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Fair Coexistence of DECT and PHS working in the same Frequency Band in Fixed Wireless Access Networks

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Abstract — **Coexistence issues of PHS and DECT in Fixed Wireless Access Network environments, working in exactly the same frequency band rather than using frequencies as currently defined by its respective ARIB- and ETSI standards, are covered in this contribution. An overlapping configuration is chosen by regulators of developing countries, i.e. Colombia and Thailand, under support of uncoordinated installation and coexistence for all systems, to insoire new operators to invest into the radio access networks. By means of simulations of asynchronous DECT and PHS applications, the mutual interference levels are examined and the Grade of Service of both systems are measured and evaluated. Frequency Sharing Rules are defined for spectrum efficient and fair coexistence of PHS and DECT.**

***Keywords* – Wireless Local Loop, Fixed Wireless Access Networks, DECT, PHS, Coexistence, Frequency Sharing Rules**

I. INTRODUCTION AND MOTIVATION

Japanese *PHS (Personal Handyphone System)* and European *DECT (Digital Enhanced Cordless Telecommunications)* are both suitable for connecting subscribers of telecommunication services to their local exchange of the PSTN *(Public Switched Telephone Network)* in place of conventional copper cable [1–5]. Using a wireless link shortens the construction period and also reduces installation costs.

Fixed Wireless Access Networks (FWA Networks) covering this so–called last mile offer the flexibility to meet all the needs of future applications [6, 7]. There are a few equivalent expressions for these radio networks for coverage of the last mile, e.g. *Wireless Local Loop* or *Radio in the Local Loop*. According to [8], this contribution adopts the ITU terminology. Henceforth the term FWA Networks is used in this context.

The deregulation of the world–wide telecommunication market is currently leading to new entrant companies in this area. These companies need direct access to their customers without being dependent on the infrastructure of the present fixed network operators. FWA Networks will help unlock competition in the local loop, enabling new operators to bypass existing wireline networks to deliver voice and data access to new regions.

Economically important, the emerging economies of the world very often lack the resources and financial support to install conventional wired telecommunication systems [9]. In this context, telecommunications can be seen as one of the key drivers which will ultimately determine the future of developing countries. As a matter of fundamental relevance, a fast roll–out of telephone services with the help of FWA Networks should be encouraged. Developing nations like China, India, Brazil, Russia, and Indonesia look to FWA Network technology as an efficient way to deploy telecommunications for millions of subscribers, without the expense of burying copper wire. FWA Networks applying established systems such as DECT and PHS have the potential of bringing telecommunications to many areas for the first time ever, where access to traditional fixed services is still many years away.

It is against this background that our work should be examined. Initially, in two countries, Colombia and Thailand, PHS and DECT are licensed for use in FWA Networks equally within the frequency bands 1900 .. 1920 MHz, and 1902 .. 1918 MHz, where they are required to maintain the fair coexistence. Since PHS as well as DECT apply *Dynamic Channel Selection (DCS)* except for the control carriers in PHS, the systems are expected to offer the capability of coexisting in the same frequency band.

In this paper, simulation results are presented to show the influences of DECT and PHS on each other in specific channel configurations. Assuming two control frequencies of PHS which must be guarded not to be interfered by DECT, independent and asynchronous systems are simulated within FWA Network environments.

In the next section, DECT and PHS are briefly described and confronted, but without comparison in terms of traffic capacity per transmitter or spectrum efficiency. See [5] or [10] for a complete evaluation.

The propagation and system models used in simulations are described in Section III. Simulated scenarios and configurations are discussed in Section IV. Results are given in Section V, where fundamental Frequency Sharing Rules are discussed.

II. PHS AND DECT [5], [11]

The PHS and DECT systems are designed to cope with high voice and data traffic loads. Table 1 gives an overview about both techniques. To allow the traffic to be distributed unevenly where peak loads are time and geographically varying, Dynamic Channel Selection (DCS) is applied in both systems. Basically the entire frequency spectrum with all channels is available in each cell to provide terminals with suitable connections at a low blocking probability even in areas where the number of calls is very high.

By means of DCS applied in DECT and PHS, base station positioning is simplified and a flexible multi-operator environment in the same service area is supported. However, some restrictions concerning the fixed control frequencies in PHS systems still require a certain amount of frequency planning in advance for PHS.

The aims of PHS span those of cordless and cellular systems,

Table 1: Summary of PHS and DECT Characteristics

Parameter	PHS	DECT
Invented Region	Japan	Europe
Standardized by	TTC/ARIB	ETSI
First Service	1995	1993
Initial Frequency Range [MHz]	1893,5–1919,6	1880–1900
Radio Carrier Spacing [MHz]	0,3	1,728
Data Rate per Carrier [kbit/s]	384	1152
Channel Assign. Method	DCS	DCS
Speech Data Rate [kbit/s]	32	32
Speech Coding	ADPCM	ADPCM
Control Channels	fixed Control Carriers	In-Call-Embedded (logical channels: C, P, Q, N)
Duplexing Technique	TDD	TDD
Multipl. Acc. TDMA [Timeslots]	4 TDD	12 TDD
Timeslot Duration (incl. Guard Time) [μs]	625	417
TDMA Frame Period [ms]	5	10
Modulation Technique	π/4-DQPSK	GMSK
Handover between Base Stations	Yes	Yes
Cellular Capability	Yes	Yes

encompassing the idea of a low-cost wireless handset that can be used in both indoor and outdoor environments, to access fixed network supported services. In Japan PHS forms the basis for public micro-cellular network access by subscribers moving with pedestrian speed. As PHS is a system for private and public use, *portable stations (PS)* support two modes of operation, public and private. The public operation mode enables the PS to access the public PHS service areas. The private operation mode enables a PS to access private systems like a wireless PBX or the home digital cordless system.

The PHS technology was developed in Japan and standardized by Japanese standards organizations. The Association of Radio Industries and Businesses (ARIB), formerly known as the Research and Development Center for Radio Systems, drafted the standard for the PHS Common Air Interface, which was published as RCR STD-28 [1]. Further extensions to the basic PHS standards are being developed. One extension is aimed at FWA Network applications (including support of ISDN services) and another at PHS over cable TV (CATV) networks.

PHS employs a $\pi/4$-shifted DQPSK modulation with a roll-off factor of 0.5. This modulation scheme permits a variety of demodulation techniques to be used, such as delay detection, coherent detection and frequency discrimination detection. Furthermore, the use of the DQPSK modulation method enables a high spectrum utilization compared with GMSK modulation applied in DECT, but on the cost of higher requirements on the signal to interference ration C/I. Therefore in DECT and PHS, traffic capacity per cell in multicellular environments is nearly the same [5].

In contrast to the DECT system, where it is the mobile's task to select a suitable channel, in PHS this is done by the base station. With a link channel establishment request or a TCH switching channel request, the PS asks for the assignment of a channel. The base station can automatically pick up carriers at random and select an available carrier. If no carrier is available, the CS refuses the request. The PS will then automatically request again, up to three times. In case there is still no channel available, the PS waits then a certain time before another try is possible.

The DECT standard was specified by the European Telecommunications Standards Institute, ETSI in 1992. A DECT network is a micro-cellular digital mobile radio network for high user density and primarily for use inside buildings. However, outdoor applications are also possible. The DECT standard permits the transmission of voice and data signals. Consequently, cordless data networks can also be set up on a DECT basis. The use of ISDN services is also possible. In outdoor areas the maximum distance between base and mobile station is approx. 300m; in buildings, depending on the location, it is up to 50m. Larger distances to the base station can be bridged through the installation of appropriate base stations using the relay concept.

III. DECT–PHS SIMULATION TOOL

At the chair of Communication Networks (ComNets), a simulator was designed that allows the analysis of a multitude of different DECT-installations: The **DE**CT–**SI**mulator DESI.
This DECT simulation tool has been enhanced to run protocols following the Japanese PHS standard [1] as well. With the help of the simulator it is possible to perform a detailed facsimile of characteristic qualities of either DECT- or PHS-systems or their coeval operation. Thus it is possible to achieve information about system behaviour in certain environments. Examples are predictions concerning the probability of blocked resp. lost calls, handover behaviour or capacity limits.
The number of systems to be simulated, together with their respective amount of base– and mobile stations is arbitrarily available, only restricted by hardware capacity and simulation time. Using well defined interfaces enables the simulator to interact with a various kind of existing or to be developed system components.

In addition to the specifications of the respective standards, specific parameters of each system can be varied, such as the total number of channels, the mutual position within the frequency band or, in case of PHS, the number and position of the fixed control carriers. Thus it is possible to run standard-conform simulations on the one hand and evaluating coexistence rules by varying some of these parameters on the other hand.

The mutual impact is determined by fixing the respective frequencies and slots for a connection of the one system in the slot-matrices of instantiations of the other system. Possible delays or drifts between the individual systems are taken into account. Interfering channels are only regarded if a transmitted burst overlaps with the considered interfered burst. Overlapping of guard-times does not pay a contribution. In the frequency domain, the impact of PHS on DECT is modeled as non-correlated narrow band noise. Thus a PHS connection interferes a respective DECT channel by the whole received signal power. To determine the impact of DECT on PHS, the respective bandwidths as well as the power spectral density of the modulated DECT signal are regarded. Depending on the relative frequency shift of the PHS channel to the interfering DECT channel only a certain part of the transmitted power is taken when calculating the noise level for this connection.

IV. SCENARIO

The aim of this work is to investigate the amount of traffic that still can be handled in a WLL scenario, where both DECT and PHS providers offer their service.

Due to [12], there is a linear relation between system radius and portable traffic, if the same pathloss model is used. The portable traffic is independent from the coverage (cell-size) because it only results of the co-channel interference ratio C/I. Within PCS-systems underneath house roofs, it can be assumed that for distances of more than 150m, the pathloss-model is independent from the cell-radius [13]. If the cell-size is rather small (e.g. less than 50m), the probability for line of sight (LoS) connections increases and thus a minor pathloss-coefficient has to be employed. For the following simulations a cell-radius of 180m was chosen. The transmission power was adjusted in such a way, that a reception level of -65 dBm at the boundaries of each cell is possible. Due to [14], the chosen cell-size is sufficient to carry traffic of 200 Erl/km^2 which responds to 100% of the traffic in local networks.

In the scenario, 19 BSs of each kind of system are arranged. Together they form a hexagon with one centered BS of each system, surrounded by six other BSs and another circle of 9 BSs. For the analysis of the results, only the 7 inner BSs of one system are evaluated. This is to minimize side effects which would arise by the absence of interferences of further connections.

A. Clustering in PHS

For the fixed CC of PHS a network planning with an underlying 7-cell clustering, as shown in Figure 1 was performed.

Due to [15] the co-channel interference ratio C/I is obtained by the following equation:

$$\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{k=1}^{K_I} D_k^{-\gamma}} \quad (1)$$

whereby R stands for the cell-radius, D_k is the distance to mobile station k and γ is the pathloss-coefficient. Since in Figure 1 K_I = 6 cells are arranged around the central cell and all distances are set to be equal, equation 1 can be simplified to

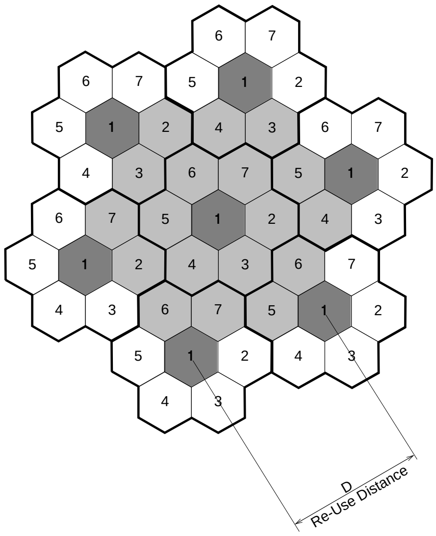


Figure 1: Frequency-planning with fixed cluster structure

$$\frac{C}{I} = \frac{R^{-\gamma}}{6 * D^{-\gamma}} = \frac{1}{6} * q^{\gamma} \quad (2)$$

In this equation, q=D/R is called the *Co-channel Interference Reduction Factor*.

$$q = \frac{D}{R} = \left(6 * \frac{C}{I}\right)^{\frac{1}{\gamma}} \quad (3)$$

For an assumed cluster-size of 7 the co-channel interference reduction factor is given to q=4.58 [15]. Together with an pathloss factor $\gamma = 3.5$ and equation 2 this leads to a C/I ratio of $C/I = \frac{1}{6} * 4.58^{3.5} = 15.35\,dB$ which satisfies the for PHS required C/I value.

V. RESULTS

A. Positioning of the Base Stations

Regardless whether several operators commence offering service in new areas simultaneously or whether one operator enters a territory already supplied by a competitor: The first step lies in a sophisticated network engineering. Some important aspects which have to be considered are the traffic to be carried (subsequently the cell-size), pathloss and attenuation. Closely connected to these considerations is the positioning of the BSs. Often, local authorities offer suitable places for installation, e.g. at the top of public buildings or schoolhouses, such that installation costs can be kept more minimal. On the other hand this includes a tendency for establishing a likewise cell-infrastructure among the competitors. However, investigations in [13] and [12] on the operation of several DECT systems in the same area have shown the influence of the positioning of the BS on the portable traffic. It was shown that in scenarios with a shifted cell-infrastructure-arrangement more traffic could be carried than in a co-positioned-arrangement, though the scenarios had the same footpoint.

Concerning the coexistence of DECT and PHS, a qualitative adoption of these consideration was performed and simulations have shown the augmentation of portable traffic by this measure.

For the following simulation series once the BSs have been co-positioned, afterwards a shifted arrangement.

Figures 2(a) and 2(b) point out the improvements for both system types. It can be seen that both system types profit by this measure. Regarding a GoS of 2% the portable traffic of one PHS BS raises from approximately $5\,Erl$ to $5.4\,Erl$, cf. Figure 2(a). Even better results are achieved for the DECT systems. Their average traffic per BS could be enhanced from $4.5\,Erl$ to $7.2\,Erl$.

The influence of a shifted arrangement in relation of the two system types is shown in Figure 3. Since both parties profit from this measure it is evident that the globally carried mean traffic can be enhanced, namely from $4.8\,Erl/BS$ (Fig. 3(a), 2% GoS) to $6.5\,Erl/BS$ (Fig. 3(b), 2% GoS).

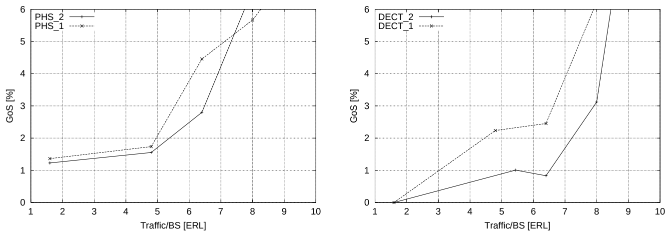
A shifted positioning of the BSs of the different systems types therefore features by favouring *both* system types, DECT and PHS. Since neither of the systems improves its service at the cost of the other the globally carried traffic (at the same GoS) can be enhanced. As a consequence, this arrangement contributes to effect a higher spectral efficiency and a better exploitation of the spectrum.

B. Exclusive Use of Frequency Bands

1) Exclusive Use by PHS-CC The most important difference between DECT and PHS is the use of fixed control channels (CCs) within PHS. Their task is to transmit control information, needed especially for mobile management and call control. The PHS standards protects these frequencies from disturbing interferences by introducing unused guard frequencies. However, this measure only protects of interferences caused by the same system type (PHS). In heavily interfered scenarios, there is a big danger of being supplanted by DECT systems.
To circumvent an extrusion of PHS, the idea is to detach a small part of the shared frequency band and assigning it for exclusive use to PHS, thus the susceptible control channels can be placed within, see Figure 4. At first sight, the only party to profit from this measure is PHS, as DECT looses bandwidth including a loss of trunking gain.

Figure 5(a) shows the improvement for the PHS systems. Regarding a GoS of 2%, the amount of portable traffic rises from $5.4\,Erl/BS$ to $7.5\,Erl/BS$. This corresponds to an increase of 39%. Table 2 shows the reasons for this performance gain.

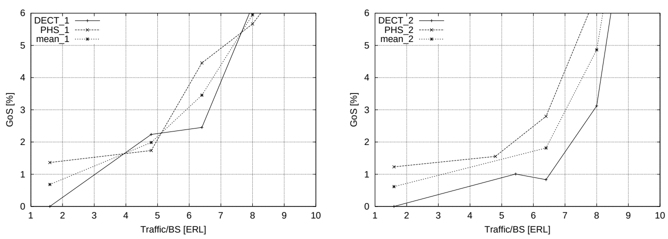
It can be seen that as a result of this measure not even one failed synchronization takes place. In general, there are two reasons for failed synchronizations: The first one is a reception level below the sensitivity of the respective system's transceiver (DECT: -86 dBm, PHS: -96 dBm at BER $1 * 10^{-2}$). However, this can be excluded since the transmission power was chosen to supply even the edge of the coverage area with a minimum level of -65 dBm. Thus the only remaining reason for a failed synchronization is an insufficient C/I ratio. Within this simulation, a mobile can synchronize, if the received C/I is equal to, or more than 12 dB for DECT and 12+3=15 dB for PHS. The additional 3 dB for PHS thereby is to consider the different modulation schemes GMSK and $\pi/4$-DQPSK [16]. Since the chosen measure provides protection to the PHS' CCs from being interfered by DECT and guard channels provide protection against PHS caused interferences, all PHS mobiles are able to synchronize. This is independent from the amount of traffic because the CCs in PHS are not allowed to be used by any traffic connections. The next



(a) PHS–PHS

(b) DECT–DECT

Figure 2: Influence of BS-Positioning within the same system type



(a)

(b)

Figure 3: Influence of BS-Positioning on the opposite system type

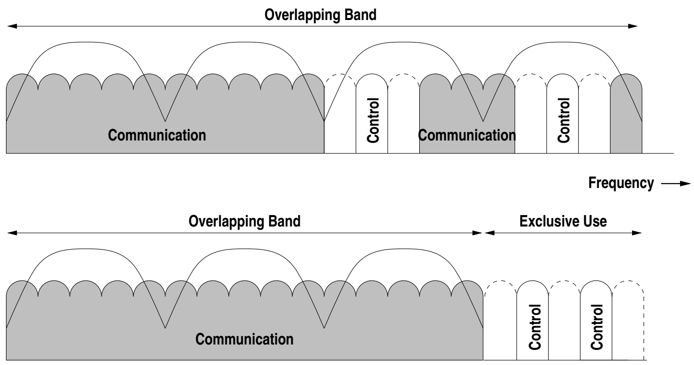


Figure 4: Exclusive Frequency Assignment for PHS-CC Use

PHS Simulation Results	Traffic/RFP [Erl] 4.8	Traffic/RFP [Erl] 6.4	Traffic/RFP [Erl] 8
bandwidth commonly shared			
No of Calls	1739	2395	3014
Failed Bearer Setups	1	4	72
Failed Synchronizations	26	57	43
Blocked Calls	**27**	**57**	**59**
Dropped Calls	0	1	14
with partial exclusive use by PHS			
No of Calls		2431	3139
Failed Bearer Setups		9	42
Failed Synchronizations		0	0
Blocked Calls		**5**	**18**
Dropped Calls		1	6

Table 2: Simulation Results for PHS with and without exclusive sub-band use

step after synchronization is a connection setup (either because of an incoming call or because of the user's setup request). Therefore the base station proposes a slot/frequency combination to the mobile, that has to confirm the applicability of this channel. The number of failed bearer setups is given in Table 2 as well. Thereby it has to be considered, that this value includes the number of failed setup requests and of failed bearer setups for handovers. More meaningful for the performance gain of PHS is the number of *blocked calls*. It can be seen, that for a traffic of e.g. $6.4\,Erl/BS$ the number of blocked calls could be reduced from 57 to 5 (with an almost similar total number of calls) whereby the number of dropped calls stayed the same. This explains the PHS performance gain shown in Figure 5(a).

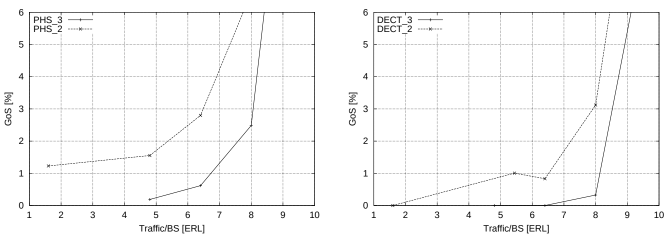
Besides this, still another aspect has to be mentioned: Having a look at the number of PHS dropped calls for a traffic of $8\,Erl/BS$ in Table 2 opens a remarkable improvement (from 14 down to 6). This is important, since their influence on the system's performance due to equation 4 is far reaching. The improvement is in so far interesting, since the chosen measure was mainly applied to protect the CCs of PHS.

Regarding the system performance of DECT, one would expect a deterioration because of two reasons: Firstly, the reduction of the number of frequencies from 10 to 9 means the loss of 12 physical channels, that otherwise could be used for connections. Secondly, as a consequence, this leads to a decrementation of the trunking gain. However, having a look at Figure 5(b) shows quite an opposite system behaviour. Considering a GoS of 2%, the portable traffic per BS could even be enhanced from $7.2\,Erl$ to $8.2\,Erl$.

It is obvious, that if DECT were the only system type in this scenario, the subtraction of one frequency could never result in an improved system availability. Therefore the reason has to cohere with the differences of DECT and PHS, or to specify this, with the different bandwidths of their channels. Figure 7 shows the upper part of the shared frequency band and its usage due to the chosen measure. Following the measure's intention, the 2 CCs are placed in the exclusively PHS-used frequency band corresponding to DECT frequency 10. But, since 1 DECT frequency covers approximately 6 PHS frequencies, two other (and a part of a third one) PHS-frequencies profit from this arrangement.

Taken together this means that there are

$$3\,\text{frequencies} * 4\,\frac{\text{channels}}{\text{frequency}} = 12\,\text{channels}$$

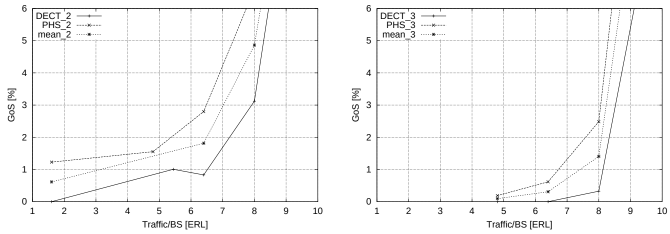


(a) PHS–PHS (b) DECT–DECT

Figure 5: Influence within the same system type for exclusive subband use by PHS

that can be used by PHS without (or only with little) impact of DECT. On the other hand, these connection do not interfere the DECT systems, too. Applying a DCA algorithm for channel selection, PHS will always chose quiet channels for setups. Since these channels are most likely not interefered, they will always be the first one to be in use. Therefore they turn out from being possible interferers for DECT and thus cannot cause blocked or dropped calls.

As shown before, the applied measure provides a performance gain for *both* systems. Therefore, as shown in Fig. 6, the mean traffic within the scenario could be enhanced from $6.5\,Erl/BS$ up to $8.1\,Erl/BS$.



(a) (b)

Figure 6: Influence on the opposite system type for exclusive subband use by PHS

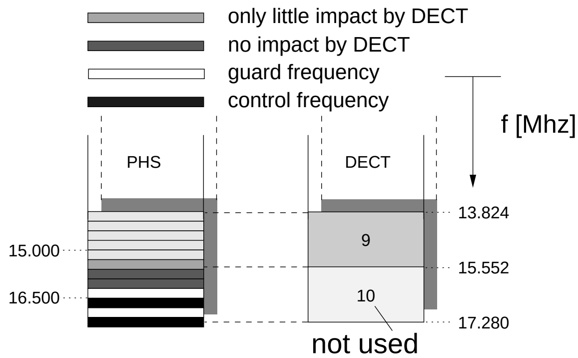


Figure 7: Upper part of the shared frequency band with exclusive use by PHS

As a result one can resume that the (enforced) readiness of DECT to convey one frequency to PHS which, at first sight, only takes advantages to the latter, finally is rewarded by a gain of performance for *both* system types. In such a way, this frequency sharing rule is able to combine the actually contrary demands for fairness and individual optimization.

C. Exclusive Use for Handover Performance

The definition of the grade of service (GoS) defines a relation of

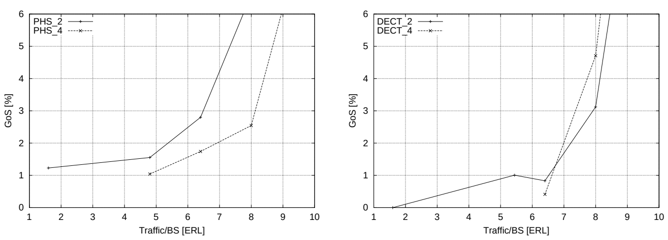
$$\frac{blocked\ call}{dropped\ calls} = \frac{1}{10} \tag{4}$$

between blocked and dropped calls. This includes the users attitude rather to accept a failed connection setup than a forced interrupt within a conversation (or data transmission). It is to investigate, whether a high GoS depends on a large number of blocked–, or a (relatively) large number of dropped calls. If the latter is the reason, measures for reducing dropped calls can achieve a namable improvement, even if this is at the cost of an increasing blocking probability.

The idea is to split up a part of the commonly used frequency band and assign it for the exclusive use in cases of handovers. In such a way, the number of dropped calls should be lowered and consequently a better GoS should attune. Within the following simulation series the upper part of the band corresponding to the last two DECT frequencies may only be used in cases of handovers. The CCs of PHS in this arrangement, are located similar to the previous arrangement in this band as well.

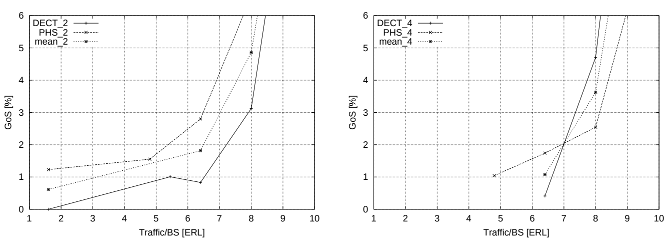
Figure 8(a) shows the improvements for PHS. It can be seen that the average traffic at 2% GoS could be enhanced from $5.4\,Erl/BS$ to $7\,Erl/BS$.

DECT, on the other hand, notes a little decrease from $7.2\,Erl/BS$ down to $7\,Erl/BS$. This is because the little improvements of dropped calls confronts a highly risen number of blocked calls. This is evident, because the restrictions of the bandwidth leads to a smaller number of trunked channels (for call setup) and thus the blocking probability increases. Obviously this effect is of more relevance in DECT than in PHS.
Nevertheless, regarding Figure 9 shows that the mean traffic carried at 2% GoS could be enhance from $6.5\,Erl/BS$ to $7\,Erl/BS$.



(a) PHS–PHS (b) DECT–DECT

Figure 8: Influence within the same system type for exclusive subband use for handovers



(a) (b)

Figure 9: Influence on the opposite system type for exclusive subband use for handovers

VI. CONCLUSIONS

The aim of this paper was to investigate existing and to work out new ways of providing coexistence of uncoordinated mobile radio communication systems. Beyond the background that more and more wireless applications become available, one has to find possibilities to satisfy their demand for non- or less interfered radio channels. The shortage of frequency as a resource requires an optimization of its exploitation by all participating parties. In order to estimate the effectiveness of several measures (frequency sharing rules, FSR), coexistence simulations with the two cordless telephone systems DECT and PHS were undertaken.
The evaluation of the respective FSR showed mentioning improvements of the overall spectral efficiency and thus a better exploitation of the spectrum, under the condition of fair coexistence. Thereby it was shown, that cooperation does not necessarily result in a poorer performance of the own system. Thus it is possible to increase all system's availability without at the cost of any party.

VII. ACKNOWLEDGEMENT

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