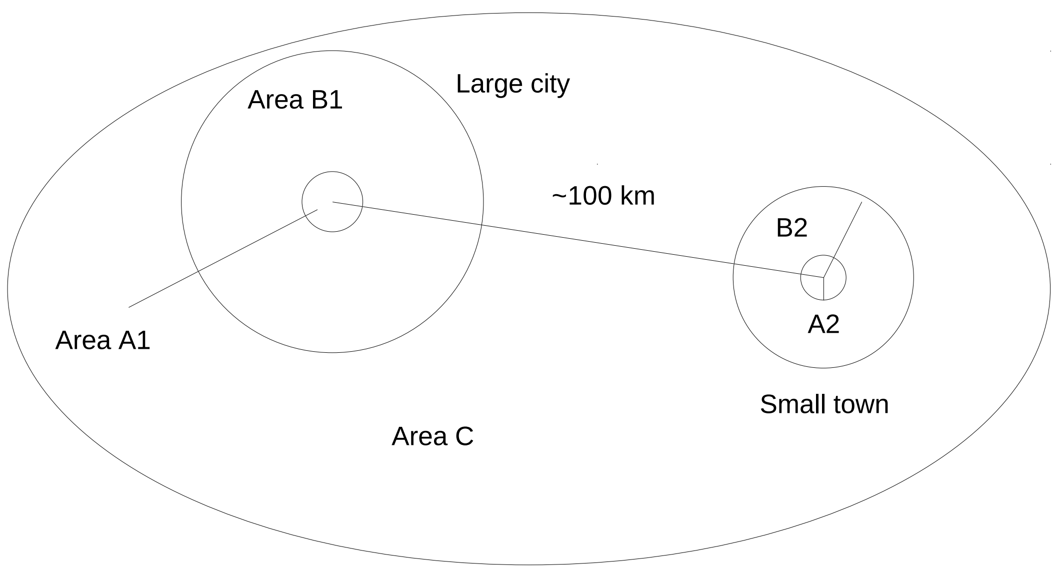



**Figure 6: The defined areas of deployment example 4**

**Table 2: The defined parameters of example 2**

| Large city | | Small Town |
|---|---|---|
| No. of lines | 500 000 | 50 000 |
| Density A1<br>Density B1 | 2 000/km$^2$<br>500/km$^2$ | 1 000/km$^2$ 25%<br>500/km$^2$ 75% |
| Radius<br>Radius | A1 - 4,5 km<br>B1 - 16 km | A2 - 2 km<br>B2 - 5 km |
| Area C | Average density 5/km$^2$, peak 50/km$^2$, no peak > 500 lines | |
| Traffic | 70 mErl | |
| Penetration | 1 % of existing users per year of covered area over 10 years | |
| Services | Preference as in subclauses 6.1.1.1 and 6.1.1.2, ISDN ~ 5 % | |
| Deployment | Fast roll-out | |

# 6 Radio local loop service characteristics

This clause describes the service characteristics which a RLL system is required to exhibit in order for it to provide a service equivalent to that of traditional wired access. It does not necessarily preclude other service characteristics being offered by specific operators.

The elements of this clause should be used to provide an objective means to evaluate candidate technologies for RLL applications.

Alternative levels of service characteristics based on speech and data capabilities of existing functions of RLL will be discussed in later clauses of this ETR.

## 6.1 Services

It is perceived as important for a RLL system to provide transmission equivalent in many respects to wired connections for basic analogue telecommunications terminals, i.e. mainly telephones, but also fax machines and modems. These are referred to below in subclause 6.1.1 as "basic services".

However, applications are seen, over a period of time, and for a small proportion of customers, for compatibility with digital ISDN terminals, and for supporting digital and analogue leased connections.

It is likely, therefore, that the interface specifications identified in the reference model will require the capability to support ISDN basic rate access, though specific implementations may not provide such service.

### 6.1.1 Basic services

For the purposes of this ETR basic services are taken to mean the facilities available to customers by basic connection to the PSTN. As well as normal voice telephony (POTS) this includes the transmission of low rate data streams and voice-band signalling tones, used, for example, by facsimile machines.

#### 6.1.1.1 Voice telephony

It should be the objective of a RLL system to provide full service transparency for voice telephony. In particular, the following points should be addressed:

- support of all the relevant technical parameters of the ITU-T transmission plan for the analogue local loop, with country specific variations where appropriate, in order to provide 3,1 kHz voice telephony. Reference should be made to international standards NET 4 [20] and ITU-T Recommendation Q.552 [19]. However, standardisation of the customer terminal interface (I/F5) will only be possible within certain geographical regions, and that any RLL technology will need to match the appropriate national requirements at this interface;

- provision of DTMF signalling tones and, if required by specific operators, loop disconnect (pulse) signalling. Additionally, two-way transmission of DTMF tones in the voice channel once established;

- provision at the customer interface (I/F5) of additional network facilities such as power feeding, ringing current, meter pulses, line reversals, and Earthed Loop Recall (ELR) and/or Timed Break Recall (TBR) facilities as required to drive attached telecommunications apparatus;

- provision of similar call set-up times to the wired loop for both incoming and outgoing calls.

The options available for the length of analogue "tail" on the customer unit should be considered, with provision for both short lines (i.e. those less than 50 m) and long lines (up to 5 km).

#### 6.1.1.2 Voice-band data and facsimile

The RLL system should support all voice-band modems which are able to operate on fixed switched connections, though it would be permissible to fallback to lower rates if required by the RLL characteristics. Data rates up to 9,6 kbit/s should be supported.

The evolution of voice-band modems to higher rates should be considered, examples being V.17 fax, and $V_{fast}$.

### 6.1.2 Analogue leased lines.

It should be the objective of a RLL system to support ordinary and special quality voice bandwidth 2-wire and 4-wire leased lines, such that end to end performance of links incorporating RLL systems conform to ETS 300 448 [21], ETS 300 449 [22], ETS 300 451 [23], ETS 300 452 [24].

### 6.1.3 Digital services

When considering the transmission of digital services support of ISDN basic rate access (2B + D) is the main priority, which should be fully transparent. However, support of n x 64 kbit/s, up to and including primary rate access, should not be excluded. For efficient data operation support of ISDN frame mode should be considered.

When voice is being carried as an ISDN service, the use of, for example, 32 kbit/s coding across the radio link should be considered in order to conserve bandwidth. Similarly, when data is being carried across an ISDN connection with rate adaptation, the possibility of de-multiplexing and carrying the data at a lower rate for bandwidth conservation should be reviewed.

Since the ISDN U interface is country-specific, the S interface is the preferred interface for an ISDN RLL system.

64 kbit/s data should be supported as a "leased line" with a ITU-T Recommendation G.703 [41] or $S_0$ interface.

## 6.2 Service attributes

This subclause details the service attributes which are perceived to be of importance to network service providers, and which should be addressed when assessing potential radio technology solutions.

### 6.2.1 Traffic requirements

For the purposes of technology evaluations within the context of this ETR the following busy hour peak traffic rates should be assumed:

- residential lines: - 70 mErl;

- small business/home-office lines: - 150 mErl.

### 6.2.2 Access network delay

The delay introduced by the radio circuits in the local loop, (i.e. between I/F 1 and I/F5 of the reference model) where techniques to enhance the terminal echo loss are not employed, should be short and comparable to that of the local exchange. It should be the objective of RLL systems to conform to the requirements of ITU-T Recommendation G.114 [25].

However, it is recognised that some radio technologies by the nature of their air interface protocol will introduce considerable delays. Where necessary, techniques to enhance the terminal echo loss should be employed in order to maintain acceptable speech quality for the end users.

It is further recognised that the Open Network Provision (ONP) technical requirements for leased line circuits in European countries require network delays of less than 10 ms, which should also be considered when radio networks are proposed.

### 6.2.3 Grade of Service (GoS)

For the purposes of this ETR the term "grade of service" refers to the statistical availability of the communications channel for a particular customer's termination.

Although GOS is an issue for an operator to determine in his network design and roll-out, a target figure is required to enable an assessment of spectrum requirements. A connection failure rate representing a GOS of < 1 % is proposed. This figure has been derived from consideration of ITU-R Recommendation 757 [2].

As a related issue, the availability of the connection for emergency calls should also be considered.

### 6.2.4 Error performance and availability objectives

The error performance and availability of digital RLL systems should generally be in accordance with ITU-R Recommendation 697 [1]. Objectives for the total bi-directional unavailability are still under study, but values ranging from 0,01 % to 1 % have been proposed in ITU-R Recommendation 697 [1], Note 2. However, ITU-R Recommendation 757 [2] sets an availability objective of not less than 99,9 % for both propagation and equipment effects for cellular type mobile systems used as fixed systems, (see also ITU-R Recommendation 755 [3] and ITU-R Recommendation 756 [4]).

NOTE: ITU-R Recommendation 697 [1] is based on ITU-T Recommendation G.821 [5]. It is applicable to 64 kbit/sec (and possibly 32 kbit/s) connections used for voice traffic or as a "Bearer Channel" for data-type services. The performance objectives for 32 kbit/s and lower bit-rate services require further study.

The system should be unconditionally stable such that established calls within a coverage zone are not lost when access exceeding the designed capacity is attempted. Under such conditions it is accepted that call blocking will occur, though the GOS design requirements described in subclause 6.2.3 should still be complied with.

### 6.2.5 Service security

A standard encrypted mode should be defined but implementation in a given network should be optional.

### 6.2.6 Authentication

A radio base station should be able to authenticate a radio terminal, and a radio terminal should be able to check that it is accessing its "correct" radio infrastructure, by appropriate authentication procedures.

### 6.2.7 Mobility

Although mobility is not a prime requirement, evolution scenarios towards terminal and user mobility should be considered when evaluating potential technologies. Cell-wide mobility should be considered as a separate feature. The implementation of mobility in RLL applications would require special attention related to GOS and error performance.

### 6.2.8 Service transparency

It should be the objective of a RLL system to maintain transmission aspects such as Bit Error Ratio (BER), audio Signal to Noise Ratio (SNR), and Quantisation Distortion Units (QDU) as similar as practicable to conventional fixed networks. In particular, speech quality should be equivalent to 3,5 QDU or better (see ITU-T Recommendation G.113 [26]), provided, for example, by 32 kbit/s ADPCM (i.e. ITU-T Recommendations G.721 [27] and/or G.726 [28]).

Additionally, the following features should be considered:

- standard calling procedures for fixed terminals should be supported;
- standard fixed network numbering plan should be supported;
- call set-up delay should be comparable with conventional fixed networks;
- transparent transmission of network originated signalling such as calling-line indication and messaging;
- transparent transmission of standard network tones (e.g. ringing indication) and voice announcements.

#### 6.2.9 Emergency calls

Access priority, including absolute priority for emergency calls should be supported.

## 7 Operational characteristics and regulatory requirements

This clause examines operational aspects of a RLL system. It also indicates, where appropriate, any national or European regulatory requirements which should be complied with by equipment manufacturers and network service providers.

### 7.1 Frequency efficiency

It is important that every system will be efficient in its use of frequency spectrum. This aspect should be assessed both by the allocated bandwidths and the method of frequency re-use inherent in the systems under examination.

In order to ensure efficient use of spectrum, it is important that the bandwidth allocated to a user should be appropriate to the services required. In particular, wide bandwidths should not be used to provide narrow bandwidth services.

### 7.2 Radio range

Depending on the service needs of a particular operator, various range requirements may be identified. However, it is not to be assumed that a different link technology is, or is not, implied by a given categorisation. For the purposes of this ETR a maximum range for RLL systems is assumed to be 50 km.

It should be noted that the range of a RLL system is related, in some degree, to the customer densities, as well as the technologies used to provide the service.

### 7.3 Radio termination power supply

A local power supply is assumed for the radio termination since line powering will not be possible.

Battery back-up of a customer's system is a definite requirement, but operational times will be determined by network operators, subject to any local regulatory requirements. As an example, the battery should be capable of providing at least 8 hours operation in standby (i.e. on-hook) mode, and 30 minutes of off-hook talk time.

The separation of mains power supply and other circuit elements may be desirable in order to improve both reliability and user safety.

A uniform requirement rather than scattered ones would enable development of cost efficient solutions through economy of scale.

### 7.4 Radio termination/antenna mounting

External mounting of the antenna is to preferred for radio performance reasons. However, internal mounting will improve environmental acceptability and installation convenience.

It is recognised that different mounting structures will result in differing environmental requirements. Any external antenna installation should be visually unobtrusive, and might be mounted below the roof-line of the building on which it is installed.

Internal antenna mounting may permit customer installation, but will reduce the operator's control over QoS.

## 7.5 Radio termination monitoring

Many parameters of the radio termination could be monitored. Examples include link quality, error rate, battery state, and line condition monitoring at interface 5. In order to enable this level of support it is of key importance that proposed radio interface protocols support the transfer of appropriate management messages.

It is also important that the interface between the radio infrastructures and the NMA (interface 2 on the reference model) should support these management messages.

## 7.6 Operation in regulated or un-regulated frequency bands

It is to be preferred that radio spectrum is allocated and regulated in such a way that an operator can control QOS.

For some applications and technologies operating in un-regulated bands may be appropriate. The implications of this need to be considered separately by any potential operator of a RLL system.

## 7.7 System deployment

Additional information on the significance of multi-tenanted buildings will also be of importance when considering the design of RLL networks.

## 7.8 Local exchange interfaces (interface 1)

A 2-wire analogue interface should be defined as a basic requirement.

A digital connection will require a 2 Mbit/s interface to be defined, examples include V5 for POTS, ISDN and leased lines, and G.703 for leased lines only.

## 7.9 Radio safety

### 7.9.1 Exposure limits

In the frequency range of a few MHz to a few GHz the Specific Absorption Rate (SAR) is the significant dosimetric quantity for establishing exposure limits. Both the average whole body SAR and the local peak SAR have to be limited to prevent health risks.

There are various national SAR limits in Europe ranging from 0,08 to 0,4 W/kg for the average SAR, and from 2 to 10 W/kg for the local SAR in the head [3,4].

The proposed EC directive on minimum health and safety requirements regarding the exposure of workers COM(92)560 [6], sets the ceiling level for local SAR at 10 W/kg and the threshold (i.e., acceptable) level at 2 W/kg. The ceiling level for the average SAR is set at 0,4 W/kg and the threshold level at 0,08 W/kg (see ITU-R Recommendation 697-1 [1]).

CENELEC TC 111 is currently drafting a standard on the human exposure to electromagnetic fields CLC/TC 111 (SEC) [7]. In uncontrolled environments, where exposed individuals have no knowledge of the exposure, the local SAR should be limited to 2 W/kg, averaged over 6 minute time intervals and any 10 g of body tissue. For uncontrolled environments the average whole body SAR limit is 0,08 W/kg.

### 7.9.2 Implications for hand-held transmitters

The maximum average transmit power of hand-held transmitters is limited by the permissible local SAR in the user's head. The 2 W/kg local SAR limit, if applied to hand-held transmitters, may limit the average power levels to values less than the 1 W level currently used in hand-held mobile phones. Hand-held transmitters used in RLL applications should clearly operate well within the safety limits of the emerging CENELEC standard on hand-held transmitters and any corresponding EC directives.

### 7.9.3 Implications for RLL systems using external antenna installations

In applications where a fixed antenna is installed outside residential buildings high-power transmitters (i.e. tens of watts) may be used if the installation method of the external antenna is such that any person is unable to remain close to it for long periods of time. Depending on the type of antenna and the transmitter power level, the required safety distance is typically less than 1 to 2 m. The near field safety distance may be reduced by increasing the size or number of the radiating elements.

## 7.10 Electromagnetic compatibility

In common with all other electrical and electronic equipment the apparatus (or "system") required for RLL services will be required to meet the "essential requirements" contained in the Council Directive 89/336/EEC [29], (EMC directive).

The standards developed by ETSI STC RES 09 and/or STC EE 4 may be used as the basis for demonstration of compliance with respect to these essential requirements. However, when setting the performance requirements it may be necessary to re-define the expectation of "intended unhindered operation of the equipment". In particular, the EMC standards developed for mobile radio technologies may require revision of the performance criteria if used in RLL applications.

Reference to the EMC standards under development for fixed radio links may be used as an example of how different performance criteria are defined for alternative deployment scenarios.

The development of a specific EMC standard for RLL systems should also be considered by ETSI. This work would be likely to reside in STC RES 9, but would require the additional expertise of STC EE 4.

## 7.11 Lightning safety

Equipment design and installation practices will need to reflect this aspect of user safety.

Existing regulations should be reviewed for applicability to RLL systems.

It would be preferable if protection was not needed, i.e. by use of internal antennas or specially designed safety barriers.

## 7.12 Relay operation

It is desirable for particular air interfaces to support possible relay operation by remotely located base stations. The effect of such techniques on operational characteristics such as network delay have to be carefully examined.

## 7.13 Electrical safety

It is necessary for radio terminations to comply with the relevant electrical safety regulations in the country of operation, or appropriate European requirements.

# 8 Analysis of cordless technologies for RLL

## 8.1 Introduction

Current cordless technologies have been designed to provide low complexity and high traffic capacity solutions for micro-cellular systems. Such systems can be successfully applied to RLL applications. Both Digital European Cordless Telecommunications (DECT) and 2nd generation Cordless Telephones (CT2) technologies are assessed with respect to service aspects, operational and regulatory aspects, local loop planning, deployment examples and evolution.

## 8.2 DECT

This subclause discusses the suitability of the DECT radio interface, as it is described in ETS 300 175 [30], for the RLL application.

### 8.2.1 Background

The DECT standard was designed to provide cordless telecommunications access to a number of different existing and future telecommunications networks, including the PSTN. Before the technical specification of the DECT standard began a Services and Facilities (S + F) study was performed by both the CEPT and ETSI, where RLL is one of the DECT applications.

### 8.2.2 DECT reference model for RLL

The DECT reference models for PSTN and ISDN RLL applications are described in ETR 056 [31], and are reproduced below.

The global network is a logical grouping that supports a long distance telecommunication service as well as address translation, routing and relaying between connected local networks. It has typically a national or international extent.

The local network supports a local telecommunications service. Typically such a network is local in extent. The characteristics of the local network may, depending on its actual implementation, vary from a multiplexer to a highly sophisticated PTN. Since the DECT Fixed radio Termination (FT) does not include switching it is important to remember this function is carried out in the local network. The local network is responsible for the translation of global network identities (e.g. PSTN and ISDN) to DECT specific identities (e.g. IPUI or TPUI). All network mobility functions including databases are resident in the local and/or global network.

The FT is a logical grouping that contains all functions on the fixed network side of the DECT air interface which are identified in ETS 300 175 [30]. The FT contains no switching entities except those required for handover and multiple cells. Multiple instances of calls can exist but can't be connected together.

The Portable radio Termination (PT) is the portable radio transmission termination and in the case of the RLL application may be fixed, for example to the wall of a subscriber's premises. It includes all protocol elements that are defined for OSI layers 1, 2 and 3 of ETS 300 175 [30].

The Portable Application (PA) is a logical grouping that contains everything beyond the DECT network boundary on the subscriber side.

Reference point D3 always corresponds to a physical boundary whilst reference points D2 and D4 indicate logical boundaries of the DECT network. Reference point D1 may correspond to a physical boundary.

Translation table to RLL reference model:

Elements: PA = Customer terminal;

PT = Radio termination;

FT = BS;

local network = Controller;

global network = LE;

Interfaces: D1 = I/F1;

D2 = I/F3;

D3 = I/F4;

D4 = I/F5.

#### 8.2.2.1 PSTN reference configuration

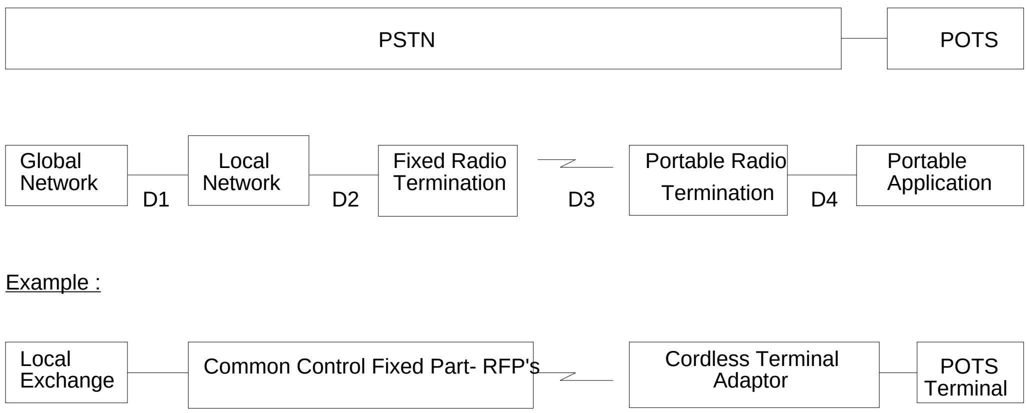



**Figure 7**

#### 8.2.2.2 ISDN reference configuration

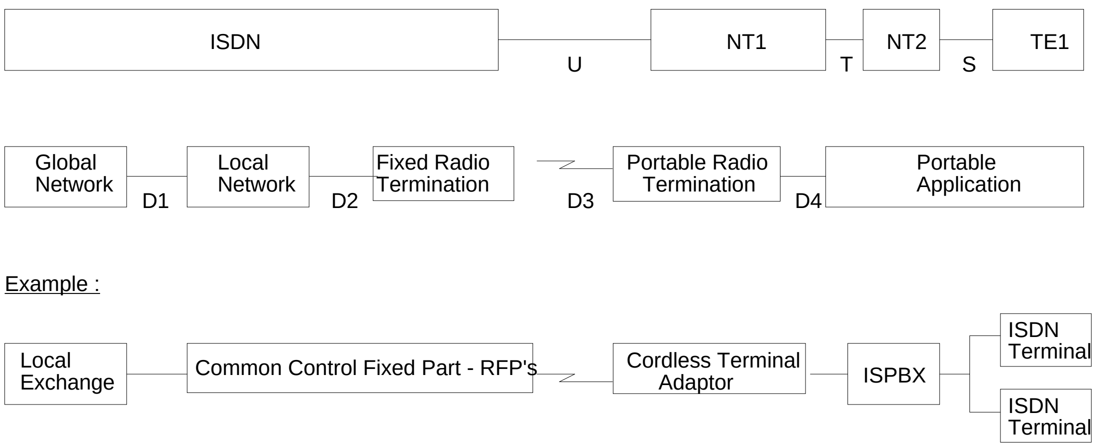



**Figure 8**

### 8.2.3 RLL service characteristics

ETR 043 [32] contains the DECT services and facilities requirement specification. One of the identified requirements is the ability to use DECT for local loop applications with either fixed or portable terminals (see ETR 043 [32], clause 9). ETR 056 [31] includes a reference configuration for this application and ETS 300 175 [30] includes several features to ensure suitable performance in this application (e.g. specific equipment identity structure, provision for antenna gain, etc.).

This subclause now considers the requirements in clause 6 that are influenced by the choice of radio access system. These are discussed with respect to the DECT standard.

#### 8.2.3.1 Services

This subclause focuses on the principle services demanded, and assesses how they are supported by the DECT standard. Particular emphasis is given to exploring the degree of transparency with which a service is supported.

1) Voice telephony.

   In the interests of the efficient use of radio spectrum the DECT voice telephony service is provided by digital 32 kbit/s ADPCM coding which is fully compatible to the ITU-T Recommendation G.726 [28]. This coding provides a high grade voice quality (QDU value of 3,5) without introducing a significant coding delay (< 0,5 ms).

   DTMF tones may be transparently carried by the ADPCM speech channel or may be supported by the DECT signalling channel. Loop disconnect signalling and recall are supported by the DECT signalling channel. A slow speed signalling channel is also available for the transmission of meter pulses and subscriber line and terminal equipment testing.

2) Voice band data and facsimile.

   Currently available voice band modems are not capable of unrestricted operation on ADPCM coded channels. The ITU-T Recommendation G.721 [27] 32 kbit/s algorithm assures the operation of modems of type V.21, V.22 bis, V. 23 and V.26 ter specifications for bit rates of up to 2,4 kbit/s. Modems at 4,8 kbit/s, such as V.27 bis can be supported but with additional degradation to that expected from conventional 64 kbit/s PCM.

   Facsimile (groups 2 and 3) is supported, but the resulting transmission rate is likely to be 7,2 kbit/s or less.

   Demonstration systems using 32 kbit/s ADPCM have been shown successfully to support a wide range of customer services, including Group 3 facsimile and data modems (up to 7,2 kbit/s).

   The complete operation of all voice band modem equipment can only be assured by either providing a 64 kbit/s DECT channel or by the use of appropriate terminal adapters included in the DECT equipment.

3) Analogue leased lines.

   Analogue leased lines are provided as permanent connections by the PSTN and are, therefore, supported by DECT.

   NOTE: A leased line fully utilises a radio channel. This needs to be considered when dimensioning the system.

4) Digital services (ISDN).

   During the DECT standardisation process significant effort was expended on the development and validation of high data rate channels and their associated protocol. This work has led to the definition of an extremely flexible radio interface which is capable of simultaneously supporting services as diverse as voice telephony and medium speed cordless LAN's. Cordless ISDN services were identified as being most important in the DECT services and facilities phase. All layers of the DECT protocol were standardised to allow the design of equipment which would provide ISDN services in the most transparent way possible. In addition, operator and manufacturer interest has been sufficiently high for RES 3 to start production of a standardised DECT - ISDN profile, the first draft of which was presented to RES 3 in May 1993.

The DECT double slot structure is used to provide user information channels of n*64 kbit/s with values of n up to 10. Two double slots may be combined with a single slot to provide a 144 kbit/s liaison suitable for ISDN 2B+D basic rate access. It is expected that this standard will go to public enquiry in November 1994 and be finally adopted in 1995.

In conclusion it is evident that DECT equipment conforming to a manufacturer's specific DECT protocol set is capable of supporting ISDN teleservices today, and from 1995 a complete DECT-ISDN inter-operability profile will be available.

#### 8.2.3.2 Service attributes

This subclause focuses on the principle service attributes requested and assesses the potential compliance of a DECT system.

1) Traffic requirements.

   Capacity calculations are based on 70 mErl busy hour peak traffic rate.

2) Access network delay.

   DECT has a basic one way delay of 10 ms corresponding to the radio interface TDMA frame length. For the POTS service ADPCM speech coding and digital processing add a further 1 or 2 ms resulting in a total of around 12 ms. This value requires the use of echo control to ensure no unnecessary disturbance to either the DECT or non-DECT far end user. Clause 8 of the DECT standard "Speech Coding and Transmission" describes the obligatory echo control mechanisms necessary for DECT systems. This work was performed by combined TE 4/RES 3 working groups and is the subject of a Common Technical Requirement, CTR 10, published by the European Commission in the Official Journal.

   The parameters for the radio local loop application are included in this DECT standard and a specific informative annex is included on the use of DECT in this application. Calls may be national or international and tandeming with other systems is considered.

3) GoS

   DECT systems may be designed for a very high GoS (1% or better) whilst still providing significant system capacity. Meaningful GoS figures may only be given for a specific scenario but attributes of a radio technology which lead to a high GoS may be identified. The principle features permitting a high GoS (i.e. low probability of call blocking or call interruption) in DECT systems are the following:

   a) multi-carrier TDMA and de-centralised radio resource management:

      the multi-carrier TDMA radio architecture of DECT is the base on which the DECT radio channel management features are built. The use of TDMA techniques simplifies channel selection, handover and antenna switching whilst still maintaining a high system capacity through the use of multiple carriers and reducing equipment costs (a single radio may simultaneously support 12 duplex traffic channels);

      decentralised radio resource management permits the dynamic channel selection algorithms to take into account local radio propagation conditions and for rapid decisions to be made on radio channel maintenance throughout a call;

   b) dynamic channel selection:

      DECT uses a dynamic channel selection protocol to gain access to the radio spectrum. It is shown in ETR 042 [33], that with short range systems a significant radio capacity increase may be achieved over that obtained with fixed channel planning techniques. The basic reason for this performance improvement is that in short range, cluttered environments the accurate prediction of channel reuse distance, a parameter necessary for fixed channel planning, becomes increasingly difficult. Dynamic radio channel selection at call set up ensures that local geographic and temporal effects are taken into account in the channel allocation. Continuous dynamic channel selection during the call, e.g. for handover purposes, ensures that the channel allocation is continually optimised to the local conditions;

c) handover:

two forms of radio channel handover are provided in DECT systems - intercell and intracell. Both types may be seamless, i.e. no loss of user information. In radio local loop applications, where it is expected that the subscriber terminals will principally be static, intercell handover may still be useful for increasing link robustness and providing redundancy;

d) antenna diversity:

simple spatial antenna diversity may be used in DECT to combat any dynamic movement of the radio channel conditions. It might be expected that in cluttered urban or suburban areas antenna diversity would be used extensively, at base station and optionally at subscriber terminal sites;

e) signalling channel characteristics:

link specific:

each DECT link has its own dedicated signalling channel which is combined with the user information channel and, therefore, experiences the same radio channel disturbances. In the case of total interruption a second signalling channel can be rapidly established;

sensitivity:

the signalling channel is capable of detecting a radio link disturbance before it becomes significant enough to disturb the user information channel. Appropriate remedial action including handover and/or antenna diversity can be planned in advance;

robust:

the signalling channel is more robust than the user information channel and is, therefore, capable of re-establishing the link quality (either by channel handover or antenna diversity switching) even when radio conditions become suddenly poor;

high speed:

the high speed channel (6,4 kbit/s with error control per half, full or double slot) ensures that once a potentially disturbing radio link condition has been detected rapid action may be taken to protect the user information channel from being broken for a significant period of time. e.g. antenna diversity switching in < 5 ms and handover in < 50 ms;

f) Error performance and availability objectives:

RLL systems based on DECT can be designed to meet the 99 to 99,99 % availability objectives given in subclause 6.2.4 by using sufficient link margins, but the achievable range depends on the objective;

NOTE: Only periods with one-second Bit Error Ratios (BER) greater than $10^{-3}$ and lasting for more than 10 seconds contribute to unavailability as defined by ITU-T and ITU-R.

further study may be required on the implications of 64 kbit/s error performance objectives of ITU-R Recommendation 697 [1] with regard to 32 kbit/s ADPCM voice. The Severely Errored Seconds (SES) objective requires that less than 0,015 % of seconds have BER > $10^{-3}$. The Degraded Minutes (DM) objective requires that no more than 1,5 % of minutes have

BER > $10^{-6}$.The Errored Seconds (ES) objective limits the fraction of seconds with errors to less than 1,2 %. An ES is likely to occur at 32 kbit/s when the bit error probability is greater than about 2 x $10^{-5}$. In addition, the ES objective implies a long-term average BER at 32 kbit/s of less than about $10^{-7}$. DECT based systems can be designed to meet the requirements for data services by using FEC and ARQ techniques specified in the standard, but the spectrum efficiency and range may be reduced;

g) service security (encryption):

a standardised encryption algorithm is specified by ETSI for DECT systems. The properties and capabilities of this algorithm are described in ETS 300 175-7 [30]. The encryption key may be derived from the authentication procedure permitting a new key to be used for each call;

h) authentication:

In parallel with the encryption algorithm there is also an ETSI defined DECT authentication algorithm. Both this and the encryption algorithm may be obtained under contract from ETSI;

j) mobility:

whilst mobility has not been identified as a prime requirement for radio local loop applications the ability to use a portable unit in and around a residential property could be extremely useful. DECT systems will of course support personal mobility at the radio interface level but in addition they provide a detailed user and equipment identity structure which via multiple subscriptions permits the use of the same equipment in various different application environments;

for ranges below maximum range of DECT handset it is feasible to switch from fixed use to mobile use if the RLL system supports that kind of scheme. In mobile use, the range will be more limited than in fixed use;

k) service transparency:

speech quality aspects are covered in subclause 8.2.3.1;

standard calling procedures are supported, since the radio system is transparent. These procedures are under control of the network;

the radio system has no impact on numbering plan, so the standard network numbering plan is supported;

the time taken to establish the radio link when originating or terminating a call will introduce a small additional delay. However, the resultant call set-up delay is comparable with conventional fixed networks;

in-band network-originated signalling, e.g. calling line identity and messaging is supported transparently.

### 8.2.4 Operational characteristics and regulatory requirements

#### 8.2.4.1 Frequency efficiency - critical factors

In evaluating and comparing different technologies on the point of frequency efficiency other factors than just modulation efficiency (Erl/MHz) have to be taken into account. The key factors that together give an indication of the degree of efficiency in the use of the spectrum are discussed below:

a) robustness and radio link quality:

the degree of overhead in the actual radio transmission including burst-by-burst synchronization and CRC error control in DECT appear to have a negative influence on frequency efficiency. They do, however, contribute to the robustness of the radio link and thereby enhance radio link performance;

b) minimum carrier-to-interference ratio and frequency re-use factor:

the smaller the cell size and the lower the channel-to-interference ratio requirements for a certain technology, the better is the frequency reuse factor in a certain area, and the lower is the overall spectrum need. Overall frequency efficiency should be considered in terms of Erlang/MHz/km$^2$. Antenna diversity permits a system to operate closer to its fundamental C/I limit as fade margin requirements are reduced. The C/I specification for a DECT system is 10 dB;

c) speech quality and bit error rate:

in the case of speech transmission the use of the radio spectrum can be increased by using low bit-rate codecs in the DECT half-slot. This will, however, in general have a negative influence on the speech quality (distortion, delay). In the case of digital services it is evident that the transmission quality in terms of bit error rate can be increased with FEC or re-transmission at the expense of radio spectrum.

#### 8.2.4.2 Radio range - critical factors

In determining the radio range of different technologies the assumptions made on some critical factors have an effect on the outcome. It is therefore crucial to make the right assumptions. The critical factors are listed below:

a) fade margin:

the deployment of antenna diversity can reduce the required fade margin in the range calculations. Antenna diversity can be applied in all DECT applications;

b) Dynamic Channel Selection (DCS):

DCS increases the cell radius above that achieved with fixed frequency planning in capacity limited systems:

c) time dispersion:

range limitations due to time dispersion depend on the assumptions on the severity of the dispersion and on the effectiveness of simple correction mechanisms (antenna directivity and diversity or frequency diversity in the form of handover to a different frequency). Research has indicated that at least in some less cluttered environments the effects of time dispersion can be reduced by this simple means.

#### 8.2.4.3 Regulated versus unregulated band

An unregulated band is available European wide for DECT systems between 1 880 and 1 900 MHz.

NOTE: The design of the system needs to consider other users of the band, in order to meet the required GoS.

#### 8.2.4.4 Electromagnetic compatibility

In 1995 the EC EMC directive will apply to all electrical and electronic installations, including telecommunications services. ETSI has developed an EMC standard for DECT (ETS 300 329 [34]) which may be used in conjunction with TBR 06 [35] to show compliance with the essential requirements of the directive.

#### 8.2.4.5 Relay operation

To extend fixed RLL application using the same radio fixed part deployment, an additional unit here called repeater is suggested. Such a repeater realises a relay function allowing services to subscribers outside the normal range of a base station.

Example:

A proposal for the hardware is that of a DECT radio fixed part, with simplified software to be implemented as the signal is not fully processed in this unit. The repeater switches from transmit to receive mode on a slot by slot basis. It memorises and re-transmits the received slot, from the subscriber as well as from the network side. The duplication/re-transmission of the slot reduces the number of available channels by half.

The relay function can also be applied in a mobile RLL application, where the subscriber is allowed to use the portable unit moving in and around a residential area. The lack of a high-gain antenna directly connected to the handset and the wall attenuation to be added when the subscriber is moving inside his premise, require typically 40 dB mean field strength more than in the fixed RLL application.

Analyses of interference effects and the impact on grade of service are for further study.

### 8.2.5 DECT local loop planning

This subclause describes some examples of how a DECT system might be planned in a radio local loop application. All equipment is assumed to be fixed.

#### 8.2.5.1 Propagation models

Hypotheses are made for the following environments which should be further validated. It should be further noted that almost all published work is for mobile subscriber terminals, rather than fixed, and that the propagation conditions are significantly different in the two cases.

1) Cluttered: $L = 58 + 35 (\log d - 1)$, $d > 10$ m

Non LOS — Source = Modification of RES 3-R. Free space to 10 m, 3rd and 5th order for $d > 10$ m.

Antenna heights = Roof-top and lamppost level (6 to 10 m).

2. Semi cluttered: $L = 58 + 30 (\log d - 1)$, $d > 10$ m

Almost LOS — Source = None published. Free space to 10 m, 3rd order for $d > 10$ m.

Antenna heights = Roof-top and lamppost level (6 to 10 m).

3. Open : $L = 53 + 20 \log d$

LOS — Source = CEPT Model A. Free space for all d, + 15 dB for obstructions.

Antenna heights = 15 m.

It should be noted that ranges calculated from propagation models above correspond with 1,8 GHz propagation measurements.

#### 8.2.5.2 System parameters

The following system parameters are taken from ETS 300 175 [30] and practical assumptions:

| | |
|---|---|
| Receiver sensitivity (RFP in both ends) = | - 86 dBm; |
| Transmitter output power (subscriber terminal and RFP) = | + 24 dBm; |
| RFP antenna gain = | + 6 or 14 dBi; |
| Subscriber Terminal (ST) antenna gain = | + 6 or 17 dBi. |

**Table 3**

| Link Budget | Radio Termination Antenna Gain | BS Antenna Gain | Total Link Budget (without fade margin) |
|---|---|---|---|
| A | 6 dBi | 6 dBi | 122 dB |
| B | 17 dBi | 6 dBi | 133 dB |
| C | 6 dBi | 14 dBi | 130 dB |
| D | 17 dBi | 14 dBi | 141 dB |

The fade margin is reduced when a high gain antenna is used at either or both link endpoints, i.e. in Link Budgets B, C and D. The fade margin is designed to provide less than 1 % outage.

**Table 4**

| Environment | Fade Margin (With antenna diversity) | Fade Margin (No antenna diversity) |
|---|---|---|
| 1) Cluttered | Link Budgets A = 10 dB<br>Link Budgets B, C, D = 8 dB | Link Budgets A = 18 dB<br>Link Budgets B, C, D = 15 dB |
| 2) Semi Cluttered | Link Budgets A = 8 dB<br>Link Budgets B, C, D = 7 dB | Link Budgets A = 15 dB<br>Link Budgets B, C, D = 12 dB |
| 3) Open | Link Budgets A = 5 dB<br>Link Budgets B, C, D = 4 dB | Link Budgets A = 9 dB<br>Link Budgets B, C, D = 7 dB |

#### 8.2.5.3 Radio range

Operating range is calculated as a function of link budget only and any multipath effects are yet to be assessed.

**Table 5**

| Link Budget | Cluttered No diversity | Cluttered With diversity | Semi Cluttered No diversity | Semi Cluttered With diversity | Open No diversity | Open With diversity |
|---|---|---|---|---|---|---|
| **A** | 210 m | 350 m | 430 m | 740 m | 1 000 m | 1 600 m |
| **B** | 520 m | 820 m | 1 300 m | 1 800 m | 4 500 m | 5 000* m |
| **C** | 420 m | 670 m | 1 000 m | 1 500 m | 3 200 m | 4 500 m |
| **D** | 880 m | 1 400 m | 2 300 m | 3 400m | 5 000* m | 5 000* m |
| NOTE: * - Range limited by TDMA/TDD frame timing. | | | | | | |

### 8.2.5.4 Traffic Capacity

To derive system capacity several assumptions are required on the type and characteristics of equipment as well as on the statistics of the offered traffic and the environment.

a) Environment.

An environment whose propagation conditions can be characterised by the semi-cluttered propagation law given above is assumed and a 12 dB fade margin is necessary. Link budget B and no diversity is assumed. The BS antenna is at lamp post height and subscriber unit antenna at roof top height.

$$L = 58 + 30 (\log d - 1) \text{ for } d > 10 \text{ m}$$

It is assumed the full 20 MHz of DECT spectrum is available for radio local loop applications.

b) Traffic characteristics.

Average traffic per subscriber during the busy hour is assumed to be a constant 0,07 Erlangs, as stated in clause 6.

Voice traffic is assumed to use the DECT full slot 32 kbit/s ADPCM traffic bearers.

c) System characteristics.

The system characteristics are assumed to be the same as those in clause 5 with the following additions:

- the "standard" DECT RFP can support up to 12 voice telephony conversations simultaneously and uses a single TDMA radio. However ETS 300-175 [30] permits a single RFP to use the equivalent number of channels to that given by the expression:

Maximum traffic bearer capacity occupied = < 14,4 half slots x Number of carriers available to system;

- for a standard DECT system in the DECT band this corresponds to 72 full slots or 72 simultaneous duplex traffic channels, requiring 6 radio transceivers. The theoretical lowest equivalent re-use factor without co-siting two or more RFP equipment is therefore 1,66, using full slots for communications.

d) Example network configurations.

In the examples given below the minimum number of operator sites has been assumed. Another approach would be to distribute smaller RFP's over a greater area. This would significantly increase the traffic capacity, allowing the system to cope with hot spots or areas of difficult coverage.

The use of dynamic channel selection techniques and directive antennas leads to very low equivalent re-use factors, potentially of 2 or less. However, the following multi-cell example is for 7, 4 and 2 equivalent reuse factors.

If an equivalent reuse factor of 7 is assumed then each base station site will contain a two transceiver base station which may support up to 14,6 E (approximately 210 subscribers) with a 1 % GoS. In order to compute the traffic demand acceptable at one BS, a first approach would be to divide the overall number of channels by the cluster size to obtain the number of channels available in the cell, and then use the Erlang-B formula. Actually, this is not true as DCA enables the BS to use more radio channels, providing they are not used by the other cells of the cluster. Traffic results used in this subclause have been obtained by simulations to take this effect into account.

The table below shows how the required maximum range and base station density vary with the offered traffic.

**Table 6: DECT multi-cellular system - cluster size = 7**

| Offered traffic (Erl/km$^2$) | Maximum range (m) | Site density (No./km$^2$) |
|---|---|---|
| 1 | Range limited - 1 300 m | 0,2 |
| 5 | 1 100 m | 0,4 |
| 10 | 750 m | 0,7 |
| 25 | 470 m | 1,7 |
| 50 | 340 m | 3,4 |
| 75 | 270 m | 5,1 |
| 100 | 240 m | 6,8 |
| 150 | 190 m | 10,3 |
| 200 | 170 m | 13,7 |

If an equivalent re-use factor of 4 is assumed then each base station site will contain a three transceiver base station which may support up to 25,2 E (approximately 360 subscribers) with a 1 % GoS. The table below shows how the required maximum range and base station density vary with the offered traffic.

**Table 7: DECT multi-cellular system - cluster size = 4**

| Offered traffic (E/sq. km) | Maximum range(m) | Site density (No./sq. km) |
|---|---|---|
| 1 | Range limited - 1 300 m | 0,2 |
| 5 | Range limited - 1 300 m | 0,2 |
| 10 | 1 100 | 0,4 |
| 25 | 710 | 1 |
| 50 | 500 | 2 |
| 75 | 410 | 3 |
| 100 | 360 | 4 |
| 150 | 290 | 6 |
| 200 | 250 | 8 |

If an equivalent re-use factor of 2 is assumed then each base station site will contain a single 5 transceiver base station which may support up to 47 E (approximately 670 subscribers) with a 1 % GoS. The table below shows how the required maximum range and base station density vary with the offered traffic.

**Table 8: DECT multi-cellular system - cluster size = 2**

| Offered traffic (Erl/km$^2$) | Maximum range(m) | Site density (No./km$^2$) |
|---|---|---|
| 1 | Range Limited - 1 300 m | 0,3 |
| 5 | Range Limited - 1 300 m | 0,3 |
| 10 | Range Limited - 1 300 m | 0,3 |
| 25 | 770 | 0,5 |
| 50 | 550 | 1 |
| 75 | 450 | 1,6 |
| 100 | 390 | 2,1 |
| 150 | 320 | 3,2 |
| 200 | 270 | 4,3 |

### 8.2.6 RLL deployment examples - DECT solution

#### 8.2.6.1 Deployment example 1

Deployment examples 1.1 and 1.2 have been treated in the same way: the number of BSs necessary to cover an area with a 0,5 km radius has been calculated by considering the traffic demand in this area. The cluttered propagation model has been used and a cluster size of 4 has been assumed, because of the short ranges.

**Table 9**

| Subscriber density | New housing area | | | New town | | |
|---|---|---|---|---|---|---|
| | **Number of BS sites** | **Number of tx/rx per BS** | **Maximum range** | **Number of BS sites** | **Number of tx/rx per BS** | **Maximum range** |
| 500/km$^2$ | 3 | 4 | 0,44 km | 107 | 4 | 0,6 km |
| 2 000/km$^2$ | 5 | 4 | 0,31 km | 486 | 4 | 0,3 km |
| NOTE: Refer to subclause 8.2.5.3 for applicable link budget/antenna diversity options meeting maximum range requirements. | | | | | | |

### 8.2.6.2 Deployment example 2

Deployment example 2 has been treated assuming a semi-cluttered propagation model and a cluster size of 4. It is assumed that the maximum subscriber density (50/km$^2$) applies in the central area (area A). We have then 2 500 subscribers in area A which corresponds to 90 % of the overall population in the area. The population in area B is, therefore, 280 subscribers (10 % of the overall population). Assuming 5 subscribers per cluster, there are 56 clusters in area B.

**Table 10**

| Centre - 4 km area (50 subscribers/sq. km) Area A | | | Outer - 40 km area (5 subscribers per cluster) Area B | | |
|---|---|---|---|---|---|
| **Number of BS sites** | **Number of tx/rx per BS** | **Maximum range** | **Number of BS sites** | **Number of tx/rx per BS** | **Maximum range** |
| 36 | 1 | 0,67 km | 56 | 1 | 1,4 km |
| NOTE : Refer to subclause 8.2.5.3 for applicable link budget/antenna diversity options meeting maximum range requirements. | | | | | |

### 8.2.6.3 Deployment example 3

Deployment example 3 has been treated by calculating the number of BS necessary to cover the area corresponding to the secondary distribution point. A semi-cluttered propagation model has been used and a cluster size of 4 has been assumed.

**Table 11**

| Subscriber penetration | Number of BS sites per distribution point | Number of tx/rx per BS site | Maximum range |
|---|---|---|---|
| 1 % (1st year) | 1 | 2 | 0,7 km |
| 10 % (10th year) | 1 | 2 | 0,7 km |
| NOTE 1: Refer to subclause 8.2.5.3 for applicable link budget/antenna diversity options meeting maximum range requirements.<br>NOTE 2: Add 24 feeder lines per BS site. | | | |

### 8.2.6.4 Deployment example 4

For this example, the cluttered propagation model has been used for areas A1 and B1 and the semi cluttered one for areas A2, B2 and C. A cluster size of 7 has been assumed. Refer to subclause 8.2.5.3 for applicable link budget/antenna diversity options meeting maximum range requirements.

a) 1 % penetration.

**Table 12**

| Area | Number of BS sites | Number of TX/RX per BS site | Maximum range |
|---|---|---|---|
| A1 | 46 | 1 | 0,67 km |
| B1 | 256 | 1 | 0,67 km |
| A2 | 2 | 1 | 1,4 km |
| B2 | 11 | 1 | 1,4 km |
| C (all cases) | 0,16 BS/km$^2$ | 1 | 1,4 km |

b) 10 % penetration.

**Table 13**

| Area | Number of BS sites | Number of TX/RX per BS site | Maximum range |
|---|---|---|---|
| A1 | 64 | 2 | 0,67 km |
| B1 | 526 | 1 | 0,67 km |
| A2 | 2 | 5 | 1,4 km |
| B2 | 12 | 2 | 1,4 km |
| C (all cases) | 0,16 BS/km$^2$ | 1 | 1,4 km |

### 8.2.7 Discussion

The following points may be noted when reviewing the example network configurations:

- whilst range is important in low density areas the majority of subscriber terminals are expected to be at shorter distances from the base station;
- the equivalent re-use factor, whilst determining the number of base station sites above 5 to 10 Erl/km$^2$ does not have a significant impact on the required range;
- DECT would appear well suited to providing the last 300 to 500 m connection at an offered traffic level of 100 Erl/km$^2$. For lower subscriber densities or radio local loop penetration DECT appears to allow subscriber connection in suburban areas at ranges of up to 1 km.

## 8.3 CT2

### 8.3.1 Background

This clause discusses the suitability of the CT2 radio interface as it is described in I-ETS 300 131 Edition 2 [36] for the RLL application. The aim of this standard is to allow the use of the same radio equipment in various environments such as public access, private PBX, domestic, etc.

### 8.3.2 CT2 Reference model for RLL

Translation table to RLL reference model.

Cordless Portable Part (CPP) = Radio termination + customer terminal;

Cordless Fixed Part (CFP) = BS.

### 8.3.3 Service characteristics

The requirements in clause 6 are here discussed with respect to the CT2/CAI standard. Only the characteristics specified in I-ETS 300 131 Edition 2 [36] as mandatory or optional are taken into consideration.

#### 8.3.3.1 Services

This subclause describes how the CT2 standard fulfils the requirements defined in clause 6. Particular emphasis is given to exploring the degree of transparency with which a service is supported.

1) Voice telephony.

   The CT2 voice telephony service is provided by digital 32 kbit/s ADPCM coding in accordance with ITU-T Recommendation G.721 [27]. This coding provides a high quality for voice communications without introducing a significant coding delay.

   DTMF tones may be transparently carried by the ADPCM speech channel, or may be supported by CT2 signalling. Loop disconnect signalling, recall, meter pulsing and line test messages are also supported by CT2 signalling.

2) Voice band data and facsimile.

   Currently available voice band modems are not capable of unrestricted operation on ADPCM coded channels. The ITU-T Recommendation G.721 [27] 32 kbit/s algorithm assures the operation of modems of type V.21, V.22 bis, V. 23 and V.26 ter specifications for bit rates of up to 2,4 kbit/s. Modems at 4,8 kbit/s, such as V.27 bis can be supported but with additional degradation to that expected from conventional 64 kbit/s PCM.

   Facsimile (groups 2 and 3) is supported, but the resulting transmission rate is likely to be 7,2 kbit/s or less.

   Demonstration systems using 32 kbit/s ADPCM have been shown successfully to support a wide range of customer services, including Group 3 facsimile and data modems (up to 7,2 kbit/s).

   To ensure the complete operation of some voice band modem equipment, particularly those operating at more than 7,2 kbit/s, terminal adapters may be required in the CT2 equipment.

3) Analogue leased lines.

   Analogue leased lines are provided as permanent connections by the PSTN and are therefore supported by CT2.

   NOTE: A leased line fully utilises a base station transceiver and a radio channel. This needs to be considered when dimensioning the system.

4) Digital services (ISDN).

   The CT2 standard provides both a full-duplex asynchronous data service and a full-duplex synchronous (transparent) data service. Data rates available are 300, 1 200, 2 400, 4 800, 9 600, 14 400 and 19 200 bit/s for the former one and 300, 1 200, 2 400, 4 800, 9 600, 14 400, 19 200, and 32 000 bit/s for the latter one. An Automatic Repeat Request (ARQ) protocol is provided for the asynchronous data bearer services. A Forward Error Control (FEC) protocol is provided for synchronous data bearer services, except for 32 kbit/s. These two protocols ensure a high quality of service for both modes.

#### 8.3.3.2 Service attributes

This subclause discuss how the CT2 standard may cope with services attributes defined in subclause 6.2.

1) Traffic requirements.

Capacity calculations are based on 70 mErl busy hour peak traffic rate.

2) Access network delay.

Additional delay introduced by the local loop radio interface should be kept as short as possible.

CT2 has a basic one way delay of over 1 ms corresponding to approximately half the radio interface TDD frame length. For the voice telephony service ADPCM speech coding and digital processing add a further 1 or 2 ms resulting in a total of around 2,5 ms. A maximum loop back delay of 5,0 ms is specified in the CT2 standard (delay measured with a worst case reference CFP). This value does not require the use of echo control to ensure that no unnecessary disturbance occurs to either the CT2 connected or non-CT2 connected users.

Whilst tandeming with a mobile radio network is not covered by the standard, such configuration is likely to occur with a CT2 system.

3) GoS.

CT2 systems may be designed for a high grade of service which is achievable due to the following characteristics:

a) dynamic channel allocation:

a dynamic channel allocation protocol is defined in the CT2/CAI standard. This protocol allows a more efficient use of the available spectrum than a fixed channel allocation and does not require frequency planning. Actually, an incoming or outgoing call chooses the best RF channel (in terms of interferences) for the link establishment, by scanning all RF channels and making strength measurements;

b) in-call switching:

an in-call switching procedure is defined so as to ensure the link re-establishment on the same or another RF channel on the same base station in case of degradation of the radio link. The standard also provides the ability to re-establish the communication on another base station. However, based on TDD/FDMA type of operation, and short frame buffer, channel exchange causes a short interruption in connection;

c) antenna diversity:

it is possible to implement antenna diversity for both the CFP and the CPP, which reduces the fade margin. Typically, only antenna diversity for the CFP is required, due to reciprocity of the TDD channel;

d) signalling channel characteristics:

the signalling channel robustness is ensured by using an error detection code and is therefore better than for the information channel. The coding scheme provides the system with the ability to re-establish the communication on another RF channel (intra or inter cell) in case of interferences before the call interruption.

4) Error performance and availability objectives.

RLL systems based on CT2 can be designed to meet the 99 to 99,99 % availability objectives given in subclause 6.2.4 by using sufficient link margins but the achievable range depends on the objective.

NOTE: Only periods with one-second bit error ratios (BER) greater than $10^{-3}$ and lasting for more than 10 s contribute to unavailability as defined by ITU-T and ITU-R Recommendations.

Further study may be required on the implications of 64 kbit/s error performance objectives of ITU-R Recommendation 697 [1] with regard to 32 kbit/s ADPCM voice. The SES objective requires that less than 0,015 % of seconds have BER greater than $10^{-3}$. The DM objective requires that no more than 1,5 % of minutes have BER > $10^{-6}$. The ES objective limits the fraction of seconds with errors to less than 1,2 %. An ES is likely to occur at 32 kbit/s when the bit error probability greater than about 2 x $10^{-5}$. In addition, the ES objective implies a the long-term average BER at 32 kbit/s of less than about $10^{-7}$. CT2-based systems can be designed to meet the requirements for data services by using FEC and ARQ techniques specified in the standard, but the maximum bit rate and range may be reduced.

5) Service security (encryption).

No standardised encryption algorithm is specified by ETSI for CT2 systems.

6) Authentication.

An authentication scheme has been standardised so as to ensure mutual authentication of both parts.

7) Mobility.

Whilst mobility has not been identified as a prime requirement for radio local loop applications the ability to use a portable unit in and around a residential property could be extremely useful. The CT2/CAI standard is designed so as to be used in a wide variety of environments (domestic, public access, cordless PBX, etc.). Therefore, there is no problem to provide the subscriber with personal mobility, either directly via the RLL Base Station or via a domestic base station connected to a roof antenna.

For ranges below maximum range of CT2 handset it is feasible to switch from fixed use to mobile use if the RLL system supports that kind of scheme. In mobile use, the range will be more limited than in fixed use.

8) Service transparency.

Speech quality aspects are covered in subclause 8.3.3.1.

Standard calling procedures are supported, since the radio system is transparent. These procedures are under control of the network.

The radio system has no impact on numbering plan, so the standard network numbering plan is supported.

The time taken to establish the radio link when originating or terminating a call will introduce a small additional delay. However, the resultant call set-up delay is comparable with conventional fixed networks.

In-band network-originated signalling, e.g. calling line identity and messaging is supported transparently.

### 8.3.4 Operational characteristics and regulatory requirements

#### 8.3.4.1 Frequency efficiency - critical factors

a) Robustness.

The robustness of the signalling channel is ensured by CRC bits. Furthermore, data transmission is made more robust by using Forward Error Control and Automatic Repeat Request. Of course, this improvement is made at the expense of spectrum efficiency.

b) Minimum carrier-to-interference ratio and frequency reuse factor.

The overall system capacity becomes higher as the carrier to interference ratio decreases and the frequency reuse factor becomes lower. Generally, the cluster size depends, amongst other parameters, on the environment: the cluster size is bigger in open areas and smaller in semi-cluttered or cluttered areas.

c) Speech quality and BER.

The maximum BER defined in the CT2 standard is $10^{-3}$, which ensures a good speech quality.

#### 8.3.4.2 Radio range - critical factors

a) Fade margin.

Fade margin has a direct impact on range and may be improved by using spacial diversity and antenna gain.

b) Dynamic Channel Allocation (DCA).

DCA is an important factor to increase the overall system capacity. With fixed channel allocation, the number of RFPs should be the same as the number of radio frequencies available for the cell. With DCA, it is possible to use more RFPs than the simple division of the overall number of frequencies available by the cluster size would allow. In this case and for a given bandwidth, a better overall capacity is achieved. This is why CT2 may achieve good traffic densities with only 4 MHz.

c) Time dispersion.

Due to the low bit rate of the CT2, time dispersion is not a limiting factor for ranges up to the limit of the time division duplex range.

#### 8.3.4.3 Regulated versus unregulated band

CT2 uses an unregulated band between 864,1 MHz and 868,1 MHz (40 channels of 100 kHz).

NOTE: The design of the system needs to consider other users of the band, in order to meet the required GoS.

#### 8.3.4.4 Electromagnetic compatibility

The EMC standard for CT2 is currently under development by ETSI RES 09.

#### 8.3.4.5 Relay operation

Relay operation is not specified in the CT2 standard but is technically feasible.

### 8.3.5 CT2 local loop planning

#### 8.3.5.1 Propagation models

Hypotheses are made for the following environments which should be further validated. It should be further noted that almost all published work is for mobile subscriber terminals, rather than fixed, and that the propagation conditions are significantly different in the two cases.

1) Cluttered: $L = 52 + 35(\log d - 1)$, $d > 10$ m

Not LOS

Source = None published. Free space to 10 m, 3rd and 5th order for d>10 m.

Antenna heights = Roof-top and lamppost level (6-10 m).

| | | | |
|---|---|---|---|
| 2) | Semi cluttered: | L = 52 + 30(log d - 1), | d > 10 m |
| | Almost LOS | Source = None published. Free space to 10 m, 3rd order for d>10 m. | |
| | | Antenna heights = Roof-top and lamppost level (6-10 m). | |
| 3) | Open model : | L = 47 + 20 log d | |
| | LOS | Source = CEPT Model A. Free space for all d, + 15 dB for obstructions. | |
| | | Antenna heights = 15 m. | |

It should be noted that ranges calculated from propagation models above correspond with CT2 propagation measurements (with reference to TD3-14 and to TD7-06).

### 8.3.5.2 System parameters

The following system parameters are assumed from I-ETS 300 131 Edition 2 [36] or other RES 3 RLL papers:

Receiver sensitivity (subscriber terminal and CFP) = - 100 dBm;

Transmitter output power (subscriber terminal and CFP) = + 10 dBm;

CFP antenna gain = + 6 dBi or 14 dBi;

Subscriber Terminal (ST) antenna gain = + 6 dBi or 14 dBi.

**Table 14**

| Link budget | Subs. Terminal Antenna Gain | RFP Antenna Gain | Total Link Budget (without fade margin) |
|---|---|---|---|
| A | 6 dBi | 6 dBi | 122 dB |
| B | 14 dBi | 6 dBi | 130 dB |
| C | 6 dBi | 14 dBi | 130 dB |
| D | 14 dBi | 14 dBi | 138 dB |

**Table 15**

| Environment | Fade margin (with antenna diversity) | Fade margin (no antenna diversity) |
|---|---|---|
| 1) Cluttered | Link Budgets A = 10 dB<br>Link Budgets B, C, D = 9 dB | Link Budgets A = 18 dB<br>Link Budgets B, C, D = 16 dB |
| 2) Semi-cluttered | Link Budgets A = 8 dB<br>Link Budgets B, C, D = 7 dB | Link Budgets A = 15 dB<br>Link Budgets B, C, D = 13 dB |
| 3) Open | Link Budgets A = 5 dB<br>Link Budgets B, C, D = 5 dB | Link Budgets A = 9 dB<br>Link Budgets B, C, D = 8 dB |

#### 8.3.5.3 Radio range

**Table 16**

| Link budget | Cluttered no diversity | Cluttered with diversity | Semi-cluttered no diversity | Semi-cluttered with diversity | Open no diversity | Open with diversity |
|---|---|---|---|---|---|---|
| A | 310 m | 520 m | 680 m | 1 200 m | 2 000 m | 3 200 m |
| B | 590 m | 940 m | 1 500 m | 2 300 m | 5 000* m | 5 000* m |
| C | 590 m | 940 m | 1 500 m | 2 300 m | 5 000* m | 5 000* m |
| D | 1 000 m | 1 600 m | 2 700 m | 4 300 m | 5 000* m | 5 000* m |
| NOTE: * Range limited by FDMA/TDD frame timing. | | | | | | |

#### 8.3.5.4 Traffic Capacity

To derive system capacity several assumptions are required on the type and characteristics of equipment as well as on the statistics of the offered traffic and the environment.

a) Environment.

An environment whose propagation conditions can be characterised by the semi-cluttered propagation law given in subclause 8.3.5.1 is assumed. A 16 dB fade margin and a 14 dBi antenna gain are assumed.

b) Traffic characteristics.

The average traffic per subscriber during busy hours is assumed to be 0.07 Erlangs as stated in subclause 3.2.1. The average duration of a call is assumed to 3 minutes, as in the PSTN.

All traffic is assumed to be voice telephony using the CT2 32 kbit/s ADPCM traffic bearers.

c) System characteristics.

The CT2 BS can support up to 12 transceivers (corresponding to 12 duplex traffic channels) simultaneously using frequency division multiple access.

It is assumed the full 4 MHz of CT2 spectrum is available for radio local loop applications. DCA is taken into account by considering the probability for a base station to have N radio frequency channels (N12) available. This probability is calculated assuming that all the cells in the cluster have the same average offered traffic.

The system characteristics are assumed to be the same as those in subclause 8.1.

d) Example network configurations.

In the examples given below the minimum number of operator sites has been assumed. Another approach would be to distribute a larger amount of smaller CFP's over the same area.

The use of dynamic channel selection techniques and directive antennas leads to low cluster sizes, potentially of 4. However, the following multi-cell example is for both 7 and 4 cluster sizes.

The tables below show how the required maximum range and base station density vary with the offered traffic for a semi cluttered environment.

**Table 17: CT2 Semi-cluttered environment - cluster size = 7**

| Offered traffic (Erl/km$^2$) | Maximum range (m) | Site density (No./km$^2$) |
|---|---|---|
| 1 | 1 400 | 0,16 |
| 5 | 520 | 1,2 |
| 10 | 360 | 2,5 |
| 25 | 230 | 6 |
| 50 | 170 | 11 |
| 75 | 140 | 16 |
| 100 | 120 | 22 |
| 150 | 100 | 35 |
| 200 | 80 | 50 |

**Table 18: CT2 Semi-cluttered environment - cluster size = 4**

| Offered traffic (E/km$^2$) | Maximum range (m) | CFP site density (No./km$^2$) |
|---|---|---|
| 1 | 1 400 | 0,16 |
| 5 | 610 | 0,9 |
| 10 | 440 | 1,64 |
| 25 | 240 | 5,5 |
| 50 | 190 | 8,8 |
| 75 | 170 | 11 |
| 100 | 140 | 16 |
| 150 | 120 | 22 |
| 200 | 100 | 32 |

### 8.3.6 RLL deployment examples - CT2 solution

#### 8.3.6.1 Deployment example 1

Deployment examples 1.1 and 1.2 have been treated in the same way: the number of BSs necessary to cover an area with a 0,5 km radius has been calculated by considering the traffic demand in this area. The cluttered propagation model has been used and a cluster size of 4 has been assumed, because of the short ranges.

**Table 19**

| Subscriber density | New housing area | | | New town | | |
|---|---|---|---|---|---|---|
| | Number of BS sites | Number of tx/rx per BS | Maximum Range | Number of BS sites | Number of tx/rx per BS | Maximum Range |
| 500/km$^2$ | 5 | 12 | 0,23 km | 480 | 12 | 0,23 km |
| 2 000/km$^2$ | 19 | 12 | 0,12 km | 1 920 | 12 | 0,12 km |
| NOTE: Refer to subclause 8.2.5.3 for applicable link budget/antenna diversity options meeting maximum range requirements. | | | | | | |

#### 8.3.6.2 Deployment example 2

Deployment example 2 has been treated assuming a semi-cluttered propagation model and a cluster size of 4. It is assumed that the maximum subscriber density (50/km$^2$) applies in the central area (area A). We have then 2 500 subscribers in area A which corresponds to 90 % of the overall population in the area. The population in area B is therefore 280 subscribers (10 % of the overall population). Assuming 5 subscribers per cluster, there are 56 clusters in area B.

**Table 20**

| Centre - 4 km area (50 subscribers/sq. km) Area A | | | Outer - 50 km area (5 subscribers per cluster) Area B | | |
|---|---|---|---|---|---|
| **Number of BS sites** | **Number of tx/rx per BS** | **Maximum range** | **Number of BS sites** | **Number of tx/rx per BS** | **Maximum range** |
| 44 | 12 | 0,94 km | 56 | 3 | 2,3 km |
| NOTE: Refer to subclause 8.2.5.3 for applicable link budget/antenna diversity options meeting maximum range requirements. | | | | | |

### 8.3.6.3 Deployment example 3

Deployment example 3 has been treated by calculating the number of BS necessary to cover the area corresponding to the secondary distribution point. A semi-cluttered propagation model has been used and a cluster size of 4 assumed.

Incremental growth is achieved by adding transceivers and base stations associated with each distribution point throughout the 10 year period. In year one 1 base station with 5 transceivers is installed and by year ten there are 3 base stations each with 10 transceivers.

**Table 21**

| Subscriber penetration | Number of BS sites per distribution point | Number of tx/rx per BS site | Maximum range |
|---|---|---|---|
| 1 % (1st year) | 1 | 5 | 0,7 km |
| 10 % (10th year) | 3 | 10 | 0,32 km |
| NOTE: Refer to paragraph 5.2.5.3 for applicable link budget/antenna diversity options meeting maximum range requirements. | | | |

### 8.3.6.4 Deployment example 4

For this example, the cluttered propagation model has been used for areas A1 and B1 and the semi-cluttered one for areas A2, B2 and C. A cluster size of 4 has been assumed for cell range up to 0,6 km. Otherwise cluster size 7 has been assumed.

a) 1 % penetration.

**Table 22**

| Area (subscriber. density) | Number of BS sites | Number of TX/RX per BS site | Maximum range |
|---|---|---|---|
| A1 | 24 | 10 | 0,93 km |
| B1 | 270 | 4 | 0,93 km |
| A2 | 2 | 1 | 2,3 km |
| B2 | 4 | 12 | 0,6 km |
| C<br>(5/km$^2$)<br>(50/km$^2$) | <br>0,06 BS/km$^2$<br>0,06 BS/km$^2$ | <br>2<br>2 | <br>2,3 km<br>2,3 km |

b) 10 % penetration.

**Table 23**

| Area (subscriber. density) | Number of BS sites | Number of TX/RX per BS site | Maximum range |
|---|---|---|---|
| A1 | 151 | 12 | 0,36 km |
| B1 | 648 | 12 | 0,936 km |
| A2 | 22 | 12 | 0,49 km |
| B2 | 58 | 12 | 0,6 km |
| C<br>(5/$km^2$)<br>(50/$km^2$) | <br>0,06 BS/$km^2$<br>0,06 BS/$km^2$ | <br>2<br>12 | <br>2,3 km<br>2,3 km |
| NOTE: Refer to subclause 8.2.5.3 for applicable link budget/antenna diversity options meeting maximum range requirements. | | | |

### 8.3.7 Discussion

Some general conclusions may be drawn from the deployment example studied:

- in high capacity deployment example CT2 is generally limited by capacity rather than range. Hence CT2 generally does not require antenna gain only a low (6 dBi) gain at one end;
- the relatively high base station densities required for high traffic densities are a result of the small spectrum used (4 MHz) and should be viewed in relation to the simplicity of each base station;
- at low traffic densities CT2 can provide range of at least 1 to 2 km;
- a CT2 solution was found for each deployment example by adapting base station densities in order to cope with traffic requirements.

## 8.4 Cordless technology evolution

### 8.4.1 DECT

Evolution of the DECT standard to improve radio range in the RLL application could be considered in four areas :

1) receiver sensitivity - the receiver sensitivity specification could be significantly improved to optimise range for the RLL application;

2) transmitter output power - the transmitter output power specification could be increased to increase range. Co-existence of the higher output power with current DECT equipment is for further study. Increased antenna gain may also be considered;

3) relay operation - changes to the specification to accommodate relay operation can extend radio range without the need for landline connections;

4) regulated spectrum - technically the most feasible solution is an extension to currently existing DECT band 1 880 - 1 900 MHz. Due to US-PCS deregulated band 1 890 - 1 930 MHz potentially allowing also DECT equipment, the DECT extension should reside either below 1 880 MHz or above 1 930 MHz.

### 8.4.2 CT2

1) Transmitter output power - the transmitter output power specification could be increased to provide greater range. The co-existence of increased output power with current CT2 equipment requires further study.

2) Receiver sensitivity - the receiver sensitivity specification could be significantly improved to optimise range for the RLL application.

3) 64 kbit/s bearer channel - a 64 kbit/s bearer channel could be provided by using two RF channels to the subscriber. An alternative approach would be to use a higher order modulation scheme such as QPSK. The transmit spectrum would be similar to that of GFSK allowing co-existence with current equipment.

4) Change of frequency band - should RLL operators require a regulated band, CT2 equipment can easily be designed to operate at an alternative frequency close to the existing 864 to 868 MHz allocation. Such frequency changes have already been implemented for certain territories where the specified CT2 band is not available.

5) Co-channel interference specification - a significant (greater than 10 dB) improvement in co-channel interference specification could be made for RLL applications. This would allow reduced frequency re-use distances resulting in smaller cluster sizes and increased traffic capacity.

# 9 Analysis of cellular technologies for RLL

## 9.1 Introduction

Current cellular technologies are designed for macro-cellular applications and restricted traffic densities. Hence cellular technologies could provide feasible solutions for remote, rural and suburban RLL deployment. High traffic densities require micro-cellular or short range radio technologies and conventional cellular frequency re-use planning becomes complex.

The RLL concept can be beneficial because of the cellular bands which the European mobile operators already have, especially in sparsely populated areas. Offering RLL can bring new customers to the mobile operator and also make the investments at the base station site more beneficial or even trigger the decision to build up new base stations. In some cases cellular customers can get wider mobile coverage at the same time. A RLL service could be added to a full mobile network as a specific service profile with restricted or denied mobility, modified numbering plan, specific charging etc.

European PSTN/ISDN network operators can build RLL access to their networks by using mobile technology when it is not feasible to build wired connections. An operator could provide radio access to the public telecommunications network when:

- costs of radio access network are lower due to the traffic density;

- the location of a subscriber or the shape of the landscape; or

- the need for telecommunications services are urgent or temporary and wired connections are not available.

For operators which have both PSTN/ISDN and cellular networks the possibility to share cellular mobile infrastructure with RLL is an alternative to reduce the overall RLL infrastructure cost. The "final" goal of the development of the access network could be an access network with flexibility to support different access types. In this concept the basic transmission and switching capabilities of the access network could be used by a mobile subscriber, wired subscriber or RLL subscriber. Therefore, the possibility to support different access types in the same access network could be included in the development of the RLL system.

Deployment of analogue mobile telephony (NMT and TACS) based systems are described in subclause 9.1.1. In this ETR, however, only digital cellular technologies are more thoroughly analysed as they have been subject to ETSI standardisation.

### 9.1.1 Analogue cellular overview

#### 9.1.1.1 Introduction

The analogue systems NMT and TACS provide 3 kHz speech services at 450 MHz (NMT only) and 900 MHz frequency bands, and are currently used in many countries as the main cellular system.

NMT 900 has been used as technology e.g. for the German "DAL" RLL system for which the amount of subscribers is approaching to 45 000.

TACS has been used as the technology for the Spanish "TRAC" RLL system. The most important feature of this application is that the same TACS system is shared for mobile and fixed users. Presently the number of fixed subscribers using the "TRAC" RLL system is approaching 75 000.

The open NMT and TACS standards have resulted in service and cost efficient system solutions and equipment's from competing sources. The NMT standard, though formally owned by the NMT group, is a fully open standard, down to all interfaces necessary to make NMT based applications.

#### 9.1.1.2 Capacity

The NMT 900 system uses 25 kHz/12,5 kHz interleaved channel raster system which is practically available throughout the world. This interleaved channel raster system gives a total of 1 999 radio channels within the 25 MHz spectrum supported by the system. This amount of channels ensures that the NMT 900 system can be used in high-capacity environments.

Below follows a calculation of the cell sizes and customer densities. The calculations has been based on the assumptions given in subclause 6.3.1. These are:

- available spectrum: 2 x 10 MHz;
- traffic intensity: 70 mErl/customer;
- GoS: 1 %.

The calculations are made for 12 and 21 cell re-use patterns. Hexagonal cell shapes are assumed.

**Table 24: Cell radius vs. customer density**

| Customer density/km$^2$ | Cell radius | |
|---|---|---|
| | 12 re-use | 21 re-use |
| 10 000 | 168 m | 120 m |
| 1 000 | 530 m | 380 m |
| 100 | 1,7 km | 1,2 km |
| 10 | 5,3 km | 3,8 km |
| 1 | 17 km | 12 km |

**Table 25: Customer density vs. cell radius**

| Cell radius | Customer density/km$^2$ | |
|---|---|---|
| | 12 re-use | 21 re-use |
| 50 | 113 000 | 58 000 |
| 100 | 28 000 | 14 000 |
| 150 | 12 000 | 6 500 |
| 300 | 3 100 | 1 600 |
| 500 | 1 100 | 580 |
| 800 | 440 | 230 |
| 1 000 | 280 | 150 |
| 2 000 | 71 | 36 |
| 3 000 | 31 | 16 |
| 5 000 | 11 | 6 |
| 8 000 | 4 | 2 |
| 10 000 | 3 | 1 |

#### 9.1.1.3 Service aspects

Being an analogue system with no digital speech transcoders present, the NMT system is transparent to DTMF tones, facsimile and voice band data up to 4,8 kbit/s. The analogue system does not support the high speed data and ISDN services. The standard NMT does not provide speech channel signalling simultaneously with speech.

As the NMT is based on an analogue radio interface, there is no digital speech transcoder involved. This results in that NMT has no speech degradation, both in terms of quality and delay, due to speech transcoding. Furthermore, there are no fading countermeasures, such as channel coding and interleaving, present in the system, i.e. no delays are introduced due to such measures. These factors result in that a high speech quality, both in terms of quality and delay, can be achieved in a NMT system.

The analogue system does not include speech scrambling as standard but, where necessary, this function has been added for dedicated systems. There is a trade-off between speech quality, delay and the speech security functionality.

The current analogue cellular system products have a high level of functionality and intelligence at low system hierarchy levels. This has made the NMT and TACS systems a flexible tool to provide new type services, such as company wide cellular PABX extension lines.

The benefits of narrow band FDMA include the ease of achieving long range, especially at 400 - 500 MHz frequencies, and also the ease using sectored/directive antennas in the base station as well, based on single user/carrier principle.

#### 9.1.1.4 Conclusion

The fact that NMT fulfils the need for the basic RLL services requirements (except the high data rates), with a high grade of transparency together with the ability to support high capacity and large area coverage make the RLL solution based on the NMT system an appropriate choice in many cases.

### 9.1.2 GSM Overview

GSM is a digital cellular telecommunication system standardised by ETSI. The scope of the standard is very broad and embodies all elements of a Public Land Mobile Network (PLMN), from subscriber equipment (including interfaces to subscriber equipment) through to Network to Network Interfaces (NNI). Figure 9 depicts the GSM reference model.

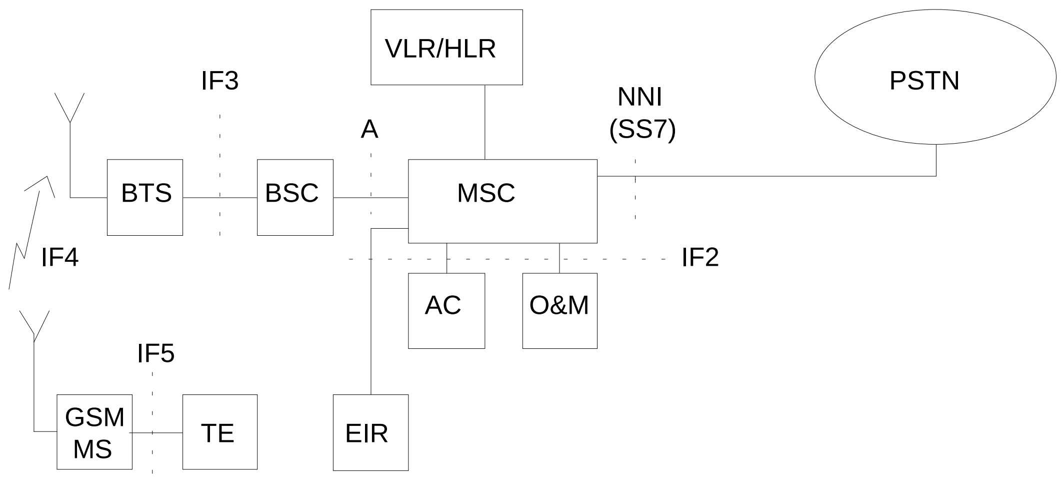



**Figure 9: The GSM reference model**

The major components of the GSM system and their functions are as follows:

a) Mobile Switching Centre (MSC): each PLMN has exactly one or several MSC´s. The MSC is both the call routing entity and the central intelligence for the PLMN. In addition to the call routing functions normally associate with fixed network switches, the MSC supports roaming within the PLMN, and may support roaming between different PLMN's;

b) Visitors Location Register (VLR) and Home Location Register: these registers are data bases used by the system to manage roaming subscribers (alien PLMN) and mobile subscribers (home PLMN) respectively;

c) Authentication Centre (AC);

d) Equipment Identification Register (EIR);

e) Base Station Controller (BSC): each BSS has one BSC. The BSC manages a group of one or more BTS's. The BSC relieves the MSC of the burden of local radio resource management, and may concentrate many of the facilities (e.g. speech codecs) for multiple BTS's;

f) Base Station System (BSS): comprises a BSC and one or more BTS's. The function of the BSS is to manage the radio resource to facilitate connection of the mobile to the network;

g) Base Station Transceiver (BTS): essentially a layer 1 facility providing the radio connection to the mobile equipment;

h) Mobile Station (MS): provides a subscriber with access to the GSM network. The MS usually supports voice, but data only MS terminals are also permitted. Data services can be provided via the R and S interfaces, as appropriate;

j) Terminal Equipment (TE).

## 9.2 Services aspects of GSM/DCS1800

### 9.2.1 GSM/DCS1800 standard services

As voice is the most important, and the main bulk of traffic, in cellular networks, specific voice compression and error coding is used over the air interface to provide high radio spectrum efficiency and robust voice quality with error coding. As the codec is optimised for voice, voice band modem (data) signals are not supported by the voice codec and should be routed over the air interface as a data service. This also means that a separate interface from a data terminal to the radio terminal is needed.

GSM voice and data services are designed to comply with the all digital network era. Voice band data services, however, require specific actions both at the radio termination interface and at the gateway from GSM network to PSTN as the mobile radio interface does not support transparent voice band data services. DTMF signals are not transparent over the radio interface and need special treatment.

GSM provides a wide range of specific data services (FAX, modem bearer services..) as well as a number of supplementary services. Supplementary as well as bearer GSM services are important to evaluation of the standard GSM network for RLL, and to the use of GSM radio interface as an access to PSTN (without GSM network), the GSM bearer services are important, as supplementary services can be provided by the local exchange.

**Table 26: GSM bearer data services**

| | |
|---|---|
| **Circuit switched services** | |
| Asynchronous, non-transparent: | 300, 1 200, 1 200/75, 2 400, 4 800, 9 600 bit/s |
| Asynchronous, transparent: | 300, 1 200, 1 200/75, 2 400, 4 800, 9 600 bit/s |
| Synchronous, transparent: | 1 200, 2 400, 4 800, 9 600 bit/s |
| Alternating speech and data, transparent (P2) | |
| Alternating speech and data, non-transparent (P2) | |
| Speech followed by data, transparent (P2) | |
| Speech followed by data, non-transparent (P2) | |
| **PAD services** | |
| Asynchronous, transparent: | 300, 1 200, 1 200/75, 2 400, 4 800, 9 600 bit/s |
| Asynchronous, non-transparent: | 300, 1 200, 1 200/75, 2 400, 4 800, 9 600 bit/s |
| **Packet switched services (P2)** | |
| Synchronous, transparent: | 1 200, 2 400, 4 800, 9 600 bit/s |
| Synchronous, non-transparent: | 1 200, 2 400, 4 800, 9 600 bit/s |
| **3,1 kHz Ex PLMN services** | |
| Asynchronous, transparent: | 300, 1 200, 1 200/75, 2 400, 4 800, 9 600 bit/s |
| Asynchronous, non-transparent: | 300, 1 200, 1 200/75, 2 400, 4 800, 9 600 bit/s |
| Synchronous, transparent: | 1 200, 2 400, 4 800, 9 600 bit/s |

GSM supports asynchronous and synchronous data services at rates up to 9,6 kbit/s via digital interfaces to terminals employing either V.24/V.28 (R interface) or V.110 (S interface). Figure 10 illustrates terminal support via R and S interfaces.

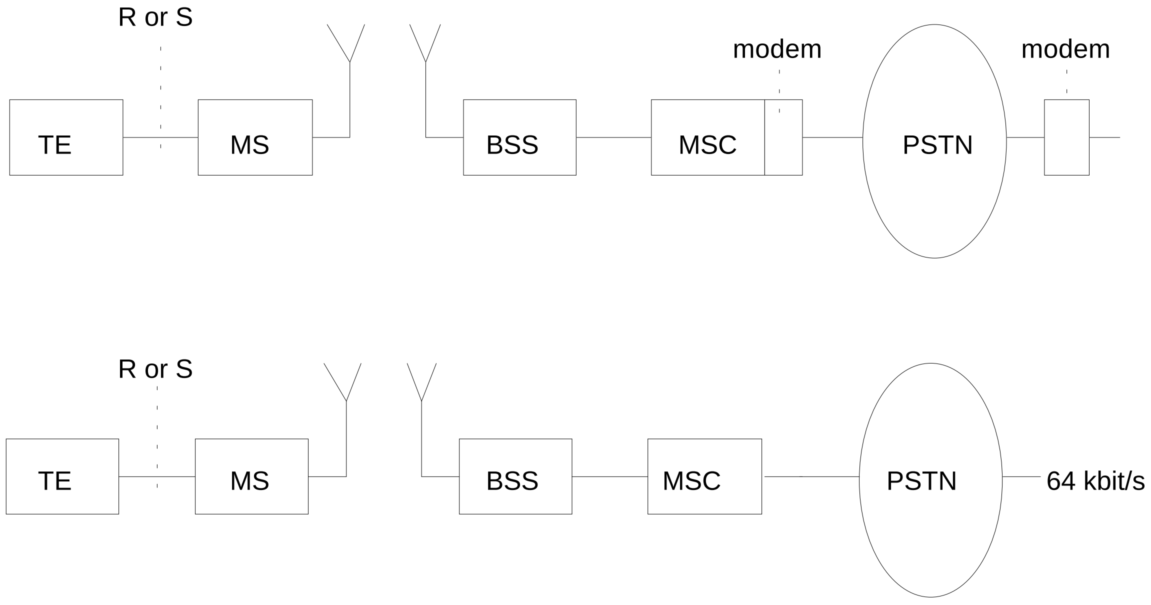



**Figure 10: Terminal support via R and S interfaces**

Only digital transmission is available over the radio path and data transmission using a conventional modem cannot be achieved. The GSM network therefore provides a modem in order to inter-work with the PSTN (see figure 10).

A special adapter is required in order to support the facsimile service. This converts the analogue signal, produced by the fax machine, to a digital interface conforming to V.24/V.28 (see figure 11). A complimentary function at the MSC converts the digital encoding of the facsimile transmission back to an analogue signal.

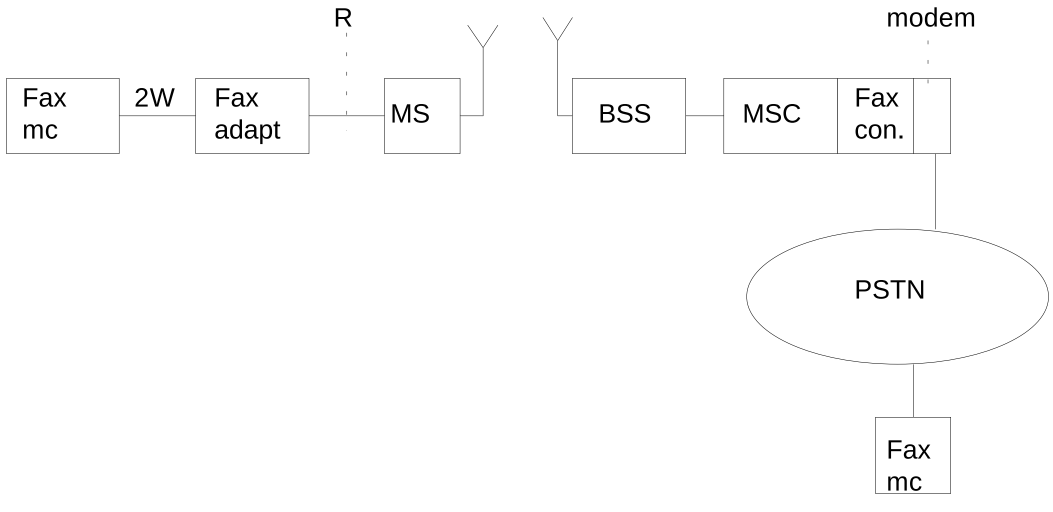



**Figure 11: Support of Fax**

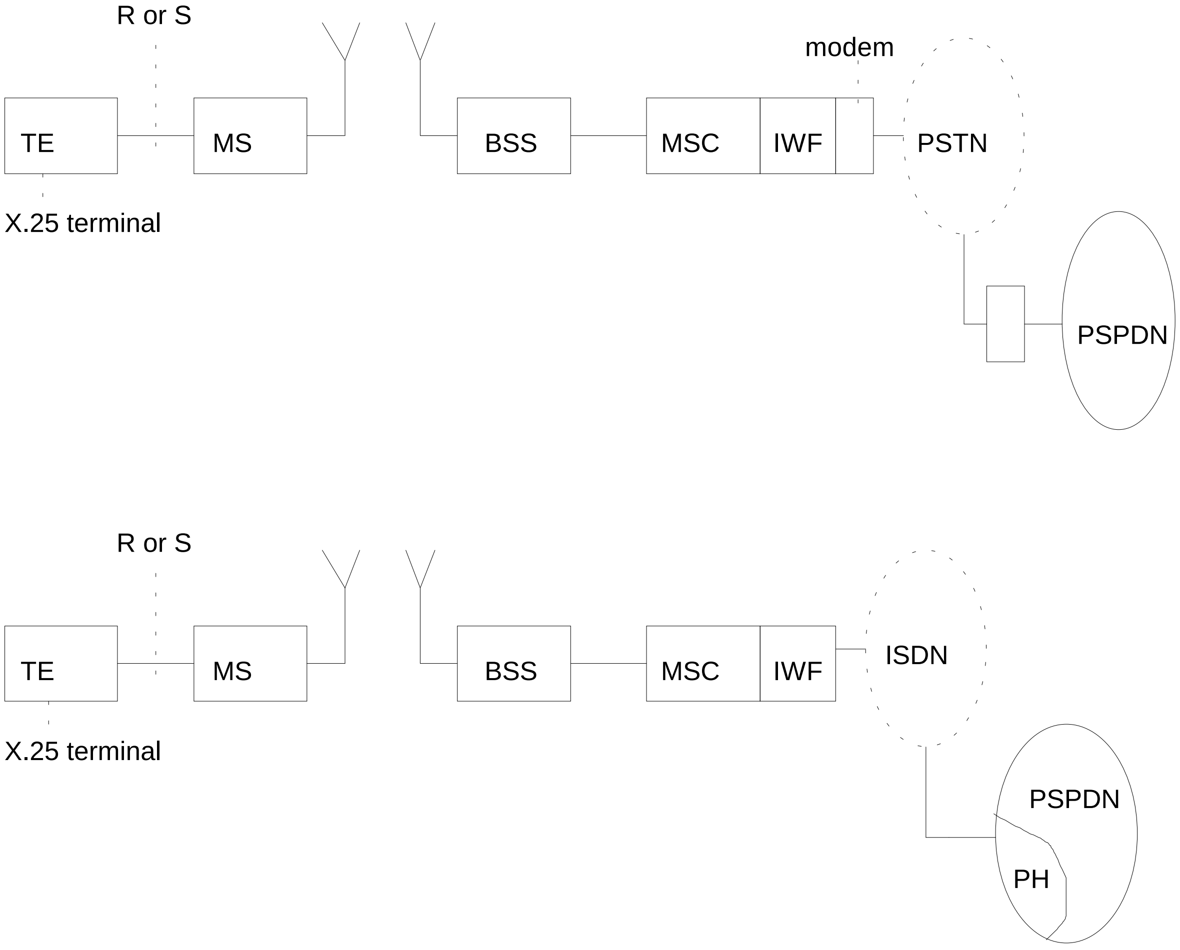



**Figure 12: Support of X.25**

X.25 is supported via modems and X.32 procedures or via the ISDN packet handler (see figure 12).

GSM provide messaging services, both point to point and broadcast message services. GSM enables messages to be displayed by the mobile terminal and it also enables messages to be transferred to and from the mobile terminal via the R interface.

GSM supports the following data service functionality:

- the interface to data terminal equipment at the mobile termination is standardised;

- inter-working with ISDN, PSPDN and CSPDN (as well as with PSTN) is standardised.

### 9.2.2 GSM/DCS1800 service provision

### 9.2.3 GSM/DCS1800 service attributes

1) Voice telephony.

   GSM full rate does not fulfil the QDU objective stated in subclause 3.2.8. ETSI SMG is standardising a half-rate speech codec. The half rate (TCH/HS) speech codec development is well advanced. The half rate speech codec being developed for GSM is intended to provide the same or better quality than the full rate codec. In return for the coding gain, the half rate codec has been allowed a complexity of up to four times that of its full rate counterpart.

2) DTMF support in GSM network.

   This subclause briefly describes the DTMF support in a standard GSM network. GSM does not provide DTMF transparency in a down link.

In the PSTN, dual tone multi-frequency refers to the transmission of dual-frequency tones generated on the speech path by pressing the number keys of the telephone set (or by a separate tone generator with old-fashioned sets). The specification of the GSM mobile station requests that DTMF tones are not generated by mobile station, but instead by the MSC, to avoid going through the 13 kbit/s speech encoding. Let us recall that the speech coder in GSM has been optimised for speech signals, and DTMF tones going through a coder-decoder ordeal will not meet the quality required by external networks. This is why signalling means are used for conveying DTMF signals on the MS to MSC segment.

Signalling messages are sent as the result of pressing keys on the mobile station side, and tones are generated by the MSC at the reception of such messages. Note that this applies only for transmission from the mobile station. Nothing precludes sending DTMF tones to a mobile station, and they will go through the 13 kbit/s encoding. As a consequence, there is no guarantee that a DTMF receiver of the mobile station will detect the tones.

3) Voice band data and fax.

GSM does not provide analogue voice band data and fax services in a transparent way as stated in 3.1.1.2. GSM supports data services up to 9,6 kbit/s as described in clause 6.2.1.

4) ISDN.

GSM supports most of the ISDN standard voice and supplementary services and supports ISDN signalling, see clause 6.2.1. GSM does not provide ISDN 2B+D capacity and has capacity restrictions in ISDN bearer services.

4) Leased lines.

GSM can provide leased lines in the way it provides analogue and digital data services.

5) Delay.

The GSM system specifies the air interface one-way delay around 90 ms, consisting of about 40 ms for transmission of 8 interleaved frames, 20 ms for the speech codec, 20 ms for the Abis TRAU frame and 10 ms for MSC-BS propagation and implementation.

GSM uses echo cancellers for voice connections to compensate the delay caused predominantly by speech coding and interleaving which are necessary to the robustness of the radio interface in the presence of fading.

6) GoS.

GSM network can be dimensioned to the required GoS.

7) Error performance and availability.

The GSM can be designed to an appropriate C/I. The GSM network is designed to a C/I value at lest 9 dB for good voice quality. The required C/I for high quality data may be higher, but it is very difficult to investigate and figures for that have not been formed.

8) Service security.

GSM provides an encrypted service that complies the RLL characteristics in clause 3.

9) Authentication.

GSM provides an authentication that complies the RLL characteristics in clause 3.

10) Mobility.

GSM provides full mobility as an option to be used in RLL.

11) Service transparency.

See clause 6.2.1. The standard terminal equipment interface to the GSM MS will need a specific adapter to support the standard telephone. If we impulse the requirement of a standard calling procedure the call set-up delay is affected. GSM provides a change of charge providing the charging information. The numbering plan is discussed in clause 6.5.1.

12) Emergency calls.

GSM provides higher priority for emergency calls. GSM can cut a lower priority call for a higher priority call in a case of all lines are in use.

### 9.2.4 Operational requirements and regulatory aspects

1) Frequency efficiency.

GSM provides high level frequency efficiency by using efficient modulation and speech coding, see subclause 6.3.1.

2) Radio range.

Normally deployed, and assuming sufficient link budget, the GSM standard is intended to support cell radii of up to 35 km. This limit is set by timing advance control considerations. By leaving some time slots unused, and assuming an adequate link budget, the range can be extended to 120 km (see ETR 103 subclause 4.10 [42]). Consider a normally deployed GSM mobile system comprising an outdoor 8W mobile with an omni-directional antenna and a 16W BTS with 12 dBi antenna gain. Such a system will support mobile subscribers over a cell radius of approximately 30 km (see ETR 103 Annex A2 [42]) in quasi open areas. Thus, GSM is able to serve all RLL range categories, see subclause 6.3.2.

3) Radio termination monitoring.

The standard GSM does not support radio termination monitoring. GSM radio termination could be added with a monitoring function with a small addition in the GSM specification, see clause 6.6.2.

4) Operation in regulated bands.

GSM operates in regulated bands (see subclause 4.6).

5) Local exchange interfaces.

As GSM implements a network also in RLL, it provides (network) interface to the PSTN. GSM radio subsystem could be interfaced to a local switch V5 interface as described in clause 6.5.3.

6) Radio safety.

GSM fulfils radio safety regulations as devised in SMG standardisation.

## 9.3 Radio coverage and spectrum efficiency

### 9.3.1 Estimate of radio spectrum needs for RLL using GSM/DCS1800

Estimates of radio spectrum needs for RLL as a function of the cell radius has been made using GSM and DCS1800. The calculations and resulting graphs in this clause show the dependencies of cell radius, customer density, modulation efficiency and carrier re-use on the required spectrum.

The simple model for calculating the radio spectrum is as follows:

From customer density values (1, 10, 100, 1 000, 10 000 customers/km$^2$) the number of customers in a hexagonal shaped cell is calculated as a function of cell radius.

Assuming a blocking probability of 1 % and offered traffic 70 mErl/customer the number of required service channels/cell is calculated using Erlang equations. The amount of spectrum necessary for RLL is calculated on the basis of a frequency reuse cluster size of 7 and 4, respectively.

NOTE: Normal planning rules for analogue mobile radio systems such as NMT and TACS predict cluster size (re-use) 21 using C/I = 18 dB. GSM, with C/I = 9 dB, normally has cluster size 12, (size 9 with frequency hopping). Lower cluster sizes are defensible for GSM and NMT/TACS if directional antennas are employed at the subscriber units. Frequency hopping in GSM could also reduce the cluster size.

Assuming that the main part of traffic within the RLL-system is speech, the spectrum efficiency of GSM and DCS1800 is 50 kHz/duplex channel deployed with full rate speech codec and 25 kHz/duplex channel deployed with half rate speech codec.

Due to the access method TDMA and the fact that GSM/DCS1800 base stations are not synchronised in time, the minimum amount of necessary spectrum for GSM/DCS1800 is 1,6 MHz with cluster size 4, and 2,8 MHz with cluster size 7.

The following two figures show the spectrum needs for different systems calculated as a function of cell radius, cluster size and customer density. Figure 13 shows the spectrum needs for RLL using GSM/DCS1800 with the full rate speech codec, and figure 14 with the half rate speech codec.

The spectrum need increases strongly as a function of cell radius. In the case of having a number of GSM carriers available in each base station, by using random frequency hopping, the spectrum efficiency can be substantially increased (near to re-use factor 1) and frequency planning is reduced to concern only about BCCH frequencies. Other frequencies are allocated as in cordless system by using dynamic channel allocation. Thus it is evident that, especially in the high customer densities, random frequency hopping will be used.

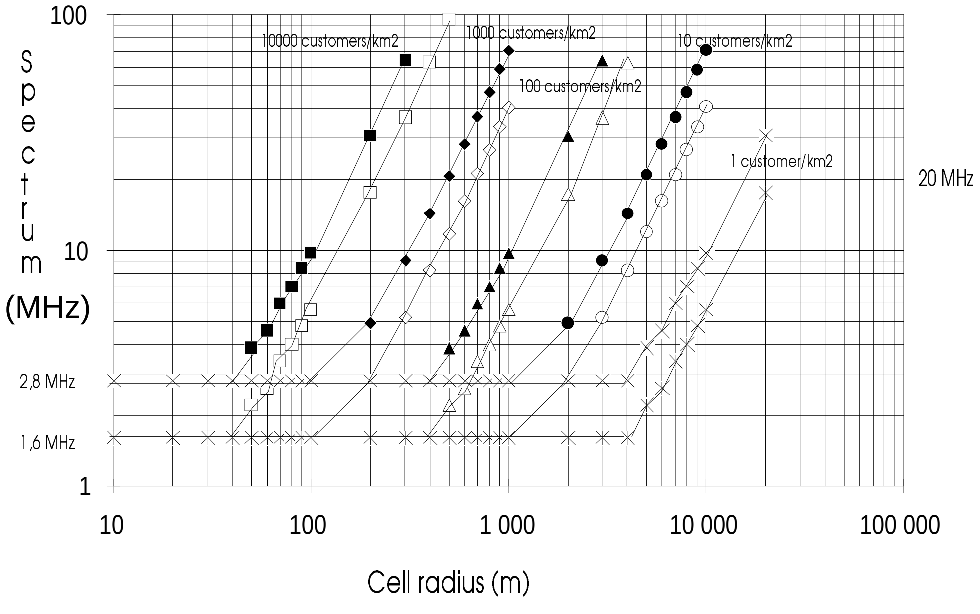



**Figure 13: Spectrum needs for GSM (full rate speech coder)**

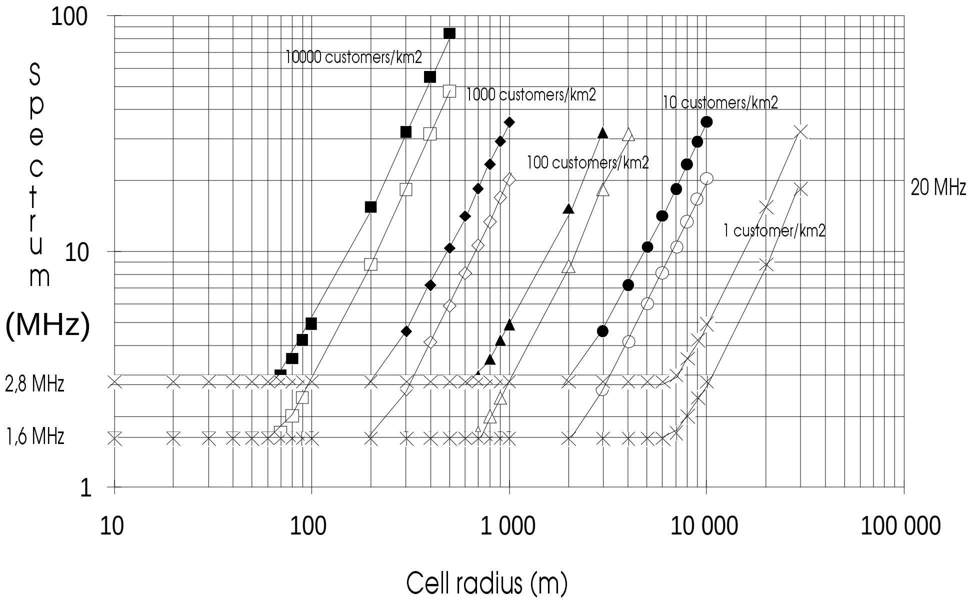



**Figure 14: Spectrum needs for GSM (half rate speech coder)**

The possible customer density and cell size depend on each other. Assuming 20 MHz to be used for the service, possible cell sizes and customer densities are presented in the following two tables. Table 26 gives the achievable cell radius as a function of customer density and table 27 shows maximum possible customer density as a function of cell radius.

**Table 27: The achievable cell radius of GSM/DCS1800 as a function of customer density and cluster size.**

| | GSM/DCS1800 half rate | | GSM/DCS1800 full rate | |
|---|---|---|---|---|
| **Customer density/km$^2$** | **Cluster 4** | **Cluster 7** | **Cluster 4** | **Cluster 7** |
| 10 000 | 310 m | 230 m | 210 m | 150 m |
| 1 000 | 1 km | 730 m | 680 m | 500 m |
| 100 | 3,1 km | 2,3 km | 2,1 km | 1,5 km |
| 10 | 10 km | 7,3 km | 6,8 km | 5 km |
| 1 | 31 km | 23 km | 21 km | 15 km |
| NOTE: The amount of available spectrum is limited to 20 MHz. | | | | |

**Table 28: Maximum possible customer densities of GSM/DCS1800 as a function of cell radius.**

| | GSM/DCS1800 half rate | | GSM/DCS1800 full rate | |
|---|---|---|---|---|
| Cell radius/m | Cluster 4, customers/km$^2$ | Cluster 7, customers/km$^2$ | Cluster 4, customers/km$^2$ | Cluster 7, customers/km$^2$ |
| 50 | 395 000 | 214 000 | 185 000 | 97 000 |
| 100 | 99 000 | 5 300 | 46 000 | 24 000 |
| 150 | 44 000 | 24 000 | 20 000 | 11 000 |
| 300 | 11 000 | 5 900 | 5 100 | 2 700 |
| 500 | 3 900 | 2 100 | 1 800 | 970 |
| 800 | 1 500 | 840 | 720 | 380 |
| 1 000 | 980 | 530 | 460 | 240 |
| 2 000 | 250 | 130 | 110 | 60 |
| 3 000 | 110 | 60 | 50 | 27 |
| 5 000 | 39 | 21 | 18 | 9 |
| 8 000 | 15 | 8 | 7 | 3 |
| 10 000 | 9 | 5 | 4 | 2 |
| NOTE: The amount of available spectrum is limited to 20 MHz. | | | | |

### 9.3.2 Radio range estimates

The radio range estimates are made both for LOS and NLOS situation. The propagation models that are applied are ITU-R Recommendation 370 [37] for LOS case and Okumura-Hata for rural and suburban NLOS case. The propagation models are shown in table 29. Due to the lack of an appropriate model for urban environment the radio range estimates are not produced for the urban case.

In the next two tables the radio application conditions and the radio system parameters that are used in the calculations are defined. Table 28 contains the parameters for antenna heights and gains, cable loss, indoor loss and information about antenna diversity defined for LOS, and NLOS case in rural, suburban and urban environment. Table 30 lists the transmitter power and the receiver sensitivity of each system, which with a fading margin of 20 dB give the total path loss in dB. This corresponds to some 99,5 % radio link availability for suburban and 99,9 % link availability for rural cases according to the measurements made by Telia Research, Sweden. In the calculations concerning different environments the antenna gains are added and cable losses are subtracted from the total path loss.

NOTE 1: The examples in table 30 are made for specific transmitter powers. If mobiles with higher or lower power classes are employed, the total loss figure has to be adjusted accordingly.

NOTE 2: In GSM the receiver sensitivity is defined for a mobile fading channel where the GSM error correction gives a substantial error correction contribution. For the stationary RLL case, the receiver antenna is in a fading dip or it is not, and the GSM error correction does not contribute significantly.

Therefore in table 30 the sensitivity figures for GSM have been improved a few dB's compared with the GSM specification to be relevant for a stationary Gaussian channel.

A 20 dB fading margin has also been added, as for all the NMT and TACS systems, to provide the required service quality (i.e. > 99,5 % availability). The fading margin requirements would, however, be lower for LOS and directional antennas at both ends of the radio link.

Applying frequency hopping for GSM would reduce the required fade margin, but it has to be considered that the control channels necessary for the call set-up cannot use frequency hopping.

In this ETR rural environment corresponds to open rural areas, and not, e.g. forested area. Suburban area consists of one or two storey houses. Base station antennas are assumed to be outside in every case, and diversity gain is assumed to be 4 dB in uplink direction.

**Table 29: Radio application conditions**

| Applications: | Base station: | | | Mobile station: | | Indoor loss | Diversity | |
|---|---|---|---|---|---|---|---|---|
| | Antenna height (m) | Antenna gain (dBi) | Cable loss (dB) | Antenna height (m) | Antenna gain (dBi) | (dB) | BS | MS |
| LOS: outdoor | 60 | 14 | 4 | 10 | 10 | - | Yes | No |
| NLOS: | | | | | | | | |
| a) Rural, outdoor | 60 | 14 | 4 | 5 | 10 | 0 | Yes | No |
| b) Rural, indoor | 60 | 14 | 4 | 2 | 0 | 10 | Yes | No |
| c) Suburban, outdoor | 20 | 14 | 2 | 5 | 0 | 0 | Yes | No |
| d) Suburban, indoor | 20 | 14 | 2 | 2 | 0 | 10 | Yes | No |
| e) Urban, outdoor | 15 | 14 | 0 | 2 | 0 | 0 | Yes | No |
| f) Urban, indoor | 15 | 14 | 0 | 2 | 0 | 20 | Yes | No |

**Table 30: Propagation models**

| Applications: | Propagation model |
|---|---|
| LOS, outdoor | ITU-R Recommendation 370 [37] |
| NLOS:<br>a) Rural: outdoor, indoor<br>b) Suburban: outdoor, indoor<br>c) Urban: outdoor, indoor | <br>Okumura-Hata<br>Okumura-Hata<br>Estimate |

**Table 31: Radio system parameters.**

| | GSM | DCS 1800 | NMT 900 | NMT 450 | TACS |
|---|---|---|---|---|---|
| BS power, (W) | 20 | 10 | 50 | 50 | 50 |
| BS power, (dBm) | 43 | 40 | 47 | 47 | 47 |
| Tx filter loss, (dB) | 4 | 4 | 4 | 4 | 4 |
| BS cable loss, (dB) | see cond. | see cond. | see cond. | see cond. | see cond. |
| Antenna gains, (dB) | see cond. | see cond. | see cond. | see cond. | see cond. |
| MS sens. Gauss. (dBm) | - 104 | - 104 | - 113 | - 113 | -113 |
| MS power, (W) | 2 | 1 | 6 | 15 | 10 |
| MS power, (dBm) | 33 | 30 | 38 | 42 | 40 |
| Antenna gains, (dB) | see cond. | see cond. | see cond. | see cond. | see cond. |
| BS cable loss, (dB) | see cond. | see cond. | see cond. | see cond. | see cond. |
| BS sens. Gauss (dBm) | - 106 | - 100 | - 115 | - 115 | - 116 |
| Margin (dB) | 20 | 20 | 20 | 20 | 20 |
| Total loss, (dB) | 119 | 116 | 133 | 137 | 136 |

The radio range (km) using GSM and some other systems in different environments is shown for LOS and NLOS case in table 31. The minimum usable signal level at cell border is assumed to be the receiver sensitivity level in static Gaussian channel + Rayleigh fading margin 20 dB (0,1 to 1 % outage).

Okumura-Hata model is officially valid in the range 1 to 20 km, and applicable down to approximately 0,2 km. The used probability of coverage inside a cell is 90 %. In non coverage places an alternative antenna siting may be required.

**Table 32: Cell radius of different radio systems in km**

| | GSM | DCS 1800 | NMT 900 | NMT 450 | TACS |
|---|---|---|---|---|---|
| LOS, outdoor | 16 | 10 | 30 | > 30 | > 30 |
| NLOS | | | | | |
| Rural, outdoor | 11,0 | 4,6 | >20 | >20 | > 20 |
| Rural, indoor | 1,6 | 0,6 | 4,2 | 9,5 | 5,0 |
| Suburban, outdoor | 3,6 | 1,6 | 8,5 | 16,8 | 10 |
| Suburban, indoor | 1,2 | 0,5 | 2,8 | 5,8 | 3,3 |
| Urban, outdoor | No model. | No model. | No model. | No model. | No model. |
| Urban, indoor | No model. | No model. | No model. | No model | N0 model. |
| NOTE: No model = no appropriate propagation model available. | | | | | |

## 9.4 Local loop deployment examples

### 9.4.1 Assumptions

The following deployment examples are based on:

- the previous analyses of cellular technologies spectrum efficiencies, figures 4 and 5, and from them derived achievable cell sizes, tables 2 and 3. The spectrum efficiency of analogue systems is assumed to be similar to the full rate GSM case, 50 kHz for each duplex voice channel. In one base station only every second GSM carrier can be used. This may limit the capacity in single base station solutions;

- the previous assumptions on antenna installations, table 5, power budgets, table 6, propagation environments, table 4, and subsequent analyses of achievable radio ranges in urban, suburban and rural deployment for indoor and outdoor antenna installations, table 7. For extended GSM ranges, using 8W peak output power, see ETR 103 [42];

- the availability of 20 MHz of spectrum to the example case in the frequency areas 450 MHz, 900 MHz and 1800 MHz, depending on the use of analogue cellular, GSM or DCS1800 technologies. Both full rate and half rate speech codec options are used. It is defined in each case example, if the whole 20 MHz can be used that another case of the example would not occur in an area of the same channel interference, or a cell repetition pattern has to be applied over a bigger contiguous area. The assumed cluster size (re-use factor) in the evaluations is 4;

- the deployment examples are described in clause 5 of this ETR.

### 9.4.2 Example 1.A: new housing area

The example 1.A describes a new housing area of 500 m radius having customer density 500 to 2 000 customers/km$^2$. In this cellular deployment example it is anticipated that a number of these housing areas are being build, some of which lying aside each other, while most of them spread out in a larger area.

Assuming < 50 % coverage of the whole area by these 500 m cell radius housing "islands", a frequency re-use factor of about 2 can be assumed (instead of 4 in the case of covering the whole area 100 %). Thus the referred customer densities 500 to 2 000 customers/km$^2$ would lead to cell radius of 1 to 2 km for the GSM/DCS1800 half rate codec case and to cell radius 0,7 to 1,5 km for the GSM/DCS1800 full rate codec and analogue cellular technology (NMT, TACS) case.

Assuming the use of cheap indoor radio terminations are not requiring any antenna installations and a suburban environment, the DCS1800 solution is radio range limited to 500 m cell radius and the GSM solution is radio range limited to 1 200 m cell radius. The analogue cellular radio ranges in this case are between 2,8 and 5,8 km and, thus the analogue cellular application, in this example this spectrum availability limits the range to 0,7 to 1,5 km.

The straight forward solution for the 500 m cell radius new housing areas is to establish one base station at the centre of the housing area, serving the whole set of customers. Because of the extensive ranges of GSM and analogue technologies, there is a lot of freedom to find a site for the base station when applying these technologies. In the case of several housing areas situated near by each other, a single base station site with possibly using sectored cells is a very cost efficient solution. For DCS1800 one single base station at the centre of the housing area provides the feasible solution.

In the case of a large number of these small housing areas, a centralised mobile exchange and base station controller could serve the whole area. The cellular solution is efficient in terms of having minimal number of base station sites and transmission requirements. It also provides much flexibility to grow from low customer densities.

### 9.4.3 Example 1.B: new town

This example resembles much the previous case with the exception that a larger contiguous town area, consisting of a large number of the small housing areas, described in the previous example, which are situated side by side each other. The town is to be built in a period of 10 years so that there is a need to start with a "lighter" RLL system which could grow to full coverage and penetration in the 10 years. Thus in the cellular RLL solution the first step would be to deploy a smaller number of large cells with a radius of 1,2 to 5 km as the traffic need is small. The large cells can subsequently be separated into a cluster of smaller cells and thus the capacity increased. At the phase of saturation the 5 km area could be served with some 20 to 75 smaller cells, having a cell radius 0,5 to 1,2 km, corresponding the population density variations 500 to 2 000 customers/km$^2$. A sectored cell solution might provide better method to limit interference.

The same assessment of services as in the previous example applies.

### 9.4.4 Example 2: Replacement of existing copper lines in rural areas

This is a typical rural example, to serve customer densities 5 to 50/km$^2$ in sparsely populated areas of small villages and scattered single dwellings. As 90 % of the population is in areas < 4 km from the local exchange, making customer densities in the range 5 to 50/km$^2$, the remaining 10 % are very scattered over an area of 50 km radius, making customer densities in the range 0,003 to 0,03/km$^2$. This corresponds to 250 to 2 500 customers near the local exchange (< 4 km) and 25 to 250 customers in the 7 500 km$^2$ rural surrounding areas (4 to 50 km).

This example is radio range limited in all cases and the most efficient solution is to apply extended GSM radio ranges to serve all customers from the site of the local exchange. Assuming a 50 m base station antenna and an outdoor antenna over the tree top level (10 to 15 m) at the extended ranges from 4 to 50 km, a LOS would provide the 50 km required range (up to 120 km by referred SMG estimations). A 10 dB gain antenna and 8 W peak output power at the mobile terminal are assumed. Analogue systems provide also extensive ranges to serve the example deployment from a single base station site.

The 90 % of the customers in the 4 km radius central area can be served with standard analogue cellular or GSM outdoor or indoor (analogue) antenna solutions.

The required POTS and low speed data services can be provided by GSM and also analogue cellular with low speed data up to 4 800 bit/s.

The single cell site solution provides full coverage at day one and is efficient in terms of base station sites, transmission and maintenance costs. Good flexibility to varying customer densities and siting as well as limited growth exist.

The obvious cost efficient cellular solution is to serve a number of this kind of areas in a country from a central mobile exchange.

### 9.4.5 Example 3: capacity increase of existing network

a) Short description of the example case:

- this example describes a typical 10 000 to 30 000 customer local exchange area covering typically suburban areas with a typical radius from 1,5 km, extending to 15 km. The local exchange area is divided into several distribution areas, each being served by a 2 000 telephone line feed cable. The last drop cable to the customer is some 100 m long being served from a passive cable tap serving 5 to 20 customer lines. A cable segment of 100 to 600 lines serves a chain of 20 to 100 of these 5 to 20 customer taps. The 2 000 line feed cable from the local exchange serves 2 to 20 of these cable segments;

- the example describes a situation where some of the feed or segment cables become congested as the number of customers for some reasons exceed the assumptions made when the cable plant was initially designed, perhaps a long time ago;

- we assume this congestion to occur in 10 % of the feed cables and a 3 % yearly growth in telephony lines in these areas. This would mean a yearly growth of some 60 new lines in the 1 to 4 km$^2$ distribution areas. It may be assumed that it is not cost efficient to replace the existing copper plant by a cellular radio solution, but try to handle new growth by that. It may be assumed, however, that the operator could replace to some of the existing wired POTS customers a RLL solution instead and thus free copper pairs for customers, who need extended services like leased lines or ISDN. Thus the RLL solution for new growth could support only POTS customers, who need voice and low speed data services. It is very doubtful that the operator could rearrange the copper pair lines in the copper plant to isolate the possible new RLL solution to a smaller area and thus free copper lines for new growth in the rest of the area;

- a scenario to extend the exhausted copper plant by 10 years with the radio solution is to be provided.

Cellular solution to the capacity increase to existing network example case:

- examining the whole 20 000 customer LE area with the assumed 10 % feeder cable congestion and 3 % annual growth would mean 60 new lines yearly in the LE area. The obvious cellular solution, again, would be a single base station sited at the local exchange and serving up to 15 km LE area. As it can be assumed that the majority of customers are in the 1,7 km range from the local exchange, a digital or analogue cellular solution with an indoor antenna installation serves most cases. In the case of customers at longer distances from the LE, an outdoor (rural) antenna installation would be needed. 2 to 3 MHz of spectrum would serve the whole 10 year growth period when having isolated LE areas. If contiguous LE areas, requiring cellular planning, are used a fourfold final capacity is needed (8 to 12 MHz). The cost efficient cellular solution, again, is one centralised mobile exchange serving a large number of the LE areas;

- the cellular solution provides the required voice and low speed data services.

### 9.4.6 Example 4: new operator in competitive environment

This example is divided to three different kinds of areas:

- rural area (area C) with low average population density, but small villages with significantly higher density but still a relatively small total number of connections;

- a small town with 50 000 lines (in the residential and small business sector), equivalent to a population at 100 000 to 150 000;

- a city with 500 000 lines (in the residential and a small business sector), equivalent to a population of 1 to 1,5 million.

The following solutions are possible in these cases:

a) small town:

- maximum subscriber numbers are on year one 125 and on year ten 1 256. Small business sector (A) 72,5 $km^2$ area can be covered by one site from year 1 to year 10. On residential (B) area the maximum subscriber numbers are on year one 393 and on year ten 3 930;

- it is possible to provide initial coverage from a single 5 km cell for both A and B areas (over 10 years period). Using an outer ring of the sites a better coverage into area B and neighbouring rural areas can be provided by using sectorization and extended range sites, figure 15.

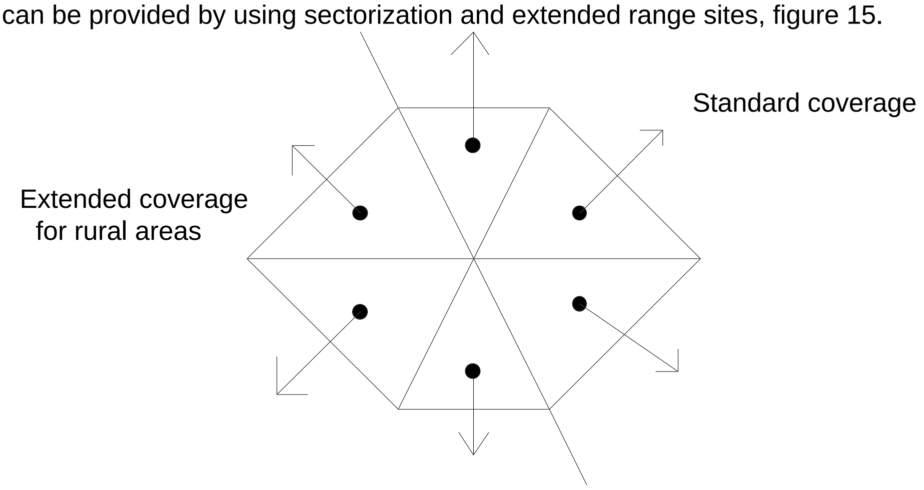



**Figure 15: Sectored cells**

Maximum subscriber numbers on year one by single site with 4 km radius is 1 760 (35 subs/$km^2$) and on year 10 by splitting original site to cells of 2 km radius is 19 330 (221 subs/$km^2$) on business area. On residential area the maximum subscriber numbers are on year 1 by five 8 km sites is 14 371 (14,3 subs/$km^2$) and on year 10 by splitting the original sites to provide 18 cells with 4 km radius is 31 500.

This is a short fall of 8 500 subscribers which could be covered by cell splitting (4 km sites to 2 km sites) where necessary for subscriber demand.

b) City scenario:

- The radius of outer ring is 16 km subdivided into eighteen 4 km sites by year 10. The radius of the inner ring is 4 km on year one subdivided into seven 2 km cells by year 10.

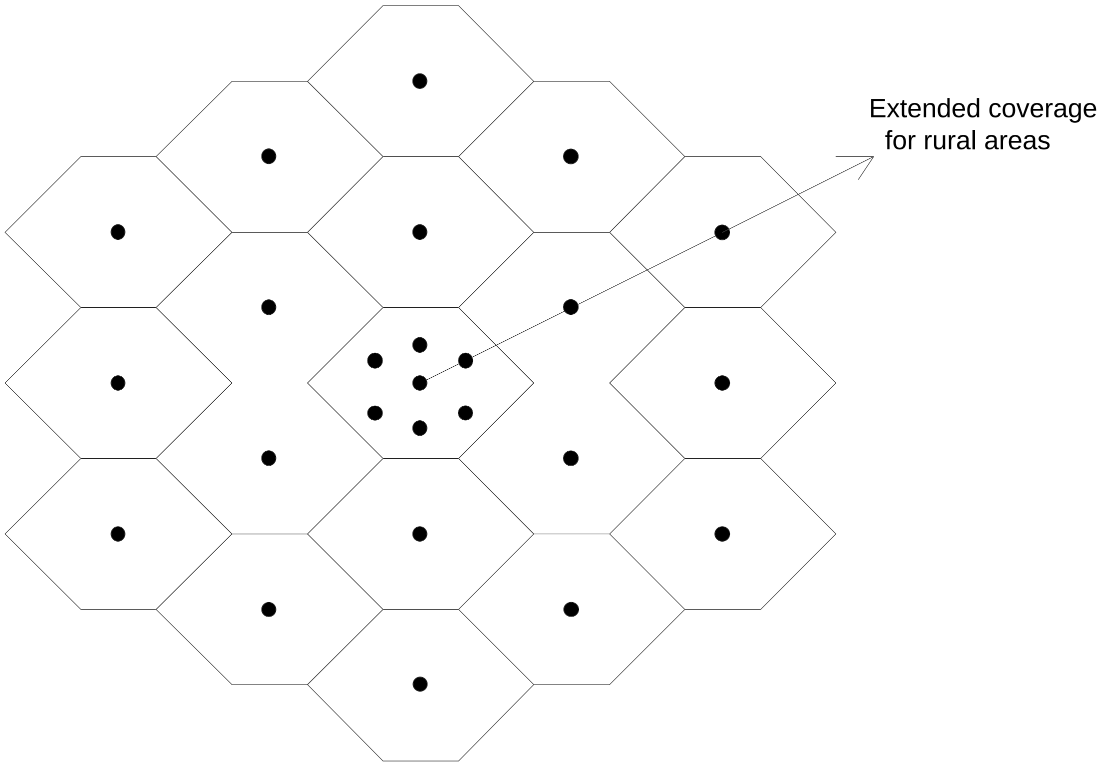



**Figure 16: City scenario**

The outer ring of sites could be further split between extended coverage and standard coverage cells, e.g. from six sector sites 3 are for standard coverage and 3 are for extended coverage to rural areas.

The case example is a typical candidate for real cellular network planning. The cellular solution can provide gradual capacity growth with good coverage from the beginning by using cell splitting and sectorization as the growth takes place. All the areas with various customer density can be flexibly served by cellular technologies. The city and suburban areas (A and B) can be covered by a dense BS network in a way like in example 1.

POTS, fax and low speed data services can be provided as described in subclause 6.2.2. ISDN BA or 64 kbit/s leased lines cannot be supported always by the cellular technology alternatives and they require a separate (wired, P-MP radio, cordless) solution.

## 9.5 Use of GSM/DCS1800 standards for RLL

The GSM standards define a complete digital cellular network, including a number of interfaces between different GSM network elements (BTS, BSC, MSC, HLR, VLR, AC, EIR, OMC), which implement the GSM network functions. Hence the GSM network could be used in various ways for RLL. The GSM network architecture, interfaces, services and signalling procedures are described in the ETSI GSM recommendations. In this ETR only those GSM specific aspects are discussed which are considered to be useful for the RLL application.

This subclause describes three main options to implement RLL using GSM network and its interface standards. All options assume a standard GSM air interface and thus either a standard GSM terminal may be used or a GSM fixed installed radio with a normal telephone, ISDN terminal or FAX adapter.

### 9.5.1 Use of the GSM/DCS1800 network for RLL

Use of the GSM network for RLL is depicted in figure 17. This option allows concurrent use of a standard GSM/DCS1800 network for mobile users and RLL customers. RLL customers can be offered a local PSTN tariff, restricted or no mobility, PSTN/ISDN (see ITU-T Recommendation E.164 [43]) numbering plan, but would otherwise be served with normal GSM/DCS1800 services and service quality.

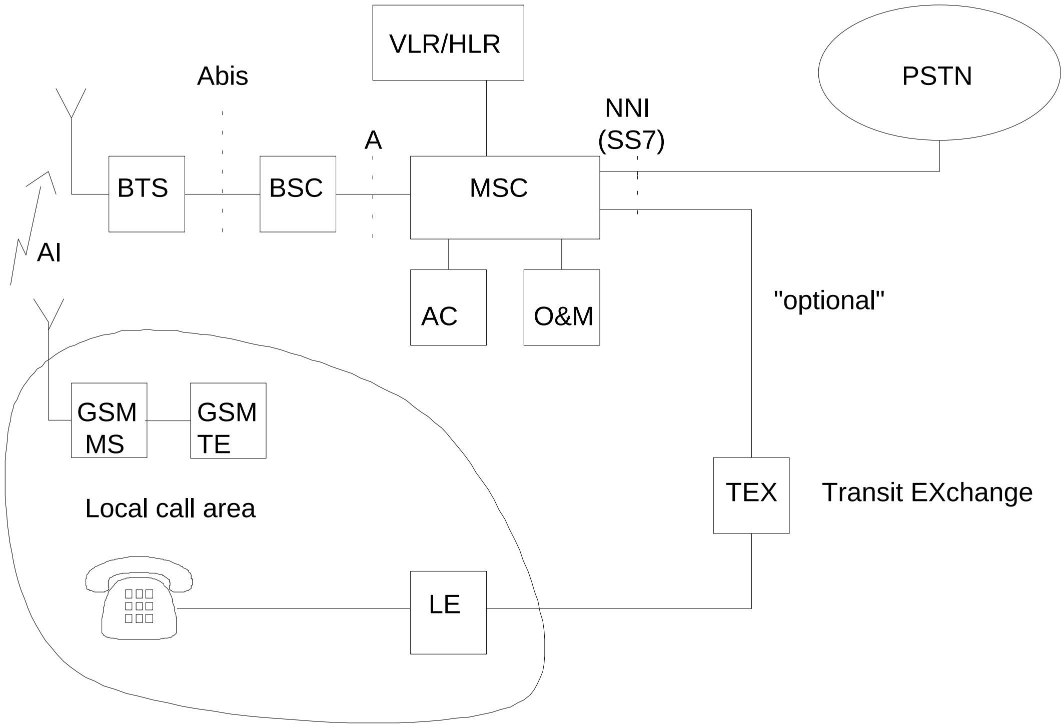



**Figure 17: Use of the GSM network for RLL**

This option is basically for the addition of RLL customers to an existing mobile network by implementing possibly small software modifications for the RLL but without changing the GSM standards. The alternative allows, concurrently, RLL and mobile users in the same network so that all RLL specific implementation modifications does not influence the normal GSM implementation for normal mobile customers in any way.

The obvious modifications to tailor a RLL service to the GSM/DCS1800 network are local PSTN numbering, restricted mobility, PSTN tariffing and possibly local routeing from the MSC to the PSTN TEX/LE of a RLL area.

#### 9.5.1.1 Local numbering plan

To enable RLL customers to use local numbers between RLL terminals and fixed access PSTN terminals, a direct gateway MSC function from the MSC, supporting local RLL customers to a local switch or a transit switch in that area would be needed. The GSM standard gateway function to the PSTN could be used with possibly small modifications in the ITU-T Recommendation E.164 [43] numbering conventions. This requires co-ordination of the numbering schemes between the fixed access and RLL access.

The following call types should be taken into account:

1) Local call within a RLL (MSC number analysis);

   basically, for a normal GSM call, a national destination code (NDC) and a subscriber number (SN) are used when making a call to a GSM user. However, in the RLL application it should be possible to make local calls by using normal local call dialling numbers;

2) Local call from a RLL subscriber to a fixed terminal in the fixed network;

   in this case, the MSC should be considered similar to a normal local exchange (LE) as far as the number analysis is considered;

3) Non-local call from a RLL subscriber to a fixed terminal;

   the MSC will handle a call as a normal long-distance call. No specific numbering requirements are to be seen;

4) Local call from a fixed network (PSTN) to a RLL subscriber in the same local call area;

   the MSC should be considered similar to a normal local exchange (LE) as far as the number analysis is considered, i.e. the MSC connected to the TEX should have capabilities to receive a local call dialling and should be able to analyse the dialling;

5) Non-local call from a fixed network (PSTN) to a RLL subscriber;

   the normal fixed network addressing and routing principles should be applied.

#### 9.5.1.2 Restricted mobility

In a digital cellular mobile network with GSM 900/DCS1800 standard (GSM PLMN) a mobile subscriber (MS) is normally allowed to set-up and receive calls in every place (roaming) within the coverage area of the PLMN.

Some references for mobility restriction possibilities in GSM can be found in:

ETS 300 530 [38] Location registration procedure;
ETS 300 599 [39] MAP.

To restrict the mobility of subscribers within a PLMN the following methods are described in GSM standards:

1) Mobility restriction to one or more VLR areas;

   the subscriber data set in the HLR includes an entitlement with all VLR areas where roaming is allowed. If a location update is requested and the current VLR area is different to the previous one, a location update in the HLR is necessary. It is checked there whether roaming is allowed and whether there exists any roaming restrictions. In the case of restrictions the current VLR number is checked against the subscriber entitled VLR list. If the VLR area is restricted, the location update is rejected and the subscriber cannot receive or set-up a call in that area. The area where subscriber roaming is restricted composes an coverage area of a VLR;

2) Mobility restriction to one or more zones within VLR areas;

   the subscriber data set in the HLR includes an entitlement with all allowed VLR areas and for each VLR area a list of allowed zones (composed of one or more location areas), at maximum 10. The current VLR number is checked in the HLR. When it results in a VLR where roaming is restricted to a number of zones, the zone code list is sent to the appropriate VLR and the current location area code is compared with those ones in the restricted zone. Here the mobility of the subscriber is restricted to parts of a VLR.

#### 9.5.1.3 Specific tariffing

As RLL customers are identified in the GSM system, by a specific numbering plan or by some other means, tailoring a specific tariff, being similar to the fixed local network tariffing (fixed amount/local call, depending on duration, time-of day dependent etc.) can be implemented.

PLMN and fixed access network operator tariffing procedures may differ from each other, which may cause problems if an unified tariffing scheme for both RLL and wire line access customers is needed.

### 9.5.2 Use of a localised GSM network for RLL

Use of a localised GSM network for RLL is depicted in Figure 18. This alternative uses the standard GSM/DCS1800 terminals and BS access network, using the standard AI and Abis interface, but has a a tailored controller (BSC, MSC, VLR, HLR, AC) to act as a controller from the RLL access network. The controller includes LE-functions and is connected with a normal NNI interface to the PSTN network.

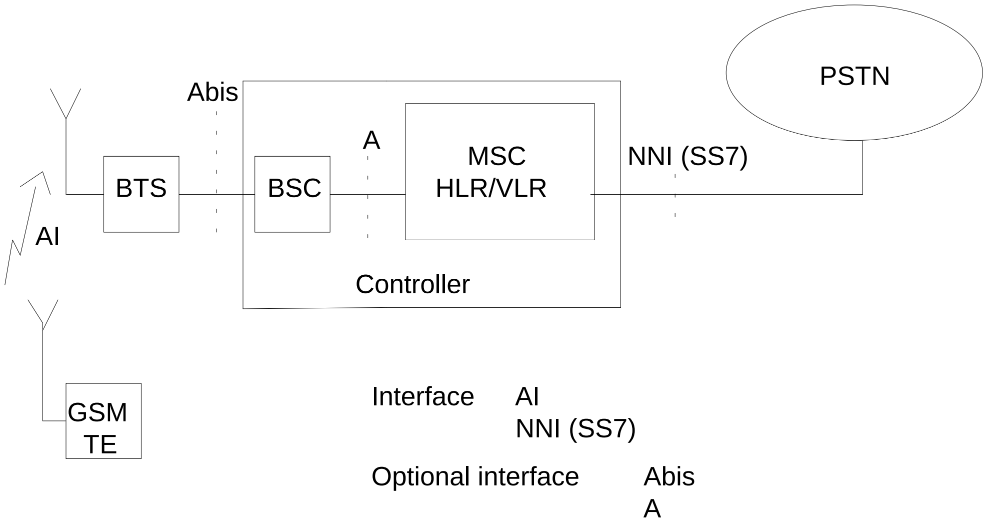



**Figure 18: Use of a localised GSM network for RLL**

This alternative uses the standard GSM/DCS1800 Base Station access network, using the standard Air and optionally also Abis and A interfaces, but has a tailored controller from the RLL to the PSTN network. The controller could be built by a separate BSC and RLL switch using also the standard A interface. This option would enable use of local telephone numbering and efficient routing of local calls as in the alternative in subclause 9.4.1 but reduces the number of various network elements and optimises the GSM functions for RLL, as all functions of the (BSC)/MSC/HLR/VLR/AC, needed in the RLL, would reside in the controller.

The customer could be offered restricted mobility within own RLL system (controller). The RLL localised system would preclude full mobile customers, which roam between PLMN networks.

### 9.5.3 Use of GSM air interface for RLL

Use of the GSM air interface for RLL of PSTN/ISDN local exchanges is depicted in figure 19. This alternative enables the use of standard GSM/DCS1800 terminals but has a full freedom to realise the required network functionality from the base station to a local switch interface. An intermediate interface between a base station and a controller (I/F3) may be used.

This alternative enables the use of standard GSM/DCS1800 terminals and provides a direct access to a local switch. The switch interface would predominantly be either an analogue PSTN interface or a standard 2 Mbit/s V5.x interface. The latter alternative is the preferred as ETSI standards on V5.1 and V5.2 are being produced and are anticipated to be widely available within a few years from now. The alternative precludes the standard GSM fixed network and has thus a full freedom to realise the required network functionality in an optimised way from the GSM air interface to the local exchange interface. It may, however, still be possible to retain the standard GSM base station and use the Abis interface to a controller.

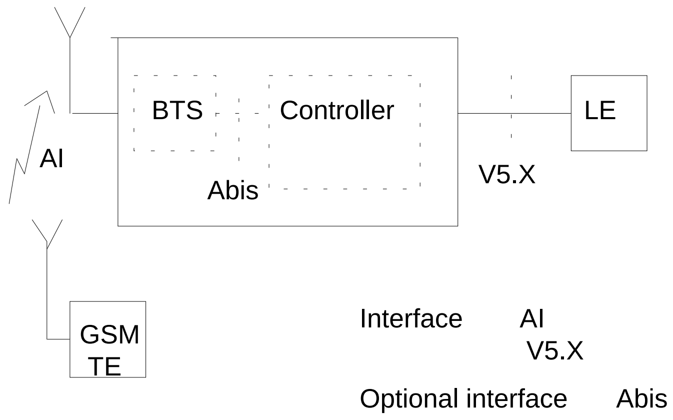



**Figure 19: Use of the GSM air interface for RLL**

This option needs a mapping of all the GSM mobility, authentication, signalling, and air interface management functions between the GSM air interface and the local exchange interface. GSM signalling mapping to analogue PSTN local exchange interface may be complicated and has not been analysed. An analysis of these mappings to the V5.x local exchange interface is presented in the following.

### 9.5.3.1 GSM Air Interface signalling mapping to ISDN access signalling

When connecting a subscriber to an ISDN local exchange via the GSM radio interface the protocols can be left unchanged. All protocol inter-working is performed within the RLL access network (including the controller and the base stations). GSM signalling layer 3 comprises the following groups of signalling functions:

- Call Control (CC);
- Short Message Service (SMS);
- Supplementary Services Support (SSS);
- Mobility Management (MM);
- Radio Resource Management (RRM).

These groupings are specified as independent protocol entities and are arranged in a hierarchy of three sub-layers. RRM sub-layer provides functions necessary for the establishment, maintaining, change and release channel connections. MM sub-layer provides the procedures to support the mobility of users. The procedures include also radio related features. The Connection Management sub-layer (CM) include CC, SMS and SSS entities. The CC provides the procedures defined for the call control of the ISDN subscriber access. The ISDN does not support all GSM supplementary services nor the SMS.

The interface between an access network and the local exchange can be based on the V5.1 or V5.2 interface. The V5.1 access network interface with a flexible information channel allocation supports the ISDN basic access. A complementary standard specifies the interface V5.2 supporting both ISDN basic and primary rate access. The V5 access network interfaces are transparent to the LAPD-frames. Therefore the application of V5 interfaces between the RLL system and the local exchange has no impact to the protocol structure.

The ISDN network does not support mobility management and radio resource management functions. Therefore, those protocols should have the termination point at the RLL access network.

### 9.5.3.2 The specific signalling functions of the RLL system using GSM air interface

This subclause briefly describes the functions that are needed in the RLL system when a standard GSM air-interface is utilised as a substitute for a fixed subscriber line towards ISDN back-bone network. The functions are related to the RRM, MM and CM. The functions related to the RLL network management are also listed.

The ISDN backbone network does not support certain functions, such as paging and security related functions which are necessary when using the radio local loop. The functions of this kind are allocated into the RLL access network, because the ISDN fixed network part functionality is left unchanged in the RLL system.

The following RRM and MM functions are allocated into the RLL system:

a) RRM:

- system information broadcasting;
- radio resources connection establishment;
- radio resources connection release;
- paging;
- measurements;
- handover (e.g. for redundancy purposes):
    - intracell change of channels;
    - intercell change of channels;
- ciphering mode setting;

b) MM:

it should be studied how the mobility management functions could be used for the maintenance of radio termination and how to provide the radio path with security and redundancy functions. For example, the following functions could be considered:

- identification of the radio termination;
- authentication of the radio termination;
- identification of the "correct" BS performed by the radio termination;
- location registration/updating;
- periodic location updating;
- attach/detach.

The basic requirement for CM functions is that the RLL system does not impact on the functionality of the fixed network. Thus the ISDN-LE (Local Exchange) will perform the normal call control procedures including the handling of the RLL subscriber signalling, i.e. number analysis of the RLL subscribers and charging.

The CM sub-layer of GSM includes CC, SSC and SMS support. In GSM, the CC will have useful functions, such as emergency call and call re-establishment. The ISDN fixed network does not support all the CM sub-layer services, e.g. SMS. In general, supplementary services are mainly the same both in ISDN and GSM (Call Restriction (CR) supplementary service is only in GSM).

In GSM, the MSC has capabilities for certain procedures related to the radio resource allocation and resource management. In ISDN, this kind of functionality does not exist in the ISDN-LE. Due to this, the RLL network management should be implemented in the RLL access network. The RLL network management includes the following functions:

- base station control;
- radio resource control;

- radio network configuration management;
- terminal/radio termination control (maintaining reliability);
- radio path control/measurements/power control;
- supervision and diagnostics of RLL elements ;
- handling of RLL parameters (system, radio, security).

## 9.6 Evolution

ETSI SMG has opened the issue to continue GSM standardisation after phase 2. RLL is currently in the SMG phase 2 work plan. This ETR may be useful to SMG for the evaluation of realistic possibilities for new/additional ETSI SMG standardisation efforts to comply with RLL requirements. Further standardisation for GSM should be done in relation to SMG.

In this subclause are listed some enhancements to comply with the RLL requirements specification, but which evidently would cause further standardisation in SMG. Some of the desired enhancements for RLL applications would evidently be beneficial to GSM enhancement in general, not only restricted to RLL use.

### 9.6.1 GSM/DCS1800 further standardisation in SMG

The following items could be further analysed in ETSI to enhance GSM radio interface for RLL services. The topics may have relevance not only to RLL use but also to enhance the GSM services and are as such potential candidates for further GSM standardisation:

a) Better speech quality.

- As cordless systems use an ADPCM 32 kbit/s speech codec, which provides a high speech quality and some transparency to voice band data and FAX signals, adaptation of an ADPCM codec to the GSM air interface could be studied. This would evidently need either using multiple time slot or a higher bit-rate and more spectrum efficient multilevel modulation as well as designing a specific channel coding scheme for the ADPCM codec. This enhancement would evidently need a major revision in GSM air interface.

  New 16 kbit/s and 8 kbit/s ITU-T LD-CELP high quality speech codes provide a substantially better speech quality than the current GSM RPE-LPC and could be channel coded into the GSM 22,8 kbit/s gross bit-rate burst structure without changing the GSM frame/burst structures, signalling procedures and the fixed network functions. For stationary RLL use some of the training sequences could be used for the coded speech as well increasing to gross bit-rate to some 28 kbit/s.

  The speech codec generated delay reduces from the 20 ms of GSM to under 1 ms by using an LD-CELP codec.

  An enhanced speech codec could provide a more transparent DTMF transmission than current GSM speech codec. This is of relevance for DTMF signals, coming from the PSTN network having a poor signal quality, as the GSM network could transmit the DTMF tones transparently to the terminal.

- An enhanced speech codec could provide some transparency to low speed voice band data modems (1 200/2 400 bit/s).

b) Reduced radio interface delay.

   Use of low delay speech codec and non-interleaved air interface could reduce the delay to under 10 ms. This would imply on the other hand a much higher fading margin, possibly use of diversity antennas. The channel coding scheme could be optimised to the RLL stationary propagation environment with a stand still or slowly moving terminal.

   These modifications could result in a substantially modified GSM without the need of an echo canceller in the system and reduce the system cost.

c) Support for higher bit-rates and ISDN 2B+D.

The RLL requirements specification states ISDN basic rate support as main priority. Fractional or basic rate ISDN could be supported by multi-slot assignment GSM system. Full ISDN 2B+D would require at least 8 time slots, which would change the GSM air interface current function totally. Further studies on multiple time slot allocation for fractional ISDN and digital 64 kbit/s services support could be studied.

d) Terminal monitoring.

In all these alternatives it may be possible to add some minor functionality's, like terminal monitoring over the air interface without degrading the concurrent use of standard mobile terminals in the same network and in the same frequency carriers in the air interface. The GSM mobility management procedures could be applied to the RLL application for the terminal control and the radio path maintenance. If similar reliability and accessibility as in the fixed line case is required from the RLL radio termination and related access network, it is probable that enhancements are needed for mobility management procedures. The GSM procedures such as paging, periodic location updating, location registration/updating and detach/attach are examples that could be used for continuous monitoring and measurement also in the case, when the radio termination is in the idle state.

### 9.7 Conclusions

General conclusions:

1) Cellular network can be used to serve simultaneously mobile and RLL customers in the cases that the provided services, i.e. speech, FAX and low speed data, are sufficient. While full service transparency to all copper pair access services is not provided, the cellular networks provide good spectrum efficiency and extensive coverage ranges for cost efficient and fast deployment. RLL specific functions, like special tariff, local numbering plan adjustment and restricted mobility may also be added to a cellular network serving both cellular and RLL customers.

2) Cellular standards can be used to create dedicated RLL solutions, giving an optimised grade of service, equipment capacity fit to the local RLL access cases as well as access network interfaces. A number of various ways to build dedicated GSM based solutions have been described in this subclause.

3) Minor enhancements to the GSM standards, like terminal monitoring functions and local routing could be added to improve GSM applicability to RLL use.

4) Major enhancements to the GSM standards, like better speech quality, transparency to voice band modem signals, support for higher bit-rate data services (>9,6 kbit/s) and reduced radio interface delay have been discussed and could be items for GSM further standardization. These issues are proposed to be tackled in ETSI SMG in the connection of possible further GSM standardization in the phase 2+, where RLL is currently one item in the workplan.

5) Cellular standards are not capable to comply with the RLL higher bit-rate services and full ISDN bearer services. The very short fixed access network delay requirement (2 ms) is also outside the reach of GSM. Current cellular standards define a whole mobile network, including also switching. Thus current cellular solutions are heavy and expensive for RLL applications with a small total number of connected customers.

Conclusions from the example cases:

1) Use of cellular technologies in RLL the example cases imply the existence of the cellular bands to the operator, which is not the case but only for mobile operators. The cellular subclause describes a number of example cases and describes solutions based on the availability of up to 20 MHz spectrum in some of the bands 450, 900 or 1 800 MHz. Very attractive, efficient and fast solutions to the example cases have been shown, especially when using the 450 or 900 MHz bands.

2) The cellular solution to the example cases show typically a very cost-efficient use of large cells served from a single base station, thus minimising site and transmission costs. In most of the example cases the overall customer density is rather low, the density of customers to be served (penetration) is low or at least the initial density of customers to be served is low, even in suburban and urban cases where the overall population density may be rather high. These examples thus lead to the efficient use of cellular ranges and solutions with one or a few base station sites.

3) The cellular solutions to the example cases typically require the operator to build an overall solution to the case, applying the cellular solution to a larger number of the example cases to have a large number of customers served by a single system.

4) Higher speed data services are not provided. Low speed voice band data and DTMF transparency are not provided.

5) Solutions are not optimal for the example cases which require simultaneously extended ranges (5 to 50 km) and need for a simple small (from a few to a few tens of customers) RLL system. The example cases 1A, 2 and 3 could imply this kind of a need.

# 10 Application of Microwave Point-to-Multipoint (MPMP) systems for RLL

## 10.1 Introduction

This clause briefly considers the application of MPMP systems for radio local loop applications. Such systems are available today from a number of manufacturers, and are mainly used to provide telecommunications to isolated subscribers or small communities in rural areas, in Europe and other continents.

Four aspects are considered:

- service compatibility;
- planning flexibility;
- spectrum efficiency and requirements;
- deployment and cost factors.

The main conclusions are as follows:

1) MPMP systems meet the service requirements for RLL systems well: this is to be expected as they are designed for local loop replacement, mainly for rural applications, and support 64 kbit/s transmission. They can also operate at very long range, typically up to 50 km in a single hop. The range can also be extended by using repeater stations, but at the expense of spectral efficiency.

2) MPMP systems today are not used to provide cellular coverage. The rather high channel bit-rates used would lead to total frequency allocations of 30 MHz or more being needed, for each network in a given area, just to allow for flexible cell planning. In addition, installations must follow "point-to-point" fixed link practice to optimise propagation. Repeaters are unlikely to be used in cellular coverage applications.

3) The spectrum efficiency of the systems for cellular applications, in terms of users/MHz/km$^2$ is poor compared to systems such as DECT and GSM. However, this should be qualified: the systems use efficient modulations (typically QPSK), but speech, in particular, is coded using 64 kbit/s pcm. Also, the radio channel bit-rates are high, leading to too large a capacity module for efficient cellular planning.

4) MPMP systems are presently uneconomic except for long range applications, and their poor spectrum efficiency may not permit their development for high production volumes and hence low cost.

## 10.2 System description

MPMP systems are available from a number of suppliers, and though there is no air protocol standard as such, they generally conform to similar design principles, (see also ITU-R Recommendation 756 [4]).

The physical layer is normally based on 2 Mbit/s transmission, with a total capacity equivalent to a 2 Mbit/s pcm system but additional signalling to control the radio link. Radio carrier spacing is typically 2 MHz. Systems are frequency-division-duplex, and require an appropriate paired frequency allocation. Some systems are also available using 4 Mbit/s transmission and providing 60 traffic channels, with 3,5 MHz channel spacing.

Access is by TDM (downlink), TDMA (uplink), demand assigned, with frequency division duplex (FDD). The "base station" transmits, continuously, a frame structure which is based on pcm but with normal pcm slots concatenated to longer radio slots: the radio frame length is typically 1 to 10 ms (depending on system), longer than the normal 125 µs pcm frame.

The uplink is burst-mode; the reason for concatenating pcm slots is to make the active up-slot length longer and reduce the effect on efficiency of the required up-link guard periods. Adjustable timing advance (see GSM) is provided to make sure all incoming bursts at the base station fit exactly in their allocated slots.

Figure 20 shows a possible frame format for a point-to-multipoint system, and how a single 64 kbit/s user accesses the system. On the down-link, a 2,048 Mbit/s pcm stream, which is augmented with additional control information for radio access, is mapped onto the downlink frame structure. The down-link frame has 32 slots, but in this example its length is 5 ms instead of the normal pcm frame of 125 µs. Therefore, the contents of time slot 31 (for example) of 40 successive pcm frames are stored and loaded into time slot 31 of the TDMA frame. Similarly, on the uplink, a single 64 kbit/s tributary stream will be stored for each 5 ms frame period and loaded into a single, 156,25 µs up-link burst. The timing of this burst will be adjusted so that it received at the central station in synchronism with the down-link frame.

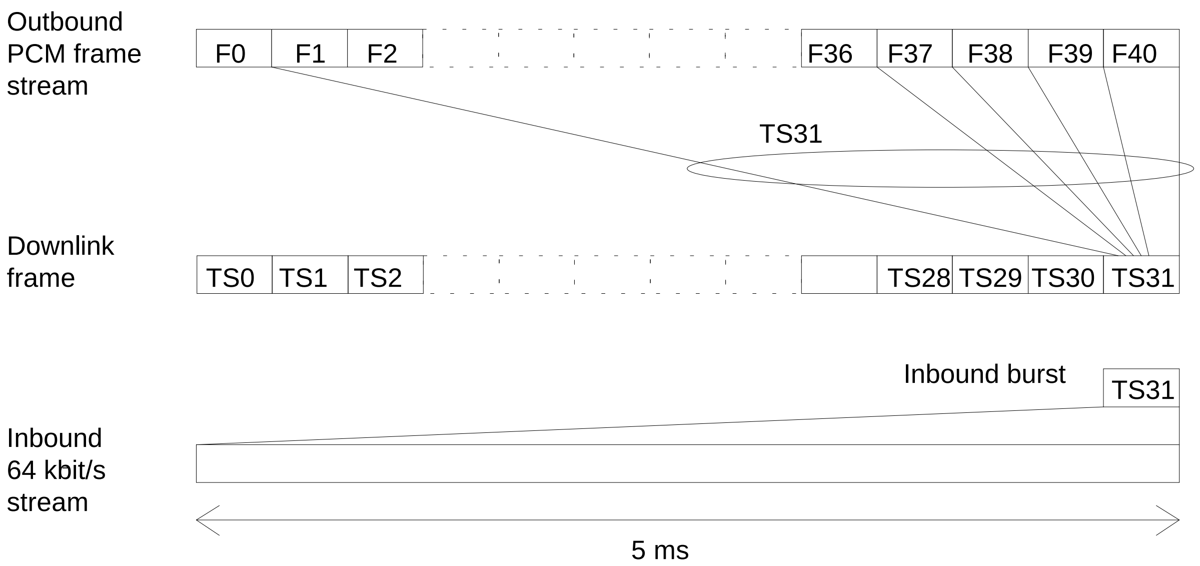



**Figure 20: MPMP frame format**

Since the protocol is based on pcm, traffic is carried in 64 kbit/s channels, and the system is therefore fully transparent to normal speech-band services. Certain suppliers provide terminal equipment with full ISDN 2B+D capability. Terminal equipment capable of supporting either single subscribers, or groups of subscribers, is generally available.

Systems operate typically between 1 and 3 GHz in normal "fixed-service" frequency allocations, and frequency rasters aligned with microwave point-to-point systems (see also ITU-R Recommendation 701 [40]).

Base station to subscriber system range can be typically up to 40 km. Both are installed to obtain a good line-of-sight path. This ensures that multipath delay spread is minimised. In addition, most systems make provision for a "repeater" mode which allows ranges of several hundred kilometres to be attained in several "hops".

Systems are normally installed to provide service to scattered groups of subscribers, and cellular coverage is not a consideration[1)].

There are no air interface protocol standards for this type of system, but ETSI TM 4 is working on a coexistence standard for system RF. characteristics[2)].

We will consider a "typical" MPMP system to use 2 Mbit/s transmission, channel spacing 2 MHz, TDMA/FDD, providing 30 traffic channels, each of 64 kbit/s bandwidth per duplex radio bearer.

### 10.3 Service considerations

As described above, MPMP systems generally provide 64 kbit/s traffic channels, and are therefore "transparent" to normal telecommunications services, except that the TDMA structure imposes a round-trip delay in the region of 2 to 20 ms.

System installations are planned to provide transmission quality conforming to ITU-T Recommendation G.821 [5].

Network termination equipment can provide a wide range of conventional interfaces, from 2-wire POTS through 4-wire analogue to ISDN on some systems.

Systems are designed specifically to support fixed communication services, and mobility is not supported either in the radio transmission system design or system control aspects.

### 10.4 Cell planning considerations

In normal applications of MPMP systems today, the location of all the remote stations is known prior to system deployment (for example they may correspond to existing rural telephone exchanges or communities). Therefore the system can be planned to provide a line-of-sight path to each remote station, and frequency re-use, if appropriate, allowed for by conventional microwave link planning methods.

An operator using MPMP technology for an RLL application may well not know, except in general terms, the locations of customers. Therefore it will be more appropriate in this situation to provide coverage by cellular methods, as in modern mobile telecommunication networks.

A cellular MPMP system will therefore require a minimum of 1 radio bearer per base station, with a total spectrum requirement of 4 MHz. Assuming either 4 or 7 cell re-use cluster sizes, the minimum spectrum requirement per cluster will be 16 or 28 MHz. This would assume also that the adjacent-channel characteristics of the system are such that operation with an adjacent channel in an adjacent cell is practical. (However, little information is available on the likely re-use cluster size possible with a system of this type, in which the remote stations use highly directional antennas. It may be that smaller clusters are possible, which would reduce the required spectrum.)

In any practical situation an operator will have to deploy a system to cover a wide range of user densities. This is conventionally done by adjusting the number of radio bearers per cell and adjusting cell size, to meet the demand. In an area of very dense user population, cell sizes are small and many channels per cell are assigned, whilst in sparsely populated areas cells are large with few channels.

When planning cellular coverage, whether for mobile, cordless, or MPMP technologies, the operator has to manage the transition from small cells to large cells. This is complicated by the need to manage co-channel interference between cells. Figure 21 shows that radio frequencies in use in the larger cells A to F could not be re-used within the smaller cells 1 to 7, since the interference radius of the larger cells, typically 4,5 times their service radius, is larger than the cluster of small cells itself. Thus additional spectrum is required to manage the transition in cell size. In the example shown, 7 radio bearers would be

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**1)** RES 3 RLL TD 4 - 10.
**2)** TM 4 (93) 62 Annex 2.

needed for the inner cluster, and if the ring of larger cells formed the outer ring of, effectively, one cluster of large cells, at least a further 6 channels would be needed to manage re-use, apart from any capacity considerations.

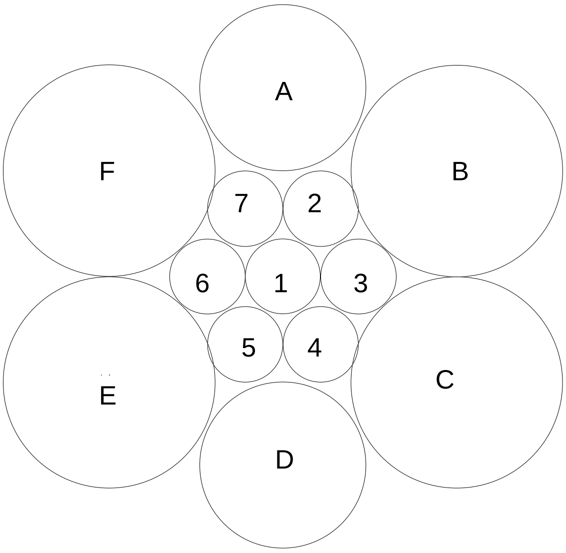


**Figure 21: Cell size transition**

Thus we see that the minimum spectrum requirements have to be increased considerably in order to obtain enough flexibility for cellular planning. Further increases, for example to allow base antenna sectoring, may also be required.

Thus the minimum spectrum required for cellular MPMP applications will have to be of the order of 56 MHz (assuming 7-cell cluster), to allow for reasonably flexible cell planning. This compares with allocations of the order of 10 to 20 MHz for DECT and GSM systems[3,4]. If a 4-cell cluster were possible, the spectrum will be increased from 16 MHz to approximately 32 MHz.

As an alternative, the same cell size could be used throughout the system. However, the cell size would then be set by the capacity needed in the densest areas, the cells in the less dense areas would be under-utilised, and much more capital investment would be required.

## 10.5 Capacity considerations

The minimum capacity of the assumed MPMP system is 30 traffic channels per cell. Assuming 0,07 Erl per user and maximum blocking of 1 %, the number of users per single radio bearer is 315[5].

Assuming that each cell then had a single radio bearer, and a 7-cell cluster, the cell radii required for various user densities are:

**Table 33**

| **User density ($km^2$)** | 1 | 10 | 100 |
|---|---|---|---|
| **Cell radius (km)** | 10 | 3,2 | 1 |
| **Cell radius (GSM) (km)** | > 10 | 6 | 1,8 |

The last row of this table compares the cell radius with that possible using GSM (taken from table 1 of ITU-R Recommendation 755 [3]).

**3)** RES 3 RLL TD 4 - 11.
**4)** RES 3 RLL TD 4 - 18.
**5)** Assuming Engset statistics, since the number of users and channels is quite small.

It can be seen that the cell radii necessary using MPMP systems are significantly lower, when assuming one radio bearer per cell, than those necessary using GSM. The calculations for GSM assumed that the total spectrum used was 20 MHz; for the MPMP system the minimum bandwidth needed is ~ 28 MHz for the 7-cell cluster.

It may thus be seen that the MPMP system, at least for the most dense case in the table above, is $1{,}8^2 \times 28/20 = 4{,}5$ times less spectrally efficient, in terms of users/MHz/km$^2$, than GSM for this application. If additional spectrum is needed to allow for cell size adjustment the comparison is even less favourable[6)].

## 10.6 Deployment and cost factors

MPMP systems are normally deployed by operators providing services in rural areas, with very long distances between exchange and user. Experience reported by Telia in Sweden[7)] shows that the systems are not cost-effective today compared to wired systems for distances shorter than 3 km and using single-user radio terminations. In addition to the cost of the equipment, additional high costs are incurred by the need in many cases for an antenna tower and the planning of the link for individual users.

It is more usual to deploy systems with multiple-user terminations, but these then require copper pairs to be installed to reach the larger number of users. Again, the Telia experience shows the systems to be economic only when these pairs are ready-installed and the radio termination is replacing a previous small local exchange or flexibility point. The cost of installing and maintaining the "final drop" is a major factor in wired network costs, and a motivation for using RLLs.

The costs of MPMP equipment could be significantly reduced by scale economies which would result from widespread use in RLL systems. However, the costs of installation and planning would remain high, and the poor spectrum efficiency may not allow the development of a large market because of the unavailability of sufficient spectrum.

## 10.7 Analysis of RLL application example

MPMP systems are designed mainly for rural telephony applications. For this reason, only application example 2 has been analysed, as this corresponds very well to the normal scenario in which the systems are used.

The example describes a rural area where 90 % of the subscribers are located within a radius of 4 km. The other 10 % are located in small clusters with 3 to 10 customers in each. These clusters have a radius smaller than 2 km and are located 5 to 10 km from each other. The customer density of 25 to 250/km$^2$ given in the example corresponds to 250 to 2 500 customers in the centre area (< 4 km) and 25 to 250 in the other area.

If we assume that we use one 60 channel MPMP system in 2,5 GHz, it is possible to connect up to 670 customers with the given traffic and blocking rates (0,07 Erl, 1 % blocking). If more customers have to be connected, several MPMP systems must be used. We also assume that it is possible to obtain line-of-site from one site to all customers. Otherwise repeaters have to be used.

Somewhere in the centre of the area a site with a tower, high enough to obtain line-of-site to the customers, is deployed. At this site the central station of the MPMP-system is installed. It is connected to a switch or concentrator with a 2 Mbit/s interface. Omni-directional or sector antennas with a typical gain of 10 to 17 dBi are used at this site.

At the customers a small outstation (2 lines) is deployed. The equipment can be mounted inside or outside the customers building. Small parabolic antennas with typical gain of 15 to 22 dBi are used. If customers living in apartment blocks are to be connected, a larger outstation can be used for all customers in the same block.

The spectrum need for this example depends on whether repeaters have to be used and in that case how many. It also depends on how many systems are needed to connect a number of customers in that area. The minimum spectrum needed in this example would be 7 MHz and the maximum about 28 MHz assuming 4 cell re-use cluster size.

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6) However, it must be emphasised that these users have access to 64 kbit/s channels.
7) RES 3 RLL TD 5 - 26.

With today's equipment prices it is not very likely to deploy one outstation at every customer especially those in the centre of the area.

The most likely way to use a MPMP-system in this example would be as follows:

a) the copper cable network in the centre of the area is kept or replaced with another type of RLL system;

b) outstation cabinets for up to 32 customers installed in the centre of each cluster. The copper cable network between the customer and the outstation is also kept here, or replaced with another type of RLL system;

c) small outstations (2-lines) are used at scattered customers.

In this case the MPMP solution is a cost effective way to modernise old analogue networks in rural areas, which also makes it possible to provide the customers with ISDN services up to BRA (2B+D).

### 10.8 Summary

The analysis above shows that MPMP systems, though they meet most of the services requirements for RLL applications, would be inflexible for cellular planning, and offer poor spectral efficiency compared, for example, to GSM. This comparison is slightly unfair, since the MPMP systems offer full 64 kbit/s transparent channels, and the ability to provide a user with several channels (for example for ISDN 2B+D), whilst GSM provides narrow-band channels with specialised speech coding and data rates limited to 9,6 kbit/s. However, in one case (user density of 100/km$^2$), with the MPMP system 4,5 times more cells would be required to cover the same area with 1,5 times more spectrum than GSM - the impact on infrastructure cost would be considerable.

Like GSM, MPMP systems can operate to very long ranges, while there seems no obvious lower range limit. However, the wide-band channel requires that installation practice similar to point-to-point links is needed to ensure a line-of-sight path with no significant multipath; whereas GSM can cope with severe multipath because it incorporates an equaliser.

MPMP systems provide capacity in large increments, 30 traffic channels per (duplex) bearer, and the bearer requires 4 MHz total bandwidth, leading to inflexibility in cell planning within reasonably small spectrum allocations.

The economics of existing applications of these systems tends to show that they are ideal for use only in very sparsely populated areas

## 11 Spread spectrum technologies assessment

### 11.1 Introduction

#### 11.1.1 Scope

This clause deals with a class of technologies which are not yet the subject of European standards. This contrasts with the scope of the other technology assessment clauses which address specific implementations of technologies based on existing ETSI standards. This clause, therefore, concerns itself more with the capabilities, merits and disadvantages of spread spectrum techniques, rather than addressing specific realisations of these techniques.

In this clause the general attributes of spread spectrum techniques are outlined. The features of the two broad categories of spread spectrum systems are discussed and conclusions drawn on the applicability of spread spectrum to radio local loop.

#### 11.1.2 Spread spectrum technologies

In Code Division Multiple Access (CDMA) systems, multiple subscribers share the same spectrum. In these systems individual bearers are coded, prior to transmission, in a way which enables their separation at the receiver. This coding increases the radio channel bandwidth, hence the term spread spectrum.

Such coding is usually achieved by one of two means; direct sequence coding (DS-CDMA), or frequency hopping (FH-CDMA).

Strictly speaking TDMA systems also belong to the general spread spectrum class. However, since TDMA systems are well covered elsewhere, this clause will confine itself to CDMA systems, which use pseudo-noise spreading.

#### 11.1.3 Status of CDMA technology in Europe

Current ETSI standards for both cordless and cellular digital telecommunications systems employ TDMA and FDMA as the radio access method. There is currently a considerable amount of European research effort directed at CDMA[8,9]. particularly with a view to its suitability for use in the ETSI UMTS standard.

#### 11.1.4 Merits of spread spectrum technologies

Many advantages have been claimed for spread spectrum radio, amongst these are the following:

- relatively simple support for multiple bearer services on a single air interface;
- high immunity to interference sources;
- ability to co-exist with other low power services, easing some spectrum management issues;
- increased resistance to interception;
- inherent frequency diversity provides robust operation in a fading channel;
- improved capacity and spectrum efficiency relative to other access techniques;
- optimum path diversity possible using a RAKE receiver structure;
- equalisation to combat multipath effects is not required (DS-CDMA).

### 11.2 Direct Sequence CDMA (DS-CDMA)

#### 11.2.1 Overview

DS-CDMA is a spread spectrum technique in which multiple subscribers occupy the same spectrum simultaneously. Individual channels are coded by multiplication with a spreading sequence, and recovered by correlation at the receiver. Exact time synchronisation is usually not assumed, and codes behave in an uncorrelated rather than an orthogonal way. It follows that upon recovering the wanted signal, the remaining signals appear as noise. Thus the capacity of the system is limited by the effect on the de-spread Signal-to-Noise Ratio (SNR) of each additional subscriber. DS-CDMA is therefore referred to as an interference limited system. The resource allocated by a TDMA system is time, and by an FDMA system it is frequency. In a DS-CDMA system the allocated resource is signal power, relative to the noise of the other subscribers.

#### 11.2.2 Capacity factors

##### 11.2.2.1 Other active subscribers

The receiver SNR for an individual user will be the wanted signal power divided by the sum of the background noise plus the signal power of all the other users. Ignoring the effects of adjacent cells, the capacity of a single cell is limited by that total power which can be received by all subscribers whilst each still maintains an acceptable SNR.

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8) RACE R2020 - CODIT UMTS Code Division Testbed.

9) UK DTI/SERC LINK project "A rigorous evaluation of CDMA for future European personal communications systems".

#### 11.2.2.2 Co-frequency adjacent cells

The capacity analysis of a CDMA system allows for the effect of adjacent co-frequency cells. Assuming that RLL subscribers use directional antennae, it follows that the worst case occurs for a subscriber positioned on the periphery of his own cell and on line passing through his own base station and that of a neighbouring cell. If it further assumed that the cells are of equal size, then such a subscriber will be three times as far from the interfering base as he is from his own. For reasonably large cells the average path loss difference between each of the cells and the subscriber is of the order of 18 dB. This figure is based on a 4th power propagation law, and corresponds closely to calculations made using the Hata model (> 1 km). Assuming all users are in such a worst case position relative to adjacent cells, the system would experience a reduction in capacity of less than 10 %. This is an extremely pessimistic model since it assumes that all users to adopt worst case positions with respect to their neighbours. Using the same propagation law and assuming a randomly distributed population, the average path loss difference has been shown to be only 28 dB.

#### 11.2.2.3 Power control

Since co-frequency subscribers contribute noise to the remainder of the population, the effects of imperfect power control must be accounted for. Signals must be received at the relative power level appropriate to their required quality of service. This is not a problem in the down link. However, for the up link each RT will have a different propagation path loss to the BS, and therefore the powers received at the BS will cover a wide range. In mobile DS-CDMA systems, this is a major technical problem, since fast, accurate power control of individual mobiles is essential. Furthermore, this power control must be effected over a very wide dynamic range of 80 dB or so (see Gilhousen [11]. This problem will not be trivial in a fixed subscriber environment, though it is reasonable to suppose that it will be considerably mitigated.

Published results (see Holtzman [12]) show that, in the uncoded case, a 10 % rms variation in power causes a reduction in capacity of approximately 2 %. Cost and technology factors may make such an exacting power control requirement difficult to meet.

#### 11.2.2.4 Voice activity detection

If the number of users is reduced, even briefly, the quality of service for those remaining is improved. DS-CDMA inherently supports packet mode transmission, since a simple break in transmission by one subscriber makes his radio resource available to other subscribers. By using discontinuous transmission, the gaps in speech can be used to momentarily reduce the interference experienced by other users. For a statistically significant subscriber base, the interference level is reduced by some "activity factor" $\alpha$. For speech, $\alpha$ is close to 0,5, and in the limit could be used to increase voice circuit capacity by a factor of two. It should be noted that speech clipping due to discontinuous transmission may degrade the speech quality.

### 11.2.3 Cell planning

#### 11.2.3.1 Near-far effects

The near-far effect describes the phenomenon whereby the signal from a near subscriber overwhelms that from a far subscriber. Within a cell, the problem is overcome by a suitable power control strategy. A more difficult problem is posed by the inter-cell case in which a mobile in one cell is far from the base station which is controlling its power, and near to that in a neighbouring cell. The phenomenon is not unique to CDMA systems, but their inherent dependency on power control makes them especially sensitive to this effect. The problem occurs when base stations are non co-located and serve cells of differing size.

The problem is considerably reduced by the use of directional antennae at the subscriber equipment. Properly installed, these should provide sufficient inter-cell isolation to eliminate this problem in most situations. If the use of properly installed, reasonably high gain antennae cannot be assumed the problem may be addressed at the expense of increased frequency re-use. This involves the provision of co-frequency macro-cellular blanket coverage, with underlaid non co-frequency cells providing extra coverage where required. In mobile systems this is unattractive, since hand-off between cells on different frequencies is not simple. However, in fixed subscriber systems this need not be an issue.

#### 11.2.3.2 Resource re-use

In principle, cells may be isolated from their neighbours by suitable code management. This promises a frequency re-use factor of 1. However, the near-far effect discussed in subclause 11.2.3.1 would require the use of properly installed high gain antennae. If this is not to be the case a non co-frequency multiple overlay cell system would be best suited to radio local loop.

### 11.2.4 Radio channel robustness

#### 11.2.4.1 Diversity

An inherent feature of DS-CDMA systems is their frequency diversity. This provides for robust operation in the presence of narrow band fading, and/or narrow band interferers. In a dispersive channel environment, the receiver can track individual multipath components with a resolution determined by the chipping period (see Allpress [13]). This is much less than the symbol period. By using a RAKE architecture to combine the multipath components, the receiver is able to benefit from path diversity. The use of a three branch RAKE with simple equal gain combining could yield a 4 dB improvement in SNR (see Beach [14]). However, it should be noted that the channel appropriate to a radio local loop system with directional antennae is not well researched, and the multipath diversity gains may be significantly different from those in the highly dispersive mobile environment.

Active narrow band interference rejection schemes have been proposed (see Milstein [15]) for spread spectrum systems. These rely on the relatively wide auto-correlation function of narrow band signals to facilitate prediction based on previous observation. These schemes promise to allow the sharing of spectrum with existing narrow band users. The effect on the narrow band user needs to be carefully considered, as does the complexity of the rejection process, before such a system could be seriously proposed.

### 11.2.5 Bearer service support

The bearer services for radio local loop differ significantly from those supported by current generation mobile telecommunications systems. Terminals which are intended for connection to the fixed network often make demands on the bearer in terms of bit rate and bit error rate which are not supported by existing mobile radio systems.

DS-CDMA can support continuously variable quality of service at different bit rates on a single air interface. This feature makes DS-CDMA radio very attractive as a replacement for copper, since it provides a simple means to allocate radio resource in according to the needs of individual services being carried. A multi-rate DS-CDMA air interface, capable of supporting bit rates between 2 kbit/s to 2 Mbit/s is currently being researched within the RACE CODIT programme (see Baier [16]).

For a given modulation scheme, the relative resource requirements of different bearers can be easily calculated. The network can dynamically control the power of all subscriber equipment to achieve an optimum allocation of radio resource. This optimum solution satisfies the specific bearer requirements of each subscriber within the minimum total power budget.

### 11.2.6 Spectrum efficiency

DS-CDMA is an interference limited system. The number of users that can be supported within a given bandwidth is inversely proportional to the $E_b/N_0$ required to achieve the necessary BER. In the field of mobile communications, very promising comparisons have been made between DS-CDMA and current European TDMA technologies (see beach [14]). Gilhousen [11] makes the point that as an access technique, CDMA is at least competitive with other access techniques (FDMA and TDMA) in terms of spectrum efficiency.

Intra-cell capacity advantages are, in the main, attributable to the elegant way in which discontinuous transmission makes any briefly unused resource generally available. The overall spectrum efficiency must take into account any frequency re-use factor, which is generally assumed to be unity for CDMA schemes. Based on the product of these factors, DS-CDMA would appear to offer significantly improved spectrum efficiency compared to existing cellular systems. However, the use of directional antennae in a fixed subscriber system effectively reduces inter cell effects, and all access techniques should be capable of achieving near unity frequency re-use. If it can be assumed that voice traffic predominates, and that voice activated discontinuous transmission is not unacceptably detrimental to the perceived quality, DS-CDMA provides the simplest means of realising the full potential fractional voice activity. To approach the same spectral efficiency, other access techniques will need complex circuit allocation protocols.

### 11.2.7 Range considerations

Cell radius may be limited either by capacity or by the physical range achievable by the equipment. Cells which are radio range limited, rather than capacity limited, are inefficient in their use of spectrum and infrastructure. Under conditions where subscriber density is low, efficient use of spectrum may be achieved either by employing large cells, or by distributing low capacity equipment over the whole area. The latter option sacrifices the benefits of concentration, and in any case the coarse spectrum segmentation inherent in DS-CDMA makes such strategy unattractive in all but the densest traffic scenarios.

NOTE: Range and capacity are interdependent. The thermal noise floor, and therefore the attainable range, can be traded for additional users. It follows that for a given link budget, the maximum range will be function of cell loading.

### 11.2.8 Quality of Service (QOS)

In a DS-CDMA system a reduction in the number of users accessing the system is translated into a gain in QOS, in terms of improved Eb/No, for the remaining users. Thus, although if the system is fully loaded all users will obtain their rated BER performance, when it is less loaded, all users can experience a much lower BER.

In addition to the potential benefits from under loading, the graceful degradation feature inherent in DS-CDMA can be used to provide exceptional overloading, e.g. emergency calls, without dropping in-service calls.

TDMA systems have an inherent delay associated with their frame structure. DS-CDMA does not suffer from the framing delays associated with TDMA systems. This is only a significant advantage provided other delays due to, for example, interleaving do not predominate.

## 11.3 Frequency Hopping Spread Spectrum (FHSS) systems

### 11.3.1 Overview

FHSS describes a class of digital radio systems where the carrier is changed or "hopped" over a wide range of frequencies. The systematic variation of the carrier frequencies as a function of time is known as the hopping pattern and is typically achieved by applying a pseudo random sequence of inputs to a frequency synthesiser, or frequency hopper.

Typically the RF bandwidth allocated to the service is partitioned into q equal, non overlapping frequency intervals or slots, and the centres of these slots are the carrier frequencies generated by the frequency hopper.

In contrast to DS-CDMA systems, at any instant one bearer channel only occupies a small part of the total allocated spectrum, corresponding to one slot, although the actual centre frequency varies rapidly with time. However, since FHSS also benefits from frequency diversity, many of the desirable characteristics of DS-CDMA are echoed in FHSS systems.

FH systems can be divided into Fast FHSS (FFHSS) and Slow FHSS (SFHSS): if the carrier is hopped at a rate which exceeds the symbol rate then the system is classified as FFHSS, if the hopping rate is lower than the symbol rate, the system is classified as SFHSS.

### 11.3.2 Robustness

The inherent robustness claimed for FHSS systems stems from their frequency diversity which provides a degree of protection in the presence of narrow band fading. In particular, for a given fading environment, fading associated with multipath propagation is likely to affect only a small proportion of the slots from the q available. Furthermore, the fragmentation of fading effects makes them more amenable to forward error correcting schemes. This may be particularly important in a quasi static channel.

FHSS systems have been shown to operate without apparent degradation in the presence of high levels of narrow band interference. Some FHSS systems can detect the presence of narrow band RF interference and adjust the hopping sequence so as to skip the slots which are suffering the interference. This is similar to the DCA mechanism employed by cordless systems, and provides FHSS systems with the means to co-exist with existing spectrum users.

FHSS systems have been shown to co-exist quite successfully in the Industrial, Scientific and Medical (ISM) frequency band within an almost uncontrolled, and often unknown, interference environment.

Gudmunson [17] concludes that a random frequency hopped half rate GSM system would be at least as spectrally efficient as the CDMA system described by Gilhousen [11]. This conclusion is further borne out by DS/FHSS simulation results published (see Swales [18]).

### 11.3.3 Bandwidth issues

With q slots available, a bearer channel occupies each slot for 1/q of the time. Thus q bearer channels can be supported simultaneously, where each bearer channel has the bandwidth equal to the bandwidth of one slot, providing the hopping pattern is synchronised for all bearer channels.

FHSS systems fragment a single bearer into time slots, which are subsequently transmitted at different frequencies. This requirement for a time slot structure gives FHSS much in common with TDMA systems, and the same constraints apply in the allocation of resource to different bearer services.

## 11.4 Summary

Spread spectrum techniques, both direct sequence and frequency hopping, are in use today in both mobile telecommunications and military applications. The European Commission is funding research into CDMA techniques for a future UMTS ETSI standard. This research is being advanced under a pre-competitive RACE project. Independent research, also in support of ETSI UMTS standardisation is being undertaken in the UK under the DTI/SERC programme.

Both DS-CDMA and FHSS systems offer robust operation attributable to their inherent frequency diversity. This is a critical feature in the local loop where a very high quality of service is demanded, and where the delays of elaborate coding and interleaving to achieve the same performance may be unacceptable. The GSM system currently makes use of frequency diversity to improve its immunity to fading.

DS-CDMA promises to offer near optimum spectral efficiency, subject to adequate power control. However, because spectrum must be allocated in a relatively coarse manner, it is most suitable where a significant number of subscribers can be accommodated in a given cell. It has been shown that by using active interference rejection DS-CDMA systems can co-exist with narrow band users, but not without some effect on them. Frequency hopped systems benefit from being able to use discontinuous spectrum assignments, and consequently co-existence is not a problem. The spectral efficiency of spread spectrum systems is further improved relative to other techniques because they do not inherently rely on frequency re-use. Simulations have shown that by using random frequency hopping, GSM can achieve 10 % to 15 % fractional loading at 1 cell frequency re-use in mobile telephone application.

DS-CDMA promises to provide a simple and elegant means to support a wide range of teleservice bearers, ranging from low bit rate, high error rate speech through to high bit rate low error rate data services. This allows the technology to offer a quality of service comparable with copper in the most bandwidth efficient way.

Spread spectrum techniques have attracted most attention in the field of mobile communications, where the operating environment is formidable. In the mobile environment, practical considerations make the full potential of DS-CDMA difficult to realise. In the local loop. With fixed subscriber equipment, and the benefit of directional antennae, it is likely that these benefits can be attained at much lower complexity than in mobile systems.

## 11.5 Conclusion

Should ETSI embark upon the creation of a standard for RLL, it is recommended that the suitability of spread spectrum technologies should be properly explored. Much of the necessary research is already well advanced in Europe, in support of ETSI UMTS standardisation.

# 12 RLL service and deployment assessment

Subclause 12.1 summarises the technologies and estimates briefly, without going to comparisons or trying to put absolute performance figures. It outlines the use of technologies in different deployment examples introduced in clause 5.

Subclause 12.1 also analyses previous results and discusses the kinds of services to which existing technologies are capable. It discusses factors affecting frequency efficiency, independent of technology, but related to the type of service provided by RLL.

Subclause 12.1 concludes with some remarks on economy and potential deficiencies of existing standards, laying the ground for recommendations proposed in the clause 13.

## 12.1 Technology assessment

The most relevant features of technologies presented in clauses 8 to 11 for RLL applications are summarised and briefly analysed.

### 12.1.1 Analogue Cellular technologies

Existing analogue technologies are already in use for RLL (e.g. NMT, TACS).

Strengths:

- speech and voice band data up to 4,8 kbit/s;
- good range up to 35 km;
- low complexity;
- mature technology;
- low delay;
- non line-of-site operation.

Weaknesses:

- **s**ecurity - only analogue scrambling and poor authentication (except NMT);
- no support to digital services or high speed voice band data;
- degraded performance at cell boundaries.

RLL application would benefit improvements in:

- authentication;
- PSTN network compatibility.

As an existing solution, analogue cellular will have a role as an available system for basic service RLL applications and stationary service from mobile networks. Some evolution may take place to further increase network capacity and performance of analogue networks, reinforced by existing 450 and 900 MHz area coverage networks throughout the world.

### 12.1.2 GSM/DCS digital cellular

The GSM standard is a comprehensive standard entering use in Europe and large parts of the world.

Strengths:

- coverage up to 10 km (DCS) and up to 35 km (GSM 900);
- open and existing system standard;
- consistent speech and service quality within the whole cell;
- very secure authentication and encryption algorithms are defined;
- comprehensive set of standardised services, including ISDN;
- supplementary services.

Weaknesses:

- speech quality (including delay) does not meet fixed network service standards;
- data throughput limited with respect to fixed network - no ISDN high speed bearer services;
- poor service transparency (e.g. DTMF in downlink);

  network solution with no interface to conventional PSTN local exchange.

RLL application would require improvements in:

- speech quality, including reduced delay;
- PSTN network compatibility;
- data transparency.

The data functionality of GSM/DCS, relies on separation between speech and data including fax. Data is transmitted using GSM/DCS RF channels digital bearer services. GSM data requires either an adapter or GSM data rate specific TEs. The GSM/DCS does not apply to bit rates above 9,6 kbit/s without substantial new standardisation.

Major enhancements of GSM are planned to it for latter part of 1990's. Developments affecting usability of GSM for RLL include introduction of already standardised GSM data services into use and the standardisation of a new speech codec optimised for RLL applications with better speech quality and lower delay.

### 12.1.3 DECT technology

Strengths:

- capability up to ISDN 2B+D;
- high capacity due to 20 MHz spectrum allocation;
- transparency to voice band data to 4,8 kbit/s;
- supports conventional PSTN switch interfaces;
- secure and authentication encryption defined;
- low complexity.

Weaknesses:

- range limited by RF power;
- sensitivity to delay dispersion.

RLL application would require improvements in:

- increase of range.

DECT offers a 32 kbit/s ADPCM voice band transmission with 12 to 14 ms one way delay, and a 64 kbit/s non-voice transmission. Also protocols for ISDN inter-working, including an option for 2B+D and a network supported mobility are being specified.

The DECT technical standards do not necessarily require modifications of substance but usage limitations built in to the standards (such as restriction of 64 kbit/s transmission for non-speech and 20 % of DECT carriers) should be reviewed, both technically and from regulation's point of view.

### 12.1.4 CT2 digital cordless technology

Strengths:

- low delay (2 ms) for voice;
- transparency to voice band data to 4,8 kbit/s;
- low complexity;
- relatively multipath immune at designed range;
- supports conventional PSTN switch interfaces.

Weaknesses:

- range limited by RF power;
- limited data capability, no ISDN bearer services.

RLL application would require improvements in:

- more RF power and range;
- provision of additional privacy and data encryption.

CT2 meets the RLL speech requirements with 32 kbit/s ADPCM codec.

### 12.1.5 Microwave Point-to-Multipoint (MPMP)

Strengths:

- all services supported;
- very long range up to 50 km (LOS)/hop;
- relay operation;
- supports conventional PSTN switch interfaces.

Weaknesses:

- low spectrum efficiency;
- inflexible for cell planning;
- requires LOS path;
- no open air interface standard.

RLL application would require improvements in:

matches into planned deployment scenarios - no changes needed.

There are ongoing standardisation activities for PMP applications. The standard will be based on RF coexistence of different systems.

### 12.1.6 CDMA technologies

Strengths:

- flexible RF resource allocation, up to ISDN 2B+D;
- robust radio interface;
- ability of FHSS to utilise fragmented spectrum;
- low delay.

Weaknesses:

- commercially immature technology;
- requires large spectrum allocation increments, e.g. 5 MHz;
- no ETS available (in short term);
- capacity compromised by long range operation.

RLL application would require improvements in:

- further consideration for potential ETSI work.

CDMA technologies are not yet mature for commercial use. CDMA is a very potential solution for radio operation with variable user bit rates and BER requirements. After commercial CDMA proposals entered public awareness in early 1990´s, a number of different proposals with varying parameters and algorithms have been published both commercially and through research channels.

## 13 Recommendations to ETSI

Considering that:

1) existing cordless, cellular and MPMP technologies are all suitable for some service characteristics and deployment examples. Further spectrum might be required for cordless and cellular technologies to allow such systems to operate in RLL applications without mutual interference with mobile applications;

2) existing cellular and cordless service and technologies are already used for RLL application;

3) no single radio technology standards simultaneously provides long range, fixed network speech quality, full voice band data transparency, 64 kbit/s and ISDN 2B+D together with spectrum efficiency and planning flexibility;

4) there is a need for an RLL solution meeting all above requirements provided it can be deployed more cost efficiently than technical alternatives such as copper pair or fibre;

5) there is a need for further studies for propagation models for RLL;

6) concentrating interfaces to the local exchange are being defined within ETSI and are relevant to RLL;

it is recommended that:

1) the feasibility of GSM, DCS1800, DECT, CT2 and MPMP technologies to be realistically modified for meeting all the requirements of 4 above should be studied by the relevant ETSI TCs;

2) ETSI should obtain from relevant bodies already working on this matter (e.g. COST) realistic propagation models meeting all the requirements of RLL applications. In particular the effect of directional antennas and Almost Line-Of-Sight (ALOS) paths need to be considered;

3) the associated spectrum requirements should be assessed and the allocation process should be initiated through relevant bodies;

4) depending on the outcome of these studies, appropriate standardization activities should be established;

5) the relevant ETSI groups should consider the requirements of RLL systems in designing concentrating interfaces to local exchanges. In particular, the desirability of providing multiplexing of channels at rates below 64 kbit/s in the V 5.2 standard should be considered, making use of low bit-rate speech coding on the air interface, to improve the efficiency of back haul links from RLL base stations.

## History

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|---|---|
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