

**Digital Enhanced Cordless Telecommunications (DECT);
Traffic capacity and spectrum requirements for multi-system
and multi-service DECT applications co-existing in a
common frequency band**



Reference

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Foreword

This Technical Report (TR) has been produced by ETSI Project Digital Enhanced Cordless Telecommunications (DECT).

The information in the present document is believed to be correct at the time of publication. However, DECT standardization is a rapidly changing area, and it is possible that some of the information contained in the present document may become outdated or incomplete within relatively short time-scales.

1 Scope

The present document describes the traffic capacity and the spectrum requirements for multi-system and multi-service Digital Enhanced Cordless Telecommunications (DECT) applications coexisting on a common frequency band. Configurations for typical DECT applications, and relevant mixes of these, including residential, office, public and Radio in the Local Loop (RLL) applications, are defined and the traffic capacity is analysed, mainly by advanced simulations. These results are used together with relevant deployment scenarios to estimate spectrum requirements for reliable services, specifically for a public multi-operator licensing regime. Recommendations are given on conflict solving rules that conserve the high spectrum efficiency gain of shared spectrum while maintaining control of the service quality in one's own system. These recommendations cover synchronization, directional gain antennas, traffic limits per DECT Radio Fixed Part (RFP), use of Wireless Relay Stations (WRSs), different rules for private and public operators and procedures needed for timely local adjustments where and when the local traffic increases. Results of studies on compatibility with other relevant radio technologies using spectrum adjacent to the DECT band, are also included.

2 References

For the purposes of this Technical Report (TR) the following references apply:

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- [2] ETSI EN 300 175-2: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 2: Physical Layer (PHL)".
- [3] ETSI EN 300 175-3: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 3: Medium Access Control (MAC) layer".
- [4] ETSI EN 300 175-4: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 4: Data Link Control (DLC) layer".
- [5] ETSI EN 300 175-5: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 5: Network (NWK) layer".
- [6] ETSI EN 300 175-6: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 6: Identities and addressing".
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- [19] TIA/EIA-662: "Personal Wireless Telecommunication Standard (PWT)".
- [20] TIA/EIA-696: "Personal Wireless Telecommunications - Enhanced Interoperability Standard".
- [21] ETSI ETR 042: " Digital Enhanced 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".
- NOTE: ETR 042 has been given historical status, which means that this report will not be maintained by ETSI any longer. The historical status indicates that parts of this report may no longer be considered valid.
- [22] ETSI ETR 139: "Radio Equipment and Systems (RES); Radio in the Local Loop (RLL)".
- [23] Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity (R&TTE Directive).
- [24] Council Directive 91/287/EEC of 3 June 1991 on the frequency band to be designated for the coordinated introduction of digital European cordless telecommunications (DECT) into the Community.
- [25] Council Recommendation 91/288/EEC of 3 June 1991 on the coordinated introduction of digital European cordless telecommunications (DECT) into the Community.
- [26] ETSI EN 301 406: "Digital Enhanced Cordless Telecommunications (DECT); Harmonized EN for Digital Enhanced Cordless Telecommunications (DECT) covering essential requirements under article 3.2 of the R&TTE Directive; Generic radio".
- [27] ETSI EN 301 908-10: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Base Stations (BS), Repeaters and User Equipment (UE) for IMT-2000 Third-Generation cellular networks; Part 10: Harmonized EN for IMT-2000, FDMA/TDMA (DECT) covering essential requirements of article 3.2 of the R&TTE Directive".
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- [33] ERC/DEC/(94)03 ERC Decision of 24th October 1994 on the frequency band to be designated for the coordinated introduction of the Digital European Cordless Telecommunications system
- [34] European Commission Decision of 6 April 2000 establishing the initial classification of radio equipment and Telecommunications terminal equipment.

- [35] ERC Decision of 23 November 1998 on Exemption from Individual Licensing of DECT equipment, except fixed parts which provide for public access and associated identifiers.
- [36] CEPT/ERC Recommendation 21-13 E: "Licensing regime for digital European Cordless Telecommunications (DECT) Equipment", (Brussels 1994).

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

antenna diversity: implies that the RFP for each bearer independently can select different antenna properties such as gain, polarization, coverage patterns, and other features that may affect the practical coverage

NOTE: A typical example is space diversity, provided by two vertically polarized antennas separated by 10 cm to 20 cm.

broadcast: simplex point-to-multipoint mode of transmission

NOTE: The transmitter may disregard the presence or absence of receivers.

call: all of the Network (NWK) layer processes involved in one NWK layer peer-to-peer association

NOTE: Call may sometimes be used to refer to processes of all layers, since lower layer processes are implicitly required.

cell: domain served by a single antenna(e) system (including a leaky feeder) of one Fixed Part (FP)

NOTE: A cell may include more than one source of radiated Radio Frequency (RF) energy (i.e. more than one radio end point).

centrex: implementation of a private telecommunication network exchange that is not located on the premises of the private network operator

NOTE: It may be co-located with, or physically a part of a public exchange.

cluster: logical grouping of one or more cells between which bearer handover is possible

NOTE 1: A Cluster Control Function (CCF) controls one cluster.

NOTE 2: Internal handover to a cell which is not part of the same cluster can only be done by connection handover.

Cordless Radio Fixed Part (CRFP): WRS that provides independent bearer control to a PT and FT for relayed connections

coverage area: area over which reliable communication can be established and maintained

double-simplex bearer: use of two simplex bearers operating in the same direction on two physical channels

NOTE 1: These pairs of channels always use the same RF carrier and always use evenly spaced slots (i.e. separated by 0,5 Time Division Multiple Access (TDMA) frame).

NOTE 2: A double-simplex bearer only exists as part of a multibearer MAC connection.

down-link: transmission in the direction FT to PT

duplex bearer: use of two simplex bearers operating in opposite directions on two physical channels

NOTE: These pairs of channels always use the same RF carrier and always use evenly spaced slots (i.e. separated by 0,5 TDMA frame).

End System (ES): logical grouping that contains application processes and supports telecommunication services

NOTE: From the OSI point of view, end systems are considered as sources and sinks of information.

external handover: process of switching a call in progress from one FP to another FP

Fixed Part (DECT Fixed Part) (FP): physical grouping that contains all of the elements in the DECT network between the local network and the DECT air interface

NOTE: A DECT FP contains the logical elements of at least one FT, plus additional implementation specific elements.

Fixed radio Termination (FT): logical group of functions that contains all of the DECT processes and procedures on the fixed side of the DECT air interface

NOTE: A FT only includes elements that are defined in EN 300 175, parts 1 [1] to 8 [8]. This includes radio transmission elements (layer 1) together with a selection of layer 2 and layer 3 elements.

full slot (slot): one 24th of a TDMA frame which is used to support one physical channel

guard space: nominal interval between the end of a radio transmission in a given slot, and the start of a radio transmission in the next successive slot

NOTE: This interval is included at the end of every slot, in order to prevent adjacent transmissions from overlapping even when they originate with slightly different timing references (e.g. from different radio end points).

half slot: one 48th of a TDMA frame which is used to support one physical channel

handover: process of switching a call in progress from one physical channel to another physical channel

NOTE 1: These processes can be internal (see internal handover) or external (see external handover).

NOTE 2: There are two physical forms of handover, intracell handover and inter-cell handover. Intracell handover is always internal, inter-cell handover can be internal or external.

incoming call: call received at a Portable Part (PP)

inter-cell handover: switching of a call in progress from one cell to another cell

internal handover: handover processes that are completely internal to one FT.

NOTE 1: Internal handover reconnects the call at the lower layers, while maintaining the call at the NWK layer.

NOTE 2: The lower layer reconnection can either be at the DLC layer (see connection handover) or at the MAC layer (see bearer handover).

interoperability: capability of FPs and PPs, that enable a PP to obtain access to teleservices in more than one location area and/or from more than one operator (more than one service provider)

InterWorking Unit (IWU): unit that is used to interconnect subnetworks

NOTE: The IWU will contain the InterWorking Functions (IWF) necessary to support the required subnetwork interworking.

intracell handover: switching of a call in progress from one physical channel of one cell to another physical channel of the same cell

multiframe: repeating sequence of 16 successive TDMA frames, that allows low rate or sporadic information to be multiplexed (e.g. basic system information or paging)

network (telecommunication network): the means of providing telecommunication services between a number of locations where the services are accessed via equipment attached to the network

operator (DECT operator): individual or entity who or which is responsible for operation of one or more DECT FPs

NOTE: The term does not imply any legal or regulatory conditions, nor does it imply any aspects of ownership.

outgoing call: call originating from a PP

paging: process of broadcasting a message from a DECT FP to one or more DECT PPs

NOTE: Different types of paging message are possible. For example, the {Request paging} message orders the recipient to respond with a call set-up attempt.

paging area: domain in which the PP will be paged as a part of incoming call establishment

NOTE: In general, the paging area will be equal to the Temporary Portable User Identity (TPUI) domain, since the TPUI is used for paging.

Portable Part (DECT Portable Part) (PP): physical grouping that contains all elements between the user and the DECT air interface.

NOTE 1: PP is a generic term that may describe one or several physical pieces.

NOTE 2: A DECT PP is logically divided into one PT plus one or more portable applications.

Portable radio Termination (PT): logical group of functions that contains all of the DECT processes and procedures on the portable side of the DECT air interface

NOTE: A PT only includes elements that are defined in EN 300 175, parts 1 [1] to 8 [8]. This includes radio transmission elements (layer 1) together with a selection of layer 2 and layer 3 elements.

private: attribute indicating that the application of the so qualified term, e.g. a network, an equipment, a service, is offered to, or is in the interest of, a determined set of users

NOTE: The term does not include any legal or regulatory aspects, nor does it indicate any aspects of ownership.

public: attribute indicating that the application of the so qualified term, e.g. a network, an equipment, a service, is offered to, or is in the interest of, the general public

NOTE: The term does not include any legal or regulatory aspects, nor does it indicate any aspects of ownership.

public access service: service that provides access to a public network for the general public

NOTE: The term does not imply any legal or regulatory aspect, nor does it imply any aspects of ownership.

radio channel: See RF channel.

Radio Fixed Part (RFP): one physical sub-group of a FP that contains all the REpeater Parts (REPs) (one or more) that are connected to a single system of antennas

REpeater Part (REP): WRS that relays information within the half frame time interval

RF carrier (carrier): centre frequency occupied by one DECT transmission

RF channel: nominal range of frequencies (RF spectrum) allocated to the DECT transmissions of a single RF carrier

service provider (telecommunications service provider): individual, or entity, who, or which, interfaces to the customer in providing telecommunications service

NOTE 1: The term does not imply any legal or regulatory conditions, nor does it indicate whether public service or private service is provided.

NOTE 2: The term service provider is also used with a different meaning in the ISO/OSI layered model.

simplex bearer: simplex bearer is the MAC layer service that is created using one physical channel

NOTE: See also duplex bearer and double simplex bearer.

subscriber (customer): natural person, or the juristic person who has subscribed to telecommunication services, and is, therefore, responsible for payment

TDMA frame: time-division multiplex of 10 ms duration containing 24 successive full slots

NOTE: A TDMA frame starts with the first bit period of full slot 0 and ends with the last bit period of full slot 23.

telecommunication: any transmission and/or emission and/or reception of signals representing signs, writing, images, and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems

teleservice: type of telecommunication service that provides the complete capability, including terminal equipment functions, for communication between users, according to protocols that are established by agreement

up link: transmission in the direction PT to FT

user (of a telecommunication network): person or machine delegated by a subscriber (by a customer) to use the services, and/or facilities, of a telecommunication network

Wireless Relay Station (WRS): physical grouping that combines elements of both PTs and FTs to relay information on a physical channel from one DECT termination to a physical channel to another DECT termination

NOTE: The DECT termination can be a PT or an FT or another WRS.

3.2 Abbreviations

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

C/I	Carrier to Interference ratio
CDCS	Continuous Dynamic Channel Selection
CRFP	Cordless Radio Fixed Part
CTA	Cordless Terminal Adaptor
DAS	DECT Access Site
DCS	Dynamic Channel Selection
DECT	Digital Enhanced Cordless Telecommunications
E	Erlangs
ES	End System
FCA	Fixed Channel Allocation
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FP	Fixed Part
GAP	Generic Access Profile
GFSK	Gaussian Frequency Shift Keying
GoS	Grade of Service
GPS	Global Positioning System
IS	Intermediate System
LOS	Line Of Sight
NLOS	Near Line Of Sight
O&M	Operations and Maintenance
PABX	Private Automatic Branch Exchange
PCS	Personal Communications Systems
PP	Portable Part
REP	REpeater Part
RFP	Radio Fixed Part
RLL	Radio in the Local Loop
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telephone System
WPBX	Wireless PABX
WRS	Wireless Relay Station

4 Introduction to DECT services and applications

DECT is a general radio access technology for wireless telecommunications. It is a high capacity, picocellular digital technology, for cell radii ranging from about 10 m to 5 km depending on application and environment. It provides telephony quality voice services, and a broad range of data services, including Integrated Services Digital Network (ISDN) and packet data over the Internet. It can be effectively implemented as a simple residential cordless telephone or as a system providing all telephone services in a city centre. Applications include Radio in the Local Loop, RLL, with ranges of several kilometres. Figure 1 gives a high level graphic overview of DECT services and applications. The basic 2 level modulation of DECT allows up to 552 kbit/s, and with implemented higher level modulation options, bitrates exceeding 4 Mbit/s are possible. Protected asymmetric links with bit rates beyond these bit rates are possible if needed, for example by having multiple radio circuits in a subscriber unit. Together with DECT/GSM/UMTS interworking evolving products will provide 3rd generation mobile radio services.

DECT is one of the IMT-2000 radio technologies, denoted "IMT-2000 FDMA/TDMA (DECT)". It is the only IMT-2000 family member optimized for uncoordinated use in unlicensed spectrum.

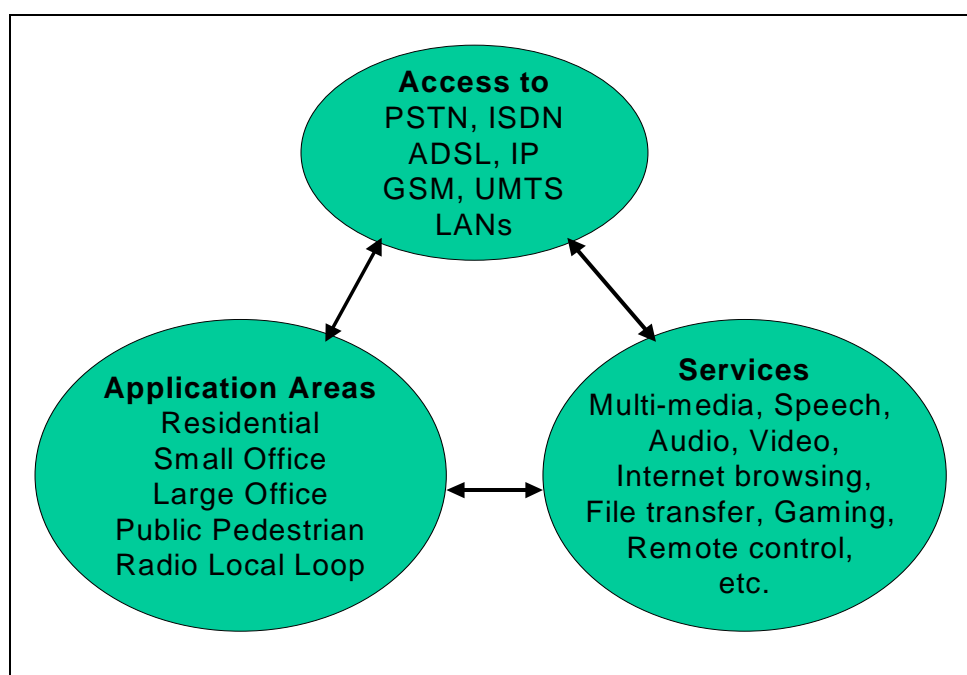


Figure 1: Graphic high level overview of DECT services and applications

The aim of the DECT standardization has been to develop a modern and complete standard within the area of cordless telecommunications.

The DECT standardization effort has received substantial legal and financial support by the European Commission (EC). The CEPT European wide allocation of the frequency band 1 880 MHz to 1 900 MHz has been reinforced by the Council Directive 91/287/EEC [24]. The Directive states that "DECT shall have priority and be protected in the designated band (1 880 MHz to 1 900 MHz)" and "recognizing that, subject to system development of DECT, additional frequency spectrum may be required".

NOTE: Most of the examples in the present document are based on the initial European allocation of 1 880 MHz to 1 900 MHz. However the results can be applied to a different spectrum allocation as well. The most common protected spectrum allocation is 1 880 MHz to 1 900 MHz, but outside Europe spectrum is also available in 1 900 MHz to 1 920 MHz and in 1 910 MHz to 1 930 MHz (several countries in Latin America).

For rapid introduction on European wide basis, harmonized standards [26], [27] according to the R&TTE Directive [23] have been developed for DECT. Conformance to the relevant harmonized standard gives access to a single European market. DECT is classified under the R&TTE Directive as class1 equipment. That means that it can be placed on the European market and be put into service without restrictions [33], [34], [35], [36].

The Council Recommendation 91/288/EEC [25] recommends that the DECT standard should meet user requirements for residential, business, public and RLL applications. The standard should also provide compatibility and multiple access rights to allow a single handset to access several types of systems and services, e.g. a residential system, a business system and one or more public systems. The public applications should be able to support full intersystem European roaming of DECT handsets. The DECT standard provides these features. Of special importance is the Generic Access Profile (GAP) which define common mobility and interoperability requirements for private and public DECT speech services. For a more comprehensive overview of the DECT standardization, see TR 101 178 [13].

The deregulation of fixed services will speed up fixed-mobile convergence in service offerings from operators. The different DECT interoperability profile standards are designed to facilitate provision of mixtures of fixed and mobile services through a single infrastructure. See clause A.5.2.3.1 and examples in ETR 308 [16].

The DECT instant or Continuous Dynamic Channel Selection (CDCS) provides effective coexistence of uncoordinated installations of private and public systems on the common designated DECT frequency band, and avoids any need for traditional frequency planning. The present document describes configurations for typical DECT applications and relevant mixes of these, including residential, office, public pedestrian and RLL applications, and the traffic capacity is analysed, mainly by advanced simulations. These results are used together with relevant deployment scenarios to estimate spectrum requirements for reliable services, specifically for a public multi-operator licensing regime. Recommendations are given on conflict solving rules that conserves the high spectrum efficiency gain of shared spectrum while maintaining control of the service quality in one's own system. These recommendations cover synchronization, directional gain antennas, traffic limits per DECT RFP, use of WRS, different rules for private and public operators, and procedures needed for timely local adjustments where and when the local traffic increases. Annex B contains results and recommendations on coexistence with other relevant radio technologies operating on the same or adjacent frequency band. Annex F gives information on RF modifications of DECT enabling applications on FDD (paired up-link/down-link) spectrum.

5 Principles for providing required traffic capacity and link quality on a common spectrum allocation

The key DECT features and principles that provide a required traffic capacity and link quality are described below. Annex E of the present document gives further information on fundamental aspects of DECT for providing a required traffic capacity and link quality.

NOTE: The earlier ETSI technical report, ETR 042 "Digital Enhanced 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" [21], is now declared "historical", has a good description of the fundamental aspects of DECT. The simulation results presented below in the present document, are more complete and more accurate than the results of ETR 042 [21], since more complete simulation tools have been available for the more recent simulations.

5.1 A new concept: the local load on the spectrum

The present document introduces a new concept, the "local load on the spectrum". This concept has been a very useful tool to estimate the local interference potential of different DECT system deployments. The local load on the spectrum from one system is defined as the number of *different* full-slot duplex (or equivalent) access channels that this system *on average* occupies in a specific *local* area. For simplicity we have expressed the local load on the spectrum in Erlangs (E). A local load of N E means that N different full-slot duplex access channels in average are occupied in a specific local area. The total local load shall be related to the local load that can be carried by the allocated spectrum. 10 carriers, as available within the frequency band 1 880 MHz to 1 900 MHz, provide 120 full-slot duplex access channels. This means that there are 120 local trunks available in the ether. The Erlang B traffic formula shows that 120 trunks can carry 100 E average traffic for about 0,5 % blocking probability. Therefore, for 10 DECT carriers, the total local load always has to be less than 100 E. We call these 100 E the local loadable traffic. A local area may be defined as the area in which a traffic channel typically can not be reused. It must be understood, that for example for above roof top RLL systems, sectorized antennas decrease the size of the above roof top local areas, and that large obstacles like houses create separate local areas below roof top level. This concept of "local load on the spectrum" is useful due to the instant Dynamic Channel Selection feature of DECT, which makes it feasible to use the average load measure, since those few connections that become interfered from traffic in adjacent local areas can find escapes to non-interfered channels.

Since the present document deals with spectrum requirements, the high capacity Carrier to Interference ratio (C/I) limited scenarios are relevant, but not the range limited or device trunk limited scenarios. Trunk limitation can however be a means to limit the local load on the spectrum from a single system. The present document does not contain any detailed range calculations for different propagation models. The ETR 139 [22] contains some scenarios and range calculations these are partly re-used below.

Many of the results in ETR 042 [21] (see above note in clause 5) are trunk limited by the maximum 12 access channels per single radio RFP. It is very important to differentiate between device (RFP) trunk limited capacity and capacity limitation due to the local load on the spectrum (C/I limitation). An example is a double-slot for fax transmission that may have a larger blocking probability than a full-slot due to trunk limitation in the RFP or WRS. However, fax services over double slots give lower average local load on the spectrum than fax services over a full-slot, since the double-slot transfers faxes (28,8 kbit/s) more that twice as fast as a full-slot (4,8 kbit/s to 9,6 kbit/s). See clause 7.

5.2 Dynamic Channel Selection (DCS)

A main characteristic of DECT is the instant DCS. DECT has 10 carriers available on a 20 MHz bandwidth (1 880 MHz to 1 900 MHz). For speech services each carrier is divided in frames of 24 full-slot time slots (12 in one direction and 12 in the other direction for symmetric duplex services). A DECT access channel is defined by a carrier frequency and a time slot. If for example 10 DECT carriers are allocated, as in the frequency band 1 880 MHz to 1 900 MHz, totally 120 full-slot duplex access channels will be provided. A more detailed description of the DECT instant DCS procedures is found in annex E of in ETR 042 [21] and in EN 300 175-3 [3], clause 11.4.

The terminals select the DECT traffic channel. Each terminal maintains an ordered list of the 6 to 10 least interfered channels. This list, and information on strongest detected base station (to which the PT has access rights), are regularly updated in order to detect changes in the local environment and to detect movement between basestations. The least interfered channel of its list is used for the first bearer set up attempt to the strongest accessible base station.

The big advantage of this kind of channel selection is that the set-up of a new channel takes into account the local interference situation in that instant: in this way the system is self-adapting. There is no need for a pre-planning of the system, but different applications and different operators can share dynamically the same spectrum resource without prior distribution of channels to specific services or base stations.

This will give to each user an additional capacity when compared with cellular systems using Fixed Channel Allocation (FCA) mechanisms. See clause 5.2.1 and annex D.

DECT systems provide micro-cellular coverage; a very good frequency reuse can be achieved because of the intrinsic high robustness of the DECT channel to interferers. For example, the separation of an obstacle such as a wall or a floor can be sufficient for the same channel to be reused on both sides of the obstacle at the same time.

Another very important factor for providing the high traffic capacity and the maintenance of a high quality radio link, is the quick DECT seamless inter-cell and intra-cell handover that does not depend on signalling on the old (interfered) access channel. More details on this can be found in annex E.

5.2.1 Spectrum efficiency of DECT compared with a system using FCA

The spectrum required for different DECT systems compared with the spectrum required by a comparable system using FCA has been analysed in annex D. A comparable technology is a duplex 32 kbit/s service transfer by Frequency Division Multiple Access (FDMA) or TDMA, Frequency Division Duplex (FDD) or Time Division Duplex (TDD), using radio receivers with limiter/discriminator detector or differential detector. The modulation type has only secondary influence. The spectrum efficiency of DECT compared with FCA is indicated by the factor K and has been calculated in annex D for a typical large office and for a suburban outdoor pedestrian application. The conclusions are as follows:

- for indoor multi-storey applications, DECT is typically 7 to 10 times more spectrum efficient than a comparable technology using FCA, $K = 7$ to 10 ;
- for outdoor pedestrian suburban applications, DECT is typically 3 to 7 times more spectrum efficient than a comparable technology using FCA, $K = 3$ to 7 .

DECT is therefore, basically very spectrum efficient compared to the technologies using FCA. This property is amplified the smaller the cells are and the more irregular the propagation patterns are.

Furthermore, with FCA, it is not possible to share spectrum between operators of different systems. Therefore DECT will, for example for office applications, gain another factor N in efficiency over FCA, where N is the number of operators of office systems not sharing spectrum for office applications. See clause 5.2.2.

5.2.2 Spectrum efficiency due to multi-operator multi-application coexistence on a common allocation

In clause 5.2.1 the spectrum efficiency for one operator having one system was analysed for DECT and for a comparable system having FCA. In this clause we will analyse the gain of having *several systems* and *operators sharing a common spectrum*, compared to allocating a *specific spectrum per system and/or operator*, but supposing that DECT is used in both cases. So we only deal with the gain of sharing spectrum, isolated from the gain of DCS verses FCA, which has been analysed above. DCS is of course a prerequisite for being able to share spectrum.

The spectrum efficiency gain due to multi-system multi-application coexistence on a common spectrum allocation depends on the deployment scenarios, the number of operators, and the level of co-ordination of installations between operators. See clauses 9 and 10.

5.2.2.1 Residential base station applications

Residential base station applications are either private residential systems operating on a common spectrum or residential base stations supplied by a public operator as an addition to a public mobile or cordless telephone subscription to offer low cost mobility service within the subscriber's residence.

Basic characteristics of these systems are that they mainly operate within the user premises, and that these premises may be close to each other, but do not normally overlap.

Another basic characteristic is that the geographical location of a system will vary when the owner changes residence.

It is obvious that offering substantive penetration of *reliable* residential services is very difficult without having some type of semi-fixed sharing or instantaneous dynamic sharing of control and traffic channels. With FCA theoretically one unique access channel per residential system in a country would be needed, which of course is totally impractical. To let the user manually select between a limited number of channels is more practical, and obviously works well for low cost analogue cordless telephones due to the relatively low traffic density. A divided spectrum between N public operators offering residential base stations, will require N times more spectrum than a shared spectrum as applied for DECT, since any of the operators may get all residential customers in an area or in a block of domestic flats. However, the office traffic (see below) is much higher than the residential traffic, and residential and office traffic are typically in different buildings. Therefore, only the spectrum requirements for offices need consideration in the context of residential and office systems of this clause.

Therefore, we can conclude that:

- general application of residential base stations requires some kind of semi-fixed sharing or instantaneous dynamic sharing of control and traffic channels. The traffic density is so low that the spectrum need for residential applications will be covered by the spectrum needs for office applications.

5.2.2.2 Office base station applications

Office base station applications are private systems operating on a common spectrum or base stations supplied by a public operator to offer telecommunications services for a company.

A basic characteristic for office systems, as for residential systems, is that they mainly operate within the user premises, and that these premises may be close to each other, but do not normally overlap. For office systems, at least for the larger ones, we may assume that they are more stationary than residential systems, and that a traditional FCA planning is possible. There is normally a natural isolation between office installations as indicated in figure 4. Therefore in a first approximation, the spectrum requirements are the same for covering one multi-story office, as for covering all offices in a city. Therefore, a divided spectrum between N public operators, providing office telecommunications services, will require N times more spectrum than a shared spectrum as applied for DECT.

Therefore, we can conclude:

- unlicensed office systems operating on a common spectrum requires dynamic sharing of control and traffic channels;
- a divided spectrum between N public operators offering office telecommunications applications, will require N times more spectrum than a shared spectrum as applied for DECT.

5.2.2.3 Public outdoor above roof top RLL systems

The public systems generally cover the same area and compete for the same subscribers, whereby the total (shared) local traffic will be limited by the total local number of potential subscribers.

A multi-operator scenario with RLL applications with above roof-top base station installations is a typical example.

If the spectrum is (equally) divided between N operators, the spectrum efficiency will decrease due to loss of trunking efficiency even with equal traffic share between the operators. In reality the local loss of spectrum utilization will further decrease, due to the uneven local market share of the different operators.

Results from simulations in clause A.3.2 show that the spectrum efficiency can be increased by up to 60 % by not dividing the 20 MHz of spectrum between 3 operators. This is for the case where all 3 systems have equal local load on the spectrum. In reality, for RLL, we can expect that there will be many local areas where one of the operators will be dominating. In such areas the spectrum efficiency can be up to 3,1 times (2 operators) and 4,8 times (3 operators) better compared to splitting the frequency band between operators. This assumes frame and slot synchronization between the systems and about *equal cell sizes* in the different systems. The gain will be considerably reduced for above roof-top cases if synchronization is not provided. In the case of the dominant operator having 90 % of the traffic and a second operator has 10 % and *nine times larger cell area than the dominant operator*, the spectrum efficiency gain over an equal split of the spectrum is reduced to 1,6 instead of 3,1 with equal cell sizes. In this case it was necessary to reduce the number of carriers of the dominant operator from 10 to 8, to provide escapes for the large cell connections. See clause 10.

Therefore, for case with three operators, by providing synchronized systems, sharing spectrum will, compared to equal division of the spectrum, provide up to between 3,1 and 4,8 times more efficient use of the spectrum. The 3,1 times relates to trunking efficiency gain when all operators have equal share of the traffic, and 4,8 times for the case when one of three operators has all the traffic in a local area. In the latter case only a fraction of the spectrum will be utilized if the spectrum has been divided between the operators.

Therefore we can conclude:

- there is a large preference for DECT outdoor public operators to share a common spectrum instead of dividing the spectrum. This requires synchronization within and between the systems. The simulations made, indicate a spectrum efficiency gain factor of at least 1,6 for above roof top installations. The more operators the larger the gain of sharing compared to dividing the spectrum;
- there must be a mechanism to ensure that a dominant operator does not limit the spectrum access of the other operators in case of hot spot local area with large differences of cell sizes. This is covered in clause 10.6.

5.2.2.4 Summary on multi-operator multi-application coexistence on a common allocation

Sharing by instant DCS and the use of a common spectrum are necessary requirements for unlicensed (no limit on number of system operators) operation of office and residential systems.

The total spectrum requirement for office and residential systems will not be larger than the requirement for a single operator having a dedicated spectrum. Therefore, dividing the spectrum between N operators would require N times more spectrum.

For outdoor public systems the gain of not dividing the spectrum is estimated to be at least a factor 1,6 for above roof top installations, provided the systems are synchronized. Since there is no natural isolation between above roof-top public systems, additional rules are required to guarantee proper fair coexistence between the operators in local hot spot areas. See clause 10.

There is a spectrum efficiency gain in also letting the different applications (fully or partly) share a common spectrum. The gain is typically 30 % to 50 %.

Table 1 illustrates the combined gain of letting different applications and operators coexist on a common spectrum allocation.

The spectrum estimates allow for a predicted increase in the use of data and multimedia services (see clause 6).

Table 1: Spectrum efficiency gain by sharing spectrum between applications and operators for speech and emerging data services

Scenario (speech and estimated emerging data services)	Office and Residential	Public pedestrian hot spots	RLL	Separate allocations for all applications	Total spectrum requirement (multi-application shared allocation)
N operators having own spectrum	N x 15 MHz	N x 7 MHz	N x 7 MHz	N x 29 MHz	N x 15 MHz
Operators share spectrum (see note)	20 MHz	8 MHz	20 MHz	48 MHz	28 MHz
NOTE 1: At least four RLL operators, a number of public street system operators and an unlimited number of private operators for office and residential DECT systems.					
NOTE 2: Public applications should use all the spectrum, private applications should only use the basic 20 MHz DECT spectrum.					

The basis for the figures in table 1 is the following:

- **Office and residential applications:** office traffic is much higher than residential traffic, and residential and office traffic is typically in different buildings. Therefore only the spectrum requirements for offices need consideration. From clause A.1.2 it can be seen that 7 carriers (about 15 MHz) will provide 5 to 6 E per base station. This capacity is as regarded feasible for one operator, including a predicted increase in the use of data and multi media applications. See clauses 6, 7 and 9. Clause A.2 also shows that if operators share a common spectrum in the same building, at most 20 % additional capacity is required than for a single operator. Therefore, including provision for some emerging increase of data and multi media applications 10 carriers (20 MHz) will be adequate for a shared spectrum.
- **Public pedestrian hot spots:** the hot spot public areas are railway stations, airports and sport arenas. We see from clause 6.3 that the public pedestrian hot spot application will have an office Private Automatic Branch Exchange (PABX) type infrastructure, but the traffic may be a quarter of high traffic office applications. On the other hand, the public pedestrian applications are in larger open spaces/halls than offices, which will require a somewhat higher reuse. Therefore 3 carriers (7 MHz) will be reasonable for a single operator and 4 carriers (8 MHz) reasonable for a shared spectrum, because possible different cell sizes may require some extra spectrum. More is not needed since they share the same potential number of customers. See clause 8.6.
- **RLL:** the above roof top RLL applications are simulated in clause A.3. Clause 8.7.1 concludes that, including the estimated increase of data traffic, 4 carriers (7 MHz) is needed for a single operator, and that shared spectrum for at least 4 operators will need 10 carriers (20 MHz).
- **Common allocation for different applications:** for a single operator we estimate instead of the total sum (15 + 7 + 7 = 29 MHz) that only 15 MHz are needed, if all applications share the same allocation. The reason is the limited interference between office, public pedestrian and RLL systems. See clause 8.10. Similarly when all operators share the same allocation, only 28 MHz are estimated to be needed instead of the sum 48 MHz.

5.2.2.4.1 Conclusion for the case with speech and estimated emerging data services

From the table above we see that the combination of sharing spectrum both between DECT applications and operators compared to splitting spectrum between DECT applications and operators, the spectrum efficiency gain is expressed by the factor $N \times 29 / 28$. Therefore, the gain is about a factor N, where N is the number of public operators. This is however not a realistic case, since if the spectrum is split between a few operators (typically 4), they will share applications on their part of the spectrum. Therefore, the gain will be $(N \times 15) / 28$ equal to a factor 2 for four public operators. Remember that an assumption here is that DCS is used both for the shared and split spectrum cases, and that, as shown in clause 5.2.2.3, the gain for sharing spectrum will further increase for cases with very uneven local operator market shares.

5.2.2.4.2 Conclusion for the case with mainly speech services

From the calculations above, we can also make adjustments for *excluding* the increase of data services and try to fit into the initial 1 880 MHz to 1 900 MHz DECT allocation by limiting the number of RLL operators to 3 (see table 2).

Table 2: Spectrum requirements for mainly speech services

Scenario (mainly speech services)	Office and Residential	Public pedestrian hot spots	RLL	Total spectrum requirement (allocation shared by all applications and operators)
Shared spectrum, 3 RLL operators	10 MHz	7 MHz	16 MHz	20 MHz

The office system will only need 5 carriers (10 MHz). There will be no significant change for the public pedestrian systems. For RLL systems, in total up to about 120 (see note) E can be shared by similar sized DECT access nodes with 8 carriers (16 MHz). Three operators will have up to 40 E per DECT access node each (per site with 6 sectors). See clause 6.4.1 and the summary in clause 8.10.

NOTE: Up-link power control implemented. See clause A.3.4.

5.3 Increase traffic by denser infrastructure, C/I limited capacity

The capacity of a system can be trunk limited or C/I limited. It is very important to distinguish between the two cases of traffic limitation, especially when analysing the simulation results. The trunk limitation is caused by limited provision of number of simultaneous connections via some interface, for example the line interface or the air interface of a base station.

The traffic capacity that depends on the amount of allocated spectrum is related to the C/I limited traffic only. The least interfered channel selection principle of DECT does not impose any additional upper limit that the interfering signal must not exceed on a monitored access channel candidate. Therefore, the capacity of DECT will be C/I limited also at very short cell radii. Therefore, as a first approximation, the capacities per base station shown in the simulations in annex A are constant, independent of the selected distance between the base stations (a practical lower limit may be 10 m to 15 m separation). Therefore, on a given spectrum, the capacity, E/km², will be proportional to the base station density.

This is an essential property to provide required traffic density:

- any operator can locally always increase his traffic density by increasing his base station density.

DECT provides easily engineered and economic installation of closer and closer cells, whereby the efficiency of the DCS algorithms, DCS, and the high radio link quality is maintained.

NOTE: This does not mean that large capacity systems can be implemented on a very limited amount of spectrum. There is a minimum amount of spectrum required to provide an economically defensible infrastructure. This is further explained in annex C.

5.4 Increasing link quality without increasing the load on the spectrum

Another basic property of DECT is, that if an operator increases his base station density without increasing his traffic density, he will increase his own radio link quality without causing more average interference to other systems in the same area.

For example, with twice as dense infrastructure, the average distance for the wanted signals will be 30 % shorter. Therefore, in an environment with d^{-4} propagation law, the wanted signals will in average be 6 dB stronger. The average interference (or load on the spectrum) has not increased, since the traffic per subscriber and the subscriber density has not been altered. Therefore, the own average C/I has increased by 6 dB. Since the local load on the spectrum has not increased, it is obvious that the interference to other systems has not increased as a result of the dense base station deployment.

This is an essential property to provide required radio link quality in an environment of local interference from other DECT systems:

- any operator can, without increasing the load on the spectrum, always increase his local radio link quality by locally increasing his base station density.

NOTE: This does not mean that required link quality can be maintained for systems implemented on a very limited amount of spectrum. There is a minimum amount of spectrum required to provide an economically defensible infrastructure. This is further explained in annex C. See also clause 5.5.

5.5 Means for adjusting to emerging growth of traffic (subscribers)

In this clause we discuss means for adjusting to emerging growth of the local traffic. Growth of local traffic may be caused by increased number of users in the system, by new services (for example Internet) or by geographical redistribution of users. It is therefore important that larger multi-cell DECT systems provide means for the operator to monitor the traffic generation, blocking probabilities and early call curtailments at each base station of the system. This enables him to timely adjust his infrastructure to cope with the emerging traffic growth. Increased local load on the spectrum may also be caused by another system increasing its traffic.

If the capacity is trunk limited, the solution is to provide more radio resources in the infrastructure, either by installing more base stations or by employing more radios in each base station (one special trunk limited case is a mixture of full-slot connections and double-slot connections, where the double-slot connections will have consistently higher blocking probability than the full-slot connections. It is therefore, in this case, important to provide enough radio resources to meet the Grade of Service (GoS) requirements not only for the full-slot connections but also the double-slot connections).

If the capacity is C/I limited, the means to **increase the own traffic** density is to make the cells smaller by employing more base stations (or more and/or narrower sectors in RLL installations). See clause 5.3. This is an obvious natural action within the operators own control. For indoor systems and outdoor below rooftop public pedestrian street systems, such traffic increases do normally not require any precautions regarding increased interference to other systems. But for above rooftop installations special precautions are required.

If the capacity is C/I limited and the own traffic is the same, but the load on the spectrum is increased due to **increase of traffic of other systems** in the same area, the means to maintain the own required link quality is again to make the cells smaller by employing more base station (or more and/or narrower sectors in RLL installations). See clause 5.4. The potential threat for this situation is mainly when the own installation is an above rooftop installation.

Summary:

- for public systems and larger office systems the operator should monitor the traffic and the blocking probabilities at each base station of the system. This enables him to timely adjust his infrastructure to cope with emerging local traffic growth;
- if the local traffic tends to become trunk limited, more radio resources shall be added;
- if the local traffic tends to become interference limited, the local cell density shall be increased (more and narrower cell sectors and/or more cell sites).

It is important that an operator is not forced to increase his cell density beyond economic limits because other operators in the same area increase their traffic. Procedures for economic handling of hot spots are described in clause 10.

6 DECT applications - scenarios

The traffic requirements are based on speech services and the traffic needs for emerging data services are estimated as a factor in proportion to the speech traffic.

A reasonable estimate is that the speech traffic per subscriber in offices and residents will be about the same as today and that the additional traffic per subscriber due to use of data services, within a few years, in average will be of the same magnitude as for speech. See also note 3. This expected doubling of the traffic will also apply to RLL applications, but not the public street public pedestrian application, see clause 7. Table 3 shows the estimated busy hour traffic per subscriber figures used for the different applications:

Table 3: Estimated average busy hour traffic per subscriber

Subscriber	Speech service only	Speech and emerging data services
Office worker	150 mE to 200 mE	300 mE to 400 mE
Resident	50 mE to 70 mE	100 mE to 140 mE
RLL	See office and resident	See office and resident
Public pedestrian	30 mE	30 mE

NOTE 1: The data traffic figures above should be understood as equivalent voice Erlang load. In DECT, 1 E corresponds to a pair of full slots, a duplex pair or a double simplex pair, using 2-level modulation.

NOTE 2: There are residents and offices with broadband data, where traffic is higher than indicated above. A single radio residential base station can support about 0,5 Mbps with 2-level modulation and 1 Mbps with 4-level modulation. This is suitable to support an ADSL residential access.

NOTE 3: In the estimates below, data traffic is estimated to increase to the same level as the speech traffic that today dominates in DECT applications. However, if higher level modulation options are implemented for DECT, the traffic figures below including data traffic, will correspond to data traffic having increased to twice the level of speech traffic. See clause 7.3.1.

6.1 Residential application

A typical scenario for residential DECT applications is a multi-storey apartment block or a single house maybe in a group of villas. The speech traffic generated by this application can be typically 50 mE to 70 mE per household, and the peak hour is usually in the evening. Base stations are normally unsynchronized.

In the most densely populated areas, blocks of flats with 4 to 8 storeys, there are 2 000 to 4 000 households per km². This corresponds to 100 E/km² to 280 E/km² or 25 E/km²- 35 E/km²/floor. In villa areas, there can be 500 to 1 000 households/km². This corresponds to up to 25 E/km² to 70 E/km². These traffic densities are estimated to be doubled within a few years due to emerging increase of data services.

The traffic densities of residential applications are typically 1/10 of the traffic densities in office environments and most residential systems are deployed in other houses than office systems. Therefore, spectrum requirements for the office applications will cover the deployment needs for residential systems as well.

6.2 Office/factory application

Metropolitan centres may have exceptional peaks of 40 000 employees/km², more typical about 10 000 employees/km². The Wireless PABX (WPBX) user has a speech traffic of 150 mE to 200 mE. This gives an average speech traffic of 1 500 E/km² to 2 000 E/km² for metropolitan centre areas. About 40 % of the PABX traffic is internal traffic. These traffic densities, and the other office traffic density figures below, are estimated to be doubled within a few years due to the increase of data services.

The WPBX applications can be classified in 3 types depending on traffic densities, described in subclauses 6.2.1 to 6.2.3.

6.2.1 Large companies in a business centre

Even if the average speech traffic load is typically about 2 000 E/km², the local traffic density within a building can be much larger. Some large multi-store offices may have a very high density of employees, one every 20 m². If all employees have a DECT handset, this would mean a total traffic of 7 500 E/km²/floor to 10 000 E/km²/floor with a traffic of 0,15 E to 0,2 E per user. This very high local traffic density must sometimes be offered. This will require 22 m to 26 m rectangular grid base station separation with 5 E average traffic per base station. More typical, 25 % of the employees will have wireless access. Then the traffic required would be 2 500 E/km²/floor with 45 m separation between 5 E base stations.

6.2.2 Large companies in industrial zones

The most common profile is a company with few buildings in a zone with outdoor parking and some surroundings green zones. A dense zone of this kind can be 4 50 m x 50 m buildings with 5 levels in a 300 m x 300 m area. Assuming the same penetration (25 %) of wireless handsets and 0,2 E average traffic per user and one user per 40 m², the total traffic generated in such a zone will be 140 E/km²/floor or 700 E/km².

6.2.3 Small/medium size companies

In this category, companies with an average of 20 telephone extensions are considered; In this case, it could be realistic to suppose that each handset is a DECT handset with a traffic of 0,2 E, that is a total traffic of 4 E per company. This traffic can be provided by a single DECT base station. Considering a maximum of 100 companies of this kind in a km², this will give 400 E/km².

6.3 Public pedestrian application

The public pedestrian DECT application gives local mobility to subscribers in an urban or suburban area. There are two main application areas, indoor public zones like shopping centres, railway stations or airports, and outdoor streets.

For each mobile user, the traffic is assumed to be 30 mE.

For indoor hot spots public zones like shopping centres, railway stations or airports, there may be crowds with 1 person per m². Assuming again the penetration of 5 %, the traffic generated is 1 500 E/km². In these cases, the maximum traffic density handled by DECT for a public application is very similar to the one in the wireless PBX environment, and the infrastructure will have similar base station density as for offices.

The street coverage is obtained by positioning the base stations (RFPs or WRSs) at lamp post height along the streets. If it is assumed that a maximum penetration for this application could be the 5 % of the population, this means, for a city of 2 millions of inhabitants over 100 km², a traffic of 30 E/km². People are however not always on the streets. An other way to estimate the traffic, is to use an estimated number of pedestrians in a metropolitan centre, 10 000/km². Having 5 % penetration leads to 15 E/km².

As a further example, the coverage of a typical (not hot spot) base station located in a street, as shown in figure 2, is analysed.

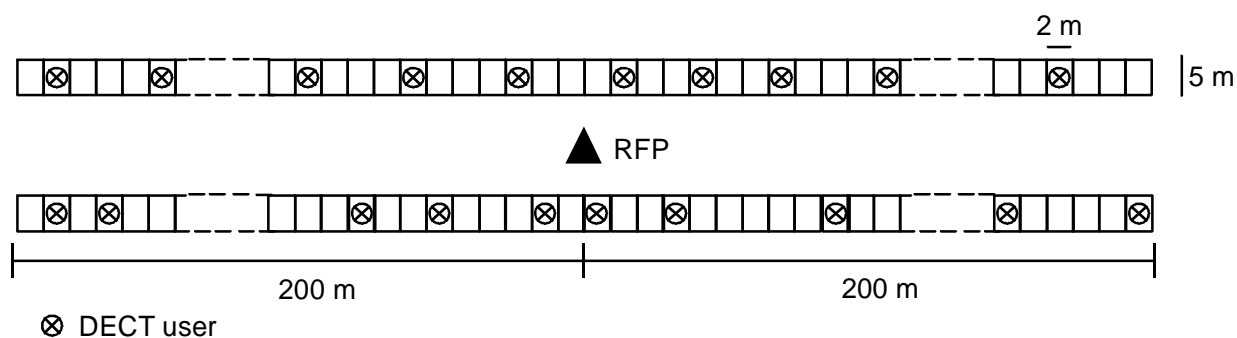


Figure 2: Example of a typical coverage of a street base station

A large main street with a 5 m wide pavement on each side is taken into account; the base station has a range of 200 m to each side, so that its total coverage is 4 000 m² of pavements. In the street there is one person every 10 m², in total 400 people, but only the 5 % of them use a DECT handset, that is 20 people.

If for each user the traffic is 30 mE, the average total traffic at the base station will be 0,6 E, corresponding to 30 E/km², if the streets are separated by 100 m (10 streets + 10 perpendicular streets per km², each street having 2,5 base stations) and if all streets had the same high pedestrian density.

Only a few main streets in a city centre have such high load, therefore for average load over a km² will be 10 E/km² to 15 E/km² as estimated above. The average traffic per base station will be less than 1 E .

6.4 RLL application

RLL is an important DECT application. Below are requirements related to one low density scenario and one high density scenario with (fixed) Cordless Terminal Adaptor (CTA) type of subscriber terminal only (not PPs).

It should be noted that effective radio ranges achieved in the DECT RLL application using CTAs, will be considerably greater than when DECT is used in the mobile mode. The signal path is more consistent, it is often line-of-sight and base stations and CTAs may use high gain antennas, whose directionality also reduces multipath signals.

6.4.1 Rural area - range requirements

A rural area may consist of a large area where few houses are spread out within a range of 10 km, eventually grouped in small clusters. The typical subscriber density within the area is 5 to 50 subscribers per km². Traffic per subscriber is 70 mE during busy hour. This means that the total traffic in the area is 0,35 to 3,5 E per km².

For this scenario, the capacity is not an issue, but the range is. Directive antennas and WRSs (see clause A.6), are often applied in order to increase the range of the links. The service and facilities description for DECT RLL, ETR 308 [16] requires a range up to 5 km for a DECT radio link. A line-of-sight (LOS) range up to 5 km is feasible with 12 dBi antennas at each end and reasonable antenna heights. Therefore, adding a WRS will provide a 10 km range.

A DECT radio access site will typically be supplied from the local exchange, LE, with one or two 2 Mbit links (primary rate access). These will provide 30 or 60 trunks, which with 0,5 % GoS will support 19 E (271 subscribers) or 45 E (643 subscribers) average traffic per site. Table 4 shows how low subscriber densities are supported as a function of the cell range, supposing 271, 643 or 2 000 subscribers per radio site. (2 000 subscribers require six 2 Mbps lines or 180 trunks). Hexagon cells are used. The range R km is equal to the length of the hexagon side, and the cell area is $2,6 \times R^2$ km². It could be estimated that with 270 subscribers being served per site, the CTA related costs still dominate over the radio site related costs. If so, requiring more than 270 subscribers to be served per site, would not further dramatically reduce deployment costs. We could however expect that with the popularity of Internet, the 70 mE/subscriber may be substantially increased whereby about 300 subscribers could correspond to about 40 E per DAS. Thus about 40 E per DAS could be a required minimum available capacity per operator for economical deployment.

Table 4: Economic support of low subscriber density applications as a function of range

Range R km. Hexagon cell	1 km	2 km	3 km	4 km	5 km	10 km
Site separation	1,7 km	3,5 km	5,2 km	6,9 km	8,7 km	17 km
Subscriber density with 19 E or 271 subscribers per radio site	104 subscr./km ² (7.3 E/km ²)	26 subscr./km ²	12 subscr./km ²	6,5 subscr./km ²	4 subscr./km ² (0,3 E/km ²)	1 subscr./km ²
Subscriber density with 45 E or 643 subscribers per radio site	247 subscr./km ² (17 E/km ²)	62 subscr./km ²	27 subscr./km ²	15 subscr./km ²	10 subscr./km ²	2,5 subscr./km ²
Subscriber density with 140 E or 2 000 subscribers per radio site	769 subscr./km ² (54 E/km ²)	192 subscr./km ²	85 subscr./km ²	48 subscr./km ²	31 subscr./km ²	8 subscr./km ²

Table 4 shows that DECT with suitable antenna site arrangements will support economic deployment of RLL systems with 4 to 250 subscribers per km² without need to stretch the 5 km range requirement.

6.4.1.1 Special provisions for single link ranges beyond 5 km

In EN 300 175, parts 1 [1] to 8 [8], advance timing of the CTAs has been introduced, which allows up to 17 km range with maintained TDD guard space. This feature was not available when ETR 139 [22] was published. LOS ranges of 10 km to 15 km are therefore, in principal possible to a CTA or to a pool of WRSs in a remote village. This however requires higher antenna gain (larger antennas) and higher antenna installation.

The higher antenna gains, narrows the transmission beam and also the reception angle, which reduces time dispersion and required fading margins. For example, traditional 2 GHz 2 Mbit/s radio links without equalizers provide reliable services over 15 km to 25 km typically using 30 dBi high gain elevated antennas. The LOS propagation model of ETR 139 [22] requires for a 15 km single link range, antennas at 15 m height with 17 dBi gain at one end of the link and 14 dBi gain at the other end. A 12 dBi patch antenna has an area of about 600 cm² at 1,9 GHz. A 17 dBi patch antenna has an area of about 2 000 cm², etc.

6.4.2 Urban area - traffic capacity requirements mainly for speech services

Typical urban scenarios are the extension of the fixed network to a new housing area near an existing town, a new town or a new operator in a urban area.

The connection density ranges from 500 (villa area) to 2 000 (blocks of flats, 2 to 4 stories) connections per km²; each connection has a traffic of 70 mE, which means a total traffic in the area of 35 E/km² to 140 E/km².

The highest residential traffic is 140 E/km² to 280 E/km² for blocks of flats with 4 to 8 stories. This is for a built up city, but not typical for new housing areas.

A business centre metropolitan area may have about 10 000 employees per km². The traffic density is 1 500 E/km² with 150 mE average traffic per employee. Since about 40 % of all traffic is internal in a PABX, the required traffic density is about 1 000 E/km².

If second operators in an area deploying RLL will get 10 % of the total business traffic in a metropolitan area, 100 E/km² must be supported by DECT RLL.

We may conclude that a traffic capacity of 100 E/km² to 150 E/km² is required to support speech RLL services.

These traffic densities are estimated to be doubled within a few years to 200 E/km² to 300 E/km² due to emerging increase of data services.

In developing countries may be up to 30 % of the metropolitan traffic (mainly speech) will need to be served by RLL. This corresponds to 300 E/km².

6.5 Summary of traffic requirements

Table 5 gives a summary of the traffic density requirements. These requirements have been related to typical application examples indicating the average traffic required per radio site and the required radio site density (site separation).

Table 5: Summary of traffic requirements for mainly speech services

Service type (mainly speech)	E/site, site separation	Traffic load
Residential	< 1 E	25 E/km ² to 280 E/km ²
Office	< 5 E, 25 m (rectangular grid)	Maximum 10 000 E/km ² /floor
Public pedestrian hot spots	2,5 E, 40 m (rectangular grid)	1 500 E/km ² at 5 % penetration
Public pedestrian street	< 1 E, < 400 m (along a street)	15 E/km ² at 5 % penetration
RLL	40 E, 8,7 km (hexagon grid) 40 E, 430 m (hexagon grid) 140 E, 1,7 km (hexagon grid) 140 E, 400 m (hexagon grid)	0,6 E/km ² 250 E/km ² 54 E/km ² Maximum 1 000 E/km ²

7 ISDN, data and multimedia applications

The DECT standard (EN 300 175, parts 1 [1] to 8 [8]) provides a comprehensive set of interworking profiles for ISDN, data and multimedia applications. There is a rapid world-wide growth of Internet residential and office subscriptions. Therefore, it is foreseen that the present dominance of DECT speech services will within a few years shift so that data services will be as important as speech services. A reasonable estimate is that the speech traffic per subscriber will be about the same as today and that the additional traffic per subscriber due to use of data services in average will be of the same magnitude as for speech.

The discussions below lead to the assumption that the increased use of data services in offices and homes will increase the load on the DECT spectrum by a factor of two compared with speech only services.

7.1 ISDN services

So far two profiles have been defined for DECT/ISDN interworking, the ISDN Intermediate System (IS) and the ISDN End System (ES). The IS standard provides the user with the ISDN B and D channels whereas the ES standard only gives access to ISDN services such as the 64 kbit/s unrestricted bearer service and the ISDN supplementary services. The spectrum requirements for the ISDN interworking profiles can be found in the tables below.

Table 6: Intermediate System (IS) spectrum requirements

DECT ISDN (IS)	Total bearer requirements
D	1 full slot
1B (32 kbit/s)	1 full slot
1B (64 kbit/s)	1 double slot

NOTE: The standard allows for combinations of multiple B-channels and D-channels. Furthermore, after call establishment both the B-channel and D-channel can be combined in one slot (e.g. after establishment only one full slot is required to carry a 32 kbit/s B-channel and the corresponding D-channel).

Table 7: End System (ES) spectrum requirements

DECT ISDN (ES)	Total bearer requirements
Speech	1 full slot B-channel is transcoded to ADPCM with 32 kbit/s
3,1 kHz audio	1 full slot B-channel is transcoded to ADPCM with 32 kbit/s
Unrestricted digital information	1 double slot

A double slot occupies the position of two adjacent full slots. It provides an unprotected data rate of 80 kbit/s or in the protected mode 64 kbit/s.

ISDN as such does not cause increased load on the DECT spectrum, because an ISDN speech call does not require more spectrum than a "POTS" call. (Both use 32 kbit/s ADPCM speech over the air interface, and the ISDN D-channel information is transferred to the A-field of the full slot duplex bearer during the call).

We may assume that people will not speak more in the telephone because they have ISDN, but they will have access to data services over a second line. It is the increased use of data services that will increase the load on the spectrum.

ISDN B-channel data services will use a double slot duplex bearer. ISDN D-channel packet data will use a full slot duplex bearer (as the normal speech service). A double slot compared with a full slot will momentarily use twice as much spectrum, but because of the higher data rate, the time to transfer the data will typically be half. Therefore, using double slots for data transfer, will in many cases provide equal or less load on the spectrum than using full slots for the data transfer.

The trunk limited blocking probability in a base station will however be larger for a circuit switched double slot than for a full slot. Therefore for system planning more radio resources are needed to avoid trunk limited blocking when double slots are being used. But this is a separate issue than load on the spectrum.

NOTE: The blocking probability of a double slot (occupying the positions of two adjacent full slots) is higher than the blocking probability of two non-adjacent full slots for a multi bearer connection. Due to this, recommendations for packing of full and double slots reduce double slot blocking probability. Such rules have been included in the DECT base standards but their implementation is not mandatory.

7.2 Data services in general

Besides ISDN, data services may also be provided via modems over analogue connections using full slot and double slot (transparent 64 kbit/s) bearers.

Data over the DECT air interface may also be transferred using some of the specified family of packet data profiles, which are far more spectrum efficient. The data profiles offer a variety of services varying from low speed messaging to high speed frame relay. The user bitrates available are up to 552 kbit/s using 2-level modulation, and up to more than 4 Mbit/s using higher level modulation options. Two classes of mobility support have been defined for the data profiles. The first class, Class 1, concerns local applications where the terminals are pre-registered off-air with one or more specific FPs. The second mobility class, Class 2, cares for roaming applications. All data profiles make use of the full slot for the data transfer though the number of slots that are used vary, see table below for the 2-level option.

Table 8: Required number of bearers for the DECT data profiles

DECT data profile	Maximum sustainable throughput using 2-level modulation	Bearer requirements
DPRS	24 kbit/s per bearer	1 full slot per bearer
D (transparent and isochronous connections)	32 kbit/s	1 full slot
E (low rate messaging services)	1,38 kbit/s (A-field, Cs channel) 17,6 kbit/s (CF channel)	1 full slot

The data profiles use single and multi bearer connections in protected and unprotected mode based on full slots. Both symmetric and asymmetric connections are possible.

A reasonable estimate is that the speech traffic per subscriber will be about the same as today and that the additional traffic per subscriber due to use of data services, within a few years, in average will be of the same magnitude as for speech. Therefore, we get the following estimated busy hour traffic per subscriber.

Table 9: Estimated busy hour traffic per subscriber

Subscriber	Speech service only	Speech and emerging data services
Office	150 mE to 200 mE	300 mE to 400 mE
Residential	50 mE to 70 mE	100 mE to 140 mE
Public pedestrian	30 mE	30 mE

This expected doubling of the traffic also affects RLL applications, but hardly the public street public pedestrian application.

NOTE: In the estimates above, data traffic is estimated to increase to the same level as the speech traffic that today dominates in DECT applications. However, if higher level modulation options are implemented for DECT, the traffic figures including data traffic, will correspond to data traffic having increased to twice the level of speech traffic. See clause 7.3.1.

7.3 The DECT 4-level, 8-level, 16-level, 64-level modulation option

The latest version of the DECT base standard includes backwards compatible 4-level, 8-level, 16-level and 64-level modulation options as shown in table 10a.

Table 10a: Available physical layer bit rates

Levels	Narrow bandwidth
2	1,152 Mbit/s
4	2,304 Mbit/s
8	3,456 Mbit/s
16	4,608 Mbit/s
64	6,912 Mbit/s

The 4-level modulation is $\pi/4$ -DQPSK, the 8-level modulation $\pi/8$ -D8PSK, the 16-level modulation 16-QAM and the 64-level modulation 64-QAM. The shaping filter shall be root-raised cosine with $T_s = 1/1\ 152\ 000$ s (T_s = symbol duration) and roll-off (α) = 0,5 for all types of modulation. $\pi/2$ -DPSK may be generally used as 2-level modulation instead of the GFSK modulation.

This will increase the bit rate of single radio DECT equipment by a factor 2, 3, 4 or 6 with retained transmitter bandwidth, carrier spacing and slot structure.

Asymmetric data services with user data rates exceeding 4 Mbps are provided by a single DECT radio.

A typical sensitivity of -95 dBm is expected for the 4-level modulation if coherent demodulation is implemented, and about -93 dBm with a differential digital detector. This sensitivity is similar to typical sensitivity for 2-level modulation.

7.3.1 Higher Level Modulation impact on traffic capacity

Due to the retained transmitter bandwidth, carrier spacing and slot structure when higher level modulation is used, the Dynamic Channel Selection mechanism is fully functional in environments with mixed modulation techniques and mixed voice and data transmissions.

We could expect that the voice service remains with 2-level modulation since normally no shorter slots than full slots are used. Therefore, the voice traffic capacity is not expected to be increased by introducing higher level modulations.

But data traffic capacity could increase by typically a factor 2 in average. The main gain is in implementing the 4-level modulation, giving 2 times larger data rate. Since the sensitivity for 2-level and 4-level DECT receiver detectors in practice will be rather equal, we could expect doubling of the data capacity in single cell or other typical range or trunk (DECT slots) limited installations, by just implementing 4-level modulation. In capacity limited environments, the gain would be lower, because C/I for 4-level modulation will be lower than for 2-level modulation.

8 Multi-system and multi-service DECT applications coexistence analysis for speech services and emerging increase of data related services

In this clause an analysis of the coexistence of the different applications described above is made. The analysis supposes a basic 20 MHz spectrum allocation and speech services and emerging increase of data related services with subscriber traffic as indicated in clause 7.2 table 9. The conclusions are based on calculations and a large number of simulations, which are described in more details in annex A.

8.1 Interference between residential systems

The critical scenarios in which interference between residential systems could reduce the system capacity, may be when users are close to each other like in adjacent flats or villas (see figure 3). However, interference between residential systems is not critical, since the local load from residential users on the spectrum is very low, < 1 E/base station, much lower than from offices.

Application of large numbers non-synchronized mutually interfering residential systems can be up to 3 times more spectrum efficient than if they were synchronized. This is because the very short dummy bearer (down link only), if synchronized, only has 12 different time domain positions, but 60 to 120 non-overlapping positions if unsynchronized. (A dummy bearer only consists of the S + A fields, 96 bits, as described in clause E.2.1. This gives up to $11\ 520 / 96 = 120$ positions during a 10 ms frame. In the calculations below this figure is reduced by a factor of 2 due to unsynchronized packing.) Since the residential speech traffic is only 0,07 E, most of the time only the short dummy bearer is transmitted. Therefore, since the load on the spectrum from a synchronous system is 1 E, the load from an asynchronous system is $12 / 60 = 0,2$ E from the dummy bearer plus 0,14 E (2 times 0,07 E) from the speech traffic, which equals 0,34 E. Including foreseen emerging increase of data services 2 times 0,07 E has to be added, which gives 0,48 E average load on the spectrum per household.

Residential systems shall not be required to be synchronized. Residential systems provide a very limited load on the spectrum.

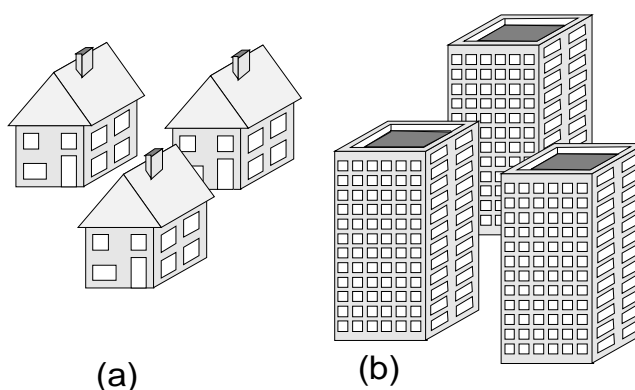


Figure 3: Coexistence between residential systems

8.2 Interference between residential systems and other applications

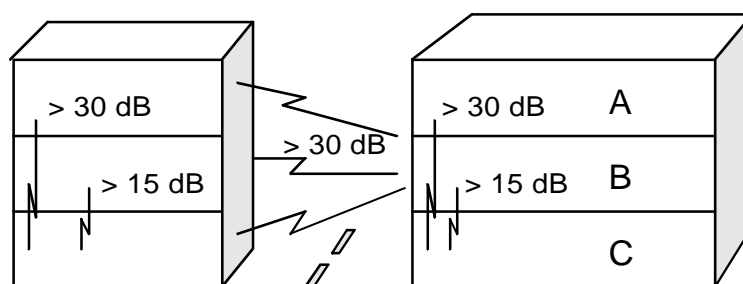
The coexistence between a residential system and other DECT applications such as Office, public pedestrian and RLL is not critical. The low traffic of the residential system is not an interference risk, and the residential system will have no difficulty to find a good single channel for its connection. This conclusion is related to the conclusions below on interference from and between office systems.

8.3 Interference between office systems

As described above the business application is the one with the largest traffic densities, up to 10 000 E/km²/floor for speech services. Simulations have been carried out in a 3 storey building with varying total number of carriers available. They show that with half of the 20 MHz spectrum (5 carriers) the capacity of a stand alone system with synchronized RFPs still will be about 7 000 E/km²/floor with 25 m base station separation. This corresponds to 11 000 E/km²/floor with 20 m separation (see clause A.1.2). This shows that there is local capacity left for other systems. We see from clause 6.2.1 that a more typical local peak speech traffic density is 2 500 E/km²/floor.

When different unsynchronized office systems are close to each other (adjacent floors) in the same building, the potential interference between systems could increase the local load on the spectrum by about 20 % (see clause A.1.2).

Therefore, in spite of the high local traffic, the natural average isolation between office systems provides effective coexistence of different office systems (see figure 4).



NOTE: In the figure typical loss values for external walls and floors are indicated.

Figure 4: Coexistence between office systems

Since typical loss for external walls is 15 dB, interference between systems in different buildings are very limited, with some exceptions as a base station positioned along the window in front of the street. Anyhow, the average mutual load on the spectrum between systems in different buildings is very low.

Synchronization of RFPs within a DECT system (FP) is essential for all high capacity multi-cell systems. In-system synchronization is normal practice for multi-cell office systems, where the RFPs obtain the synchronization over the connection wires to the radio exchange (RFP controller). Synchronization is regarded essential by manufacturers both to provide efficient handover and to meet internal system capacity requirements. Whether or not two systems within a building are synchronized to each other does not influence the interference to systems outside the building. Therefore inter-system synchronization within a building can be left to be agreed between the system owners.

From the above information, we can conclude that 10 MHz is required for general speech only office applications, and that 20 MHz of spectrum will be adequate also for adding emerging increase of data services.

8.4 Interference between office and public pedestrian street systems

Interference between office systems and a public pedestrian street system is studied for a worst case scenario shown in figure 5.

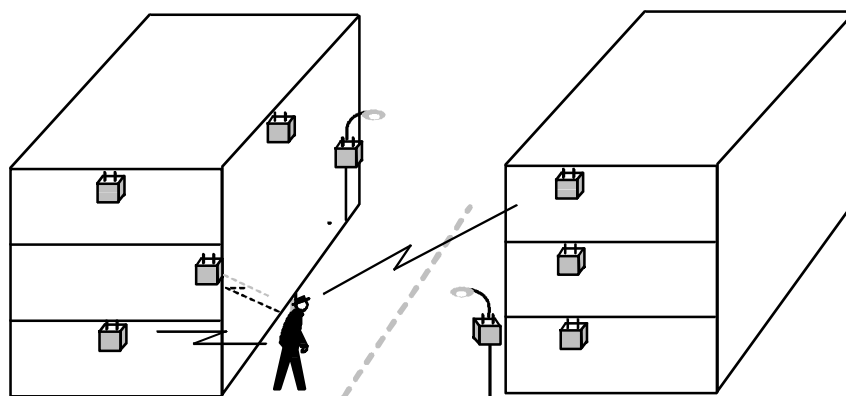


Figure 5: Coexistence between office-public pedestrian applications

It is very difficult to make accurate simulations of the interference from multi-storey indoor installations to a specific point at street level. It is however easy to estimate an upper bound of the local load on the spectrum, if we suppose that none of the channels used in the surrounding offices can be reused on the street.

For instance, the total maximum traffic from 3 floors of a 50 m long and 10m wide building on each side of the street, is 30 E. Assuming 1 terminal per 20 m², the total number of terminals is 150:

$$\frac{10 \times 50 \text{m}}{20 \text{m}^2} \times 3 \text{ floors} \times 2 \text{ buildings}$$

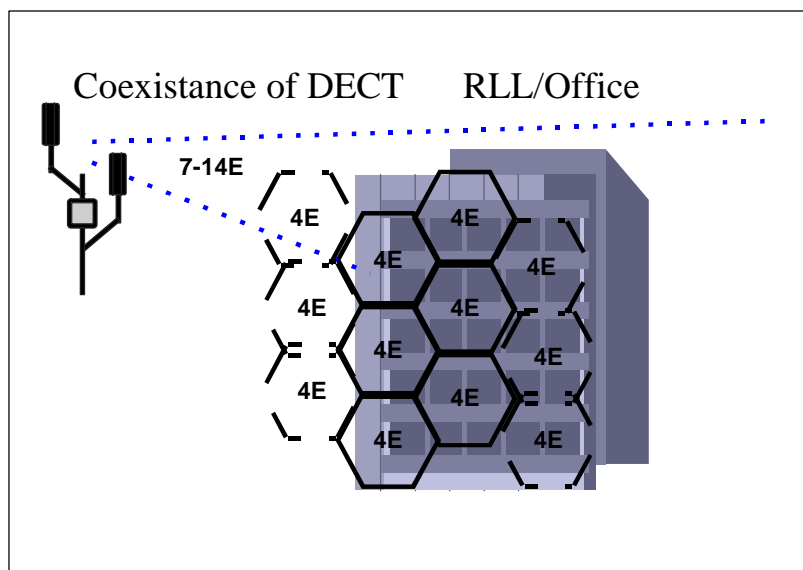
150 multiplied by the traffic of each user, 0,2 E, becomes 30 E. Therefore, the maximum load on the street is about 30 E. Some of the 30 simultaneous connections will reuse the same channels, and some extra load is caused due to unsynchronized systems. The total local load on the spectrum at street level will be less than about 40 E. Since we have concluded that the loadable local traffic is 100 E, 60 E is left for the public pedestrian system (see clause 5.1). With the estimated emerging data traffic (another 40 E) added, still 20 E are left. Therefore, also for this simplified upper bound estimation, there is enough spectrum left for a street public pedestrian application, which typically only requires 1 E per base station. In reality only channels from transmissions close to the windows may not be reusable at all at the street and it is also rather unlikely that there is a DECT office subscriber every 20 m² on all floors on both sides of a street.

Nor will the opposite case, potential interference from a public pedestrian street system to offices, cause any problems of coexistence, since the public pedestrian system typically loads the spectrum with less than 1 E per 200 m length of street.

8.5 Interference between office and RLL systems

Regarding interference from an RLL system to an office system, a critical situation could be interference from an elevated high traffic RLL access node using high gain directional antennas. In clause 8.7 and clause A.3 are described a realistic high traffic node deployment with 42 E average traffic per node. This traffic is however divided into six sectors with 7 E each. Therefore, the local load on the spectrum in any direction from this node will be limited to 14 E (maximum two sectors are overlapping in any direction). Therefore, the local load from a high traffic public node to private systems close to this node is less than 14 E. Therefore, 100 E - 14 E = 86 E is always locally accessible, which still is adequate for the private users. Note also that it is the outer cells (close to windows) in office applications that might be exposed to some interference from a public outdoor system, but that these outer cells suffer much less interference from the own close by cells than the centre office cells. Furthermore, antennas for the RLL links are usually above the roof top and this inserts a substantial average physical separation to indoor office systems.

Regarding interference from an office system to an RLL subscriber, the same conclusion as for the interference from offices to a public pedestrian subscriber can be applied; at least 20 E to 60 E will be locally available. See clause 8.4. Furthermore, antennas for the RLL links are usually above the roof top and this inserts a substantial average physical separation to indoor office systems, as exemplified in figure 6.



NOTE: RLL interferes less than another row of office cells does. RLL site with 6 sector antennae arrangement with totally 42 E as exaple.

Figure 6: DECT RLL

Interference between RLL and office systems will in average not be critical.

8.6 Interference between public pedestrian systems

Installations in hot spot areas like railway stations, airports and sport arenas with up to 1 500 E/km² will be very similar to larger office and factory installations. The difference is that a number of systems will cover the same area, without any natural floor or wall isolation as between office systems. Therefore, the public systems should be synchronized, not to cause unnecessary capacity loss. Else up to 50 % of the capacity could be wasted, and this waste would need to be compensated by installing twice as many base stations for high traffic loads.

The high traffic densities may only be a quarter of the traffic density for high traffic office applications. On the other hand, the public pedestrian multi-cell applications are in larger open spaces/halls than normal for office applications, which will require a somewhat less efficient reuse of access channels. Therefore, compared to speech office applications, see table A.1, where 2 carriers supports 2 100 E/km², here 3 carriers (7 MHz) will be reasonable for a single operator. 4 carriers (8 MHz) is reasonable for a shared spectrum between a number of operators, because possible different cell sizes may require some extra spectrum. More is not needed since they share the same potential number of customers.

For street public pedestrian the load is typically 1 E per base station, which will not provide any mutual interference. The spectrum requirement is a fraction of that required for the hot spots.

8.7 Interference between RLL systems

Various rooftop RLL system scenarios have been simulated, where each RLL base station site, DECT Access Site (DAS) support 6 sectorized cells. Also the CTAs use sectorized gain antennas (see clause A.3). The separation between DASs is 1,7 km, The major conclusions of the specific simulations are:

- a) Maximum sharable local capacity with 10 carriers is estimated to be at least 300 E for 12 sector DAN clusters and about 160 E to 200 E for 6 sector DAS clusters. This is achievable with use of a rather simple (slow and not very accurate) up-link closed loop power control.
- b) For two or more systems in the same geographical area, the total capacity/site of all operators becomes close to the above maximum sharable local capacity, if the operators have similar cell sizes.
- c) Each E corresponds to one speech connection or a data connection with about 32 kbps with 2-level modulation and about 64 kbps with higher level modulation (at least 4-level modulation). 300 E corresponds to 19 Mbps data throughput per DAN with 4-level modulation!
- d) Having 1 RFP per sector provides a trunk limited average capacity of about 5 E/RFP to 7 E/RFP, and having 2 or 3 RFPs per sector provides roughly about 8 E/RFP to 9 E/RFP of average capacity.
- e) Synchronization between DASs and between above rooftop RLL systems has a very large positive impact on the system capacity, and should be mandated for nodes with high traffic.
- f) Employing antenna gain generally increases the wanted signal and decreases interference in systems with instant DCS. Use of directional gain antenna versus omni-directional antennas at the DAS has a large positive impact on the system capacity.
- g) When several operators are active in one geographical area, sharing the spectrum will lead to a higher capacity than dividing the spectrum between the operators. Up to 3,1 to 4,8 times increase in spectrum efficiency has been found. This is when the cell sizes of the different systems do not differ too much. The lower figure is when the operators have equal local market share, and the higher figure when one operator has a local dominance.
- h) There needs to be a mechanism to ensure that a dominant operator does not limit the spectrum access of the other operators in case of a hot spot local area with large differences of cell sizes. For example, in the case of the dominant operator having 90 % of the traffic and a second operator has 10 % and *nine times larger cell area than the dominant operator*, the spectrum efficiency gain over an equal split of the spectrum is reduced to 1,6 instead of 3,1 with equal cell sizes. In this case it was necessary to reduce the number of carriers of the dominant operator from 10 to 8, to provide escapes for the large cell connections.
- i) The distance between the DASs of the above rooftop RLL system have a limited effect on the traffic capacity per DAS, as long as the different systems in a local area have similar cell sizes.

8.7.1 Spectrum requirements for RLL applications

From clause 6.4.1 we conclude that minimum 40 E per DAS should be available for each operator to build mutual price competitive networks.

We see from clause 8.7 that 160 E to 200 E per DAS could be provided with 10 carriers. Not to be too optimistic, we suppose that 140 E is the sharable capacity. Therefore, we conclude that 4 carriers (7 MHz) is required for one RLL operator including support of estimated emerging increased data traffic (40 E to 45 E per DAS).

Since the maximum sharable traffic, for the specific models used, is 140 E with 10 carriers (20 MHz), if cell sizes of the systems have similar sizes, we may conclude that probably up to say 4 operators may coexist well on 20 MHz of common spectrum. The reason that several operators will be able to share the spectrum, is that the total number of potential customers is limited. Therefore, 4 times more spectrum will not be needed when 4 instead of one operator compete for the same customers. On the other hand we should avoid too hard restriction on co-ordinating cell sizes between operators. Therefore a total of 20 MHz would be realistic including the increase of data traffic and about 4 operators. This also leaves room for the public pedestrian application described in the next paragraph using a DAS infrastructure to feed street mounted WRSs. It is essential that conflict solving rules for emerging local hot spots, like those suggested in clause 10 are imposed as part of the licensing agreement. It is important to see that when locally applying these conflict solving rules, the capacity for a split spectrum case is the bottom level.

It is interesting to note that a public pedestrian street system, employed as a DAS system linked to WRSs (CRFPs) having below roof top local links, has the same interference to RLL systems as if it was an ordinary DAS RLL system. It is interesting that this concept alternatively may be interpreted as an RLL system with local mobility (see clause 8.8.1).

8.8 Interference between public pedestrian systems and RLL systems

The largest potential interference between RLL systems and other DECT applications is between above rooftop RLL systems and a public below roof top public pedestrian street system, since the public pedestrian system has outdoor base stations (see figure 7). Such an interference scenario has been simulated, where each RLL base station site, DAS, supports 6 sectorized cells (see clause A.5). The separation between DASs is 1,7 km, and between public pedestrian base stations 300 m, both systems are installed in hexagon grid patterns. There are 33 public pedestrian base stations within the area of one DAS.

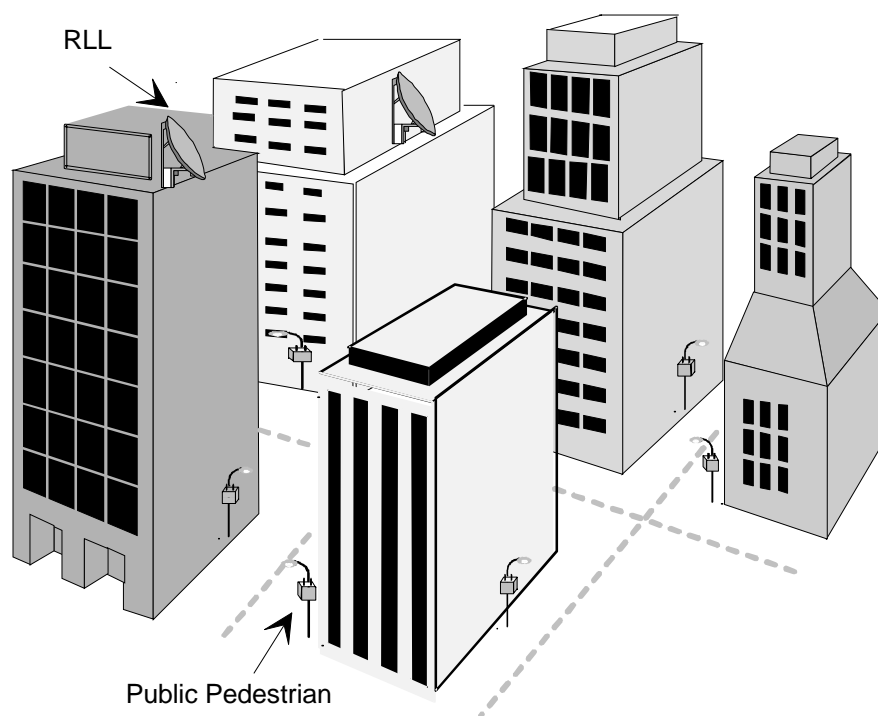


Figure 7: Coexistence between public pedestrian - RLL

The RLL traffic, up to 44 E per DAS node, did not affect the public pedestrian traffic at 3 E per public pedestrian RFP. Since public pedestrian street base stations typically have 1 E average traffic per cell, we conclude that for this scenario, the interference to the public pedestrian system is not critical.

1 E average traffic per public pedestrian cell does not affect the RLL system having up to 44 E average traffic per DAS. 3 E average traffic per public pedestrian cell however reduces the RLL traffic (0,5 % GoS) of about 40 E per DAS to about 30 E per DAS.

The large difference in cell radii is the major reason why the RLL traffic is more affected than the public pedestrian system. Typical street public pedestrian systems with 1E per cell, do not affect the RLL traffic. 3 E per public pedestrian cell gives reduction of the RLL traffic.

The above conclusions relate to intra-system and inter-system synchronization. Suppose the public pedestrian system is not synchronized to the RLL system. Since the RLL system will not differentiate between interference from RFPs and PPs, up-link/down-link mix will not contribute, as between RLL systems (DASs). Therefore without inter-system synchronization, the interference from a 1 E per cell public pedestrian system, would at most to be as from a 2 E per cell inter-system synchronized public pedestrian system. For 2 E per cell the interference to the RLL system starts to be noticeable. The need for inter-system synchronization may need to be considered.

8.8.1 Spectrum load for a system consisting of DASs and WRSs (CRFPs)

The results from the above simulated scenario can also be used to estimate the spectrum load of an RLL system with local mobility using WRSs type CRFP instead of CTAs, where the CRFPs provide local links to PPs. See clause A.6. This system concept can also be described as a public pedestrian system using CRFPs instead of wired RFPs, where the DAS infrastructure provides the above rooftop connection to the CRFPs. The antennas for the local CRFP link are supposed to be below rooftop as for the original RFPs. The CRFP antennas for the longer DAS link is supposed to be similar in position and have antenna gain as for the original CTAs (75 % are in LOS). See clause A.5.2.3.1.

The conclusion is that we can use the blocking probabilities for a DAS RLL system (with CTAs and not WRSs) to estimate the GoS and load on the spectrum for the DAS + WRS concept. This is a very interesting result, and will as a first approximation independent of the cell sizes and traffic densities.

8.9 Interference from public systems to private users

The worst interference source from a public system is an elevated high traffic node using high gain directional antennas. In clause 8.5 the potential interference between a realistic high traffic node deployment and an office system has been analysed. The clear conclusion is that due to sectorization and the average attenuation between above roof top links and indoor links, interference to offices is not a critical scenario. Potential interference to residential users will be even less, due to the low residential traffic capacity requirements.

Therefore, there is no need for special protection of private systems from interference from public systems. Public systems should be allowed to use all available carriers.

8.10 Summary on coexistence and spectrum requirements

The interference potential between different DECT systems can be summarized by table 10b.

Table 10b: The potential interference between DECT applications

Interference to	Residential	Office	Public pedestrian hot spots	Public pedestrian street	RLL
Residential	low	low	low	low	low
Office	low	some	some	low	low
Public pedestrian hot spots	low	some	high	low	low+
Public pedestrian street	low	low+	low	low	low+
RLL	low	low+	low+	some	high

NOTE: "low+" indicate that there are some circumstances where there is "some" interference.

As seen from the table 10b, the worst RLL interference is between above roof-top RLL systems. The simulations given in clause A.3 show that intra-system and inter-system synchronization is a necessity for above roof top RLL installations. Public pedestrian street systems employed as a DAS system linked to WRSs (CRFPs) having below roof top local links, are covered in the table by "RLL". The DECT standard (EN 300 175, parts 1 [1] to 8 [8]) provides for this purpose a cost effective absolute time synchronization option using the Global Positioning System (GPS) satellite system. Other means for mutual frame synchronization are also available in the DECT standard (EN 300 175, parts 1 [1] to 8 [8]). The table also indicates the potential for interference between operators for public pedestrian hot spots, such as railway stations and airports. Local inter-system synchronization is recommended for high capacity cases.

The spectrum requirements based on the simulations in annex A have estimated spectrum requirements for different blocking probabilities, typically between 0,1 and 2 %. The 1 % blocking probability cases have been used for the discussions in the present document. Adjustments to another blocking probability is possible with help of the information in annex A. The estimated total spectrum required for different DECT application scenarios from clause 5.2.2.4 can be summarized as follows.

Table 11: Summary of spectrum requirements

Scenario	Office and Residential	Public pedestrian hot spots	RLL	Total spectrum requirement
Shared spectrum, 3 (note 1) RLL operators. Mainly speech services	10 MHz <i>5 carriers 10 000 E/km² 4,5 E/base 21 m separation</i>	7 MHz <i>3 carriers 1 500 E/km² 2,5 E/base 41 m separation</i>	16 MHz <i>8 carriers Up to 120 E sharable per DAS (note 2) area</i>	20 MHz <i>All applications share the spectrum. Conflict solving rules for public operators</i>
Shared spectrum, several RLL operators. Speech and estimated emerging data services	20 MHz <i>10 carriers 20 000 E/km² 10 E/base 22 m separation</i>	8 MHz <i>4 carriers 1 500 E/km² 2,5 E/base 41 m separation</i>	20 MHz <i>10 carriers Up to 140 E sharable per DAS (note 2) area</i>	28 MHz <i>Private applications only in 1 880 MHz to 1 900 MHz. Conflict solving rules for public operators</i>
NOTE 1: May perhaps be 4, provided very well defined and regulated conflict solving rules.				
NOTE 2: A DAS area is served from one radio site with sectorized directional gain antennas and up-link power control.				

The text in *italic* in table 11 gives some basic application examples that relate the spectrum requirements to the traffic capacity requirements of clause 6. The separation distances relate to rectangular grids. The traffic served per DAS relates to the specific simulation scenario of clauses A.3.3 and A.3.4.

The European initial DECT allocation 1 880 MHz to 1 900 MHz provides 10 DECT carriers.

EN 300 175 parts 1 [1] to 8 [8] defines extended DECT carriers up to 1 937 MHz. This ensures interoperability in extended DECT allocations, or in countries with allocations other than 1 880 MHz to 1 900 MHz. Extension up to 1 910 MHz will provide a total of 16 carriers, and extension up to 1 920 MHz, 22 carriers.

In many countries and for many scenarios, depending on number of operators and other factors, we can conclude that the initial 1 880 MHz to 1 900 MHz, will support reliable and economic deployment of DECT RLL systems effectively coexisting with other DECT applications.

There may be markets with conditions favouring spectrum extension for the public DECT services. A justification for any extension of the DECT spectrum shall be related efficient use of the spectrum. Commercial RLL and point to multi-point non-DECT systems in operation in the 3,5 GHz band have been allocated totally 10 MHz to 30 MHz each, say 20 MHz each in average. Compared to allocating two separate 20 MHz allocations for two operators with traditional RLL technologies, a single 20 MHz shared allocation for the DECT services can for instance support four RLL operators plus support a number of public street system operators and also support the traffic for all private office and residential DECT systems in a city.

NOTE: Commercial RLL and point to multi-point systems operating in the 3,5 GHz band, normally have FDD duplex arrangements and not TDD duplex arrangements. Annex F gives information on RF modifications of DECT enabling applications on FDD (paired up-link/down-link) spectrum.

9 Conclusion on spectrum requirements for different scenarios

Based on the information in earlier clauses, the following is concluded on use of the DECT spectrum:

- a) By allowing all services to share the whole spectrum, in general, we will maximize the possible traffic offered, since we maximize the trunking efficiency of locally available access channels. See clause 5.2.2.
- b) Specifically we oppose to any suggestion to forbid public operators to use part of the total spectrum, since public services blocking office or residential applications is not a critical scenario.
- c) All public operators should in principle operate on the whole allocation. See clause 5.2.2. Potential problems with implementing very different RLL cell sizes in the same local area, is solved by proposals for conditional local carrier back-off rules when a local conflict occurs. This is much more efficient than having some kind of fixed split of carriers between operators. See clause 10.
- d) The public license should contain some rules for synchronization and procedures for limiting the traffic in high elevated nodes if local conflicts occur between operators. See clause 10.
- e) Results from simulations indicate that it is feasible to start implementing all intended DECT services on the current 20 MHz. But since the DECT standard is most suitable for ISDN, data, multimedia and RLL applications, we can foresee a rapid increase of applications in these areas, whereby extended spectrum (8 MHz to 10 MHz) could increase the cost effectiveness of high quality DECT services in a multi-operator environment. See clause 8.10. To retain one of the most important success factors of DECT, the multi-application platform, this extension should be a natural extension of the current 20 MHz band. DECT is an IMT-2000 technology, and is supposed to utilize IMT-2000 spectrum. See clause 4.
- f) Principally, regulators shall not limit any system to have access to the whole allocated band. The main reason is that we believe that this is the best choice for competition on an unregulated market. But also, if the band is split, we will lose the possibility for large scale realistic verification of the power and efficiency of applying uncoordinated DECT system installations on a common spectrum allocation. It is however reasonable to limit the use of any extended DECT band to public operation, since it is hard to regulate the unlicensed services with conflict solving rules.
- g) DECT FPs operating on an extended band shall have field programmable software controlled carrier allocation. This will encourage regulators to start with as few restrictions as possible, since it provides a simple means, if required, for eventual local resolution and for refinement of deployment rules once real life experience has been gained.

10 Recommendation on procedures for economic handling of hot spots and emerging traffic increase

Below are suggestions for procedures for economic handling of local emerging traffic increase and local hot spots, based on simulations and analysis performed in this report.

These suggestions are generally applicable, but as seen from the summary on coexistence, clause 8.10, agreed mutual rules for handling of local hot spot traffic only need to be considered for high traffic density public system, mainly those with above rooftop antenna installations.

10.1 Monitoring

It is standard practice in wired and wireless telecommunications systems to monitor the traffic variations and blocking rates as part of the Operations and Maintenance (O&M) support to an operator. This is required for timely adjustment of the infrastructure as the local traffic increases or varies, due to changed habits of the subscribers, new services visible or not visible for the operator and due to new subscribers.

Therefore, the need for monitoring the local traffic and service quality, and having processes for timely modification of the local infrastructure to adjust for partly unpredictable local variations, is nothing specific for DECT. The new element for DECT is that not only the own subscribers, but also the traffic variations from other systems, may influence the need to adjust the infrastructure. This is not a problem as such, as long as the economic impact of non-predictable local adjustments due to traffic from surrounding systems is low compared to other costs.

As seen from the summary on coexistence, clause 8.10, the economic impact from traffic of other systems only need to be considered for high traffic density public system, specifically between those with above rooftop antenna installations.

One aim for the suggested rules below, is to provide predictable upper bounds for the infrastructure costs at local hot spots, where special co-ordination between operators may be needed for providing mutual efficient use of the spectrum.

10.2 Adjustment of the infrastructure

The operator should monitor the traffic and the blocking probabilities at each base station of the system. This enables him to timely adjust his infrastructure to cope with emerging local traffic growth:

- a) if the local traffic tends to become trunk limited, more radio resources shall be added;
- b) if the local traffic tends to become interference limited, the local cell density shall be increased, by having more sectors per cell site and/or more cell sites.

Adding sectors or cell sites is simple in the sense that DCS is used so that the new sectors or cells do not impact the rest of the installation. If the issue is only to increase the own link quality and not increase the own traffic a simple means is to add a WRS at the area with marginal wanted signal. The WRS should have a directional antenna towards the RFP to ensure the link reliability to the RFP. Also adding sectors at a cell site is not very costly, since the transmission capacity to the site will in this case remain unchanged.

It is important that an operator is not forced to increase his cell density beyond economic limits because other operators in the same area increase their traffic. One aim for the suggested rules below, is to provide predictable upper bounds for the infrastructure costs at local hot spots.

10.3 Frame synchronization

DECT is designed not to require frame or slot synchronization between base stations or systems to maintain a high radio link quality. Synchronization between close by base stations does however in general decrease the local load on the spectrum. For high capacity indoor multi-cell systems the vast majority of the close by base stations normally belong to the own system, and synchronization is regarded essential by manufacturers both to provide efficient handover and to meet internal system capacity requirements.

Intersystem synchronization (to an absolute reference or mutual between two systems) is essential for above rooftop high capacity applications, and should be mandated for such applications. Intersystem synchronization (to an absolute reference or mutual) is also essential for "hot spot" public pedestrian applications. The DECT standard (EN 300 175, parts 1 [1] to 8 [8]) provides for this purpose a cost effective absolute time synchronization option using the GPS satellite system. Other means for mutual frame synchronization are also available in the DECT standard (see EN 300 175, parts 1 [1] to 8 [8]).

For other cases inter system synchronization is typically not critical, and should not be mandated.

In order to prevent potential problems, it could be recommended that all public systems, i.e. all systems needing a license, are forced to be locally synchronized to each other, if an operator requires it in a specific local area. This means that mutual synchronization must be a part of a public system.

In addition, intra-system synchronization, at least within local clusters, should be mandatory for public systems, although most systems already have intra-system synchronization in order to provide intercell handover.

This leads to the following simple rule:

- Public systems should provide intrasystem cluster synchronization, and should have either GPS synchronization and a SYNC output port or a complete SYNC port (both input and output). This will allow absolute time synchronization via GPS or wired mutual synchronization, if an operator requires local synchronization between operators.

NOTE: For public pedestrian street type (antennas lamp post, below rooftop, 1E per base), synchronization may improve the capacity, but is often not essential. GPS synchronization is feasible if several base stations are part of the same FP. It is not cost effective for single RFP FPs connected directly to a local exchange unless it is possible to transfer frame synchronization signals over the local exchange.

Rules in line with the above recommendation have been implemented in the second edition of TBR 006 [10].

10.4 Maximum traffic load at RFPs

Simulations indicate that it is desirable for an operator to limit the planned average traffic in any one coverage cell (omnidirectional or sector shaped) to about 30 E (full-slot duplex bearers or equivalent) per 20 MHz total allocation. Exceeding this limit could make the effective range of his cells disproportionately vulnerable to interference from other users of the spectrum.

NOTE: The RLL simulations indicate 160 E to 200 E traffic in a DAS with 6 sectors. This is about 30 E per sector cell. Due to overlapping of the sectors, this corresponds up to about 60 E load in a specific geographical direction.

The intention is to restrict the maximum load from one antenna on the DECT spectrum in a specific geographical direction. This recommendation must not be used to limit economic infrastructure implementations, but as a tool for optimizing coexistence on the common DECT spectrum when required.

Limit figures on traffic per cell for outdoor antenna installations could be part of a package of conflict solving rules, to be used if a local conflict occurs between public operators. The limits may depend on the total amount of allocated spectrum and on the degree of sector overlapping.

10.5 Sharing infrastructure

The simulations show that maximum spectrum utilization occurs when different operators use similar cell sizes. An optimal way to provide this is to locally share the infrastructure. DECT provides flexible identity structures that can provide broadcast access rights information over a base station from several service providers.

Operators should be allowed to locally share the same base station infrastructure.

10.6 Carrier back-off

When several operators are active in one geographical area, sharing the spectrum will lead to a higher capacity than dividing the spectrum between the operators. Up to 3,1 to 4,8 times increased local spectrum efficiency has been found. This is when the cell sizes of the different systems do not differ too much and includes effects of varying local distribution of market share between operators.

However, if for above roof top installations the cell sizes differ a lot, and if the operator with the smaller cells provides very high local load on the spectrum, the large cell operator may get an unacceptable high blocking probability, unless he provides as dense infrastructure as the small cell operator. Simulations show that for a case of as much as nine times difference in cell size, both systems get about the same accessibility if the small cell system or both systems back off from 2 different carriers. And still the capacity is about 1,6 times better than for a completely split spectrum between two operators. This leads to the following proposals for conflict solving rules:

- a) Any public system (and any DECT FPs operating an extended band) shall have field programmable software controlled carrier allocation. This will encourage regulators to start with as few restrictions as possible, since it provides a simple means, if required, for local conflict resolution and for refinement of deployment rules once real life experience has been gained.
- b) Above roof top system operators shall in case of conflict between them, locally, mutually back off from the same number (2) of carriers (but different carriers). They may back off until the spectrum is locally totally split between them, but going so far is not optimal. In principle only the operators that have conflicts need to back-off. An alternative where each operator always has access to one or two own carriers, seems much less attractive to all parties. All will suffer in all normal cases where back-off is not required. And if there are many operators, so much will be taken from the common spectrum, that the, in average, large economic gain of sharing may be totally lost.

By using such conflict solving rules when there are large differences in cell sizes, the local upper bound for the infrastructure cost will be as for the case of totally split spectrum. But in reality, due to varying local distribution of market share between operators, the upper bound may be as if the spectrum was split between only two operators, even if there are, say, four operators in total.

Annex A: Simulation results

This annex describes the scenarios and the results of the simulations referred to in the main text of the present document. It is a collection of information from a large number of input documents supplied to the ETSI DECT Project during development of this report.

A.1 Simulations of WPBX office systems

In this clause the main assumptions and results of the simulations carried out for WPBX systems are summarized. First the simulation scenario is described highlighting the differences, then the reported results are presented.

A.1.1 Simulation scenario

Terminals are randomly positioned (with uniform distribution) within a reference three-storey building 100 m x 100 m x 9 m, in which 16 base stations are regularly spaced on each storey (figure A.1). Each terminal generates 0,2 E of traffic and the mean duration of the call is 120 s.

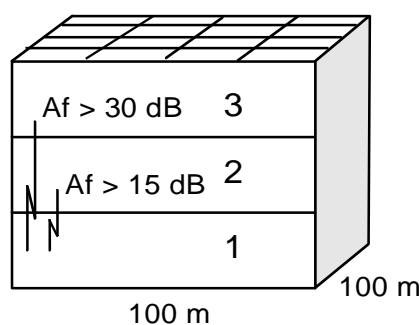


Figure A.1: Reference building

Two different radio propagation models have been considered:

The ETSI model assumes a propagation exponent accounting for the path loss equal to 3,5, an attenuation between floors of 15 dB, and a shadow margin factor uniformly distributed in the range ± 10 dB.

$$l(d) = 30 + 35 \log(d) + 15 \times (\text{number of floors})$$

A model for more heavy construction buildings, the Ericsson loss Model, has also been used.

Ericsson-in-Building loss model:

$$l(d) = 38 + 30 \log(d) + 15 \times (\text{number of floors}) \quad d < 20 \text{ m}$$

$$l(d) = -1 + 60 \log(d) + 15 \times (\text{number of floors}) \quad 20 \text{ m} < d < 40 \text{ m}$$

$$l(d) = -97 + 120 \log(d) + 15 \times (\text{number of floors}) \quad d > 40 \text{ m}$$

The shadowing margin is modelled with a log-normal law with zero mean and a standard deviation of 8 dB.

In both the models the Rayleigh fade margin is 10 dB, when antenna diversity is applied; the C/I threshold is 11 dB, so the call set-up threshold is 21 dB.

The system spectrum allocation, the radio parameters, such as transmitted power, receiver noise floor, adjacent channel rejection factors etc. and the call procedures, such as set-up and handover for both single and multi-bearer channel allocation models, are in accordance with the DECT specifications (see EN 300 175-3 [3]). Specifically, the parameters of the simulation scenario of annex E of ETR 042 [21] have been used. Base station blind slot information is available at the PPs for the simulations in clause A.1.2, whilst not in clause A.1.2.2.

The aim of this work is to evaluate the GoS versus the average traffic per base station and the total number of available DECT carriers (total spectrum). GoS is defined as follows:

$$\text{GOS} = \frac{\text{number of blocked calls} + 10 \times \text{number of interrupted calls}}{\text{total number of calls}}$$

In simulation works dealing with DECT performance (ETR 042 [21]) the desired GoS should be less than 1 %.

A.1.2 Simulation results

For the simulations in this subclause, DECT capacity in offices, intracell and intercell handover is provided and 20 % of the users are moving. The capacity is expressed in average speech traffic (Erlangs) per base station, as a function of the number of carriers that has been allocated to the system. Table A.1 provides a summary for the 1 % blocking case using the ETSI loss model. Table A.2 is the same summary for a heavy construction building where the Ericsson Loss model has been used.

Table A.1: Average traffic per base station (at 1 % blocking probability) in an office application as a function of total number of DECT access channels (the ETSI loss model has been used)

No. of carriers/ access channels	Average traffic per base station	Average number of users (at 0,2 E) per base station	Traffic/km ² /floor, if 625 m ² per base station (25 m separation)
2/24	1,3 E	7	2 100 E
4/48	3,2 E	16	5 100 E
6/72	4,5 E	23	7 200 E
8/96	5,3 E	27	8 500 E
10/120	5,6 E	28	9 000 E

It can be seen from table A.1 that the capacity is C/I limited up to about 6 carriers. For higher number of carriers the capacity becomes trunk limited (maximum 12 simultaneous calls per base station). For table A.2 the limit is at 4 to 5 carriers.

Table A.2: Average traffic per base station (at 1 % blocking probability) in an office application as a function of total number of DECT access channels (the Ericsson loss model has been used)

No. of carriers/ access channels	Average traffic per base station	Average number of users (at 0,2 E) per base station	Traffic/km ² /floor, if 625 m ² per base station (25 m separation)
2/24	2,1 E	11	3 400 E
4/48	4,4 E	22	7 000 E
6/72	5,5 E	26	8 800 E
8/96	6,1 E	31	9 800 E
10/120	6,1 E	31	9 800 E

Regarding capacity calculations, the figure average traffic (E) per base station is the essential parameter. The traffic density figures, traffic/km² and number of users per floor, depend directly on the base station density (base stations per km² or per floor). The results below may be extended to cover other base station densities, by varying the base station density, but keeping the E/base figures from the tables. We may conclude that with about 20 m base station separation 5 carriers (10 MHz) will provide about 10 000 E/km².

A.1.2.1 Capacity in large office landscapes with soft partitioning

Simulations have also been made for a very large single floor 300 x 300 m office landscape with semi-high soft partitionings, but without interior walls. The propagation model is:

$$L = 41 + 20 \log(d) + \Gamma \times \text{Max}[0, (d - 10)] \text{ dB}, \text{ where } \Gamma \text{ is } 0,37 \text{ dB/m or } 0,59 \text{ dB/m}.$$

The higher attenuation figure corresponds to a high density of partitions.

The results are summarized in table A.3.

Table A.3: Average traffic per base station (at 0,5 % blocking probability) in a large (300 m x 300 m) office landscape with soft partitioning as a function of total number of DECT access channels and as a function of total traffic

No. of carriers/ access channels (Γ)	Average traffic per base station	Number of base stations (base station separation, rectangular grid)	Traffic/km ² (total traffic in the office)
5/60 (0,37 dB/m)	4,2 E	12 (87 m)	556 E (50 E)
5/60 (0,37 dB/m)	6,0 E	42 (46 m)	2 778 E (250 E)
5/60 (0,37 dB/m)	5,6 E	90 (32 m)	5 556 E (500 E)
5/60 (0,37 dB/m)	3,7 E	272 (18 m)	11 111 E (1 000 E)
10/120 (0,37 dB/m)	4,2 E	12 (87 m)	556 E (50 E)
10/120 (0,37 dB/m)	6,9 E	36 (50 m)	2 778 E (250 E)
10/120 (0,37 dB/m)	7,8 E	64 (38 m)	5 556 E (500 E)
10/120 (0,37 dB/m)	5,9 E	169 (23 m)	11 111 E (1 000 E)
5/60 (0,59 dB/m)	2,5 E	20 (67 m)	556 E (50 E)
5/60 (0,59 dB/m)	6,0 E	42 (46 m)	2 778 E (250 E)
5/60 (0,59 dB/m)	6,2 E	81 (33 m)	5 556 E (500 E)
5/60 (0,59 dB/m)	4,2 E	240 (19 m)	11 111 E (1 000 E)
10/120 (0,59 dB/m)	2,5 E	20 (67 m)	556 E (50 E)
10/120 (0,59 dB/m)	6,9 E	36 (50 m)	2 778 E (250 E)
10/120 (0,59 dB/m)	7,8 E	64 (38 m)	5 556 E (500 E)
10/120 (0,59 dB/m)	6,4 E	156 (24 m)	11 111 E (1 000 E)

We see that the installation is range limited for the low traffic cases, and starts to be come interference limited for the high traffic density cases. We also see that with about 20 m base station separation 5 carriers (10 MHz) will provide about 10 000 E/km², as for the simulations in clause A.1.2.

A.1.2.2 Interference to and from offices

The potential Interference to and from different WPBX systems in the same building has also been analysed. Below the main results are presented.

Two different scenarios are taken into account:

- a) a single system in the building;
- b) three different unsynchronized systems (one per floor).

As a first assumption, systems are considered unsynchronized, i.e. frames are not aligned; the shift between the first time-slot of the frames of each system is not greater than one time-slot as shown in figure A.2.

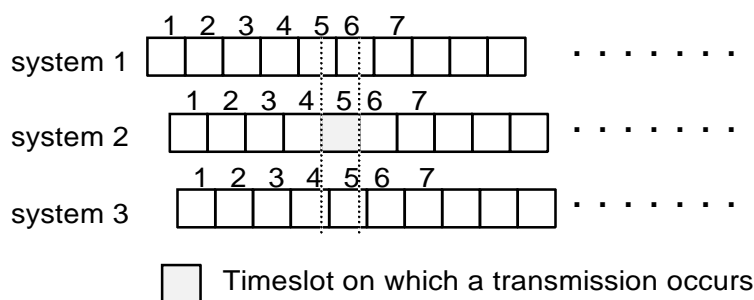


Figure A.2: Three unsynchronized systems in the building

When a single WPBX system is introduced in the building with a floor attenuation of 15 dB, the maximum capacity of the system in terms of Erlangs per RFP reached with a GoS equal to 1 % is about 5,6 E, that corresponds to 9 000 E/km²/floor; if a higher separation between floors is introduced (i.e. Af = 20 dB), this value becomes 6 E, that is 9 600 E/km²/floor. Note that blind slot information is not provided in this simulation. This explains the slight discrepancy with the results of clause A.1.2.

In the second scenario, a different WPBX system is positioned on each floor of the building; terminals can only set-up a call and make handovers with base stations of their system, that is of their floor. Two values on floor attenuation are taken into account: The different systems are unsynchronized. The comparison among the scenarios is shown in figure A.3.

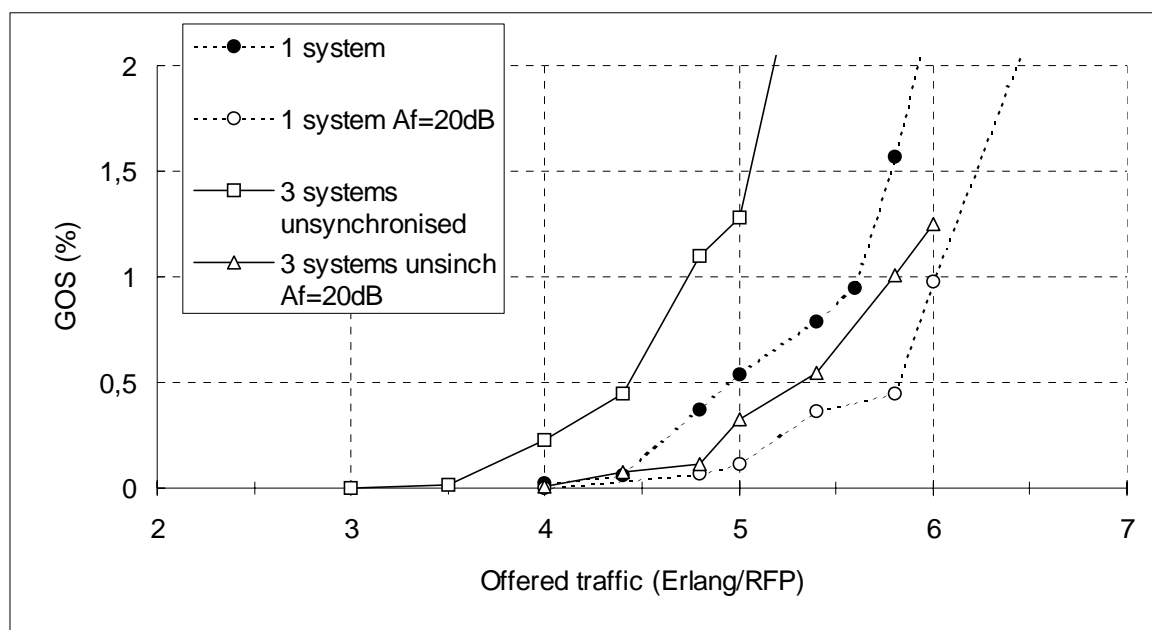


Figure A.3: Offered traffic per RFP with one and three systems in the building

The results obtained by simulations show that coexistence of different WPBX systems, also unsynchronized, is possible with a loss in capacity, in the worst case, less than 20 %; in fact the total capacity obtained is about 7 400 E/km²/floor, instead of about 9 000 E/km²/floor for the reference case of 1 system in the building with Af = 15 dB.

Better performance is obtained when the physical separation between different systems is higher, that is when the floor attenuation considered is 20 dB. In fact, in that case, the loss in capacity when 1 system in the building is substituted by 3 unsynchronized systems is almost negligible: The total capacity decreases from 9 600 E/km²/floor to 9 300 E/km²/floor.

Table A.4 summarizes the simulation results.

Table A.4: Summary of comparison of capacity for unsynchronized office systems

System types	Af (dB)	Erlangs/RFP	Erlangs/km ² /floor
1 system	15	5,6	9 000
on three floors	20	6	9 600
3 systems	15	4,6	7 400
unsynchronized	20	5,8	9 300

A.1.3 The impact of up-link power control

A.1.3.1 Introduction

Power control of subscriber units (PPs and CTAs) has in the DECT (and PWT(US)) standards been added to the Instant Dynamic Channel Selection, iDCS, procedures. It is called PP power control. It is not mandatory, but it provides a number of advantages including increased capacity where the DECT environment is dominated by uncoordinated single cell systems and RLL.

A.1.3.2 Power saving

PP power control increases the talk time of subscriber units. For this reason a number of manufacturers of residential DECT systems have already since many years used a simple (two step) open loop power control procedure.

A.1.3.3 Control of maximum interference and cell sizes

DECT RFP down-link per connection power control is not possible due to the iDCS procedure. It is however possible to have a static reduced power for all down-link transmissions from a specific RFP. A DECT system may have the same reduced power on all RFPs, or have different power on different RFPs, which will result in different "cell sizes". Information on reduced RFP power may need to be broadcast to PPs using open loop power control.

By introducing PP power control no more power will be emitted during a call than what is needed. It would also be possible to completely control the maximum emitted handset power (and RFP power) by (locally) installing the DECT base stations close enough.

A.1.3.4 Capacity impact

A.1.3.4.1 Single-radio RFPs and WRSs

A.1.3.4.1.1 Residential single cell systems

A number of adjacent residential systems appear as a set of mutually unsynchronized RFPs or cells. Since they are unsynchronized, the (in average) lower PP power will reduce the average level of mutual interference and thus reduce the local load on the spectrum.

A.1.3.4.1.2 Multi-cell systems

Multi-cell systems have all their RFPs synchronized. Since the down-link power is not changed, the down-link capacity will not be changed. Therefore the system capacity is not expected for be very much influenced by the PP power control, which has been confirmed by simulations.

A.1.3.4.2 Multi-radio RFPs and WRSs

The total capacity of a single-radio RFP is trunk (slot) limited to about 5 or 6 E. A single-radio WRS is trunk limited to about 2 E. The way to increase the local capacity without increasing the number of RFP sites, is the use multi-radio RFPs and WRSs.

In a multi-radio RFP (or WRS) the same time slots will be used simultaneously on different carriers. Therefore it is important to have enough adjacent channel selectivity/power suppression not to cause interference in the RFP between channels using the same time slot. This is not a problem for the down-links, because the down-link power is constant on channels of all radios, and the actual isolation between the channels will be equal to the specified adjacent channel selectivity of the receiver. However, there will be a problem for the up-link when constant up-link power is used, because one subscriber unit can be close to the RFP and another close to the cell range. Therefore the up-link signals received at the RFP on the same time slot (but on different carriers) could differ e.g. 30 dB in field strength, and the specified adjacent channel selectivity will not be sufficient to avoid the weaker signal to be blocked. Thus multi-radio RFPs will not be able to utilize all channels, unless up-link power control is implemented, so that all the up-links are received with equal power at the RFP/WRS.

With PP power control it is feasible to increase capacity by placing several synchronized RFPs or WRSs on the same site or spot, as long as they have the same UL/DL slot notations. This could be useful in office and residential environments. But for RLL systems where the RFP/WRS sites are very expensive, multi-radio RFPs or collocated RFPs are required, and here the capacity increase by introduction of PP power control becomes dramatic (2 times). See clause A.3.4.

A.1.4 The impact of higher level modulation options

The latest version of the DECT base standard includes backwards compatible 4-level, 8-level, 16-level and 64-level modulation options. This will increase the bit rate of single radio DECT equipment by a factor 2, 3, 4 or 6 with retained transmitter bandwidth, carrier spacing and slot structure.

Asymmetric data services with user data rates exceeding 4 Mbps are provided by a single DECT radio.

We could expect that the voice service remains with 2-level modulation since normally no shorter slots than full slots are used. Therefore, the voice traffic capacity is not expected to be increased by introducing higher level modulations.

For more or less isolated single cell single-radio systems we will get up to 6 times increased data traffic, unless they become range limited for the highest level modulation options. The 4-level modulation option will hardly introduce range limitation compared to the present implementation of 2-level radios. See clause 7.3.

For multi-cell systems, and for the total capacity locally available in an environment of several systems, introduction of higher level modulation options could increase the data traffic capacity by a factor 2 in average. The main gain is in implementing the 4-level modulation, giving 2 times larger data rate. Implementing more than the 4-level and the 16-level options provides hardly any higher interference limited capacity, but would of course increase the peak rate at short distances from the RFPs.

If some new multimedia services were standardized where voice and data to the same subscriber is mapped on a common slot, e.g. a double slot, than also the voice traffic would gain from the increased available bit rates.

Conclusion:

When introducing the higher level modulation options, we could use the results from the simulations made with standard 2-level modulation and make the following amendments:

- The offered voice traffic is not expected to be increased by introducing higher level modulation options, unless voice and data to a user is mapped on a common slot.
- The offered *data* traffic could be doubled by introducing higher level modulations, e.g. the 4-level option.

A.2 Simulations of public street public pedestrian systems

In this clause the assumptions and results of simulation studies of the capacity of public pedestrian systems in a suburban environment are described. First the simulation scenario for the public system is described. Thereafter the simulation results are presented.

A.2.1 Simulation scenario

A total number of 61 RFPs are placed in a hexagonal grid. The outer RFPs together form a new hexagon. The distance between RFPs is 300 m, whereby the area per cell becomes about 0,08 km². In total an area of 4,75 km² is covered. See figure A.4. In this area Poisson traffic is generated. Calls have a negative exponentially distributed holding time, with a mean duration of 120 seconds.

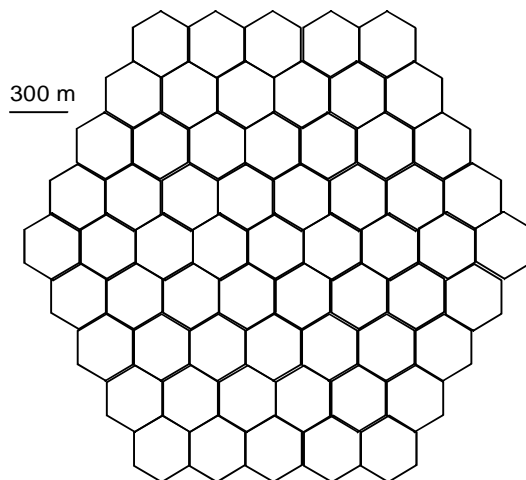


Figure A.4: Reference public pedestrian environment

The radio propagation model assumed is a mixture of 75 % LOS and 25 % Near Line Of Sight (NLOS). Which of the two models is to be used for calculating the propagation conditions is determined randomly at the start of the call. There is no preference for LOS or NLOS at an individual PP or RFP. The propagation loss model is:

75 % LOS:

$$l(d) = 38 + 20 \log(d) \quad d < 10 \text{ m}$$

$$l(d) = 30 + 28 \log(d) \quad d > 10 \text{ m}$$

25 % NLOS:

$$l(d) = 38 + 20 \log(d) \quad d < 10 \text{ m}$$

$$l(d) = 22 + 36 \log(d) \quad d > 10 \text{ m}$$

Additionally to the loss, shadowing is assumed to have a log-normal distribution with a standard deviation of 8 dB.

The assumption is made that a fade margin of 10 dB is required to combat multi path fading. This is based on the assumption of Rayleigh fading, in combination with diversity. The required C/I is assumed to be 11 dB or 13 dB. The latter to investigate the sensitivity of the results to this parameter.

Transmit power is 24 dBm, receiver sensitivity -86 dBm (GAP requirement). The antenna gain is 2 dBi at RFPs and 0 dBi at PPs. This gives a basic link budget of $24 + 2 + 86 = 112$ dB, excluding fading and shadowing margins.

The number of allocated carriers is varied between 1 and 10, assuming a variable spectrum allocation. Adjacent channel interference, set-up and handover procedures and DCS are modelled in accordance with the DECT specification. Blind slot information is available at the PP.

The capacity of the DECT system in the above described scenario is studied using the GoS, being defined as follows:

$$\text{GOS} = \frac{\text{Number of blocked calls} + 10 \times \text{Number of dropped calls}}{\text{Total number of calls}}$$

The desired GoS should be less than 1 %.

A.2.2 Simulation results

Capacity and carrier availability

The traffic capacity per RFP as a function of the available total number of carriers is shown in figure A.5. The case C/I of 11 dB is assumed to be typical for DECT.

When the DECT public pedestrian system, as described in the scenario, can use all 10 carriers, the capacity at 1 % GoS is 7,9 E, corresponding to 100 E/km². This capacity is higher than what is to be expected based on the Erlang B formula, which gives 5,9 E. This is due to the DCS, which enables a PP to set-up to an other RFP when the strongest RFP has no resources available.

The traffic capacity per RFP is more or less proportional to the number of totally available carriers. The figure also shows that 2 to 3 carriers are required to have a reasonable capacity for public pedestrian street application defined in this suburban scenario and in clause 6.3 (about 1 E per RFP).

NOTE: A city centre public pedestrian street application with consistent below roof top base station installations, will due to larger isolation between base stations, require less spectrum than indicated in figure A.5.

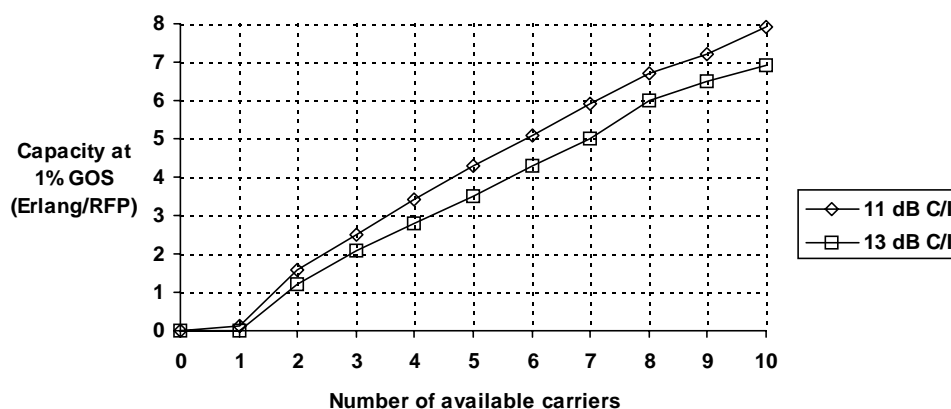


Figure A.5: Capacity at 1 % GoS versus the number of available carriers of the public pedestrian system

In figure A.5 the capacity per RFP at 1 % GoS is shown. The capacity is also shown for a C/I of 13 dB. This makes it possible to estimate the sensitivity of the capacity to the required C/I. When the system is purely C/I limited, as is the case for 4 carriers, we find a decrease in capacity of 8 % to 10 % per dB increase in C/I. When more carriers are available, the trunk size is limiting the capacity, and a reduced effect is noticed. For eight to ten carriers a decrease in capacity of 5 % to 7 % per dB increase in C/I is found.

A.3 Simulations of above rooftop RLL systems

In this clause the assumptions and results of simulation studies of the capacity of above rooftop RLL systems in a suburban environment are described. First the simulation scenarios for the RLL system are described. Thereafter the simulation results are presented. Note that in an update of the present document, simulation results using improved propagation models and scenarios are found in clauses A.3.3 to A.3.5. A summary is found in clause 3.6.

A.3.1 Simulation scenarios

A.3.1.1 Basic scenario

For the above rooftop scenarios it is supposed that a major part of the CTAs are in LOS. In LOS conditions DECT can provide reliable long range links (up to 5 km or more). To provide economic installation, the RFP stations of six cells are installed in at common site called DECT Access Site, DAS. This is possible by using directional antennas for the RFP of each cell, so that each cell gets a sector shape with the RFP placed in the corner of the sector angle. The same principle for creating sectorized cells is frequently used in mobile telephony systems.

Seven synchronized DASs, are placed above rooftop in an hexagonal pattern. The sides of the cells are 1 km, corresponding to a separation distance of 1,732 km between the DASs. See figure A.6. The coverage area becomes 2,6 km² per DAS. Poisson time distributed traffic is generated within the coverage area of the DASs. The statistics are taken only from the inner DAS.

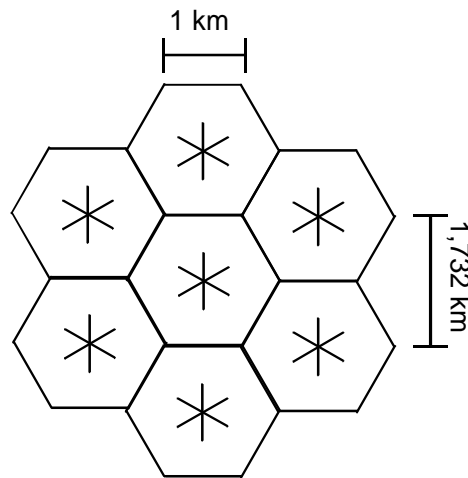


Figure A.6: Basic above rooftop RLL scenario

One DAS consists of six RFPs, each equipped with a directional antenna, and pointing in a direction 60° different from the next RFP. The DAS antenna has an opening angle of 85°. The bore sides of the antennas are directed to the corners of the DAS cell. Redundancy is provided by having an opening angle as large as 85°. Each CTA can see two RFPs, which provides redundancy. This implies that these 6 overlapping sectors are equivalent to about 3 non-overlapping sectors. Figure A.7 shows the antenna diagram. The antenna provides 12 dBi gain.

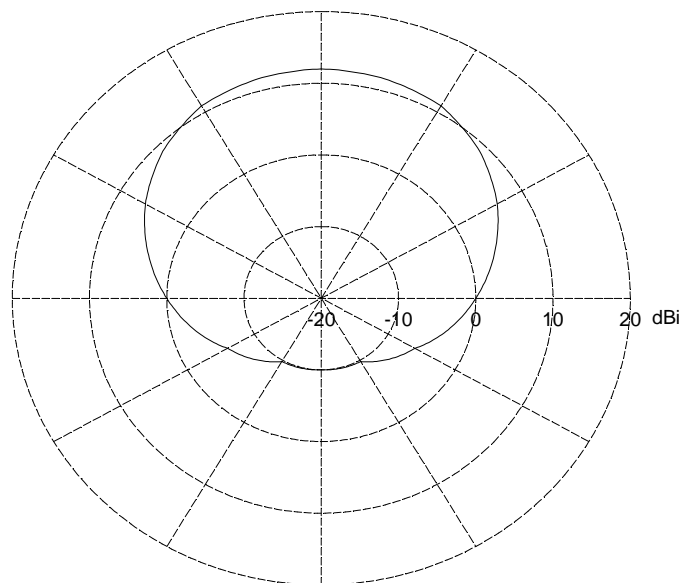


Figure A.7: Antenna diagram with 85° to 90° opening angle and 12 dBi gain

The CTAs are also equipped with a directional antenna. The CTA antenna has an opening angle of 90° and 12 dBi gain. This antenna is directed to the nearest DAS.

The radio propagation model assumed is a mixture of 75 % LOS and 25 % NLOS. Which of the two models is to be used for calculating the propagation conditions is random. It is determined when placing the CTA. The propagation loss model is:

75 % LOS:

$$l(d) = 38 + 20 \log(d) \quad d < 10 \text{ m}$$

$$l(d) = 30 + 28 \log(d) \quad d > 10 \text{ m}$$

25 % NLOS:

$$l(d) = 38 + 20 \log(d) \quad d < 10 \text{ m}$$

$$l(d) = 22 + 36 \log(d) \quad d > 10 \text{ m}$$

Additionally to the loss, shadowing is assumed to have a log-normal distribution with a standard deviation of 8 dB. Due to the shadowing model used, in combination with other defined conditions, a low number of calls will originate in CTAs out of range. These calls are taken out from the statistics, since no real CTA will be installed in such a way that it is out of range.

For multi path fading Rayleigh fading is assumed. For each radio path between a CTA and an RFP separate Rayleigh fading is calculated. When this path is the actual connection between CTA and DAS, diversity is assumed, resulting in the selection of the strongest of two Rayleigh faded signals.

There is no preference for LOS or NLOS at an individual DAS or CTA. All RFPs of a DAS will have the same loss and shadowing conditions, but different antenna gain and multipath fading, due to the difference in direction.

The required C/I is assumed to be 11 dB.

Transmit power is 24 dBm, receiver sensitivity -89 dBm (typical for DECT RLL systems). This gives a basic link budget of $24 + 12 + 12 + 89 = 137$ dB, excluding fading and shadowing margins.

The number of allocated carriers, adjacent channel interference, set-up and handover procedures and DCS are modelled in accordance with the DECT specification. Blind slot information is available at the CTA.

The capacity of the DECT system in the above described scenario is studied using the GoS, being defined as follows:

$$\text{GoS} = \frac{\text{Number of blocked calls} + 10 \times \text{Number of dropped calls}}{\text{Total number of calls}}$$

The desired GoS should be less than 1 %.

For the basic scenario, a total of 10 consecutive carriers (20 MHz) are allocated.

A.3.1.2 Additional scenarios

In addition to the basic scenario, as described above, additions have been made to the scenario:

- 1) The DASs are completely unsynchronized.
- 2) The DAS and CTA antenna were either directional or omni-directional. In order to avoid range problems, the distance between DASs was reduced to 300 m. The antenna pattern models include side lobes. The cases given in table A.5 were simulated.

Table A.5: Specification of simulated antennas

CTA antenna		DAS antenna	
Gain (dBi)	Opening angle (°)	Gain (dBi)	Opening angle (°)
12	90	12	85
12	90	2	360
2	360	2	360

- 3) The total number of carriers allocated for the system(s) is varied between 1 and 10; at each location of a DAS a second DAS is added. The second DAS is synchronized to the first. Traffic is equally spread of the DASs.
- 4) A second system of seven DASs is added to the first set of seven DASs. The second DASs have the same separation distance, and are placed at the intersections of the cells of the first DASs. See figure A.8. Any CTA belongs to either of the two systems with the same probability. The CTA is pointing to the closest DAS of the own system. (This might be further away than the closest DAS.) All DASs of both systems are synchronized.

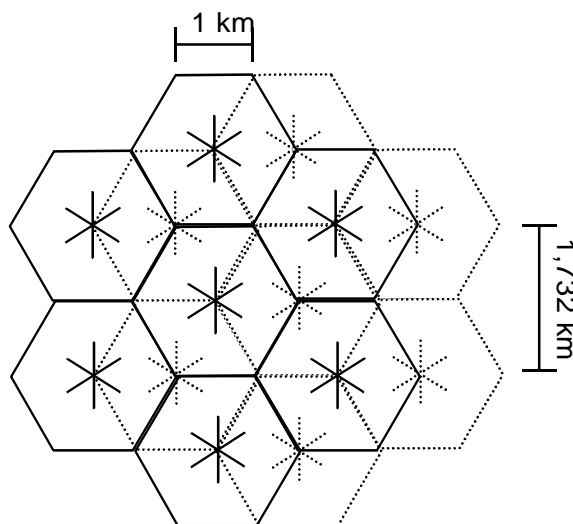


Figure A.8: Two system above rooftop RLL scenario

- 5) The required C/I is assumed to be 11 dB or 13 dB.
- 6) The side of the node cells is 100 m or 1 km, and the DAS node separation 173 m or 1,7 km, whereby the coverage area per DAS becomes $0,026 \text{ km}^2$ or $2,6 \text{ km}^2$.

A.3.2 Simulation results

A.3.2.1 Basic capacity simulation results

The capacity of the basic scenario with one and two systems is given in table A.6. For one system in this scenario the capacity per RFP is higher than what can be calculated using the Erlang-B formula for 12 servers (trunks). The Erlang-B formula shows a GoS of 1 % at 5,9 E, while the simulations show the same GoS at $40,2 / 6 = 6,7 \text{ E}$ per RFP. So to some extent CTAs make use of free channels at adjacent RFPs at the DAS. For the two system case, the simulations show $28,6 / 6 = 4,7 \text{ E}$ per RFP.

For two collocated synchronized systems, the total capacity per node at 1 % GoS is $2 \times 28,6 \text{ E} = 57,2 \text{ E}$. This is more than the 40,2 E for the single system case. Therefore, it is obvious that the capacity for the single system case is trunk limited and not C/I limited.

The total capacity per node of the two systems is the same as the capacity per DAS of one system with two RFPs in each sector cell (not trunk limited capacity). See the last line of table A.6 and compare with figure A.11.

Table A.6: Capacity per DAS for the basic scenario, totally 10 carriers

Scenario	Capacity (Erlang/DAS/system) at GoS			
	0,1 %	0,5 %	1,0 %	2,0 %
Basic, 1 system	29,0	36,2	40,2	44,3
2 synchronized collocated systems	19,5	24,5	28,6	32,2
1 system, 2 RFPs per DAS sector	39,0	49,0	57,2 (note)	64,4

NOTE: For one system with six 60° DAS sectors, 2 RFPs per sector, 25 % LOS and 75 % NLOS, the capacity per DAS at 1 % GoS is 74 E.

A.3.2.2 Capacity and carrier availability

It is important to study how the capacity depends on the total number of available carriers. This information is very helpful for estimating the local load on the spectrum and how much is left for other systems. The total number of available carriers is varied from 1 to 10.

In figures A.9 to A.11 the capacity per DAS for various numbers of carriers and various GoS is shown for the three cases of table A.6.

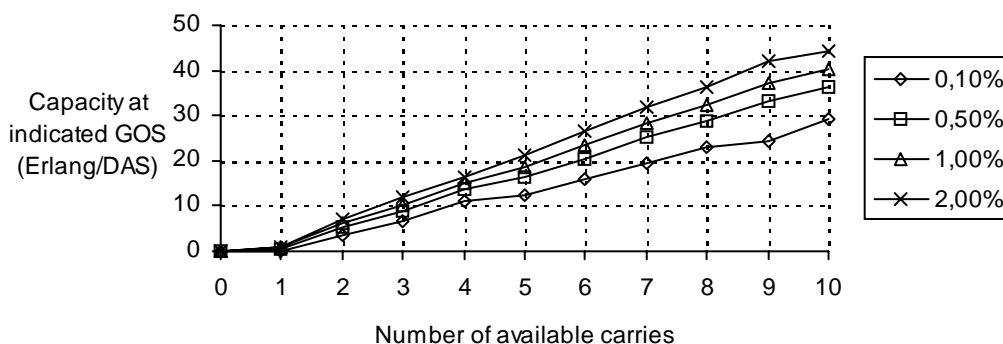


Figure A.9: Capacity per DAS versus number of available carriers of the above rooftop RLL system at 0,1 %, 0,5 %, 1,0 % and 2,0 % GoS (1 system with 1 RFP per sector cell)

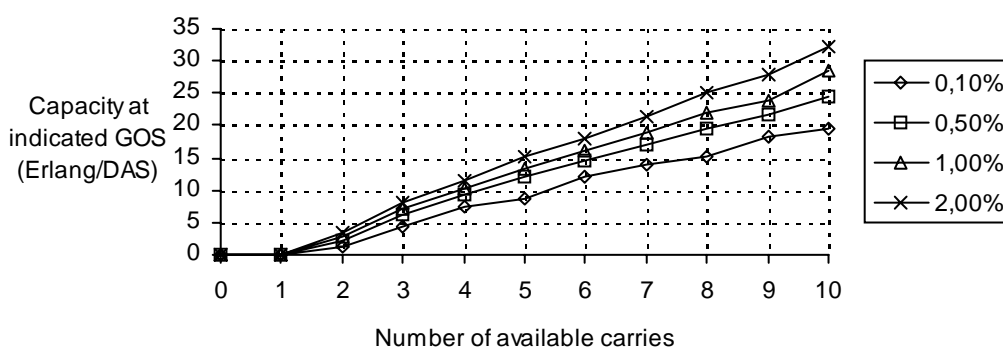


Figure A.10: Capacity per DAS/system versus number of available carriers of the above rooftop RLL system at 0,1 %, 0,5 %, 1,0 % and 2,0 % GoS (2 systems with 1 RFP per sector cell)

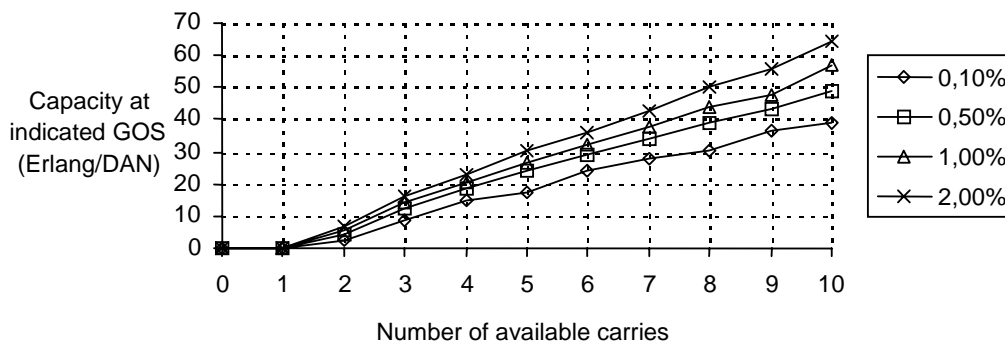


Figure A.11: Capacity per DAS (lower bound) versus number of available carriers of the above rooftop RLL system at 0,1 %, 0,5 %, 1,0 % and 2,0 % GoS (1 system with 2 RFPs per sector cell)

From figure A.11 we can conclude that the maximum (by different operators) sharable local capacity is about 57 E per DAS when totally 10 DECT carriers are available. For extended number of carriers beyond 10, a lower bound for the local capacity is 5,7 E per carrier. This assumes synchronization and use of directional gain antennas.

With 1,7 DAS separation the sharable traffic capacity becomes about $57 / 2,6 = 22 \text{ E/km}^2$ when totally 10 DECT carriers are available, and about 200 E/km^2 for 0,58 km separation, and about $2\ 100 \text{ E/km}^2$ for 173 m separation. See table A.12.

A.3.2.3 Synchronization

In tables A.7 to A.9 the results are shown from simulations with 10 carriers where the seven DASs are not synchronized.

Table A.7: Capacity per DAS for synchronized and unsynchronized DASs, 1 system with 1 RFP per sector cell (10 carriers)

Scenario 1 system, 1 RFP/sector	Capacity (Erlangs/DAS) at GoS			
	0,1 %	0,5 %	1,0 %	2,0 %
Synchronized	29,0	36,2	40,2	44,3
Unsynchronized	9,4	13,7	15,5	17,3

Table A.8: Capacity per DAS for synchronized and unsynchronized DASs, 2 co-located systems with 1 RFP per sector cell (10 carriers)

Scenario 2 systems, 1 RFP/sector	Capacity (Erlangs/DAS/system) at GoS			
	0,1 %	0,5 %	1,0 %	2,0 %
Synchronized	19,5	24,5	28,6	32,2
Unsynchronized	7,9	9,7	10,7	12,1

Table A.9: Capacity per DAS for synchronized and unsynchronized DASs, 1 system with 2 RFPs per sector cell (10 carriers)

Scenario 1 system, 2 RFPs/sector	Capacity (Erlangs/DAS) at GoS			
	0,1 %	0,5 %	1,0 %	2,0 %
Synchronized	39,0	49,0	57,2	64,4
Unsynchronized	15,8	19,4	21,4	24,2

The capacity per DAS is reduced by more than 60 % for the all cases. This means that the sharable local capacity per DAS may be reduced from 5,7 E to 2,1 E per allocated carrier.

Synchronization between DASs is required for high capacity applications. This does not mean that the above rooftop RLL system needs to be synchronized to other DECT systems.

A.3.2.4 Directional versus omni-directional antennas

Besides synchronization, also the use of directional or omni-directional antennas is crucial for the spectrum efficiency of above rooftop RLL systems. Directional antennas will have a higher gain, so a larger range is realized. Directional antennas will also radiate into and receive from the wanted direction. Interference to and from other DECT users is reduced. In the scenario to investigate the capacity effects three options are taken into account, as shown in the description of the scenario in clause A.3.1.

Table A.10: Capacity per DAS for directional and omni-directional antenna patterns at DAS and CTA, 1 system (1 RFP per sector cell) with synchronized DASs and totally 10 carriers

Scenario		Capacity (Erlangs/DAS) at GoS			
DAS	CTA	0,1 %	0,5 %	1,0 %	2,0 %
dir	dir	26,2	35,6	40,7	44,9
dir	omni	21,8	27,8	31,2	35,5
omni	omni	18,1	21,4	23,2	25,9

In table A.10 the results for the different scenarios is summarized. The figures show that antennas at the CTA and the DAS both have a large, and more or less equal, impact on the capacity of the system. The reduction in capacity in the last line of table A.10, by not using directional antennas, is about 40 % (somewhat less than for not synchronizing the DASs). Use of directional antennas is very beneficial for high capacity applications since a significant increase in capacity is realized, and interference to other systems is reduced. The case with two RFPs in each sector provides redundancy in each sector. For this case the opening angles of the DAS antennas may be reduced, allowing higher antenna gain and even more efficient use of the spectrum.

A.3.2.5 Sensitivity to C/I performance

The basic scenario has been simulated also with a 2 dB change in required C/I. For C/I limited cases the capacity reduction is typically about 6 % per 1 dB increase of C/I.

A.3.2.6 Effect of cell size on the capacity

To investigate the influence of the distance between DASs on the capacity per DAS, the radius of the cells was reduced to 100 m, corresponding to a distance between DASs of 173 m. The effect of this reduction, as shown in tables A.11 and A.12, is a somewhat reduced capacity, though the effect is limited (± 2 %). This result is depending on the propagation model used. So far no alternative propagation model has been used in these simulations.

Table A.11: Capacity per DAS for 173 m and 1,7 km node separation, 1 system (1 RFP per sector cell) with synchronized DASs and totally 10 carriers

Scenario	Capacity (Erlangs/DAS) at GoS			
	0,1 %	0,5 %	1,0 %	2,0 %
1,7 km separation	29,0	36,2	40,2	44,3
0,17 m separation	27,3	35,5	39,6	43,9

Table A.12: Capacity per DAS for 173 m and 1,7 km node separation, 1 system (2 RFPs per sector cell) with synchronized DASs and totally 10 carriers

Scenario	Capacity (Erlangs/DAS) at GoS			
	0,1 %	0,5 %	1,0 %	2,0 %
1,7 km separation	39,0	49,0	57,2	64,4
0,17 m separation	38,0	46,8	55,6	63,8

A.3.2.7 Multi-operator scenarios

When two or three operators are active in the same area with an above rooftop RLL system, several scenarios are possible regarding the locations of the DASs. The two extreme scenarios are co-located DASs or DASs located at the corners of the cells of the other above rooftop RLL systems.

Regarding the use of the spectrum also two alternatives exist. The spectrum can be shared or divided between the two operators. In case of division, the locations of the DASs do not matter, so three scenarios remain:

- shared spectrum, DASs co-located;
- shared spectrum, DASs located at corners of other system (the most unfavourable position);
- spectrum divided between systems.

The results of these simulations is shown in table A.13.

Table A.13: Capacity per DAS for second operator scenarios, 1 RFP per DAS (all DASs are synchronized)

Scenario	Capacity (Erlangs/DAS/system) at GoS			
	0,1 %	0,5 %	1,0 %	2,0 %
co-located, 2 systems	19,5	24,5	28,6	32,2
other location, 2 systems	16,0	20,0	22,4	25,3
divided spectrum, 2 syst.	12,4	16,4	18,6	21,3

The figures in table A.13 show a preference for co-locating the DASs. In practice this does not necessarily mean a pure co-location. The same effect will be noticed when the DASs are placed near each other. For "other location" (worst case), the capacity reduction is only about 20 %.

The figures also show a very large preference for sharing the spectrum instead of dividing the spectrum. This of course requires synchronization between the operators. The more operators the larger the gain of sharing instead of dividing, see table A.14.

Table A.14: Capacity per DAS for three-operator scenarios, 1 RFP per DAS (all DASs are synchronized)

Scenario	Capacity (Erlangs/DAS/system) at GoS			
	0,1 %	0,5 %	1,0 %	2,0 %
co-located, 3 systems	13	16	19	21
divided spectrum, 3 syst.	8	10	12	13,5

Tables A.13 and A.14 show that the spectrum efficiency can be increased by up to 60 % by not dividing the spectrum between operators. This is for the case where all systems have equal local load on the spectrum. In reality, for RLL, we can expect that there will be many local areas where one of the operators will be dominating. In such areas the capacity can be up to 57,2 E per DAS, which corresponds to $57,2 / 18,6 = 3,1$ times (2 operators) and $57,2 / 12 = 4,8$ times (3 operators) better spectrum efficiency compared to splitting the frequency band between operators.

Therefore, for the 3 operator case, by providing synchronized systems, sharing spectrum will compared to equal division of the spectrum, provide up to between 1,6 and 4,8 times more efficient use of the spectrum.

A.3.3 Improved realistic RLL propagation model

With more realistic propagation models for fixed WLL, the capacity per DAS node could double compared to results presented in the above simulations using the scenarios defined in clause A.3.1.

The main issue is that the propagation model in clause A.3.1 uses a ± 8 dB shadowing component on all wanted LOS and NLOS signals and also on all interfering signals without any correlation between wanted and interfering signal. This is normally made for mobile systems, but gives far too pessimistic conditions for an RLL system. See description in table A.15.

Table A.15

A.3.1 and A.3.2 simulations	Mobile subscribers	Fixed subscribers with LOS or almost LOS installation optimized for best possible wanted signal.
No correlation for use of either of the defined LOS and NLOS models for wanted and interfering signals for the same CTA.	Low or medium correlation for use of either of the defined LOS and NLOS models for wanted and interfering signals for the same CTA.	High correlation for use of either of the defined LOS and NLOS models for wanted and interfering signals for the same CTA. <i>If the wanted signal is LOS</i> , the CTA is either above roof-top or up on a wall (still in LOS), and it is likely that the <i>interferers to the CTA</i> also are LOS, but a substantial part will be NLOS (see note). <i>The interferers to the DAN</i> are also LOS, but a substantial part will be NLOS (see note). <i>If the wanted signal is NLOS</i> (below roof-top) it is very likely that the <i>interferers to the CTA</i> also are NLOS. <i>The interferers to the DAN</i> will be LOS from <i>some</i> of the LOS installed CTAs (see note), but a substantial part will be NLOS.
No correlation for the level of shadowing used for wanted and interfering signals for the same CTA.	Low correlation for the level of shadowing used for wanted and interfering signals for the same CTA.	Not a high correlation for the level of shadowing used for wanted and interfering signals for the same CTA, but the distribution is not generally log-normal. For the LOS case there is almost no shadowing for the wanted signal but could be added attenuation for the interferers, and due to the way installation is made, there is for the NLOS case often shadowing attenuation both for the wanted and interfering signals.
NOTE: LOS installed CTAs on walls will not be interfered from the 180° backwards sector, and will produce no interference in the 180° backwards sector.		

Table A.16: Void

Due to the above considerations, we may conclude that when simulating C/I limited capacity, that it is more correct to have no shadow component, than to use uncorrelated shadow components.

A.3.3.1 New simulations

By removing the shadowing components from the clause A.3.1 model we got the following results. For comparison, two other propagation/deployment models have been included.

A.3.3.2.1 Common parameters/definitions

GOS is defined as the blocking probability plus 10 times dropping probability.

There are 7 DASs in a cluster. Each DAS has 24 RFPs, 2 per sector.

The capacity is indicated per DAS. Each DAS has 12 sectors with 30° horizontal opening angle antennas.

The CTAs have 80° horizontal opening angle antennas. CTAs are not evenly distributed per sector.

A.3.3.2.2 Results

A.3.3.2.2.1 Customary model (close to model from clause A.3.1)

RLL modified Walfish Ikegami with 3dB shadowing for LOS and 8dB for NLOS. 25 % LOS.

GOS 1 %: 70 Erlang. This corresponds to 2.9 E/RFP.

Blocking 1 %: 85 Erlang (thus significant influence from dropping).

A.3.3.2.2.2 The model from clause A.3.1

The A.3.1 model shadowing 8dB, but with 25 % LOS links and 75 % NLOS links.

GOS 1 %: around 65 Erlang. This corresponds to 2.7 E/RFP.

Blocking 1 %: 81 Erlang (thus significant influence from dropping).

A.3.3.2.2.3 No shadowing path loss 100 % LOS

GOS 1 %: 198 Erlang. This corresponds to 8.3 E/RFP (close to trunk limitation).

Blocking 1 %: 202 Erlang.

An additional simulation, but with **6 sectors** (85° horizontal opening angle) instead of 12 sectors, and where GOS was calculated **only for the down-link**, the following results were obtained for 1 % GOS:

1 RFP/sector: 55 Erlang, 2 RFPs/sector: 110 Erlang, 4 RFPs/sector (totally 24 RFPs): 198 Erlang.

An interesting observation is that with a total of 24 RFPs, the down-link capacity with only 6 sectors is as large as the capacity for 12 sectors (198 E) where also the up-link limitation is included. This indicates that the up-link is limiting the capacity. See the impact of up-link power control in clause A.3.4.

A.3.3.2.2.4 No shadowing, 75 % LOS and 25 % NLOS.

If CTA is NLOS, also interferes to CTA are NLOS.

For RFPs and LOS CTAs, 75 % of the interferers are LOS and 25 % NLOS.

GOS 1 %: 170 Erlang. This corresponds to 7.1 E/RFP.

Blocking 1 %: 185 E.

A.3.3.2.2.5 Conclusion

As seen, the results depend a lot on the selection of propagation model.

The last case A.3.3.2.2.4 can be compared with the result of figure A.11 which also has 75 % LOS and 2 RFPs per sector, but only 6 sectors. Figure A.11 indicates 57 E at 1 % GOS. Suppose that going from 6 to 12 sectors increases capacity by about 50 %, corresponding to $57 \times 1,5 = 85,5$ E for the model in clause A.3.1.

Thus we could say that a more realistic model (no shadowing) than in clause A.3.1 could give about 2 to 2½ times higher capacity (from 85 E to 170 E to 200 E).

Furthermore, simulations show that decreasing the CTA antenna opening angle from 80° to 25°, increases capacity by about 60 %. This gain can be utilized by increasing the number of RFPs in each sector, or is useful when two operators are having one system each in the same geographical area.

A.3.4 Impact of up-link power control

PP up-link power control has been standardized for DECT. See clause A.1.3.

Simulation shows that CTA up-link power control increases capacity from about 80 E to 190 E for 12 sectors with 2 RFPs per sector and with a model similar to the model of clause A.3.3.2.2.1. This corresponds to 7,9 E/RFP (close to trunk limitation).

With 3 RFPs per sector the capacity increased to about 300 E. This corresponds to 8,3 E/RFP (close to trunk limitation).

Note that this 300 E traffic was obtained with a shadowing component in the propagation model, and with capacity per RFP close to trunk limitation. Thus with 4 RFPs per sector we could expect > 300 E traffic, but the DECT standard does not permit more than 3 single radio RFPs per sector (unless more than 10 RF carriers are available).

A.3.5 Impact of higher layer modulation options

The latest version of the DECT base standard includes backwards compatible 4-level, 8-level, 16-level and 64-level modulation options. This will increase the bit rate of single radio DECT equipment by a factor 2, 3, 4 or 6 with retained transmitter bandwidth, carrier spacing and slot structure. See clause A.1.4.

Asymmetric data services with user data rates exceeding 4 Mbps are provided by a single DECT radio.

When introducing the higher level modulation options, we could use the results from the simulations made with standard 2-level modulation and make the following amendments:

- The offered voice traffic is not expected to be increased by introducing higher level modulation options, unless voice and data to a user is mapped on a common slot.
- The offered *data* traffic could be doubled by introducing higher level modulations, e.g. the 4-level option.

A.3.6 Conclusions

Various rooftop RLL system scenarios have been simulated and discussed. The major conclusions of the simulations are:

- Maximum sharable local capacity with 10 carriers is estimated to be at least 300 E for 12 sector DAN clusters and about 160 E to 200 E for 6 sector DAN clusters. This is achievable with use of a rather simple (slow and not very accurate) up-link closed loop power control.
- For two or more systems in the same geographical area, the total capacity/site of all operators becomes close to the above maximum sharable local capacity, if the operators have similar cell sizes.
- Each E corresponds to one speech connection or a data connection with about 32 kbps with 2-level modulation and about 64 kbps with higher level modulation (at least 4-level modulation). 300 E corresponds to 19 Mbps data throughput per DAN with 4-level modulation!
- Having 1 RFP per sector provides a trunk limited average capacity of about 5 E/RFP to 7 E/RFP, and having 2 or 3 RFPs per sector provides roughly about 8 E/RFP to 9 E/RFP of average capacity.
- It is obvious that an isolated DAS site, will support the trunk limited traffic capacity.
- Synchronization between DASs and between above rooftop RLL systems has a very large positive impact on the system capacity.
- Use of directional gain antenna versus omni-directional antennas at the DAS has a large positive impact on the system capacity.
- When several operators are active in one geographical area, sharing the spectrum will lead to a higher capacity than dividing the spectrum between the operators. Up to 1,6 to 4,8 times increased spectrum efficiency.

- The required C/I has a limited impact on the capacity of the above rooftop RLL system (if trunk limited).
- The distance between the DASs of the above rooftop RLL system have a limited effect on the traffic capacity per DAS, as long as the different systems in a local area have similar cell sizes.

A.4 Simulations of below rooftop RLL systems and other RLL systems

Below roof top RLL applications will not have critical impact on spectrum requirements, because the radiation will be limited by surrounding buildings and the local load from such a base station will also be limited. EN 300 175-3 [3] recommends to limit the maximum load from an antenna of a sectorized cell to 36 E, which limits the average local load on the spectrum to 24 E. Furthermore 24 E corresponds to 373 households, and a below roof top installation can hardly reach 373 households. An office with $24 / 0,15 = 160$ employees could however occasionally be served this way.

Simulations have also been made for a scenario with omnidirectional base station antennas positioned just at roof top level of houses in a residential villa area. The CTAs are non LOS and ranges are limited to about 200m. Simulations are made for up to 10 transceivers per site antenna. The capacity of a single cell is trunk limited up to 6 transceivers (72 trunks) and does not increase capacity by adding transceivers. The maximum capacity is 48 E. The reason is that for this specific case only every second carrier can be used due to the interference in the first adjacent channel. As mentioned above, EN 300 175-3 [3] does not suppose more than 3 transceivers (average 24 E) to be connected to an omnidirectional antenna. Therefore the simulations have no practical importance. If more than 24 E are required from an access node, sectorized directional antennas should be used.

A.5 Coexistence between above rooftop RLL systems and a public pedestrian street system

The largest potential interference between RLL systems and other DECT applications is between above rooftop RLL systems and a public pedestrian street system, since the public pedestrian system has outdoor base stations. Such an interference scenario has been simulated.

A.5.1 Simulation scenario

The RLL scenario is the basic 7 DASs RLL above rooftop scenario defined in clause A.3.1, which will cover an area with about 4,8 km diameter. The only difference is that the antenna gain is 8 dBi instead of 12 dBi for the DASs and 6 dBi instead of 12 dBi for the CTAs. The public pedestrian scenario is a 61 cell system with 300 m RFP separation as defined in clause A.2.1, with the exception that the public pedestrian RFPs are below rooftop and only 25 % of the PPs are in LOS, instead of 75 %. The public pedestrian system will cover an area with about 2,5 km diameter. The RLL-public pedestrian propagation is assumed to always be NLOS. The blocking probabilities are calculated for the connections within the area of the inner centre DAS node, with 33 public pedestrian cells. See figure A.12. The RLL and public pedestrian systems are synchronized.

The models for LOS and NLOS are as defined in subclauses A.2.1 and A.3.1.

40 E in the RLL DAS corresponds to $40 / 2,6 = 15,4$ E/km². 1 E per public pedestrian cell corresponds to $33 / 2,6 = 12,7$ E/km², and 3 E per public pedestrian cell corresponds to 38 E/km².

A.5.2 Simulation results

The simulations gave the following results.

A.5.2.1 Interference from the RLL system to the public pedestrian system

The RLL traffic, up to 44 E per DAS node, did not affect the public pedestrian traffic at 3 E per public pedestrian RFP. Since street PCM base stations typically have 1 E average traffic per cell, we conclude that for this scenario, the interference to the public pedestrian system is not critical.

A.5.2.2 Interference from the public pedestrian system to the RLL system

1 E average traffic per public pedestrian cell does not affect the RLL system having up to 44 E average traffic per DAS. 3 E average traffic per public pedestrian cell does not affect the RLL system when having 18 E average traffic per DAS. 3 E average traffic per public pedestrian cell however reduces the RLL traffic (0,5 % GoS) from about 40 E per DAS to about 30 E per DAS. Therefore, the additional load on the spectrum for the RLL system is about the same as when adding a second RLL system. Two RLL systems can support 28,6 E each per DAS. Compare with table A.6. 28,6 E per DAS corresponds to 11 E/km² and 3 E per public pedestrian cell corresponds to 38 E/km².

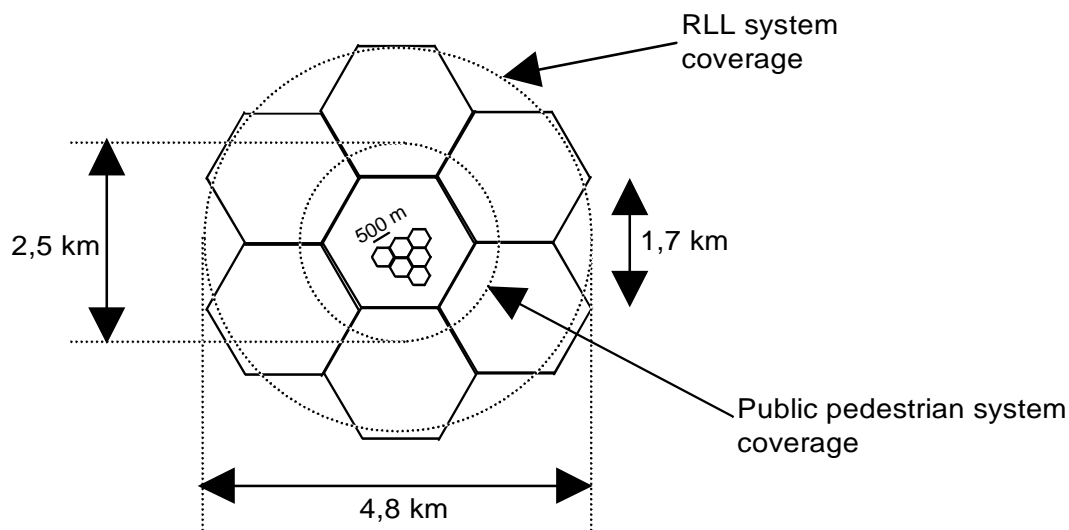


Figure A.12: Deployment of above rooftop RLL DAS nodes and street below rooftop street public pedestrian cells

A.5.2.3 Conclusions

The large difference in cell radii is the major reason why the RLL traffic is more affected than the public pedestrian system. Typical public pedestrian street systems with 1E per cell, do not affect the RLL traffic. 3 E per public pedestrian cell gives reduction of the RLL traffic.

The above conclusions relate to intra-system and inter-system synchronization. Suppose the public pedestrian system is not synchronized to the RLL system. Since the RLL system will not differentiate between interference from RFPs and PPs, up-link/down-link mix will not contribute, as between RLL systems (DASs). Therefore without inter-system synchronization, the interference from a 1 E per cell public pedestrian system, would at most to be as from a 2 E per cell inter-system synchronized public pedestrian system. For 2 E per cell the interference to the RLL system is just noticeable. The need for inter-synchronization is discussible. RLL systems with smaller separation distances between the DASs will of course be less affected.

A.5.2.3.1 Spectrum load for a system consisting of DASs and WRSs (CRFPs)

The results from the above simulated scenario can also be used to estimate the spectrum load of an RLL system with local mobility using WRSs type CRFP instead of CTAs, where the CRFPs provide local links to PPs. This system concept can also be described as a public pedestrian system using CRFPs instead of wired RFPs, where the DAS infrastructure provides the above rooftop connection to the CRFPs. The antennas for the local CRFP link is supposed to be below rooftop as for the original RFPs. The CRFP antennas for the longer DAS link is supposed to be similar in position and have antenna gain as for the original CTAs (75 % are in LOS). See figure A.13.

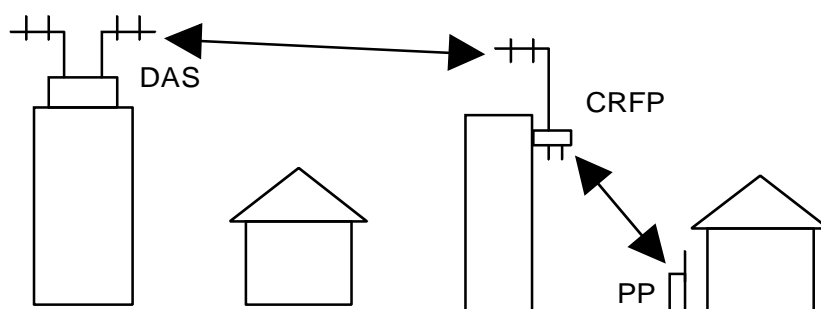


Figure A.13: RLL system with local mobility

Suppose that the CRFPs are in the same positions as the RFPs, then there are 33 CRFPs within the area of one DAS. With 1 E average local link traffic per CRFP, the traffic per DAS will be 33 E, since the DAS above rooftop link will be loaded with 1 E per Erlang of local link load. Therefore, this scenario is almost identical to the already simulated scenario. The only difference is that there are couplings between the above rooftop (RLL) links and the local (public pedestrian) links. But since the simulations show that the blocking probability of the DAS link will dominate and that the low traffic (1 E) local links will not affect that probability, we can use the blocking probabilities for the above rooftop RLL simulations of clause A.3 to estimate the GoS and load on the spectrum for the concept of figure A.13. This is a very interesting result, and will as a first approximation be independent of the cell sizes and traffic densities, since the total traffic per km² in the DAS links and in the local links always are equal, in this case 12,7 E/km².

A.6 The impact of WRSs on infrastructure cost and spectrum utilization

The DECT WRS is an important component for providing economic DECT infrastructures. WRS is an additional building block for the DECT fixed network. A WRS has the function of an RFP that need no wired connection to the FT.

The WRS is a physical grouping that contains both FT and PT elements, and that transfers information between an RFP and a PP. The FT element acts towards a PP exactly as an ordinary RFP. The PT element acts like a PP towards the RFP, and is locked to the closest RFP. The WRS contains interworking between its FT and its PT, including transparent transfer of the higher layer DECT services. WRS links may be cascaded.

A WRS has to comply with the general FT identities requirements for RFPs. Installing or adding a WRS to a DECT infrastructure is not possible outside the control of the system operator and/or system installer and/or system owner, who provides the required system identities, access rights and authentication/encryption keys.

Figure A.14 gives a graphic explanation of the WRS functionality. For more information, see the ETSI technical report on WRS, ETR 246 [14] and EN 300 700 [15].

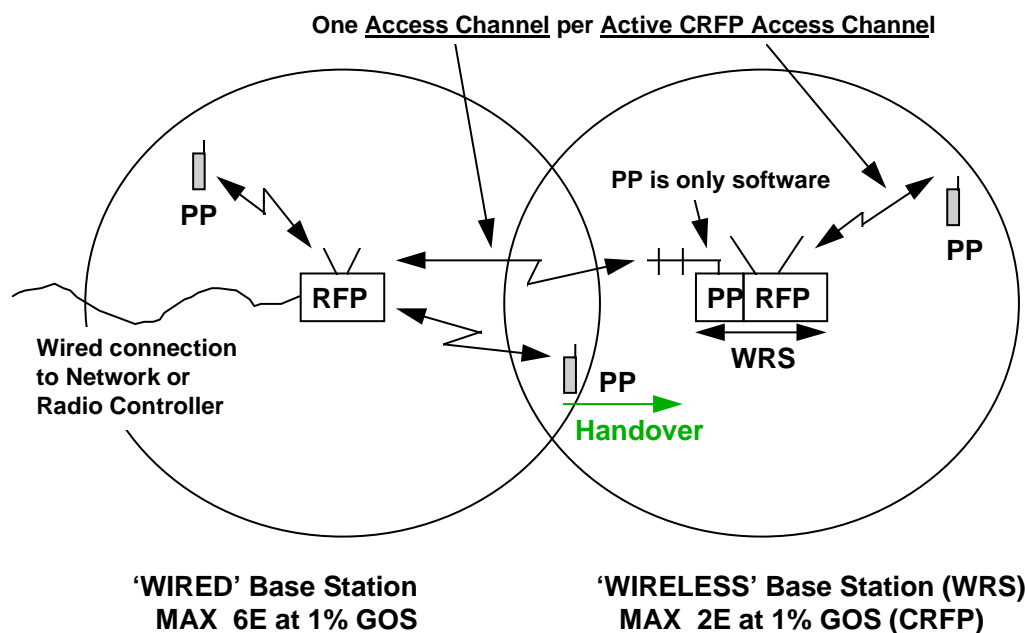


Figure A.14: Principle for WRS

No access channel is required between the RFP and the WRS when there is no local uplink traffic to the WRS. The number of access channels required and the GoS figure for WRS in the figure relates to the CRFP type. For the REP type, 2 RFP link access channels are required for the first PP link access channel. For the following PP link access channels, 1 or 2 additional RFP link access channels are required per additional PP link channel. The trunk limited capacity is maximum 1 E for the REP WRS is at 1 % GoS. A PP does not see any difference between a WRS and an ordinary wired RFP. Handover is provided between WRSs and between WRS and RFPs, as between ordinary wired RFPs.

The impact on the local spectrum utilization of a call relayed via a WRS depends on the scenario. Below are some typical scenarios that exemplify this.

A.6.1 Examples of scenarios with WRS type CRFP (this type is implemented in products)

Table A.17

Scenario	Relative local load on the spectrum for a WRS call	Total local load on the spectrum	Total additional local load on the spectrum	Impact of WRS calls on other systems	Cost savings economic benefit
Residential (typical 1 E per RFP)	2x	Low	Low	Low	Important
Office (up to 6 E per RFP)	2x	Medium to High	Low (limited line of sight, WRS not economic for high capacity)	Low (natural isolation to other systems)	Important for small systems, and generally for remote area coverage.
Public street Pedestrian (typical 1 E per RFP)	2x	Low	Low	Low	Essential, one RFP can relate to 4 CRFPs
Public "hot spot" Pedestrian (indoor, up to 6 E per RFP)	2x	Medium to High	Low (WRS not economic for high capacity)	Low	Important for remote low traffic spot coverage
Public pedestrian (below rooftop) outdoor to indoor WRS coverage and wireless centrex	Same or less on the outdoor link, since less power is needed penetrate wall	Typically low	Typically low	Typically low	Essential
RLL with residential (or small office) mobility (remote link above rooftop, local WRS link indoor)	Same (the alternative is to add a separate indoor residential system)	High to Critical for the outdoor link	0	0	Essential Provides lower delay and less quantization distortion (QDUs) than a separate DECT indoor system
RLL with local mobility/public pedestrian (remote link above rooftop, local outdoor link below roof top)	About the same (for the critical remote link) compared to no mobility	High to Critical for the remote link	Low Some small load on the remote links from the (< 1E) WRS local link	Low	Provides essential synergy between local mobility RLL and public pedestrian services

From the examples of table A.17 we can conclude that implementations of CRFPs typically has no critical impact on the local load of the spectrum.

A.6.2 Examples of scenarios with WRS type REP (not in use)

Table A.18

Scenario	Relative local load increase on the spectrum for a WRS call	Total local load on the spectrum	Total additional local load on the spectrum	Impact of WRS calls on other systems	Cost savings Economic benefit
Residential (typical 1 E per RFP)	3x	Low	Low	Low	Important
Office (up to 6 E per RFP)	3x	Medium to High	Low (limited line of sight, WRS not economic for high capacity)	Low (natural isolation to other systems)	Important for small systems, and generally for remote area coverage.
Public street public pedestrian (typical 1 E per RFP)	3x	Low	Low	Low	Important, one RFP can relate to 2 REPs
Public "hot spot" Pedestrian (indoor, up to 6 E per RFP)	3x	Medium to High	Low (WRS not economic for high capacity)	Low	Useful for remote low traffic spot coverage
Public pedestrian (below rooftop) outdoor to indoor WRS coverage and wireless centrex	2x or less on the outdoor link	Typically low	Typically low	Typically low	Essential
RLL with residential (or small office) mobility (remote link above rooftop, local WRS link indoor)	2x (the alternative is to add a separate residential system)	High to Critical for the outdoor link	High to Critical for the outdoor link	High to Critical for the outdoor link	Important, but only possible for low density REP applications
RLL with local mobility / public pedestrian (remote link above rooftop, local outdoor link below roof top)	2x (for the critical remote link) compared to no mobility	High to Critical for the remote link	High to Critical for the remote link	High to Critical for the remote link	Important, but only possible low density REP applications. Synergy between RLL and public pedestrian

From the examples of table A.18 we can conclude that "not-above-rooftop" implementations of REPs typically has no critical impact on the local load of the spectrum. Implementations of REPs with above rooftop links have critical impact on the local load of the spectrum, except for low density installations of REPs.

NOTE: If interlacing is mandated for REP, the spectrum load per simultaneous REP connection, will except for the first connection, be the same as for CRFP. However, for the two critical RLL scenarios above, the average traffic per WRS is about 1E or less. In these cases the spectrum load from the first REP connection is the relevant figure.

Annex B: Coexistence with other technologies

B.1 Coexistence on a common spectrum allocation with evolutions and derivatives (PWT) of DECT

Analysis and simulations show that the good coexistence performance of the DECT DCS procedures, as a first approximation, is independent of exact carrier positions and carrier bandwidths, as long as the frame structure is the same. Suppose for instance, that one of two neighbour systems have their carrier positions shifted by half a the carrier separation spacing. This means that the inter-system carrier interference power on the same time slot will be reduced by a factor of 2 in each carrier, but two carriers will be interfered.

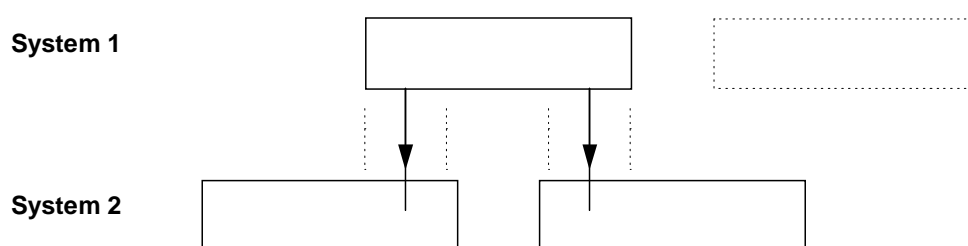


Figure B.1: Coexistence of two systems with different carrier positions

Figure B.1 illustrates this. Each box indicates the transmission bandwidth with a carrier position in the middle of the box. The arrows indicate interference. It is obvious that this gives on one hand shorter average reuse distances to a single interferer, but since the same slot on two carriers are interfered, the average interference load is about the same as if both systems had the same carrier positions.

The conclusion of this analysis is supported by simulations of a single system high density application where additional DECT carriers positions were defined on a grid of 1/3 of the standardized carrier positions. This resulted in frequent irregular interference patterns in the frequency domain of the same kind as shown in the figure above. This did not decrease the capacity, on the contrary, in this specific case the traffic capacity increased by up to 20 %, obviously due to the increased flexibility.

The conclusion is that standard DECT systems will coexist very well on a common allocation with any possible DECT evolutions with higher or lower carrier bandwidth (higher or lower bit rate) and other carrier positions. DECT and the North American DECT derivative Personal Wireless Telecommunications interoperability standard, PWT [19] and PWT/E [20], also coexist very well on a common spectrum allocation. PWT and PWT/E uses the DECT frame structure, MAC, DLC etc, but has a different modulation and different bandwidth and carrier spacing to meet local regulatory requirements. PWT operates in the US Isochronous Unlicensed PCS band 1 920 MHz to 1 930 MHz. PWT-E is an extension into the licensed PCS bands 1 850 MHz to 1 910 MHz and 1 930 MHz to 1 990 MHz. PWT may also be allowed in some Latin American countries.

B.2 Coexistence DECT and GSM 1800

In Europe and many other countries around the world, GSM down-link (base station TX band) has spectrum allocation 1 805 MHz to 1 880 MHz and DECT has 1 880 MHz to 1 900 MHz.

The coexistence properties between DECT and GSM1800 have been analysed in the CEPT ERC Report 100 "Compatibility between certain radiocommunications systems operating in adjacent bands; Evaluation of DECT/GSM 1800 compatibility", February 2000 [29].

The report analyses all possible combinations between DECT indoor systems (residential and enterprise applications), DECT outdoor below roof-top pedestrian systems, DECT above roof-top WLL systems, GSM indoor systems and GSM above roof-top macro cell deployments (with outdoor and indoor subscribers).

Important scenarios for the recommendations are a) potential interference to GSM when a GSM 1800 mobile station (MS) operates in **the same** indoor environment as a DECT indoor system, and b) potential interference to DECT when above roof-top DECT WLL systems and GSM macro cell systems operate in the same **local** outdoor environment.

The conclusions for the above two scenarios are given below. Case a) is of general interest, since the main DECT market is for residential and enterprise applications. Case b) is relevant in some countries:

a) Potential interference to GSM mobile stations (MS)

DECT has very low probability to cause harmful interference to GSM 1800 systems.

The potential victims are only the GSM 1800 mobile stations. The probability that DECT will cause harmful interference to GSM 1800 is very low in particular due to the GSM error correction capability. Moreover, GSM can escape temporary interference close to the DECT band edge by intra-cell handover to an other carrier more distant from the DECT edge. This is feasible, since macro cell systems normally have two or more GSM carriers per sector, whereby the GSM 1800 BCCH control channels should use carriers outside the frequency band 1 878 MHz to 1 880 MHz. This proposed planning does not reduce the traffic capacity of the GSM system, but will provide escapes for the few instances when harmful interference could occur to the GSM mobile stations.

b) Potential interference to DECT above roof-top WLL systems

A guard band is not required to protect DECT WLL systems from GSM 1800 interference, but measures are proposed to facilitate the coexistence when the GSM sub-band 1 878 MHz to 1 880 MHz is used.

The proposed measures include avoiding to use the sub-band 1 878 MHz to 1 880 MHz for above roof-top GSM base stations, but rather for below roof-top micro cells or indoor cells.

c) General recommendation to protect DECT

DECT should be able to detect and escape interference from a single GSM bearer, via its instant Dynamic Channel Selection procedure and intra-cell handover, which implies that, DECT should be able to process a successful handover when the up-link or the down-link is interfered as seldom as every 6th frame. See [3] clause 11.4. This requirement is generally useful, but of prime importance for DECT WLL systems.

B.3 Coexistence DECT and UMTS/TDD 3,84 Mcps

NOTE: In Europe UMTS/TDD has spectrum allocation 1 900 MHz to 1 920 MHz and DECT has 1 880 MHz to 1 900 MHz.

The coexistence properties between DECT and UMTS/TDD 4,84 Mcps have been analysed in the CEPT ERC Report 065 "Adjacent band compatibility between UMTS and other services in the 2 GHz band", November 1999 [28].

The report analyses all possible combinations between DECT indoor systems (residential and enterprise applications), DECT outdoor below roof-top pedestrian systems, DECT above roof-top WLL systems, UMTS/TDD indoor systems and UMTS/TDD above roof-top macro cell deployments (with outdoor and indoor subscribers).

Important scenarios for the recommendations are a) potential interference to UMTS/TDD when a UMTS/TDD mobile station (MS) operates in **the same** indoor environment as a DECT indoor system, and b) potential mutual interference between above roof-top DECT WLL systems and UMTS/TDD macro cell systems operate in the same **local** outdoor environment.

The conclusions for the above two scenarios are given below. Case a) is of general interest, since the main DECT market is for residential and enterprise applications. Case b) may become relevant in some countries. Note that no UTRA/TDD systems have yet (2003) been commercially deployed in Europe:

a) Potential interference to UMTS/TDD mobile stations (MS):

No additional guard bands are needed between DECT and UMTS TDD if UMTS TDD is deployed indoors.

UMTS TDD outdoor base station systems used in the band 1 900 MHz to 1 910 MHz should use interference avoidance techniques (such as intra-cell handover and instant Dynamic Channel Selection, iDCS, in the time domain) to reduce the probability of interference to Mobile Stations entering a location with DECT. Similar considerations arise **between adjacent UMTS TDD carriers** operating with indoors and outdoors base stations, within the whole 1 900 MHz to 1 920 MHz band.

The concern raised with the second bullet above, is based on the fact that UMTS/TDD MSs served from an outdoor macro base station may operate close to the sensitivity limit, and that each UMTS/TDD operator has only one carrier, and no second or third carrier to which intra-cell handover escapes are possible, if interference occasionally becomes too high on the carrier closest to the band edge. Everywhere else around the world, cellular operators have access to more than one carrier. A Monte Carlo simulation would still show a low probability for interference, but there are local environments where a more deterministic model is more correct, and has thus been applied in [28].

As seen from the text of the second bullet, mutual MS to MS interference is of main concern for two UMTS/TDD operators operating on adjacent 5 MHz bands. In reality, larger separation distances are required to MSs from an adjacent UMTS/TDD operator than from DECT MSs. Thus the problem is not emissions from DECT, but as mentioned above, the lack of multiple carriers allocated for European UMTS/TDD operators. Introduction of instant Dynamic Time Slot Selection (including control slots) to the UMTS/TDD standard, would have facilitated the application of UMTS/TDD outdoor infrastructures.

The conclusion is that possible future applications of UMTS/TDD in Europe, will be exposed to somewhat higher risk for interference from DECT, than other cellular technologies like GSM (see the GSM section above) or in other parts of the world where spectrum for several carriers is provided for each cellular operator.

- b) Potential interference mutual interference between DECT above roof-top WLL systems and UMTS/TDD macro cells:

UMTS TDD macro base station systems should not be applied on the band 1 900 MHz to 1 910 MHz in areas where DECT WLL systems are installed (Eastern Europe), unless special measures are taken.

This problem is, as mentioned above, caused by the single carrier allocation of the UMTS/TDD system in combination with the very wide bandwidth of the UMTS/TDD system and lack of a proper guard band between the systems.

The special measures, referred to in the bullet above, is coordinated site engineering including installation of external filters on most the above roof-top radio equipments.

B.4 Coexistence DECT and American PCS technologies

In many Latin American countries DECT is allocated within 1 910 MHz to 1 930 MHz. (This is the same as the US Unlicensed PCS band). Mobile PCS technologies have their base station transmit band within 1 930 MHz to 1 990 MHz and the handset transmit band within 1 850 MHz to 1 910 MHz.

In several Latin American countries DECT FWA (WLL) above roof-top applications are allowed in the band 1 910 MHz to 1 930 MHz. As a guide for these decisions, the Inter-American Telecommunication Commission, CITEL, made an in-depth coexistence study [30] on the mutual coexistence properties between DECT FWA (up to 36 dBm EIRP) and the different cellular PCS technologies at the band borders 1 910 MHz and 1 930 MHz.

Two political camps conducted the study, and it is therefore very long and detailed, and there are two views expressed on almost everything. The study showed however that the potential interference between cellular PCS technologies on adjacent PCS blocks (A, B, D etc) was higher than from DECT FWA to the adjacent PCS blocks. See [30] Part 1, clause 2.3.2. As a result several Latin American countries introduced DECT FWA.

DECT enterprise and residential systems are also allowed in many Latin American countries, whereby normally both standard DECT, PHS and equipment meeting the US UPCS **isochronous** rules are accepted in the whole 1 910 MHz to 1 930 MHz band. **Note however, that these DECT residential and enterprise applications were by CITEL not at all considered problematic as regards potential interference to adjacent block cellular PCS systems (See note below).** The only concern was if FWA in the UPCS band 1 910 MHz to 1 930 MHz would interfere with the unlicensed residential and enterprise applications in the same band. The CITEL study did not have time to finish that part, which was considered less important. See however [30] Part 3, where it is shown that DECT FWA and indoor UPCS applications (including DECT) coexist well on the same spectrum.

NOTE: The reasons why DECT enterprise and residential applications in the 1 910 MHz to 1 030 MHz are not considered problematic as regards potential interference to the adjacent PCS services, are very similar to the reasons why there are very small risks for DECT to interfere with GSM 1800 (clause B.2):

- The main case to be considered is the potential interference to A-block handsets (1 930 MHz to 1 945 MHz Rx band) being in the same indoor location as a DECT system. Potential for interference requires that both the DECT device and the PCS handset use carriers close to the 1 930 MHz block boarder.
- Monte Carlo simulations show that the average interference probability is so small that the capacity of the PCS system (or cell) is not affected at all.
- For the few cases when interference occurs, the PCS systems have several mitigation techniques:
 - a) Powerful error correcting coding combined with interleaving, which correct for low load interference from the DECT carriers closest to the A-block. A DECT handset provides such low load interference.
 - b) For the remaining cases where the error correction capability is insufficient, the PCS system will provide an intra-cell handover to a PCS carrier more distant from the 1 930 MHz boarder. This is easily made since the A-block handset Rx band is so large, 15 MHz.

The same mitigation techniques a) and b) are used to combat potential interference between the A- and B- block PCS systems. Comparing different Monte Carlo simulations makes it reasonable to suppose that average potential interference between adjacent PCS blocks (mutual BS to handset and handset to BS interference) is larger than between the UPCS block and the A-block (DECT handset to PCS handset). This further supports the conclusion that the potential interference to PCS is very small from DECT (or PWT) residential and enterprise applications in the 1 910 MHz to 1 930 MHz (UPCS) band.

B.5 Coexistence DECT and PHS

DECT and PHS are in some parts of the world, some Asian and Latin American countries, allowed to be implemented on the same spectrum, or partially the same spectrum.

There are similarities between DECT and PHS, which makes this possible, but also differences, which makes sharing spectrum less efficient in some cases.

The similarity is that that *Traffic Channels* both for DECT and PHS use instant Dynamic Channel Selection, DCS, which selects least interfered (isochronous) "time window/frequency" combinations as traffic channels. This provides efficient sharing both in the time domain and in the frequency domain within each system type. However, it also provides sharing between DECT and PHS systems when applied in the same local area. The reason for this sharing to work, is that the PHS TDMA frame is 5 ms, which is a sub-multiple of the DECT 10 ms frame. Thus time windows that are free during part of any 10 ms frame time, can be selected by DECT or PHS, whosoever may have the need. This packing (sharing) in the time domain works, but will off course be less efficient than within a single system.

A main difference is that PHS requires special carriers (spectrum) for its control signalling, control carriers. These carriers are fixed and must not be interfered by, nor be shared with traffic channels. DECT on the other hand, instant DCS and traffic channels also for the control signalling, and has no need for special spectrum for protected control carriers.

Thus the conclusion is that DECT and PHS can dynamically share spectrum for the (user data) traffic channels, but PHS needs part of the spectrum exclusively for its control carriers. In spite of this difference, in some countries both technologies are allowed to share the same common spectrum without any specific protection for PHS control carriers. DECT does not suffer from this. PHS may suffer, depending on application.

Private indoor applications

For application of indoor residential and office systems, the risk with a common spectrum is not very evident, because there is normally only one type of system per home and per office, and for these cases the wanted own signal is stronger than from a system from some other home or office. Furthermore, if PHS systems are loading their control carriers, any DECT system would automatically avoid them if they can be heard. On top of that, PHS has implemented a (slow) dynamic control channel allocation mechanism to fit the US UPCS isochronous etiquette rules, where several technologies are allowed to access a common band based on least interfered "time window/frequency" combinations.

Public outdoor applications

For public outdoor systems, where both technologies normally are used simultaneously in the same area, it is more important to protect the PHS carrier. In for instance China where public pedestrian systems are common, and in some Latin American countries where FWA are used, DECT Forum and the PHS MOU group have jointly helped regulators to find a good compromise (depending on market situation). The typical solution is like the decision in China, where PHS uses the band 1 900 MHz to 1 915 MHz and DECT the band 1 905 MHz to 1 920 MHz. Of a total of 20 MHz each technology gets 15 MHz, of which 5 MHz is protected for exclusive use for each system.

B.6 DECT coexisting on the US unlicensed bands, the UPCS band and the 900 MHz and 2,4 GHz ISM bands

Relevant unlicensed spectrum in the US are the **protected** UPCS (Unlicensed UPCS) Isochronous band 1 920 MHz to 1 930 MHz and the **unprotected** ISM bands 902 MHz to 928 MHz, 2 400 MHz to 2 483,5 MHz and 5 725 MHz to 5 850 MHz, see [2] and [32].

B.6.1 The protected UPCS isochronous band rules - good for real time/isochronous services (e.g. telephony)

The UPCS Isochronous rules provide coexistence with DECT equipment, because the basic principles and parameters for instant Dynamic Channel Selection, also called Listen Before Talk, are the same. E.g. an isochronous UPCS channel is defined as a frequency/time-window combination repeated in the time domain every frame of T_F ms, where $T_F = 10/N$ ms, where N is an integer. This provides instant spectrum sharing of high quality real time service connections both in the frequency and time domains. DECT (and PWT) has $T_F = 10$ ms. Thus DECT and UPCS rules both provide repetitive burst patterns in any repeated 10 ms frame sequence, which enable sharing in the time domain.

The US UPCS (Unlicensed UPCS) protected Isochronous band 1 920 MHz to 1 930 MHz is available for the DECT derivative PWT, but presently not for DECT, due to historic non-technical reasons. The US FCC is however currently (early 2004) revising the UPCS Isochronous rules and possibly removing the (artificial) fixed 1,25 MHz channelization and bandwidth limitation that currently (for no technical reason) bars DECT from this band. There is presently (early 2004) no protected spectrum available in the US for standard DECT equipment.

A protected spectrum is where autonomous systems follow a set of rules (an etiquette) which makes them compatible to maintain and protect high quality real time service radio links in an environment of uncoordinated system installations.

B.6.2 The unprotected ISM bands - not good for real time/isochronous services

Standard DECT equipment can since May 2002 be applied in the US within the ISM bands 902 MHz to 928 MHz, 2 400 MHz to 2 483,5 MHz and 5 725 MHz to 5 850 MHz, see [2] and [32].

Opposite to a protected DECT spectrum having an etiquette whereby high quality real time radio links of compatible but uncoordinated systems are maintained and protected, the ISM bands allow for uncoordinated usage of a variety of incompatible communication devices and also industrial, scientific and medical devices. Therefore maintenance of high quality of service will not be guaranteed when other types of ISM devices (non-DECT devices) are used in the same local area. This applies especially to voice and video services, but is less critical for best effort packet data services, where non-time-critical retransmissions are applied. If a manufacturer nevertheless would implement DECT for the US ISM bands, the band 902 MHz to 928 MHz could be preferred over the 2 400 MHz to 2 483,5 MHz band due to lack of potential interference from IEEE 802.11b WLANs, microwave ovens and Bluetooth devices. The 900 MHz spectrum provides better range than the 2,4 GHz spectrum. The 5 GHz ISM band is of less interest due to range limitations and higher cost and current consumption.

Annex C: The concepts of traffic capacity and efficient use of the spectrum

C.1 General

It is important, both from operator's, user's and regulator's point of view that the different applications of DECT do not violate reasonable requirements on spectrum efficiency and on the quality of the transferred service.

C.2 The relation between infra structure cost and spectrum efficiency

Efficient use of the spectrum cannot be determined by such a simple term as e.g. "traffic channels per MHz". For a technology like DECT spectrum efficiency for speech has been defined as E/km² per floor at comparable (speech) quality and infrastructure cost. See ETR 042 [21] clause 2.

The relation to the cost, comes from the fact that the traffic capacity (E/km²) for DECT will be proportional to the base station density (RFPs/km²) (see note). See clause 4.2. Therefore, the capacity is very dependent of the infrastructure cost.

Cost efficient implementations at required capacity and service quality is known as a prime goal for all standardization and is beneficial to the general public.

Therefore, efficient use of a spectrum has both a cost, a quality, a type of service and a spectrum efficiency (spectrum/connection) component. It is for example very important quality difference between a 4 kbit/s and a 64 kbit/s speech link.

NOTE: DECT can maintain the radio link quality at decreasing cell sizes due to the C/I limited DCS and quick seamless inter-cell handover procedures.

C.3 Maximizing the application dependent spectrum efficiency

The maximum load per cell has to be limited, at least for multi-site above rooftop applications, in order to provide efficient reuse and sharing of the spectrum. Simulations indicate that it is highly desirable for an operator to limit the planned average traffic in any one coverage cell (omnidirectional or sector shaped) to about 10 E (full-slot duplex bearers or equivalent) per 20 MHz of total allocation. Exceeding this limit could make the effective range of his cells disproportionately vulnerable to interference from other users of the spectrum.

The intention is to restrict the maximum load from one antenna on the DECT spectrum in a specific geographical direction. This advice should not limit economic infrastructure implementations, but is a tool for optimizing coexistence on the common DECT spectrum.

C.3.1 Directional gain antennas

Use of directional gain antennas generally increases the spectrum efficiency, as shown in clause A.2.3. The DECT standard (EN 300 175, parts 1 [1] to 8 [8]) recommends to allow general use of up to 12 dBi gain antennas and up to 22 dBi upon (case by case) approval by national authorities.

Sectorized antennas can also provide a common RFP site for several cells, as for the examples with the DAS nodes in clause A.3. Common cell sites provide essential cost savings for important applications.

C.3.2 Frame synchronization

DECT is designed not to require frame or slot synchronization between base stations or systems to maintain a high radio link quality. See clause E.2.8. Synchronization between close by base stations does however in general decrease the local load on the spectrum.

C.3.2.1 Synchronization between RFPs within a DECT system (FP)

Synchronization of RFPs within a DECT system (FP) is essential for all high capacity multi-cell systems, and could be mandated (within clusters) for such public applications. In-system synchronization is normal practice for multi-cell office systems, where the RFPs obtain the synchronization over the connection wires to the radio exchange (RFP controller). Synchronization within office systems is regarded essential by manufacturers, both to provide efficient handover and to meet internal system capacity requirements.

C.3.2.2 Intersystem synchronization

Intersystem synchronization (to an absolute reference or mutual between two systems) is essential for above rooftop high capacity applications, and should be mandated for such applications. Intersystem synchronization (to an absolute reference or mutual) is also essential for "hot spot" public pedestrian applications. The DECT standard (EN 300 175, parts 1 [1] to 8 [8]) provides for this purpose a cost effective absolute time synchronization option using the GPS satellite system. Other means for mutual frame synchronization are also available in the DECT standard (see EN 300 175, parts 1 [1] to 8 [8]).

For other cases inter system synchronization is typically not critical, and should not be mandated.

In order to prevent potential problems, it could be recommended that all public systems, i.e. all systems needing a license, are forced to be locally synchronized to each other, if an operator requires it in a specific local area. This means that mutual synchronization must be a part of a public system.

This leads to the following simple rule:

- public systems should provide intrasystem cluster synchronization, and should have either GPS synchronization and a SYNC output port or a complete SYNC port (both input and output). This will allow absolute time synchronization via GPS or wired mutual synchronization, if an operator requires local synchronization between operators.

NOTE: For public pedestrian street type systems (antennas lamp post, below rooftop, 1E per base), synchronization may improve the capacity, but is often not essential. GPS synchronization is feasible if several base stations are part of the same FP. It is not cost effective for single RFP FPs connected directly to a local exchange unless it is possible to transfer frame synchronization signals over the local exchange.

C.3.3 Application of WRS

Some WRS applications, for example outdoor to indoor coverage enhancements, decrease the local outdoor load on the spectrum, since no excessive outdoor field strength is required to penetrate the building.

Applications of WRS are in most applications not critical for the local load on the spectrum. A CRFP type WRS link always provides less load on the spectrum than an REP type WRS link, but the REP is not critical for the load on the spectrum except for high density WRS installations with above rooftop remote links. The GAP and RAP interworking profiles will use the CRFP type of WRS. See clause A.6.

Annex D: Comparison with systems using fixed channel selection

This annex analyses the spectrum required for different single DECT systems compared with the spectrum required by a comparable system using FCA. By comparable technology is meant a duplex 32 kbit/s service transfer and radio receivers with limiter/discriminator detector or differential detector. The modulation type has only secondary influence.

D.1 Public pedestrian outdoor suburban application

DECT simulations indicate that 61 RFPs placed in hexagonal grid with 300m separation will at 1 % GOS provide 5,2 E average traffic per base with 6 carriers, 72 access channels, allocated for DECT. See figure A.3.

We assume that a comparable system with FCA will use a 16 cell reuse pattern for a suburban 2-dimensional outdoor application [18]. We use the Erlang B traffic formula at 1 % GOS to estimate the offered average traffic per base.

D.1.1 Traffic when using the same total number of access channels as DECT

The number of access channels per base will be $72 / 16 = 4,5$. Of these 4,5, one has to be a control channel. Therefore, there are 3,5 traffic channels available per base. 3,5 trunks give 0,7 E average traffic (Erlang B). In this example DECT is $5,2 / 0,7 = 7,4$ times more spectrum efficient than the comparable system using FCA.

D.1.2 Total number of access channels required for the same traffic per base

5,2 E average traffic per base will require 11 traffic channels per base (Erlang B), plus one control channel, which gives 12 access channels per base and totally $12 \times 16 = 192$ access channels for the system allocation. In this example DECT is $192 / 72 = 2,7$ times more spectrum efficient than the comparable system using FCA.

D.1.3 Summary tables

Table D.1: Comparison for outdoor suburban case with 72 DECT access channels

Outdoor suburban, FCA 16 cell reuse, DECT totally 72 access channels (6 DECT carriers)	DECT	FCA Equal traffic/base	FCA Equal number of access channels
Total number of access channels	72	192	72
# of channels per base (incl. 1 control ch.)		11 + 1	3,5 + 1
Average traffic per base	5,2 E	5,2 E	0,7 E
DECT spectrum efficiency gain		2,7 times	7,4 times

Table D.2 shows the same calculations with 48 access channels allocated to DECT, see figure A.3.

Table D.2: Comparison for outdoor suburban case with 48 DECT access channels

Outdoor suburban, FCA 16 cell reuse, DECT totally 48 access channels (4 DECT carriers)	DECT	FCA Equal traffic/base	FCA Equal number of access channels
Total number of access channels	48	152	48
# of channels per base (incl. 1 control ch.)		8,5 + 1	2 + 1
Average traffic per base	3,4 E	3,4 E	(0,15 E)
DECT spectrum efficiency gain		3,2 times	(23 times)

From tables D.1 and D.2 we can conclude that DECT in outdoor pedestrian applications is typically 3 to 7 times more spectrum efficient than a comparable technology using FCA.

D.2 Office multi-floor applications

DECT simulations indicate that 16 RFPs per floor placed in rectangular grid on 3 floors will at 1 % GOS provide 4,4 E average traffic per base with 4 carriers, 48 access channels, allocated for DECT (see table A.2).

We assume that a comparable system with FCA will use a 32 cell reuse pattern for an office 3-dimensional application. We use the Erlang B traffic formula at 1 % GOS to estimate the offered average traffic per base.

By applying the same kind of calculations as for the outdoor case above, we obtain the results given in table D.3.

Table D.3: Comparison for indoor 3-dimensional case with 48 DECT access channels

Office multi-floor, FCA 32 cell reuse, DECT totally 48 access channels	DECT	FCA Equal traffic/base	FCA Equal number of access channels
Total number of access channels	48	352	48
# of channels per base (incl. 1 control ch.)		10 + 1	0,5 + 1
Average traffic per base	4,4 E	4,4 E	(< 0,4 E)
DECT spectrum efficiency gain		7 times	> 10 times

From table D.3 we can conclude that DECT in an indoor application is typically 7 to 10 times more spectrum efficient than a comparable technology using FCA.

Annex E: DECT instant DCS procedures

E.1 Summary of some DECT procedures providing the high traffic capacity and the maintenance of a high quality radio link

Some of the essential DECT procedures and features that provide the high traffic capacity and the maintenance of a high radio link quality, are listed below.

Handsets (idle locked or in communication) are always locked to closest (strongest) base station. Automatic seamless handover is made as soon as an other base becomes stronger. The seamless handover provides "make before break", which is important for a high quality of voice service. Being locked to the strongest base station is essential for efficient access channel reuse and link robustness, which leads high capacity.

Down-link broadcast system information and incoming call alert (paging) is distributed on each down-link dummy and traffic bearer. The more traffic, the more to lock to. There is no specific fixed control carrier that can be interfered so that the whole base station will be out of operation.

The short dummy bearers providing down-link broadcast system information and paging on idle base stations are checked at the RFP about every second, during a randomly selected odd frame, to remain on a least interfered access channel. Two dummy bearers with at least one slot separation avoid blind slots at seamless handover, since a GAP PP is not required to be able to switch carrier during the inter slot guard band time. The figures below shows an example on how blind slots are avoided when making a seamless handover from cell 1 to cell 2. If there had been no traffic in cell 2, then the traffic bearer on carrier 5 would have been a second dummy bearer.

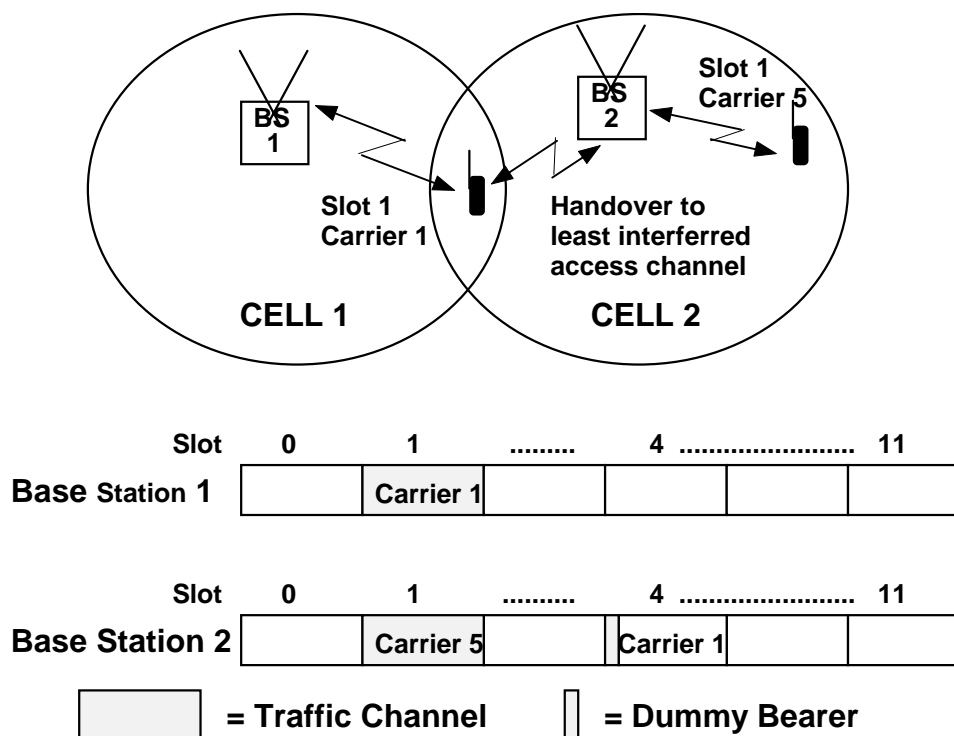


Figure E.1: Example on how to avoid blind slots at seamless inter-cell handover

For call set-up or handover, the handset selects a least interfered access channel and makes direct set-up (20 ms) on this traffic channel to the strongest base station. This provides quick bearer access, 50 ms for data.

The handover is decentralized and handset controlled. This avoids complex co-ordination or tricky channel selection requirements on the fixed infra structure. The RFPs however may provide blind slot information to the PPs to speed up the access.

E.2 Detailed description of the DECT instant DCS procedures and features

E.2.1 Instant DCS or CDCS

The principles described in this clause are based on Multi Carrier, Time Division Multiple Access, Time Division Duplex (MC/TDMA/TDD). Figure E.2 shows the TDMA/TDD frame for DECT here with 12 + 12 full slots.

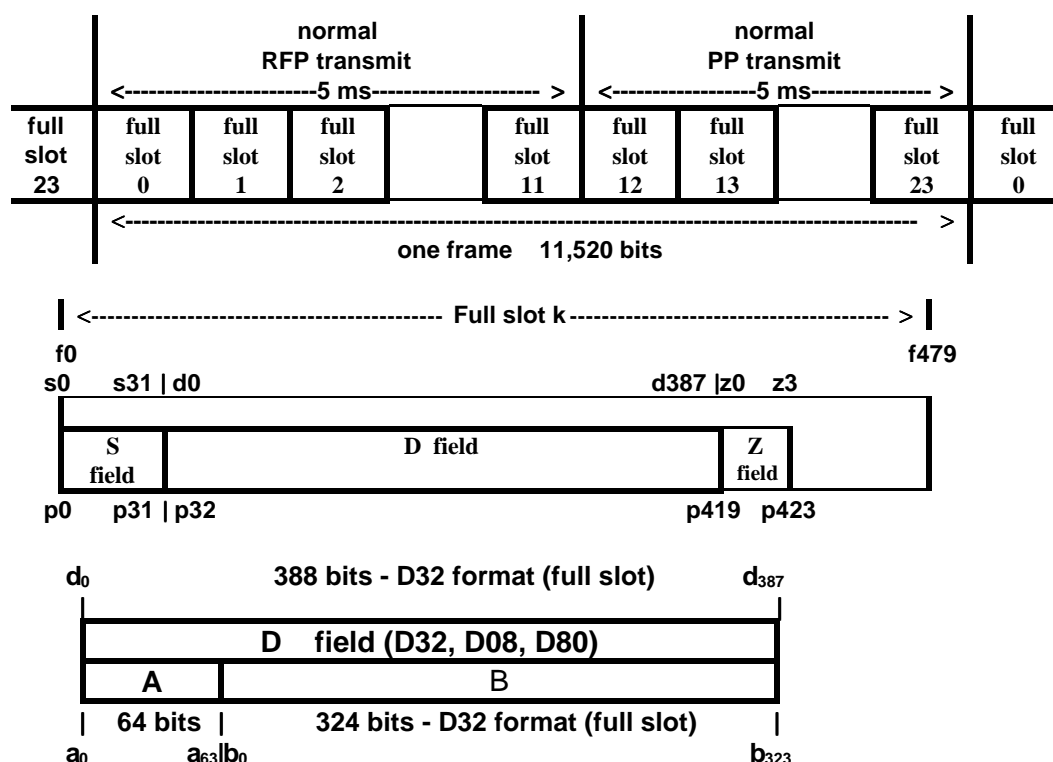


Figure E.2: TDMA slot structure for DECT

The basic property of CDCS is that a physical channel is selected, that is least interfered at the moment of selection.

The DCS includes the following:

- selection of bearers for control signalling;
- selection of simplex or duplex traffic bearers;
- selection of traffic bearers for handover;
- selection of bearers for extension of user data rate of an established connection.

Examples for selection criteria for different types of bearers can be found in EN 300 175-3 [3], clause 11.4.

In DECT a channel selected for a duplex service is changed only if the quality is degraded or if another base station of the same system becomes stronger, while *a down link broadcast or connectionless service shall be kept at a least interfered channel*, if needed by repeated moves to new channels.

E.2.2 Dynamic selection of control channels

In order to provide for uncoordinated installations in a multioperator environment where a common frequency resource is shared, it is necessary that *both traffic channels and control channels are continuously dynamically selected*.

In this kind of environment it is likely that the same handset has access rights to several systems, e.g. a residential system, an office system and several public systems.

Therefore, it is important that each base station continuously broadcasts access rights and other system information. Therefore, call set up attempts by handsets through blind interfering transmissions are avoided, since *each handset will know if a suitable service is available by listening only. DECT handsets may transmit only after they have succeeded to lock to a base station with the wanted access rights identity*.

The broadcast information on a down link control channel is most essential. If the control channel is interfered, call set up is impossible (or may be possible through a complicated escape mechanism).

It is against the general philosophy to allocate a special part of the frequency band to control channels. This may impose not wanted restrictions on the control channel structure. Furthermore, it is probably easier to find an interference free channel with unrestricted selection over the entire frequency band.

In DECT the down link broadcast and control channel is available as a part of every downlink transmission. Besides traffic bearers a down link dummy bearer is also defined, which only contains the synchronization field and the broadcast and control channel part (A-field) of a traffic bearer. See figures E.1 and E.2 and EN 300 175, parts 2 [2] and 3 [3].

The down link broadcast information has to be continuously transmitted from each DECT base station. The following combinations of downlink traffic channels and dummy bearers are allowed.

Table E.1

Downlink traffic channel	Dummy bearer
None active	1 or 2 active
At least one active	None or 1 active

When 2 active dummy bearers are used, they should be transmitted on different antennas. See clause E.2.6.

The dummy bearer is always active at low traffic, but is very short and does not steal essential capacity. e.g. in an environment of unsynchronized systems, a dummy bearer loads the radio environment with a load corresponding to only 10 % of that of a duplex traffic channel.

The system is allowed to make frequent short breaks in the dummy bearer transmission to check if it is still on a least interfered channel. If not, a change information is broadcast and the dummy bearer is moved accordingly. *This ensures that the downlink broadcast bearer stays at a least interfered channel.* When there is much traffic from a base station, no dummy bearers are needed since the broadcast information is derivable from each downlink traffic bearer.

E.2.3 The broadcast paging and system information

Since the paging and system information is available on every downlink channel, a handset can lock to any downlink transmission and derive the required system information. If it contains the wanted access rights identity, it is possible to make and receive calls. The access rights identity (the system and base station identity) is transmitted in almost every slot, while other system information is transmitted less frequently.

Examples of broadcast system information that has to be derived by a handset before it is allowed to transmit are:

- system identity (primary access rights identity);
- base station identity;
- frame synchronization;
- multiframe synchronization;
- number of transceivers per base station and the synchronization and the order of the base station receiver scanning of RF-carriers;
- frame number for cipher synchronization;
- the RF carriers allowed to be used by the system;
- FPs capabilities;
- secondary access rights information.

The base station identity makes it possible to make *call set up and handover to the closest and strongest base station*.

The multiframe synchronization is needed e.g. for the handset current saving, since a paging sequence always starts at a multiframe boundary.

The information on used carriers can be used for e.g. local barring of channels to avoid local interference, or for system related barring, or for later extension or decrease of usable frequency bands. A DECT RFP may also inform on preferred channels.

The FPs capability informs on e.g. speech codec type, fax, data services, etc.

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

The identity structure for DECT is found in EN 300 175-6 [6].

E.2.4 Dynamic selection of traffic channels and maintenance of the radio link

For simplicity only the set up of a (single) duplex bearer is described.

After having locked itself to the strongest of the wanted base stations, the handset makes *a list of least interfered channels*, which it regularly updates. For a duplex bearer, interference level is measured in the receiver channels of the handset. At call set up the handset selects "the best" channel and sends an access request to the closest (strongest) base station. This request is sent in synchronism with the derived base station receiver RF carrier scanning order. If a response is received on the relevant duplex response slot, half a frame (5 ms) later, the duplex bearer is established. Else an attempt is made on the second best channel etc.

The handover is portable controlled. Without interrupting the current connection it regularly scans the other channels and *records a ranking list of least interfered channels and of own base stations that are stronger than the original one*, and is therefore prepared to perform a very quick bearer handover (20 ms). The base station gives immediate feed back on quality of received slots to the portable.

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

The concept as implemented for DECT provides a *quick seamless handover that does not need centralized control nor complicated procedures*. The key is TDMA in combination with the portable controlled DCS. The old link is maintained on one slot in the portable, while the new link is set up to the closest base station on another "best" time slot. When the new link is established, the (new) base station requests the central control to make a seamless switch from the old to the new radio link. This is an important TDMA feature.

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

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

E.2.5 MC/TDMA/TDD simple radio multichannel base station

MC/TDMA/TDD with a reasonable number of traffic slots (8 to 12 duplex connections) provides a cost effective *Standard Base Station concept*. This concept as applied for DECT is described in ETR 042 [21].

This Base Station can access all traffic channels (common for all systems). It consists of one single radio that can instantly change carrier frequency from slot to slot. With the standard 12 + 12 time slots chosen for DECT, it offers over 5 E average speech traffic, corresponding to 25 handsets with 0,2 E each.

This provides a major system and cost benefit:

- the number of base radios needed per 12 offered speech traffic channels is reduced to 1 from to the 12 required for analogue or digital FDMA systems;
- the in-system requirements on intermodulation and adjacent channel interference are also reduced since each transmission to and from a Standard Base Station uses always different time slots;
- in-system blocking requirements will also be reduced, since escape to another available time slot will give perfect isolation;
- asymmetric links are provided with up to 23 time slots in one direction and 1 time slot in the other direction. See clause 7.2;
- furthermore, simulations for DECT (12 + 12 time slots) show that for handsets it is not essential to require carrier change within an interslot guard band.

These properties will be lost if a low number of slots per frame (e.g. 4 + 4) are chosen.

E.2.6 Antenna base station diversity

The concept as applied for DECT provides and combines different types of diversity; antenna diversity by changing the antenna radiation pattern, frequency diversity by intra-cell handover to another carrier and macro diversity by intercell handover. Diversity increases capacity, extends the range and decreases the time dispersion effects. *Application of antenna base station only diversity is simple for the Standard Base Station and is effective due to TDD.*

E.2.7 Traffic capacity

Two parameters that affect the traffic capacity are the type of modulation and the relative carrier spacing. For DECT the chosen modulation Gaussian Frequency Shift Keying (GFSK), with deviation characteristics equivalent to GMSK with a nominal BT value of 0,5, gives good sensitivity and C/I performance. It allows for a low cost, robust, fast acting, limiter-discriminator detector, with 1-threshold bit-by-bit detection. It also allows low cost IF-filters and low radio frequency stability requirements.

This modulation type, giving rather large relative carrier spacing, is optimized for low cost, high capacity, residential and office applications. With relevant diversity techniques, it is suitable for outdoor pedestrian street services with 200 m to 300 m range. 5 km Line of Sight ranges are supported for RLL applications using directional gain (12 dBi) antennas. See clause 6.4.1.

The latest version of the DECT base standard includes backwards compatible 4-, 8-level, 16-level and 64-level modulation options. This will increase the bit rate of single radio DECT equipment by a factor 2, 3, 4 or 6 with retained transmitter bandwidth, carrier spacing and slot structure.

The traffic capacity and spectrum requirements for different DECT application scenarios can be found elsewhere in this report.

E.2.8 Inter system synchronization due to TDMA and TDD

Frame and slot synchronization between base stations within a radio exchange is easily provided. *In order to avoid high handover rates and quick changes in the "least interfered channel" lists due to the slot drift from adjacent DECT systems, the frame cycle stability should typically be 5 ppm or less.* This corresponds to a drift over 1 slot per 80 seconds.

The slow slot drift from unsynchronized neighbours does not introduce a new element, but is elegantly dealt with by the standard seamless (normally intra-cell) handover and channel selection procedures. It is in fact easier to make a seamless handover due to slot drift, than to cure the normal effect of a sudden channel (slot) theft, that occasionally occurs in all DCS Systems. DECT has mechanisms to detect slot drift and make a handover before the user data is corrupted. *Slot synchronization between systems is useful, but not a requirement, for maintaining a high radio link quality. Unsynchronization between close by office systems in the same building leads to a graceful capacity decrease, which is small compared to the total capacity gain given by using CDCS. For high capacity above roof top installations synchronization is essential for the capacity.*

For the general pico cell applications, for instance in offices, there is normally no significant difference between the average interference levels from base stations or handsets from neighbour cells. Base stations and handsets are close to each other and their antennas are used at similar levels above the ground or floor. *Therefore, TDD has no drawback compared to FDD in this unsynchronized environment.*

If for a specific public service omni directional base station antennas are installed high above the level where handsets normally are used, it is recommended to at least frame synchronize close by base stations of this kind. Else these base stations would cause much more interference to the up links than the handsets. A frame synchronization (over the line connection) with an accuracy of about 1 ms (DECT), will for this case make the interference performance (when using TDD) similar to the performance when using FDD. The need for synchronization is much less critical for systems using CDCS, than for systems using FCA. An attractive solution for this specific application is to derive the synchronization reference from the GPS but other means for synchronization are also available, as seen from other parts of the present document.

Annex F: RF modifications of DECT enabling applications on FDD (paired up-link/down-link) spectrum

DECT, although basically a TDD technology, can also be applied on an arbitrary FDD spectrum, maintaining its unique instant dynamic channel selection provision and other properties. This is possible with standard DECT TDD burst mode controllers by implementing the required duplex frequency shift in the RF-part when switching between transmission and reception. In this way a DECT link provides a combination of TDD and FDD. Such a DECT FDD base station (and handset) does not transmit and receive at the same time and does thus avoid expensive duplex filters at the expense of using the spectrum resource only half the time. However, by off-setting the frame timer of every second DECT base station by 5 ms, the available spectrum will be fully used within a multi-cell system. Further information is found in TR 101 370: "Digital Enhanced Cordless Telecommunications (DECT); Implementing DECT Fixed Wireless Access (FWA) in an arbitrary spectrum allocation" [31].

History

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