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Contents

Foreword 7

1 Scope 9

2 References 9

3 Definitions and abbreviations 11
  3.1 Definitions 11
  3.2 Abbreviations 15

4 Introduction to DECT services and applications 16

5 Principles for providing required traffic capacity and link quality on a common spectrum allocation 17
  5.1 A new concept: the local load on the spectrum 17
  5.2 Dynamic Channel Selection (DCS) 18
    5.2.1 Spectrum efficiency of DECT compared with a system using FCA 19
    5.2.2 Spectrum efficiency due to multi-operator multi-application coexistence on a common allocation 19
      5.2.2.1 Residential base station applications 19
      5.2.2.2 Office base station applications 20
      5.2.2.3 Public outdoor systems 20
      5.2.2.4 Summary on multi-operator multi-application coexistence on a common allocation 21
        5.2.2.4.1 Conclusion for the case with speech and estimated emerging data services 22
        5.2.2.4.2 Conclusion for the case with mainly speech services 23
  5.3 Increase traffic by denser infra structure, C/I limited capacity 23
  5.4 Increasing link quality without increasing the load on the spectrum 24
  5.5 Means for adjusting to emerging growth of traffic (subscribers) 24

6 DECT applications - scenarios 25
  6.1 Residential application 25
  6.2 Office/factory application 25
    6.2.1 Large companies in a business centre 26
    6.2.2 Large companies in industrial zones 26
    6.2.3 Small/medium size companies 26
  6.3 Public pedestrian application 26
  6.4 RLL application 27
    6.4.1 Rural area - range requirements 27
      6.4.1.1 Special provisions for single link ranges beyond 5 km 28
    6.4.2 Urban area - traffic capacity requirements mainly for speech services 28
  6.5 Summary of traffic requirements 28

7 ISDN, data and multimedia applications 29
  7.1 ISDN services 29
  7.2 Data services in general 30

8 Multi-system and multi-service DECT applications coexistence analysis for speech services and emerging increase of data related services 31
  8.1 Interference between residential systems 31
  8.2 Interference between residential systems and other applications 31
  8.3 Interference between office systems 31
  8.4 Interference between office and public pedestrian street systems 32
  8.5 Interference between office and RLL systems 33

8.6 Interference between public pedestrian systems ... 33
8.7 Interference between RLL systems ... 34
  8.7.1 Spectrum requirements for RLL applications ... 35
8.8 Interference between public pedestrian systems and RLL systems ... 35
  8.8.1 Spectrum load for a system consisting of DASs and WRSs (CRFPs) ... 36
8.9 Interference from public systems to private users ... 37
8.10 Summary on coexistence and spectrum requirements ... 37

9 Conclusion on spectrum requirements for different scenarios ... 39

10 Recommendation on procedures for economic handling of hot spots and emerging traffic increase ... 39
10.1 Monitoring ... 40
10.2 Adjustment of the infrastructure ... 40
10.3 Frame synchronization ... 40
10.4 Maximum traffic load at RFPs ... 41
10.5 Sharing infrastructure ... 41
10.6 Carrier back-off ... 42

Annex A: Simulation results ... 43

A.1 Simulations of WPBX office systems ... 43
A.1.1 Simulation scenario ... 43
A.1.2 Simulation results ... 44
  A.1.2.1 Capacity in large office landscapes with soft partitioning ... 45
  A.1.2.2 Interference to and from offices ... 45

A.2 Simulations of public street public pedestrian systems ... 47
A.2.1 Simulation scenario ... 47
A.2.2 Simulation results ... 48

A.3 Simulations of above rooftop RLL systems ... 49
A.3.1 Simulation scenario's ... 49
  A.3.1.1 Basic scenario ... 49
  A.3.1.2 Additional scenario's ... 51
A.3.2 Simulation results ... 52
  A.3.2.1 Basic capacity simulation results ... 52
  A.3.2.2 Capacity and carrier availability ... 52
  A.3.2.3 Synchronization ... 53
  A.3.2.4 Directional versus omni-directional antennas ... 54
  A.3.2.5 Sensitivity to C/I performance ... 54
  A.3.2.6 Effect of cell size on the capacity ... 55
  A.3.2.7 Multi-operator scenarios ... 55
    A.3.2.7.1 Coexistence of DAS systems with very different cell sizes ... 56
A.3.3 Conclusions ... 58

A.4 Simulations of below rooftop RLL systems and other RLL systems ... 58

A.5 Coexistence between above rooftop RLL systems and a public pedestrian street system ... 58

A.5.1 Simulation scenario ... 59
A.5.2 Simulation results ... 59
  A.5.2.1 Interference from the RLL system to the public pedestrian system ... 59
  A.5.2.2 Interference from the public pedestrian system to the RLL system ... 59
  A.5.2.3 Conclusions ... 60
    A.5.2.3.1 Spectrum load for a system consisting of DASs and WRSs (CRFPs) ... 60

A.6 The impact of WRSs on infrastructure cost and spectrum utilization ... 61
A.6.1 Examples of scenarios with WRS type CRFP ... 62
A.6.2 Examples of scenarios with WRS type REP ... 63

Annex B: Coexistence on a common spectrum allocation with evolutions and derivatives (PWT) of DECT 64

Annex C: The concepts of traffic capacity and efficient use of the spectrum 65

C.1 General 65

C.2 The relation between infra structure cost and spectrum efficiency 65

C.3 Maximizing the application dependent spectrum efficiency 65
  C.3.1 Directional gain antennas 65
  C.3.2 Frame synchronization 66
    C.3.2.1 Synchronization between RFPs within a DECT system (FP) 66
    C.3.2.2 Intersystem synchronization 66
  C.3.3 Application of WRS 66

Annex D: Comparison with systems using fixed channel selection 67

D.1 Public pedestrian outdoor suburban application 67
  D.1.1 Traffic when using the same total number of access channels as DECT 67
  D.1.2 Total number of access channels required for the same traffic per base 67
  D.1.3 Summary tables 67

D.2 Office multi-floor applications 68

Annex E: DECT instant DCS procedures 69

E.1 Summary of some DECT procedures providing the high traffic capacity and the maintenance of a high quality radio link 69

E.2 Detailed description of the DECT instant DCS procedures and features 70
  E.2.1 Instant DCS or CDCS 70
  E.2.2 Dynamic selection of control channels 70
  E.2.3 The broadcast paging and system information 72
  E.2.4 Dynamic selection of traffic channels and maintenance of the radio link 72
  E.2.5 MC/TDMA/TDD simple radio multichannel base station 73
  E.2.6 Antenna base station diversity 73
  E.2.7 Traffic capacity 74
  E.2.8 Inter system synchronization due to TDMA and TDD 74

History 75

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Foreword

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

ETRs are informative documents resulting from ETSI studies which are not appropriate for European Telecommunication Standard (ETS) or Interim European Telecommunication Standard (I-ETS) status. An ETR may be used to publish material which is either of an informative nature, relating to the use or the application of ETSs or I-ETSs, or which is immature and not yet suitable for formal adoption as an ETS or an I-ETS.

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1 Scope

This ETSI Technical Report (ETR) 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.

2 References

For the purposes of this ETR, the following references apply:

[1] ETS 300 175-1: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 1: Overview".

[2] ETS 300 175-2: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 2: Physical Layer".

[3] ETS 300 175-3: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 3: Medium Access Control (MAC) layer".

[4] ETS 300 175-4: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 4: Data Link Control (DLC) layer".

[5] ETS 300 175-5: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 5: Network (NWK) layer".

[6] ETS 300 175-6: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 6: Identities and addressing".

[7] ETS 300 175-7: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 7: Security features".

[8] ETS 300 175-8: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 8: Speech coding and transmission".

[9] ETS 300 175-9: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 9: Public Access Profile (PAP)".

[10] ETS 300 444: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Generic Access Profile (GAP)".

[11] TBR 6: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); General terminal attachment requirements".

[12] ETS 300 765-1: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Radio in the Local Loop (RLL) Access Profile (RAP); Part 1: Basic telephony services”.

[13] ETS 300 765-2, "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Radio in the Local Loop (RLL) Access Profile (RAP); Part 2: Advanced telephony services”.

[14] ETR 178: "Radio Equipment and System (RES); Digital European Cordless Telecommunications (DECT); A high level guide to the DECT standardization”.

[15] ETR 246: "Radio Equipment and Systems (RES); Digital European Cordless Telecommunications (DECT); Application of DECT Wireless Relay Station (WRS)”.

[16] ETS 300 700: "Radio Equipment and Systems (RES); Digital European Cordless Telecommunications (DECT); Wireless Relay Station (WRS)”.

[17] ETR 308: "Radio Equipment and Systems (RES); Digital Enhanced Cordless Telecommunications (DECT); Services, facilities and configurations for DECT in the local loop".

[18] Proceedings of the IEEE 44th Vehicular Technology Conference, (Stockholm June 4-7 1994), Åkerberg, Brouwer, van de Berg, Jager: “DECT technology in the local loop”.

[19] TIA/T1 JTC(AIR)/95.02.02-012R1: “TAG 3 (PACS) Radio Channel System Report”.

[20] TIA/EIA-662: “Personal Wireless Telecommunications - Interoperability Standard (PWT)”.

[21] TIA/EIA-696, “Personal Wireless Telecommunications Enhanced - Interoperability Standard (PWT-E)”.

[22] ETR 042: "Radio Equipment and Systems (RES); Digital European Cordless Telecommunications (DECT); A Guide to DECT features that influence the traffic capacity and the maintenance of high radio link transmission quality, including the results of simulations".

[23] ETR 139: "Radio Equipment and Systems (RES); Radio in the Local Loop (RLL)".

[24] 91/263/EEC: “Council Directive of 29 April 1991 on the approximation of the laws of the Member States concerning telecommunications terminal equipment, including the mutual recognition of their conformity” (Terminal Directive).

[25] 91/287/EEC: "Council Directive of 3 June 1991 on the frequency band to be designated for the coordinated introduction of digital European cordless telecommunications (DECT) into the Community”.

[26] 91/288/EEC: "Council Directive of 3 June 1991 on the coordinated introduction of digital European cordless telecommunications (DECT) into the Community".

[27] TBR 22: "Radio Equipment and Systems (RES); Attachment requirements for terminal equipment for Digital Enhanced Cordless Telecommunications (DECT) Generic Access Profile (GAP) applications".

[28] 90/388/EEC: "Council Directive of 28 June 1990 on competition in the markets for telecommunications services".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of this ETR, the following 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 effect the practical coverage. A typical example is space diversity, provided by two vertically polarized antennas separated by 10 cm to 20 cm.

bearer: See Medium Access Control (MAC) bearer or bearer service.

broadcast: A simplex point-to-multipoint mode of transmission.

NOTE 1: 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 2: Call may sometimes be used to refer to processes of all layers, since lower layer processes are implicitly required.

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

NOTE 3: A cell may include more than one source of radiated Radio Frequency (RF) energy (i.e. more than one radio end point).

centrex: An implementation of a private telecommunication network exchange that is not located on the premises of the private network operator. It may be co-located with, or physically a part of a public exchange.

channel: See physical channel.

cluster: A logical grouping of one or more cells between which bearer handover is possible. A Cluster Control Function (CCF) controls one cluster.

NOTE 4: 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): A WRS that provides independent bearer control to a PT and FT for relayed connections.

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

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

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

down-link: Transmission in the direction FT to PT.

duplex bearer: The use of two simplex bearers operating in opposite directions on two physical channels. 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): A logical grouping that contains application processes and supports telecommunication services.

NOTE 5: From the OSI point of view, end systems are considered as sources and sinks of information.

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

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

NOTE 6: A DECT FP contains the logical elements of at least one FT, plus additional implementation specific elements.

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

NOTE 7: A FT only includes elements that are defined in ETS 300 175, parts 1 to 8 [1] to [8]. This includes radio transmission elements (layer 1) together with a selection of layer 2 and layer 3 elements.

frame: See TDMA frame or DLC frame.

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

guard space: The 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 8: 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: $^1/_{48}$ of a TDMA frame which is used to support one physical channel.

handover: The process of switching a call in progress from one physical channel to another physical channel. These processes can be internal (see internal handover) or external (see external handover).

NOTE 9: 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: A call received at a Portable Part (PP).

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

internal handover: Handover processes that are completely internal to one FT. Internal handover reconnects the call at the lower layers, while maintaining the call at the NWK layer.

NOTE 10: The lower layer reconnection can either be at the DLC layer (see connection handover) or at the MAC layer (see bearer handover).

interoperability: The 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): A unit that is used to interconnect subnetworks.

NOTE 11: The IWU will contain the InterWorking Functions (IWF) necessary to support the required subnetwork interworking.

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

multiframe: A 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): All 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): The individual or entity who or which is responsible for operation of one or more DECT FPs.

NOTE 12: The term does not imply any legal or regulatory conditions, nor does it imply any aspects of ownership.

outgoing call: A call originating from a PP.

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

NOTE 13: 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: The domain in which the PP will be paged as a part of incoming call establishment.

NOTE 14: 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): A physical grouping that contains all elements between the user and the DECT air interface. PP is a generic term that may describe one or several physical pieces.

NOTE 15: A DECT PP is logically divided into one PT plus one or more portable applications.

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

NOTE 16: A PT only includes elements that are defined in ETS 300 175, parts 1 to 8 [1] to [8]. This includes radio transmission elements (layer 1) together with a selection of layer 2 and layer 3 elements.

private: An 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 17: The term does not include any legal or regulatory aspects, nor does it indicate any aspects of ownership.

public: An 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 18: The term does not include any legal or regulatory aspects, nor does it indicate any aspects of ownership.

Public Access Profile (PAP): A defined part of this ETS, i.e. ETS 300 175-9 [9] that ensures interoperability between FPs and PPs for public access services.

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

NOTE 19: The term does not imply any legal or regulatory aspect, nor does it imply any aspects of ownership.

radio channel: No defined meaning. See RF channel or physical 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) : A WRS that relays information within the half frame time interval.

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

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

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

NOTE 20: The term does not imply any legal or regulatory conditions, nor does it indicate whether public service or private service is provided.

NOTE 21: The term service provider is also used with a different meaning in the ISO/OSI layered model.

simplex bearer: A simplex bearer is the MAC layer service that is created using one physical channel. See also duplex bearer and double simplex bearer.

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

TDMA frame: A time-division multiplex of 10 ms duration containing 24 successive full slots. 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: A 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): A 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): A 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 22: The DECT termination can be a PT or an FT or another WRS.

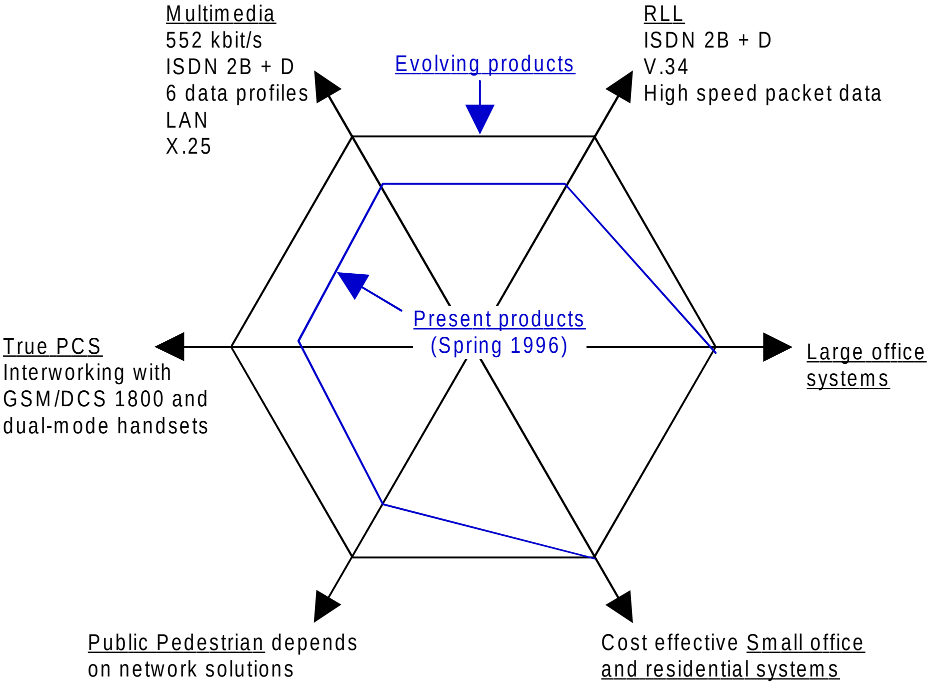
3.2 Abbreviations

For the purposes of this ETR, 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
FCA	Fixed Channel Allocation
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
FP	Fixed Part
FPLMTS	Future Public Land Mobile Telephone System
GFSK	Gaussian Frequency Shift Keying
GoS	Grade of Service
GPS	Global Positioning 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 short range 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 ISDN. It can be effectively implemented as a simple residential cordless telephone or as a systems providing all telephone services in a city centre. Together with DECT/GSM/DCS 1800 interworking and dual (triple) mode handsets, evolving products will provide 3rd generation mobile radio services. Figure 1 gives a high level graphic overview of DECT services and applications. Protected asymmetric links with bit rates beyond 552 kbit/s are possible if needed, for example by having multiple radio circuits in a subscriber unit.



PCS: Personal Communications Systems

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 common harmonized standard (see note) within the area of cordless telecommunications.

NOTE: Harmonized standards are those prepared and adopted on a European basis, with any conflicting national standards withdrawn.

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 -1 900 MHz, has been reinforced by the Council Directive 91/287/EEC [25], stating that “DECT shall have priority and be protected in the designated band (1 880 -1 900 MHz)” and “recognizing that, subject to system development of DECT, additional frequency spectrum may be required”.

For rapid introduction on European wide basis, this directive and the Council Recommendation 91/288/EEC [26] refers to the EEC Terminal Directive, 91/263/EEC [24] for mutual recognition between countries of conformity. For this purpose Common Technical Regulations, CTRs, have been established for DECT relating to harmonized DECT standards, TBRs and ETSs. Approval to a CTR gives access to a single European market through a simplified legal procedure.

The Council Directive 91/288/EEC [26] 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 Interoperability Profile, GAP, and the related TBR 22 [27], which define common mobility and interoperability requirements for private and public DECT speech services. For a more comprehensive overview of the DECT standardization. see ETR 178 [14].

The European Commission has elaborated a draft amendment of Directive 90/388/EEC [28] on competition in the market for telecommunications services. This draft Directive defines DECT as an important alternative to the wired PSTN/ISDN network access. In addition, all Member States are to grant licences for public DECT systems, and any restriction on the combination of DECT with other mobile technologies are to be withdrawn.

The deregulation of fixed services will also 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 subclause A.5.2.3.1 and examples in ETR 308 [17].

The DECT instant or Continuos 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. This ETR describes configurations for typical DECT applications and relevant mixes of these, including residential, office, public 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.

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.

The earlier ETSI technical report, ETR 042 [22], describes the fundamental aspects of DECT for providing a required traffic capacity and link quality. It is recommended to read clauses 1 to 3 of ETR 042 [22] for a fuller understanding of these fundamentals. The simulation results presented below in this document, are more complete and more accurate than the results of ETR 042 [22], since more complete simulation tools have been available for the more recent simulations.

5.1 A new concept: the local load on the spectrum

This ETR 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 -1 900 MHz, provides 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.

Since this ETR 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. This ETR does not contain any detailed range calculations for different propagation models. The ETR 139 [23] contains some scenarios and range calculations these are partly re-used below.

Many of the results in ETR 042 [22] 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 - 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 (1,88-1,9 GHz). 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 - 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, in ETR 042 [22] and in ETS 300 175-3 [3], subclause 11.4.

The DECT traffic channel selection is made by the terminals. Each terminal maintains an ordered list of the 6 - 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 subclause 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 are 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.

The ETR 042 [22] contains other examples with similar results.

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 subclause 5.2.2.

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

In subclause 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 subclause 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.

As for residential systems a basic characteristic of office 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 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 subclause A.3.2 show that the spectrum efficiency can be increased by up to 60 % by not dividing the 20 MHz 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 subclause A.3.2.7.1 and clause 10.

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. The 1,6 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 instead of dividing;

- 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 subclause 10.6.

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

Sharing by instant DCS an 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 - 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 an emerging data services

Scenario (speech and estimated emerging data services)	Office and Residential	Public pedestrian hot spots	RLL	Separate allocations	Total spectrum requirement (multi-application shared allocation)
N operators having own spectrum	N x 15 MHz	N x 7 MHz	N x 12 MHz	N x 34 MHz	N x 20 MHz
operators share spectrum	20 MHz	8 MHz	30 MHz	58 MHz	40 MHz (Public applications should use all the spectrum, private applications should only use the basic 20 MHz DECT spectrum)
NOTE: 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.					

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 subclause 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. 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 subclause 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 (8,5 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 subclause 8.6,

- **RLL.** The above roof top RLL applications are simulated in subclause A.3. Subclause 8.7.1 concludes that, including the estimated increase of data traffic, 6 carriers (12 MHz) is needed for a single operator, and that shared spectrum for at least 4 operators will need 16 carriers (30 MHz);

- **common allocation for different applications.** For a single operator we estimate instead of the total sum (15 + 7 + 12 = 34 MHz) that only 20 MHz are needed, if all applications share the same allocation. The reason is the limited interference between office, public pedestrian and RLL systems. See subclause 8.10. Similarly when all operators share the same allocation, only 40 MHz is estimated to be needed instead of the sum 58 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 Nx34/40. Therefore, the gain is about a factor 0,85 x 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 x 20)/40 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 subclause 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 - 1 900 MHz DECT allocation by limiting the number of RLL operators to 2 (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, 2 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. In total 40 E can be shared by similar sized DECT access nodes with 8 carriers (16 MHz). Two operators will have the required 20 E per DECT access node each. See subclause 6.4.1 and the summary in subclause 8.10.

5.3 Increase traffic by denser infra structure, 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 - 15 m separation). Therefore, on a given spectrum, the capacity, E/km^2, 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 increase 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 subclause 5.5.

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

In this subclause 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 narrower sectors in RLL installations). See subclause 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 narrower sectors in RLL installations). See subclause 5.4. The potential threats 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 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. 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 - 200 mE	300 - 400 mE
Resident	50 - 70 mE	100 - 140 mE
RLL	See office and resident	See office and resident
Public pedestrian	30 mE	30 mE

6.1 Residential application

A typical scenario for residential DECT application 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 - 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 4-8 storeys, there are 2 000 - 4 000 households per km^2. This corresponds to 100 - 280 E/km^2 or 25 - 35 E/km^2/floor. In villa areas, there can be 500 - 1000 households/km^2. This corresponds to up 25 -70 E/km^2. 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/km^2, more typical about 10 000 employees/km^2. The Wireless PABX (WPBX) user has a speech traffic of 150 - 200 mE. This gives an average speech traffic of 1 500 - 2 000 E/km^2 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/km^2, 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 m^2. If all employees have a DECT handset, this would mean a total traffic of 7 500 - 10 000 E/km^2/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 - 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/km^2/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 m^2, the total traffic generated in such a zone will be 140 E/km^2/floor or 700 E/km^2.

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 km^2, this will give 400 E/km^2.

6.3 Public pedestrian application

The public pedestrian DECT application gives local mobility to subscribers in an urban or suburban areas. 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 m^2. Assuming again the penetration of 5 %, the traffic generated is 1 500 E/km^2. 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 km^2, a traffic of 30 E/km^2. 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/km^2. Having 5 % penetration leads to 15 E/km^2.

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.

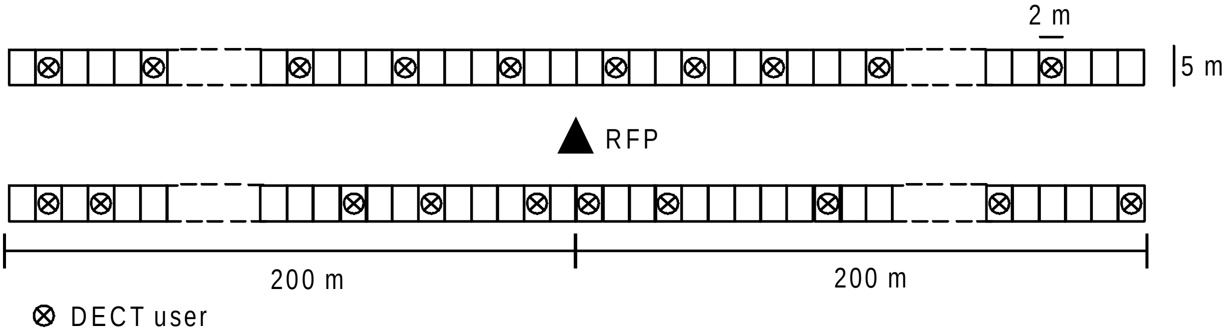


Figure 2: Example of a typical coverage of a street base station

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 m^2 of pavements. In the street there is one person every 10 m^2, 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/km^2, if the streets are separated by 100 m (10 streets + 10 perpendicular streets per km^2, 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 km^2 will be 10 - 15 E/km^2 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 reduce 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 km^2. 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 km^2.

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 [17] requires a range up to 5 km for a DECT radio link. A Line Of Sight (LOS) range up 5 km is feasible with 12 dBi antennas at each end and reasonable antenna heights [34]. 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 below shows how low subscriber densities are supported as a function of the cell range, supposing 271 or 643 subscribers per radio site. Hexagon cells are used. The range R km is equal to the length of the hexagon side, and the cell area is 2,6 x R^2 km^2. 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.

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

Table 4 shows that DECT with suitable antenna site arrangements will support economic deployment of RLL systems with 5 - 50 subscribers per km^2 without need to stretch the 5 km range requirement.

6.4.1.1 Special provisions for single link ranges beyond 5 km

In the 2nd edition of ETS 300 175, parts 1 to 8 [1] to [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 [23] was published. LOS ranges of 10 - 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 [23] 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 cm^2. A 17 dBi patch antenna has an area of about 2 000 cm^2, 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 - 4 stories) connections per km^2; each connection has a traffic of 70 mE, which means a total traffic in the area of 35 to 140 E/km^2.

The highest residential traffic is 140 - 280 E/km^2 for blocks of flats with 4 - 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 km^2 . The traffic density is 1 500 E/km^2 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/km^2.

If second operators in an area deploying RLL will get 10 % of the total business traffic in a metropolitan area, 100 E/km^2 must be supported by DECT RLL.

We may conclude that a traffic capacity of 100 - 150 E/km^2 is required to support speech RLL services.

These traffic densities are estimated to be doubled within a few years to 200 - 300 E/km^2 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/km^2.

6.5 Summary of traffic requirements

Table 5 below 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 - 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	20 E (8,7 km hexagon grid) 40 E (430 m hexagon grid) 60 E (260 m hexagon grid)	0,3 E/km^2 250 E/km^2 Maximum 1 000 E/km^2

7 ISDN, data and multimedia applications

The DECT standard (ETS 300 175, parts 1 to 8 [1] to [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 (6 million, 1995 in USA). Therefore, it is foreseen that the present (1996) 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 are 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. Some rule for packing of full and double slots may reduce double slot blocking probability. Such rules are under study.

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 with up to 552 kbit/s using some of the specified family of packet data profiles. The data profiles offer a variety of services varying from low speed messaging to high speed frame relay. 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.

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

DECT data profile	Maximum sustainable throughput	Bearer requirements
A (low speed frame relay)	24 kbit/s	1 full slot
B (high speed frame relay)	552 kbit/s unidirectional 288 kbit/s bi-directional	1 - 23 full slots 1 - 12 full slots
C (non-transparent Link Access Protocol services)	552 kbit/s unidirectional 288 kbit/s bi-directional	1 - 23 full slots 1 - 12 full slots
D (transparent and isochronous connections)	not completed	not completed
E (low rate messaging services)	1,38 kbit/s (A-field, C_S channel) 17,6 kbit/s (C_F channel)	1 full slot
F (multimedia teleservices)	as C-profile	as C profile

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 - 200 mE	300 - 400 mE
Residential	50 - 70 mE	100 - 140 mE
Public pedestrian	30 mE	30 mE

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

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 subclause 7.2 table 9. The conclusions are based on calculations and a large number of simulations which are further described 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 - 120 non-over lapping positions if unsynchronized. (A dummy bearer only consists of the S + A fields, 96 bits, as described in subclause 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.

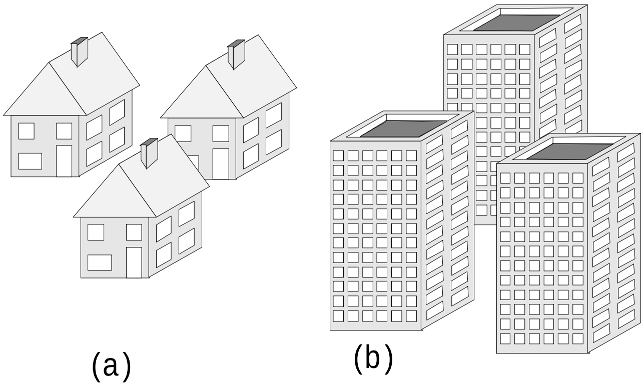


Figure 3: Coexistence between residential systems

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/km^2/floor for speech services. Simulations carried out in a 3 storey building with varying total number of carriers available 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/km^2/floor with 25 m base station separation. This corresponds to 11 000 E/km^2/floor with 20 m separation (see subclause A.1.2). This shows that there is local capacity left for other systems. We see from subclause 6.2.1 that a more typical local peak speech traffic density is 2 500 E/km^2/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 subclause 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).

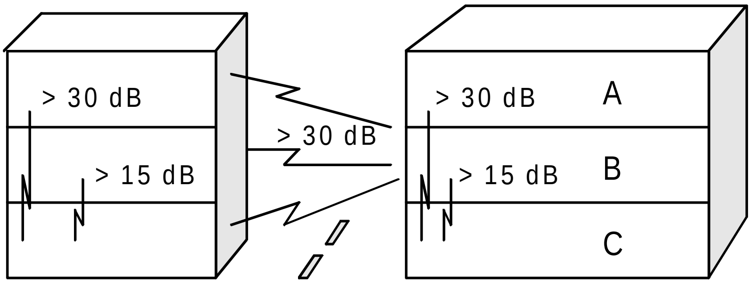


Figure 4: Coexistence between office systems; in the figure typical loss values for external walls and floors are indicated

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. 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.

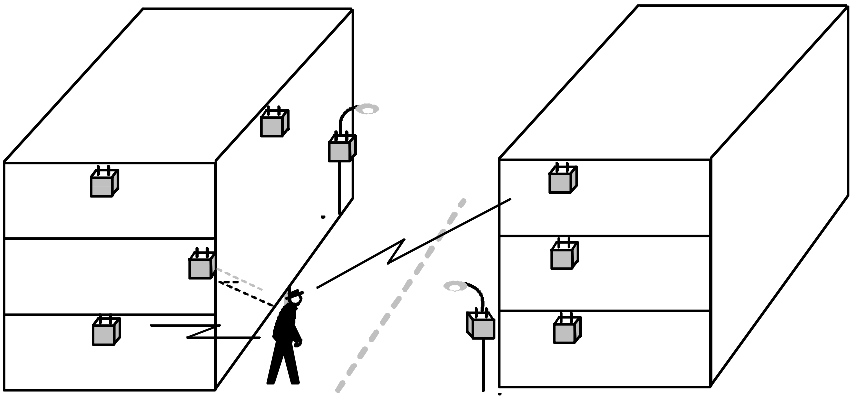


Figure 5: Coexistence between office-public public pedestrian applications

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 m^2, the total number of terminals is 150):

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

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 subclause 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 m^2 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 subclause 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 - 14 = 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 - 60 E will be locally available. See subclause 8.4 above. Furthermore, antennas for the RLL links are usually above the roof top and this inserts a substantial average physical separation to indoor office systems.

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/km^2 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/km^2 , here 3 carriers (7 MHz) will be reasonable for a single operator. 4 carriers (8,5 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) in a specific simulation scenario with 7 DECT Access Nodes, DASs, the maximum (by different operators) sharable local capacity is about 57 E per six sector DAS (90 degrees opening angles at the DASs and 85 degree directional gain antennas at the CTAs), when totally 10 DECT carriers are available. For extended number of carriers beyond 10, a lower (and may be typical) bound for the local capacity is 5,7 E per carrier. This assumes frame synchronization within and between DASs. The number of equivalent non-overlapping sectors per DAS is 3;

b) when there are several RLL operators, the above figure, 57 E, indicates the maximum total traffic in an area corresponding to a DAS cell area. It is obvious that an isolated DAS site, or DAS sites with more than 3 equivalent non-overlapping sectors will support higher traffic;

c) 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;

d) for two above roof-top synchronized identical multi-cell RLL DAS systems, where the DAS sites of one system are at the intersection points of three DAS cells of the other system (worst interference scenario with directional antennas), the maximum capacity reduction is 20 % compared with if both systems had their cell sites collocated. Uncoordinated sites will in average cause only 10 % capacity reduction;

e) 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;

f) 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 - 4,8 times increased 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;

g) we may assume that systems with up to 7 - 10 heavily loaded close by DASs represent a rather typical scenario. The propagation model used, is not suitable for systems with very large number of DASs. See the note in subclause A.3.2.7.1;

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.

8.7.1 Spectrum requirements for RLL applications

From subclause 6.4.1 we conclude that minimum 20 E per DAS should be available for each operator to build mutual price competitive networks.

Subclause A.3.2.2 shows that 6 carriers provides about 20 E with one RFP per sector cell (figure A.7). For emerging additional data traffic, 2 RFPs will be needed per sector not to introduce unacceptable device trunk limited blocking for double-slots that will be used for efficient data transfer via modem and ISDN. Still with 6 carriers this will provide 30 E per DAS (figure A.9).

Therefore, we conclude that 6 carriers (12 MHz) is required for one RLL operator including support of estimated emerging increased data traffic.

Since the maximum sharable traffic, for the specific models used, is 57 E with 10 carriers (20 MHz), if cell sizes of the systems have similar sizes, we may conclude that 2 operators and probably up to say 4 operators may coexist well on 20 MHz of common spectrum. See subclause A.3.2.7. 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 30 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.

NOTE: When the number of close by fully loaded DASs in a system goes much beyond 7 - 10, the maximum sharable traffic per DAS is reduced from the 57 E found for 7 DASs. We may assume that systems with up to 7 - 10 heavily loaded close by DASs represent a rather typical scenario. For systems with very large numbers of close by heavily loaded DASs, see the note in subclause A.3.2.7.1.

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 subclause 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 6). 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.

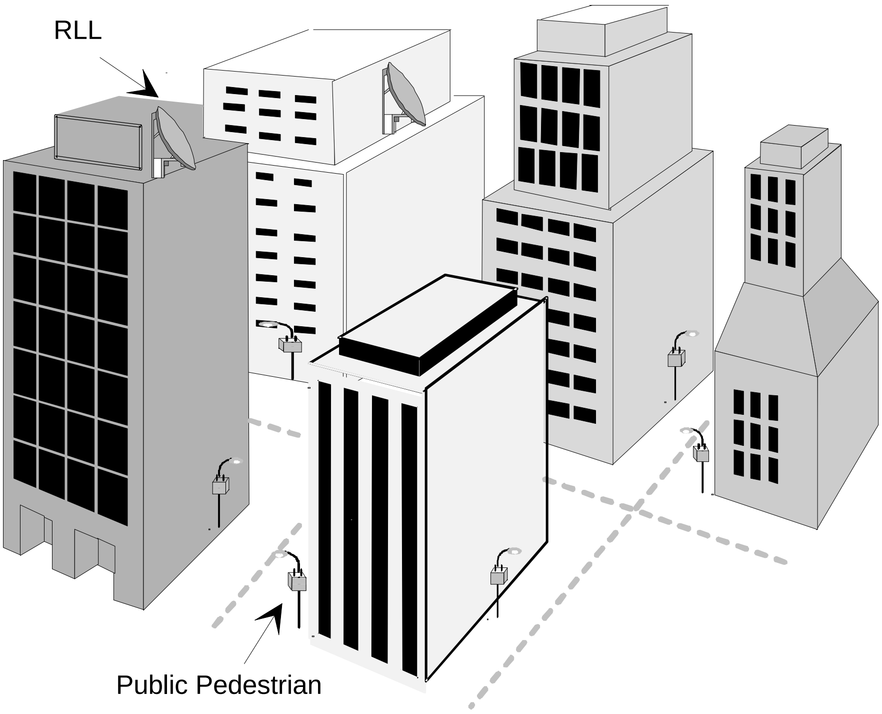


Figure 6: Coexistence between public pedestrian - RLL

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 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 subclause 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 subclause 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 the table 10 below.

Table 10: The potential interference between DECT applications

Interference from	**Residential**	**Office**	**Public pedestrian hot spots**	**Public pedestrian street**	**RLL**
Interference to					
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 were there is "some" interference.					

As seen from the table 10, 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 (ETS 300 175, parts 1 to 8 [1] to [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 (ETS 300 175, parts 1 to 8 [1] to [8]). The table also indicate 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 this 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 subclause 4.2.2.3 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, 2 (note 1) RLL operators. Mainly speech services	10 MHz *5 carriers* *10 000 E/*km^2 *4,5 E/base* *21 m separation*	7 MHz *3 carriers* *1 500 E /*km^2 *2,5 E/base* *41 m separation*	16 MHz *8 carriers* *Up to 42 E sharable per DAS (note 2) area*	20 MHz *All applications share the spectrum. Conflict solving rules for public operators*
Shared spectrum, several RLL operators. Speech and estimated emerging data services	20 MHz *10 carriers* *20 000 E/*km^2 *10 E/base* *22 m separation*	8 MHz *4 carriers* *1 500 E/*km^2 *2,5 E/base* *41 m separation*	30 MHz *16 carriers* *Up to 100 E sharable per DAS (note 2) area*	40 MHz *Private applications only in 1 880 - 1 900 MHz. Conflict solving rules for public operators*

NOTE 1: May perhaps be 3, 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.

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 subclause A.3.1. An isolated DAS site, or DAS sites with more than 3 equivalent non-overlapping sectors will support higher traffic.

The European initial DECT allocation 1 880 - 1 900 MHz provides 10 DECT carriers. The second edition of ETS 300 175, parts 1 to 8 [1] to [8] has defined extended DECT carriers up to 1 937 MHz to ensure interoperability in extended DECT allocations, or in countries with allocations other than 1 880 - 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 - 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 have been allocated totally 10 - 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 40 MHz shared allocation for the DECT services, would for instance support, at least four RLL operators, a number of public street system operators and the traffic for all private office and residential DECT systems (in a city). An interesting reference for the spectrum efficiency of the DECT technology is the estimates in CCIR for Future Public Land Mobile Telephone System (FPLMTS) (or Universal Mobile Telephone System (UMTS)), where 24 MHz is required per operator for office applications only (16 kbit/s codec speech services).

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 subclause 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 subclauses 5.2.2 and A.3.2. 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 another 20 MHz are required to secure the full benefits of cost effective high quality DECT services in a multi-operator environment. See subclause 8.10. To retain one of the most important success factors of DECT, the multi-application platform, this extension should be selected in the upper adjacent band 1 900 to 1 920 MHz. The suggested band is a TDD band right below the FDD UMTS band. DECT, DECT/ISDN IWP, DECT Data Services Profiles, DECT/GSM IWP and GSM meet together UMTS requirements and should be regarded as a migration path to or, say, components of UMTS. 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 in the extended band 1 900 -1 920 MHz 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, subclause 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, subclause 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 (ETS 300 175, parts 1 to 8 [1] to [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 ETS 300 175, parts 1 to 8 [1] to [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 means for 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 06 [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 10 E (full-slot duplex bearers or equivalent) per 20 MHz total allocation. Exceeding this limit could make the effective range of his cells disproportionally vulnerable to interference from other users of the spectrum.

> NOTE: The RLL simulations indicate 57 E traffic in a DAS with 6 sectors. This is about 10 E per sector cell. Due to overlapping of the sectors, this corresponds to about 20 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 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 1,6 - 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 (see subclause A.3.2.7.1) 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 of 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 1 900 -1 920 MHz) 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 this document. It is a collection of information from a large number of input documents supplied to the ETSI RES-3R working party during the years 1995 and 1996.

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.

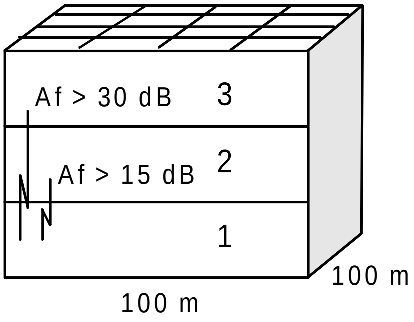


Figure A.1: Reference building

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.

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

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

Ericsson-in-Building loss model:

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

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

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

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 ETS 300 175-3 [3]). Specifically, the parameters of the simulation scenario of annex E of ETR 042 [22] have been used. Base station blind slot information is available at the PPs for the simulations in A.1.2, whilst not in 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 [22]) 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 - 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/km^2 and number of users per floor, depend directly on the base station density (base stations per km^2 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/km^2.

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:

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

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

The results are summarized in the 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 (1000 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 (1000 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 (1000 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 (1000 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/km^2, as for the simulations in A.1.2 above.

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.

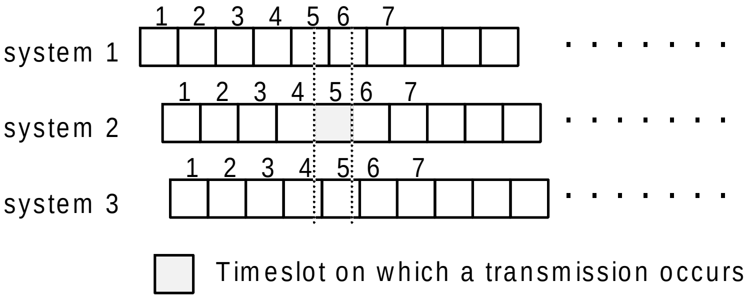


Figure A.2: Three unsynchronized systems in the building

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/km^2/floor; if a higher separation between floors is introduced (i.e. Af = 20 dB), this value becomes 6 E, that is 9 600 E/km^2/floor. Note that blind slot information is not provided in this simulation. This explains the slight discrepancy with the results of A.1.2 above.

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.

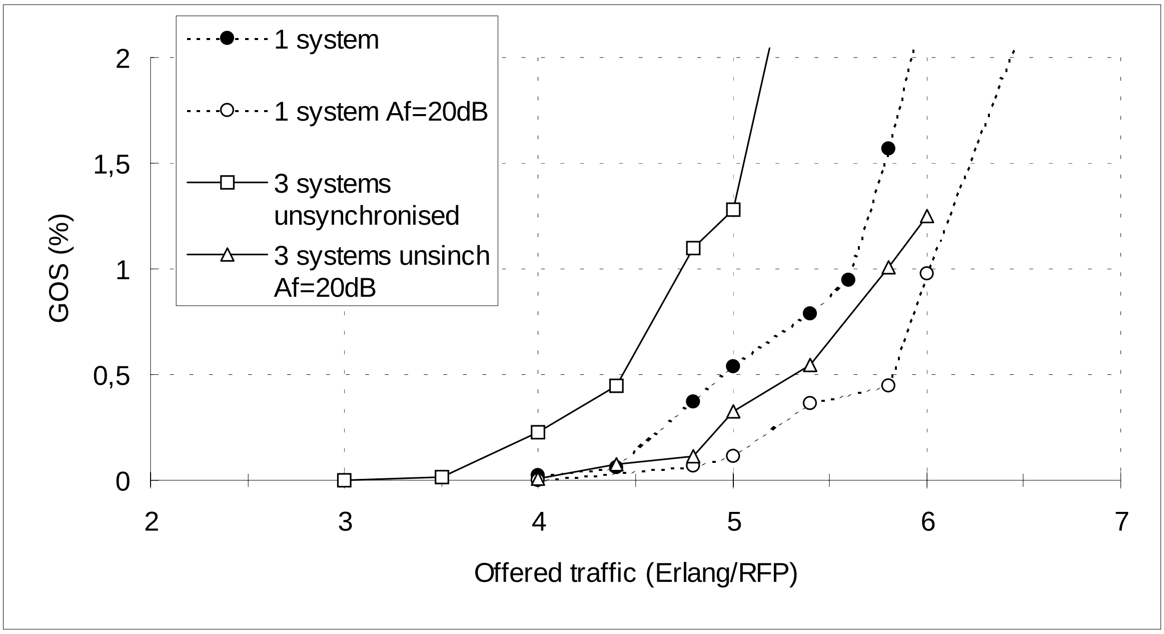


Figure A.3: Offered traffic per RFP with one and three systems in the building

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/km^2/floor, instead of about 9 000 E/km^2/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/km^2/floor to 9 300 E/km^2/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 on three floors	15	5,6	9 000
	20	6	9 600
3 systems unsynchronized	15	4,6	7 400
	20	5,8	9 300

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 km^2. In total an area of 4,75 km^2 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.

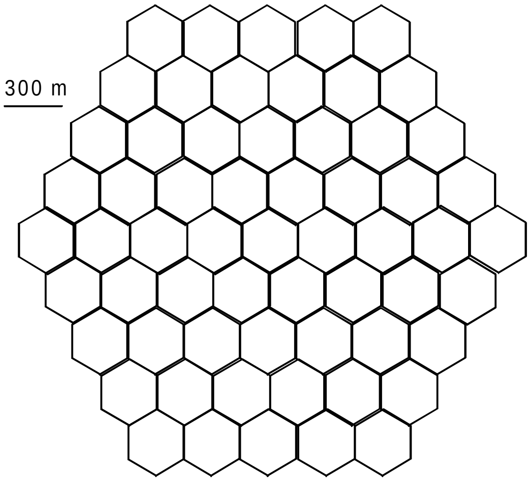


Figure A.4: Reference public pedestrian environment

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:

$l(d) = 38 + 20\log(d) \qquad d < 10\,\mathrm{m}$

$l(d) = 30 + 28\log(d) \qquad d > 10\,\mathrm{m}$

25 % NLOS:

$l(d) = 38 + 20\log(d) \qquad d < 10\,\mathrm{m}$

$l(d) = 22 + 36\log(d) \qquad d > 10\,\mathrm{m}$

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:

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

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/km^2. 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 2-3 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.

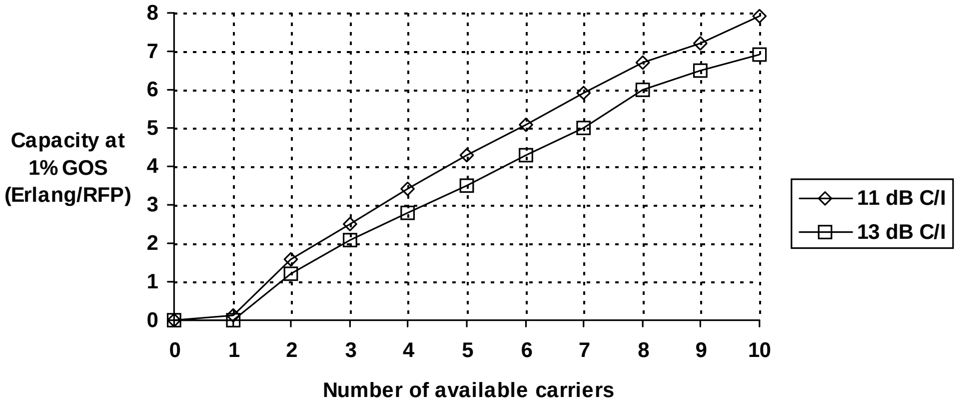


Figure A.5: Capacity at 1 % GoS versus the number of available carriers of the public pedestrian system

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 - 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 - 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.

A.3.1 Simulation scenario's

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 km^2 per DAS. Poisson time distributed traffic is generated within the coverage area of the DASs. The statistics are taken only from the inner DAS.

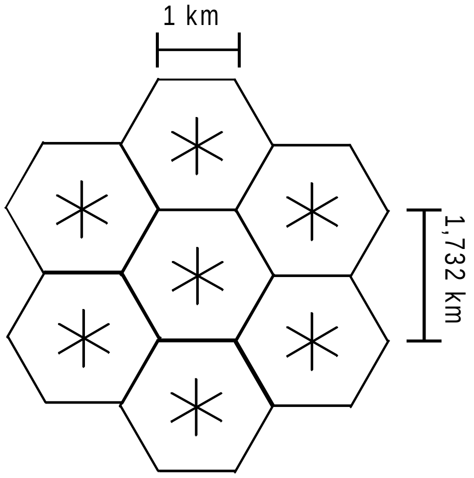


Figure A.6: Basic above rooftop RLL scenario

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. The figure A.7 below shows the antenna diagram. The antenna provides 12 dBi gain.

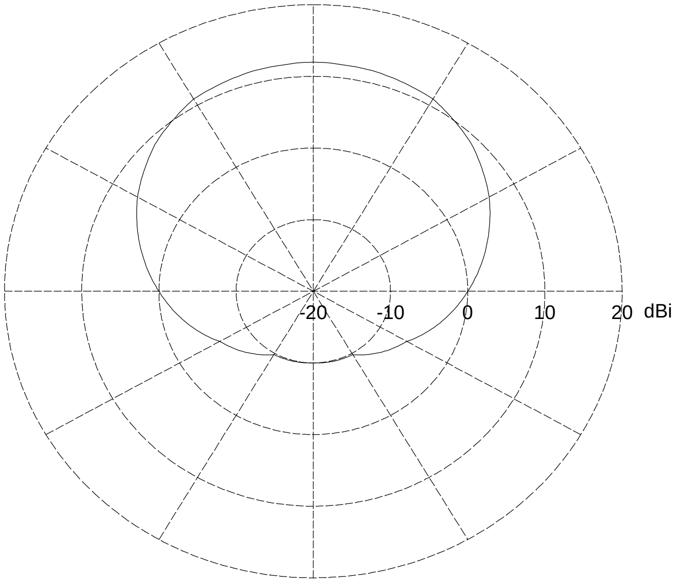


Figure A.7: Antenna diagram with 85-90° opening angle and 12 dBi gain

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:

$l(d) = 38 + 20\log(d) \qquad d < 10\,m$

$l(d) = 30 + 28\log(d) \qquad d > 10\,m$

25 % NLOS:

$l(d) = 38 + 20\log(d) \qquad d < 10\,m$

$l(d) = 22 + 36\log(d) \qquad d > 10\,m$

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 Raleigh 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:

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

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 scenario's

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 antenna's

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;

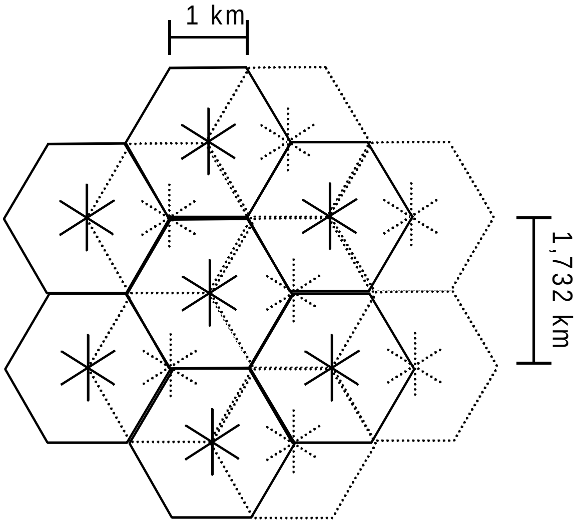


Figure A.8: Two system above rooftop RLL scenario

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 km^2 or 2,6 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 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 E per RFP.

For two collocated synchronized systems, the total capacity per node at 1 % GoS is 2 x 28,6 E = 57,2 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

	Capacity (Erlang/DAS/*system*) at GoS			
Scenario	**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 degrees 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.

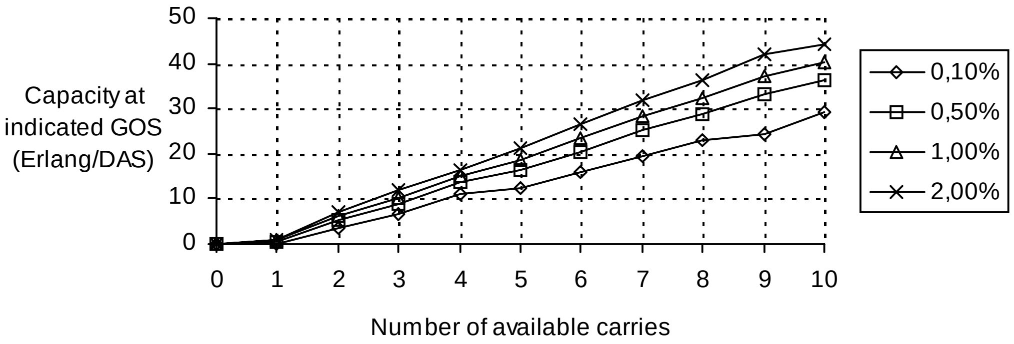


Figure A.9: Capacity per DAS versus number of available carriers of the above rooftop RLL system at 0,1 %, 0,5 %, 1,0 % and 2,0 % GoS. 1 system with 1 RFP per sector cell

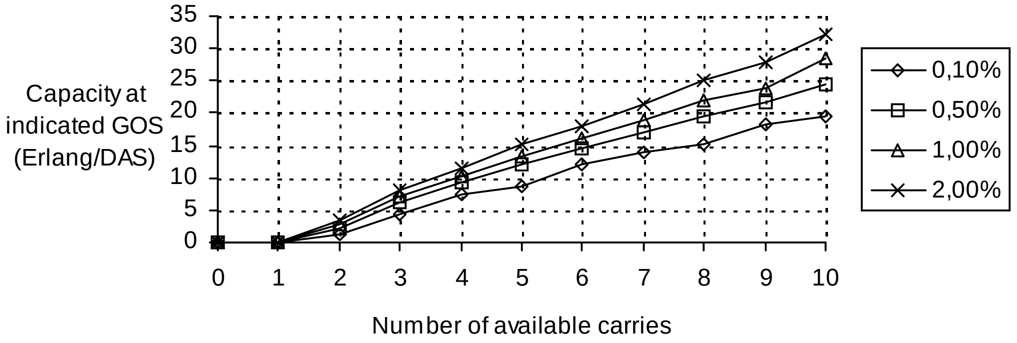


Figure A.10: Capacity per DAS/system versus number of available carriers of the above rooftop RLL system at 0,1 %, 0,5 %, 1,0 % and 2,0 % GoS. 2 systems with 1 RFP per sector cell

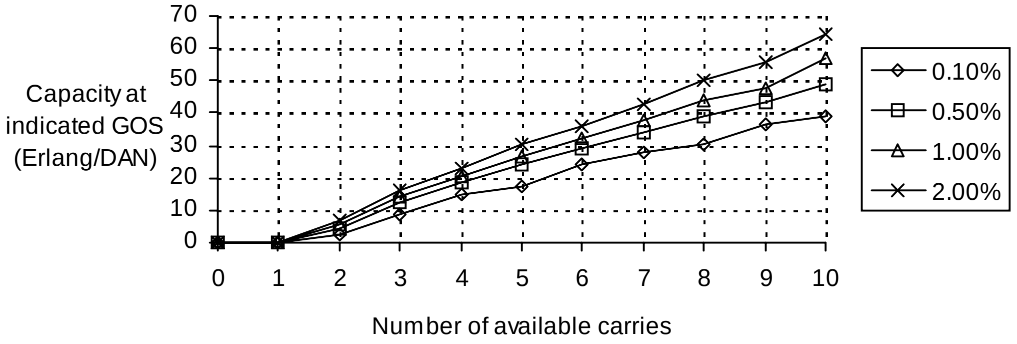


Figure A.11: Capacity per DAS (lower bound) versus number of available carriers of the above rooftop RLL system at 0,1 %, 0,5 %, 1,0 % and 2,0 % GoS. 1 system with 2 RFPs per sector cell

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 E/ km^2 when totally 10 DECT carriers are available, and about 200 E/ km^2 for 0,58 km separation, and about 2100 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	Capacity (Erlangs/DAS) at GoS			
1 system, 1 RFP/sector	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	**Capacity (Erlangs/DAS/system) at GoS**			
2 systems, 1 RFP/sector	**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	**Capacity (Erlangs/DAS) at GoS**			
1 system, 2 RFPs/sector	**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 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.3.2.7.1 Coexistence of DAS systems with very different cell sizes

Two multi-cell above roof-top DAS systems covering the same area, may sometimes have cell sizes that differ up to a factor 7 - 10 times (1,7 km and 500 m DAS separation). The reason may be that one operator has 90 % of the customers and the other only 10 %. Supposing antenna gain, height and transmit output power are the same for both systems. In this case, if both systems share the same spectrum, the interference level will be the same, no matter which system the radio receiver belongs to. But on average, the wanted signal will be much stronger for the system with smaller cells. Therefore the blocking probability for connections in the large cell system will be much higher then for connections in the other system. One way to prevent an operator with a large market share blocking the service for other operators is to leave some escape carriers for the other operators.

Such a scenario with nine times difference in cell sizes has been simulated. To make this simulation it was necessary to make clusters with as much as 19 DASs for the small cell scenario. With the propagation model used, a single 19 DAS system gives about 43 % lower traffic in the centre cell than a 7 DAS system. The table A.15 shows the capacity for the centre cells of a single 7 DAS system and a single 19 DAS system with one RFP per sector, when each system has 5 separate carriers allocated:

Table A.15: Traffic capacity for a 7 DAS system and a 19 DAS system, both with one RFP per DAS sector. The two systems operate on two separate 5 carrier allocations

Single system type	One single 7 DAS system	One single 19 DAS system
Traffic at 1 % GoS. Separate 5 carriers allocated per system	15,5 E	9 E

The capacity from a single 19 DAS system with 5 carriers is the capacity for a split spectrum (two operators) alternative. This reference is needed to judge the benefits of shared spectrum coexistence with a nine times larger cell from a second system. The simulation was made with *the same traffic in the large and small cells*. An extract of the results are given in table A.16.

Table A.16: Traffic capacity for coexistence of a 19 DAS cell system and a second system with one 9 times larger DAS covered by the centre DASs of the small cell system

Carrier allocation	Traffic per DAS	Small cell system GoS	Large cell system GoS
Totally 10 carriers. 0 shared carriers (fully split spectrum). Small cell system 5 carriers and large cell system 5 carriers.	9 E	1 %	1 %
Totally 10 carriers. 10 shared carriers. Small cell system 10 carriers and large cell system 10 carriers.	8 E 17 E	< 0,1 % 1 %	1 % useless
Totally 10 carriers. 8 shared carriers. Small cell system 8 carriers and large cell system 10 carriers.	14 E 17 E	1 % 2,2 %	0,3 % 1 %
Totally 10 carriers. 7 shared carriers. Small cell system 7 carriers and large cell system 10 carriers.	12 E 26 E	1 % useless	0,1 % 1 %
Totally 10 carriers. 6 shared carriers. Small cell system 8 carriers and large cell system 8 carriers.	15 E	1 %	1 %
Totally 16 carriers. 16 shared carriers. Small cell system 16 carriers and large cell system 16 carriers.	23 E 26 E	0,5 % 1 %	1 % 2,2 %
Totally 16 carriers. 12 shared carriers. Small cell system 14 carriers and large cell system 14 carriers.	23 E 26 E	0,5 % 1 %	1 % 2,2 %

From table A.16 we conclude that if all 10 carriers are shared, the offered traffic at maximum 1 % GoS in any cell is 8 E, about the same as for a fully split spectrum between two operators. But there is a risk that the small cell system totally blocks the larger cell. However, if the small cell system backs-off from 2 carriers (8 carriers shared) or if both systems back-off from 2 separate carriers (6 carriers shared), the offered traffic at maximum 1 % GoS in any cell is about 15 E, which is 15/9 = 1,6 times higher than for a fully split spectrum between two operators.

Therefore, including the typical more favourable scenarios from subclause A.3.2.7 we can conclude that sharing spectrum compared to equal division of the spectrum, will provide 1,6 to 4,8 times more efficient use of the spectrum.

NOTE: With the propagation model used (A.3.1), a single 19 DAS system gives about 43 % lower traffic in the centre cell than a 7 DAS system. This propagation model gives a too pessimistic result for systems with a very large number of sites, because after the first Frensel zone the attenuation tends to increase quicker than in the model used. This is illustrated by DECT RLL simulations (see reference [18]), where the exponent for the LOS attenuation is 3,8 instead of 2,8, and the system consists of **100** DASs. 62 E/DAS is supported with 600 m DAS separation, and up to 86 E/DAS with 2 km DAS separation. The DASs in reference [18] have 3 non-overlapping sectors, which is equivalent to the 6 overlapping sectors used in this ETR (See A.3.1.1). Besides, the fading and shadowing margins used in reference [18] are lower than in A.3.1, may be somewhat too low. Anyhow, reference [18] shows that the summary on spectrum requirements in subclause 7.10 indicating about 60 E sharable traffic per DAN is defensible. It is also obvious that an isolated DAS site, or DAS sites with more than 3 equivalent non-overlapping sectors will support higher traffic.

A.3.3 Conclusions

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

- the specific simulated scenario indicate a maximum (by different operators) sharable local capacity of about 57 E per DAS when totally 10 DECT carriers are available. For extended number of carriers beyond 10, a lower (and may be typical) bound for the local capacity is 5,7 E per carrier. This assumes synchronization and the use of directional gain antennas with 90 degrees opening angles at both ends. The number of equivalent non-overlapping sectors per DAS is 3;

- it is obvious that an isolated DAS site, or DAS sites with more than 3 equivalent non-overlapping sectors will support higher traffic;

- 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;

- 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 has 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. ETS 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 onmidirectional 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, ETS 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 subclause 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 subclause 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/ km^2. 1 E per public pedestrian cell corresponds to 33/2,6 = 12,7 E/ km^2, and 3 E per public pedestrian cell corresponds to 38 E/ km^2.

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/ km^2 and 3 E per public pedestrian cell corresponds to 38 E/ km^2.

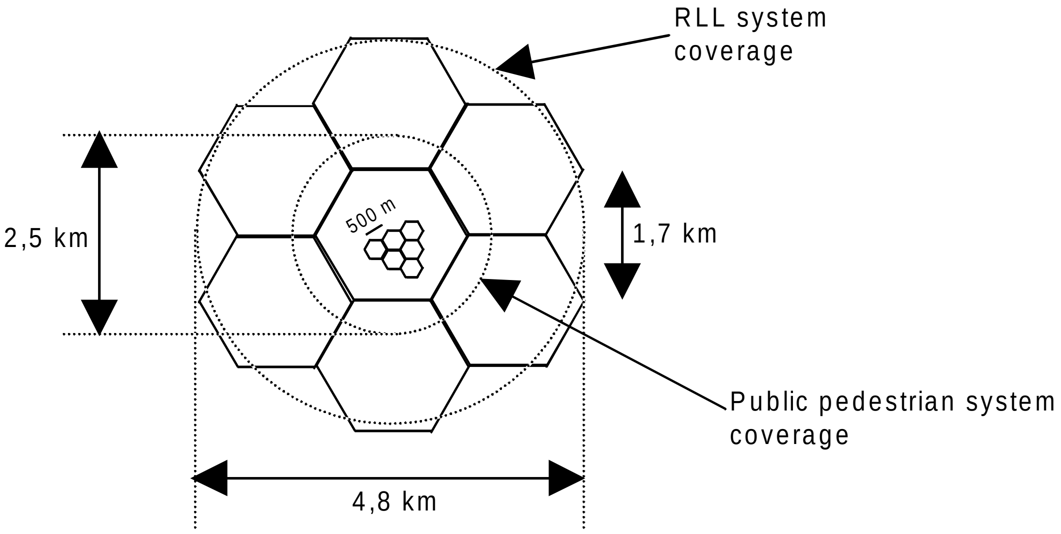


Figure A.12: Deployment of above rooftop RLL DAS nodes and street below rooftop street public pedestrian cells

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 the figure A.13 below.

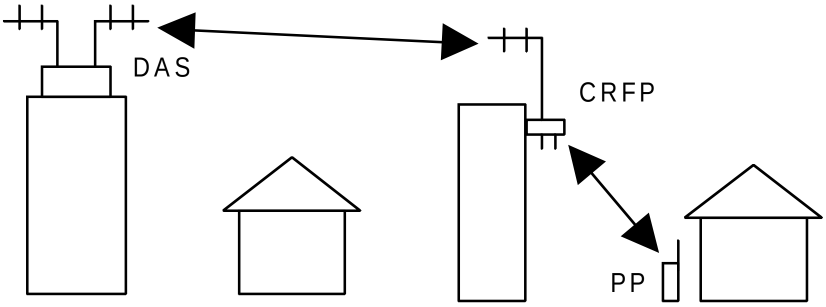


Figure A.13: RLL system with local mobility

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 subclause A.3 to estimate the GoS and load on the spectrum for the concept of the figure A.13 above. 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 km^2 in the DAS links and in the local links always are equal, in this case 12,7 E/ km^2.

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.

The figure A.14 below gives a graphic explanation of the WRS functionality. For more information, see the ETSI technical report on WRS, ETR 246 [15] and ETS 300 700 [16].

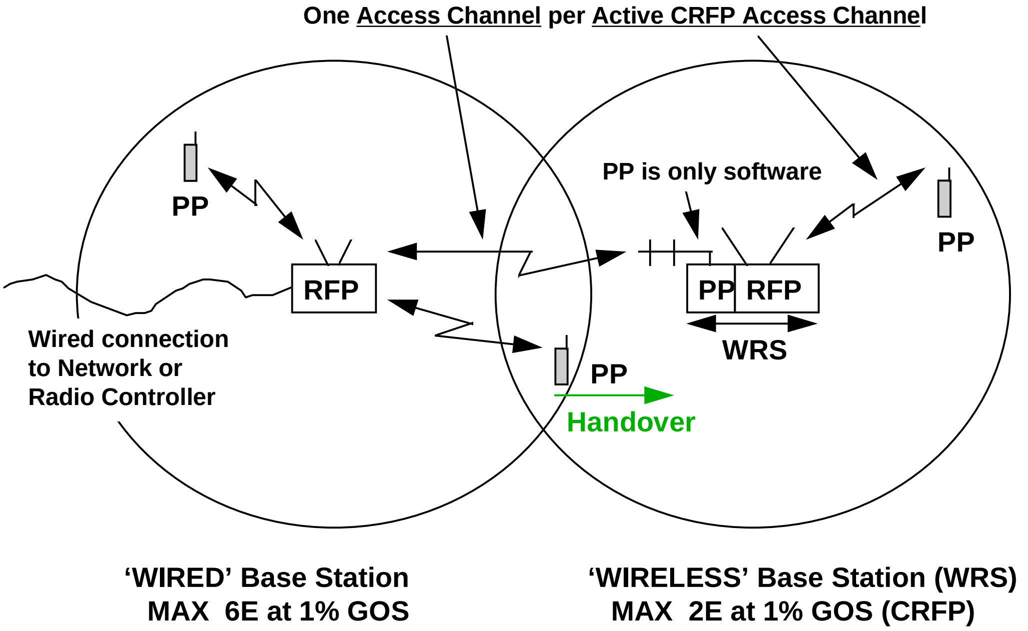


Figure A.14: Principle for WRS

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

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

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 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.

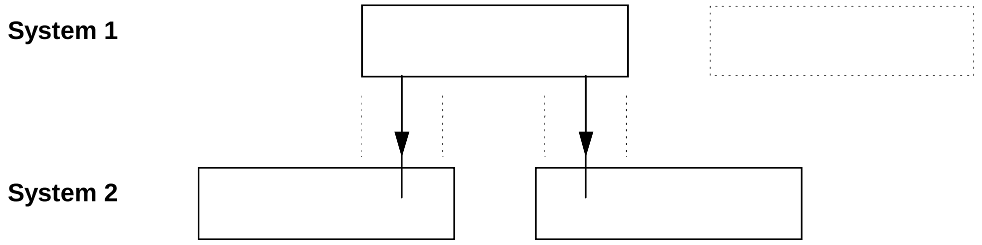


Figure B.1: Coexistence of two systems with different carrier positions

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 inter operability standard, PWT [20] and PWT/E [21], 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.

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 regulators 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 / km^2 per floor at comparable (speech) quality and infrastructure cost. See ETR 042 [22] clause 2.

The relation to the cost, comes from the fact that the traffic capacity (E / km^2) for DECT will be proportional to the base station density (RFPs/km^2) (see note). See subclause 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 total allocation. Exceeding this limit could make the effective range of his cells disproportionally 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 directional gain antennas generally increases the spectrum efficiency, as shown in subclause A.2.3. The DECT standard (ETS 300 175, parts 1 to 8 [1] to [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 provides 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 subclause 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 (ETS 300 175, parts 1 to 8 [1] to [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 ETS 300 175, parts 1 to 8 [1] to [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 means for 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 is 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 % G.O.S. 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 [19]. We use the Erlang B traffic formula at 1 % G.O.S. 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 gives 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 12x16 = 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 - 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 % G.O.S. 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 % G.O.S. 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 - 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.

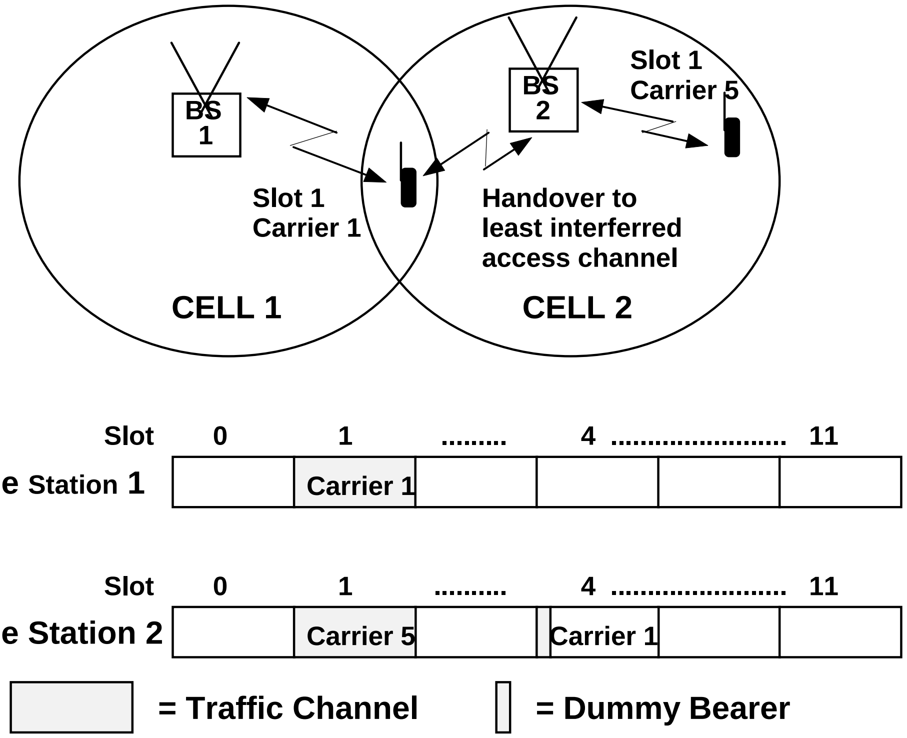


Figure E.1: Example on how to avoid blind slots at seamless inter-cell handover

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 subclause 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.

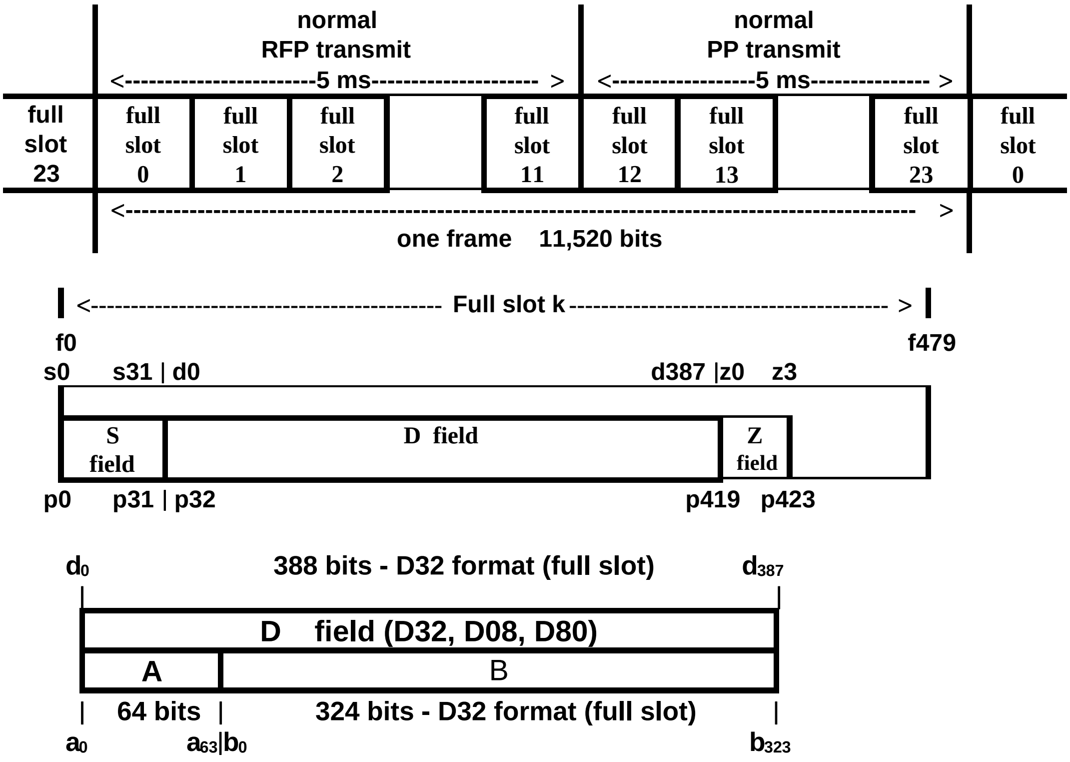


Figure E.2: TDMA slot structure for DECT

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 are found in ETS 300 175-3 [3], subclause 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 ETS 300 175, parts 2 and 3 [2] and [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 subclause 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 ETS 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 regularity 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 (8-12 duplex connections) provides a cost effective *Standard Base Station concept.* This concept as applied for DECT is described in ETR 042 [22].

This Standard 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;
- assymetric links are provided with up to 23 time slots in one direction and 1 time slot in the other direction. See subclause 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 - 300 m range. 5 km Line of Sight ranges are supported for RLL applications using directional gain (12 dBi) antennas. See subclause 6.4.1.

The traffic capacity and spectrum requirements for different DECT application scenarios are 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 unsynchron*ize*d 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 this ETR.

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