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Sharing Rules for DECT and PHS Providing Fair Access to the Commonly Used Frequency Band

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Abstract — **DECT and PHS are cordless radio communication systems applying dynamic channel allocation. They are competing candidates for use in Fixed Wireless Access Networks. By means of simulations, both systems are investigated in terms of mutual interference and possible coexistence in case they have to operate in exactly the same frequency band. Frequency sharing rule are defined to guarantee the spectrum efficient, uncoordinated, and fair operation of both radio access networks.**
Keywords — **Wireless Local Loop, Fixed Wireless Access Networks, DECT, PHS, Coexistence, Frequency Sharing Rules**

I. Introduction

In the near future, Fixed Wireless Access (FWA) Networks are expected to become a widely accepted technology for the rapid access to the network infrastructure by subscriber premises. DECT and PHS are both established cordless and micro-cellular wireless systems purposely designed to offer high-quality, low delay voice and data capability. Therefore, they are competing alternatives for use in FWA Networks [1].

DECT (Digital Enhanced Cordless Telecommunication) is the European standard for cordless telephones and micro-cellular mobile communication systems [2]. DECT systems feature a high degree of flexibility and are used for a multiplicity of applications. Contrary to many other wireless systems, e.g., GSM, DECT is based on Dynamic Channel Allocation (DCA) with a peripheral organisation controlled by the mobile stations (MSs). One discussed application of DECT systems is the utilisation as an wireless access network in the local area, as a substitute of the wiring of the final users, see Sect. II.

PHS (Personal Handy Phone System) is the Japanese ARIB standard for similar systems and currently highly accepted for micro-cellular applications in Japan[3]. While with DECT a GMSK modulation is used, PHS uses a DQPSK modulation, which bisects the data rate at the air interface. Signal distortions due to multipath propagations can therefore be rather tolerated [4] which helps in micro-cellular environments, but does not have large effects in FWA Networks with their rooftop subscriber antennas with directional antenna patterns.

One of the main differences between both systems is the use of fixed Control Channels (CCs) within PHS used in particular for location management and call setup. Since DECT conveys these information on traffic channels (or by the help of a dummy bearer, if there is no connection established) that underlie DCA, PHS behaves more static which causes problems in hot-spot scenarios in case both types of system are allowed to operate in the same band.

Similar to DECT, PHS uses DCA for the traffic channels. As both standards have been designed to perform interference avoidance the two systems should therefore be suitable to operate in a multi-operator environment [5, 6].

In order to enable both systems the existence under mutual interference when approaching new markets and regions, as for example South America, they have to operate in the same frequency spectrum. However, as originally the systems are not targeting towards being used simultaneously at the same place in the same frequency band, investigations of the mutual interference become necessary. A simulatory investigation is provided in this contribution to help clarifying the following questions:

Can PHS and DECT fairly cooperate together in the same frequency band? Which measures have to be taken, in order to ensure a fair coexistence? Do the fixed Control Channels of PHS need an individual protection from DECT and how could this be realised?

The following section provides a short introduction of FWA Networks. Then, Frequency Sharing Rules are discussed, and approaches concerning DECT and PHS are given in Sect. IV. After discussing the parameters of evaluation and the investigated scenarios, simulation results are presented and discussed in Sect. VII.

II. Fixed Wireless Access (FWA) Networks

The technological developments in the wireless area in recent years have provided opportunities for reliable, flexible, and cost-effective services offered through the deployment of FWA Networks in place of traditional copper wireline. The services may be data, video, multimedia, and obviously voice based on POTS or packet switching [7, 8].

Different technologies will serve some applications better than others. The appropriate technology, whether it is DECT or PHS, will depend on a large number of application considerations as residential versus business subscriber requirements and the environmental characteristics (area size, subscriber density, rural versus urban).

Applying established technologies allows developing countries to quickly advance their existing telephone network into the future. Fast network deployment, low capital investment and maintenance costs are attractive considerations from the operators prospective [7, 9]. Due to these key benefits, FWA Networks are gaining popularity as startup communication systems in the Asian and Latin American countries for providing data and voice services in sparsely populated rural areas.

In two countries, Colombia and Thailand, PHS and DECT have been discussed to be licensed for use in FWA Networks equally within the frequency bands 1900 .. 1920 MHz, and 1902 .. 1918 MHz, respectively, where they are required to maintain fair coexistence. An overlapping configuration is chosen by regulators of these developing countries, under support of uncoordinated installation and coexistence for both system types.

III. Fairness and Definition of Coexistence Rules

In order to achieve a fair and best possible utilisation of a shared frequency band, the participating systems have to accept the presence of further (different and foreign) systems. This includes the will of relinquishment of setup requests on the one hand and releasing, after having had an appropriate time of use, an occupied channel on the other hand. Coexistence rules (CXR) provide a framework within this context, in order to let all involved parties face the same chance of making use of the shared resource frequency spectrum.

As can be seen from Fig. 1, Coexistence Rules are the superordinate concept for measures whose task is to warrant the existence of different systems, having equal rights, in the same band.

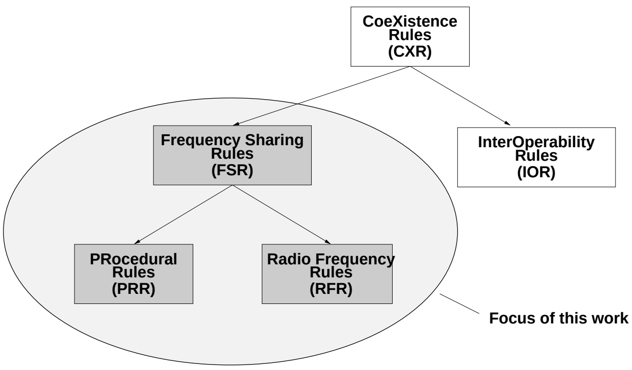

Fig. 1: Coexistence rules for radio systems [10]

The CXR are thereby divided into Frequency Sharing Rules (FSR) and Inter Operability Rules (IOR). The latter are characterised by applying information exchange between the different systems. This must be realised with the help of an upon agreed communication protocol that includes the decoding of signals. Procedures, e.g., for the logical link control (LLC) or the medium access control (MAC), are defined by the IOR. Frequency sharing rules (FSR) on the other hand imply the absence of direct communication between the systems. However, the detection of signal power is an substantial part of FSR and thus, some kind of underlying information exchange is performed nevertheless. To provide spectrum coexistence for existing, proprietary and planned radio systems, FSR have been proposed in [11]. A synonym for FSR is the notion Frequency Etiquette. They both define a set of rules, agreed upon all participants, for the coexistence of radio systems using different air interfaces in the same and in adjacent frequency bands, without the requirement for communication. FSR, again, can be subdivided into PRocedural Rules (PRR) and Radio Frequency Rules (RFR). PRR aim on logical constraints to harmonise the coexistence between systems, e.g., the duration of transmission on one frequency. RFRs, on the other hand, define the physical characteristics of the systems. Transmission power, antenna directionality, bandwidth, channelisation, out of band emissions, power spectral density and frequency stability are examples that pertain with RFR.

Since this paper concentrates on uncoordinated mobile communication systems, the possibility of information exchange is excluded. Thus, the focus is on the gray underlied FSR of Fig. 1, including PRR and RFR, some off which are presented in the following subsections. Basically, in addition to the rules investigated in this paper, the rules already defined in [5] will be always applied.

IV. Approaches of minimising the number of blocked calls

As explained in the previous section, the CCs of PHS are susceptible of being interfered by other systems, since they cannot elude to other frequencies. In a multi-operator environment, where only PHS systems are installed, this is guaranteed by guard channels enclosing the respective CC. In this way, the standard defines particular frequencies that are designed to each operator. It is then the operator‘s task to ensure the reception of a satisfying C/I ratio, such that the required information becomes available everywhere within one cell. Generally this is performed by establishing a certain cluster structure as it is known from the radio network planning of FCA systems.

By licensing DECT systems in the same frequency band this protection of the CCs by guard channels does not only take effect anymore, moreover in hot spot scenarios it adversely affects the system performance of PHS. As can be seen from Fig. 2, the frequency range of one DECT channel ($1728\ kHz$) covers approximately six PHS channels ($300\ kHz$).

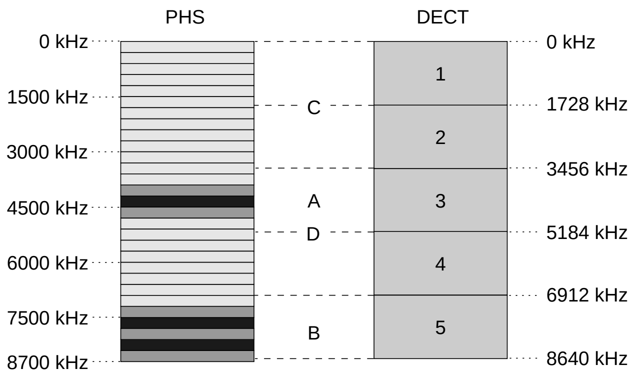

Fig. 2: Frequency allocation of PHS against DECT

For example, if the arrangement of the CC together with its guard channels corresponds position A in Fig. 2, it is most likely that in hot spot scenarios the DCA algorithm of DECT will choose frequency 3 for establishing a connection. The reason for this is, that the guard channels do not pay a contribution to the measured noise level by DECT and therefore misguide the employed DCA algorithm of DECT to having found a free frequency. In this example the relative time shifts of the respective slots are not considered, as hot spot scenario are assumed here, where all slots of one frequency are assumed to be in use. However, the simulations are performed regarding the exact position of the distinct slots. The effect of misguidance increases, if an arrangement of several CCs (here it is shown for two), as it is specified in the PHS standard (see Fig. 2, position B) is considered.

There are several approaches in order to improve the situation in terms of limiting the mutual interferences. Probably the easiest one is to assign a part of the frequency band to PHS for exclusive use. Thus, the CCs would be protected from being interfered by PHS (due to the guard channels) as well as from DECT. The analysation of field trials in the Hong Kong area (1995) leads to the same conclusion [1].

However, this solution is not satisfying as it offers the poorest exploitation of the spectrum. Thus, this kind of Frequency Sharing Rule (FSR), called Minimum Frequency Separation (MFS), should be the last measure to be taken. Moreover it contradicts the idea of a freely accessible frequency band, shared among different users. Another important aspect in this context is that as a consequence of the worldwide opening of the markets, PHS (as well as DECT) aims on breaking into new markets. Therefore PHS has to suit to local existing general conditions and cannot claim frequencies for its own, as this would mean the use of not used frequency bands originally intended to decrease mutual interference. Obviously this is not satisfying, from a technical and economical point of view.

Hence the question arises: If the CCs are supposed to operate in the same frequency band as the interfering DECT systems operate in, are there other ways to minimise these interferences?

Some first ideas discussed above show that it is not always advantageous to arrange the control channels close together. Therefore it is advisable to keep a distance of at least once the bandwidth of a DECT channel ($1728\ kHz$). However this has to be payed by a loss of capacity, since additional guard channels will be needed.

The next step is to determine the best position for the CC within the available bandwidth. For this, the power density spectrum of a GMSK-modulated signal, as it it used for DECT, is indicated in Fig. 3. Ninety-nine percent of the MSK power is found within a bandwidth $\Delta f = -0.6/T \ldots 0.6/T$. As a consequence, the CCs of PHS should be arranged between two DECT frequencies as it is indicated for position C and D in Fig. 3. This strategy has been developed in [12]. In the following, it is referred to as Power Spectral Density oriented Assignment (PSDA). Simulation results of its application are discussed in Sect. VII.

V. Parameters for Performance Evaluation

The following parameters are indicators which will allow a judgement over the effectiveness of applied FSR. It has to be considered that simulations often, due to necessary simplifications, respectively unknown or estimated basic conditions, only allow a qualitative prediction. In other words, if quantitative predictions are required, this can be achieved by stating a reference simulation and referring the following simulations to it.

Possible parameters for judging are:

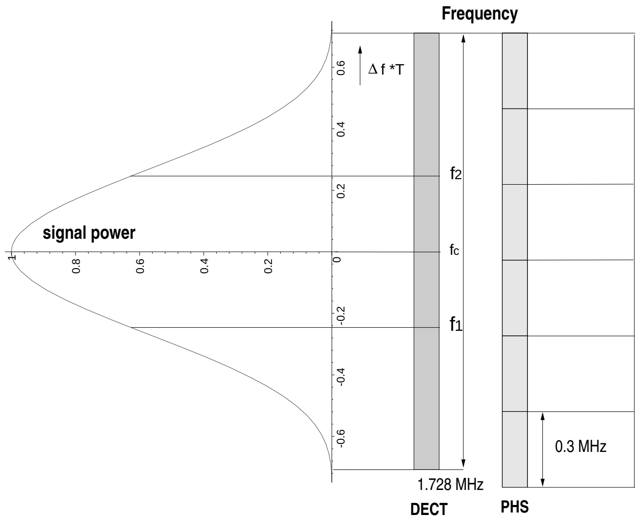

Fig. 3: Power density spectrum of DECT-MSK signals

- **Number of failed Synchronisations**
- **Grade of Service (GoS) of the system** This is a weighted variable representing the quality of the radio network:

$$GoS = \frac{blocked\ calls + 10 * dropped\ calls}{total\ number\ of\ calls} \quad (1)$$

A low GoS indicates a high availability within the system, since there are only a few blocked calls and almost no dropped calls. In wired networks a GoS of 1% is aspired whereas in mobile radio communication systems up to 2% are tolerated.

- **Distribution functions of RSSI and C/I**
The quality of supply of a mobile station depends on the level of the received signal Radio Signal Strength Indicator (RSSI) on the one hand and on the Bit Error Ratio (BER) on the other hand. In simulations, the latter can be obtained from the measured Carrier-to-Interference ratio (C/I) at the receiver locations. Thereby influencing factors, as the distance between sender and receiver, coupling loss, frequency, the kind of reception filter and in particular the used modulation method have to be considered. With the help of respective bit error models it is possible to deduce the BER. For more details refer to [4].

- **Handover Performance**
As the mobiles within the investigated scenario will have a fixed position the handover activity indicates the volume of interferences caused by different (arriving) parties (C/I-handover)

- **Spectral Efficiency**
Spectral efficiency is a key parameter. The higher the efficiency, the greater will be the traffic for the frequency band assigned by the regulating authorities per unit geographical area. In [1], the following definition is given:

$$\text{Sp. Eff.} \left[\frac{{}^{bit}/_{s}}{MHz \cdot km^2}\right] = \frac{\text{traffic}\,[Erlang]}{\text{bandwidth} \times \text{footpoint}} \quad (2)$$

VI. INVESTIGATED SCENARIOS

The aim of the simulations discussed here is to investigate the amount of traffic that can be handled in a hot spot scenario, where both DECT and PHS providers offer their service.

A fixed scenario is simulated where 19 BSs of both types of systems are arranged in a symmetric grid. Together they form a hexagon with one centered BS of each system, surrounded by six other BSs and another circle of 12 BSs. For the results, the 7 BSs in the center of the simulation area are evaluated. The radius of one cell is $180m$, and the distance to the next BS of the other type of system is $90m$. Thus, DECT and PHS systems are simulated with mutual overlapping cells. All BSs transmit with an average power of $250mW = 23dBm$. At the edge of each cell a minimum reception level of $-65dBm$ is available. For the fixed CCs of the PHS BSs a fixed channel planning with an underlying 7-cell clustering is performed.

VII. RESULTS AND DISCUSSION

Basic FSR are already defined and discussed in [5]. In this contribution, first of all a scenario where the positions of the CCs correspond to the mid-frequencies (f_c in Fig.'3) of respective DECT systems (A and B in Fig. 2) is investigated. As can be seen in Fig. 4, PHS mobiles point out lots of difficulties in synchronising to their respective base station (BS) while DECT is able to handle this interference situation.

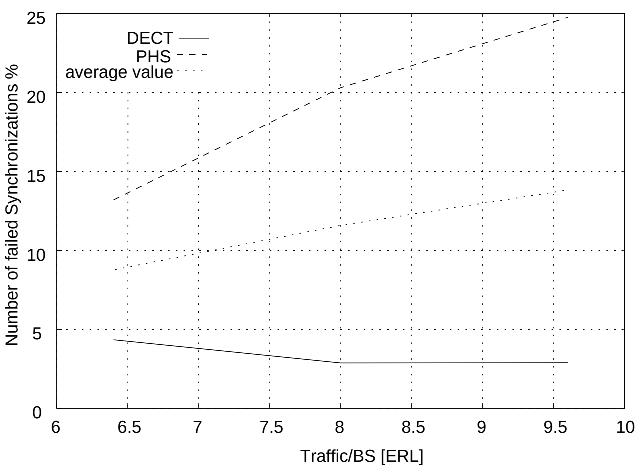

Fig. 4: Failed Synchronisations with worst case CC positions

Moreover, at first sight the probability of establishing connections seems to exalt with increasing traffic, since the number of failed synchronisations even declines. The reason for this behaviour is that a DECT BS embeds control information into *every* traffic channel. Therefore a MS is able to select the best possible connection of another MS in order to synchronise. Since more traffic means more connections, the MS has a wider range of possibilities to receive BS data and thus the number of synchronisation errors is reduced. Since PHS MSs are not able to elude to other frequencies in order to obtain the necessary information, the number of failed synchronisations increases, almost linear, with the increasing traffic offer per BS. However, the fact that DECT shows a better behaviour concerning the number of synchronisations does not mean that the MS will also be able to establish a connection. Therefore, a MS first of all has to find a suitable channel on which it can transmit to the BS its request for call setup. Fig. 5 shows the expected result, namely increasing number of failed setups accordant to the augmentation of the traffic.

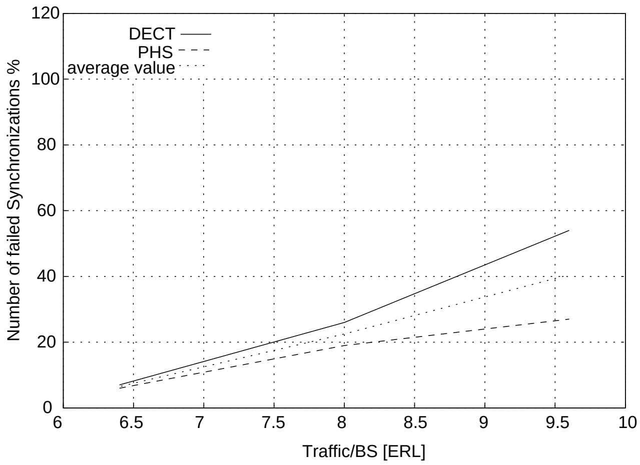

Fig. 5: Number of Failed Setups in the scenario with worst case CC positions

Comparing the absolute values of failed setups, the DECT performance is less than the one of PHS. Of course, this is not really an advantage for PHS, as most of the PHS calls have already been blocked by the failed synchronisation, see Fig. 4. On the other hand, once having managed the first hurdle (even if it is a very high one), it is more probable for PHS to find a suitable channel than for DECT. This can be explained with the same arguments as given in the previous section, where the best site of the PHS CCs is deduced: currently, the CCs are arranged in the heavily interfered parts of the frequency band. Thus, more channels having a relative position to the edge of DECT frequency channels are available for carrying the demanded traffic.

In the following simulations, the site of the PHS CCs are optimised due to the explanations in the previous section (see C and D in Fig. 2). The result can be seen in Fig. 6.

The number of failed synchronisations on the part of PHS could be reduced to almost zero. The number of failed setups therefore doubled. This is not surprising since now all synchronisations of PHS can take place, but the number of usable ('quiet') channels is restricted due to the heavily interfered scenario. Additionally, two optimal and four suboptimal PHS frequencies are now occupied by the CCs and their guard channels. Therefore new PHS connections would be supposed to be established in those parts of the commonly shared band that are mainly interfered by DECT.

It is not to mention that the gain on the part of PHS had to be purchased at the expense of DECT. The reason for this lies in the bigger number of PHS mobiles that are now able to pass the earlier described first hurdle (the synchronisation) and thus compete for free frequencies. It is therefore more probable for a mobile to be able to establish a connection. On the other hand now it is PHS to sup-

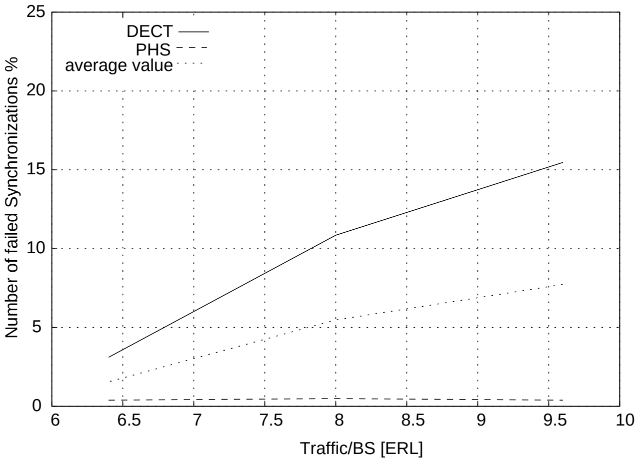

Fig. 6: Failed synchronisations with optimised CC positions

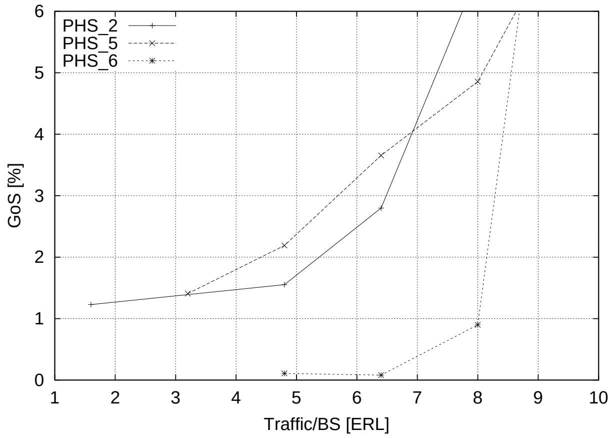

Fig. 8: PHS–PHS

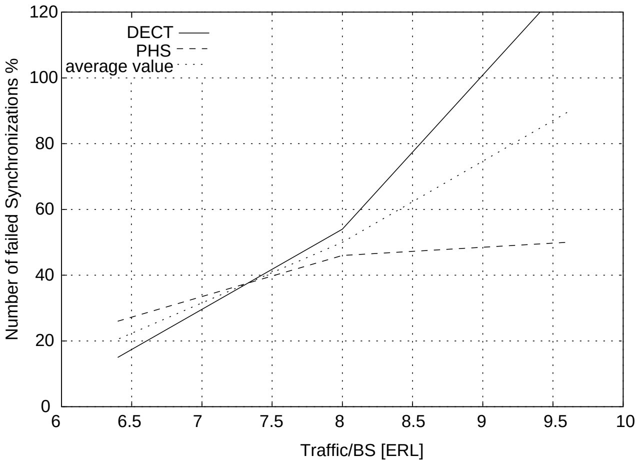

Fig. 7: Failed setups with optimizes CC positions

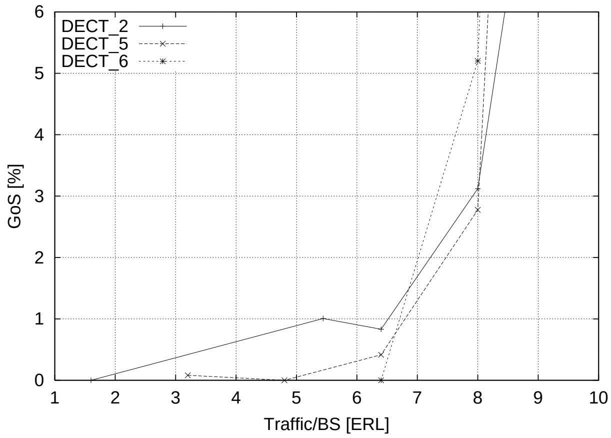

Fig. 9: DECT–DECT

plant DECT. This is also proved by the graphs represented in Fig. 7, where the traffic per BS is DECT against the number of failed setup requests. It can be seen that for a traffic of less than $7.3 ERL/BS$ the total number of failed setups on the hand of DECT is less than of PHS. In other words, similar to the first simulations, once having managed the first hurdle (synchronisation), it is more probable for DECT to find a suitable channel than for PHS. This changes, if a BS services more traffic than $8ERL$, which indicates the correctness of the assumption that now PHS tends to predominate.

In Sect. IV the idea of a PSD oriented assignment (PSDA) is presented. The following simulations are performed to investigate its applicability. The simulation series 2 with the standard-conform CC arrangement at the upper part of the bandwidth (cf. position B in Fig. 2) is hereby used as a reference. Two other simulation series (5,6) are to investigate the influence of the position of the CCs within the frequency band on the system behaviour. Therefore, in the simulation series 5, the CCs are facing a heavily DECT interfered position in the frequency band (cf. position A in Fig. 2) whereas in series 6, a less interfered position is chosen (cf. position C,D in Fig. 2).

Figs. 8, 9 picture the results. The influence of the position of the CCs on the system performance of PHS can be obtained from Fig. 8. Regarding a service of 2%, the portable traffic amounts to $4.4\,Erl/BS$ for the simulation series 5 (CCs at heavily interfered positions) on the one hand, and $8.1\,Erl/BS$ for the series 6 (reference value of simulation series 2 at 2% GoS: $5.4\,Erl/BS$). The main reason for this success is an essential reduction of the number of blocked calls in the series 2.

Naturally, the improved performance of PHS has to be paid with a decreasing performance on the part of DECT, where the average base load at 2% GoS decreases from $7.5 Erl$ within simulation series 5 down to $7\,Erl$ in series 6 (reference value of simulation series 2 at 2% GoS: $7.25\,Erl/BS$). However, the gain on the one side is significantly higher than the loss on the other. This is because from DECT's point of view, PHS connections are treated as narrow band noise. Their relative location in the frequency band towards DECT therefore is not decisive.

By applying PSDA, the average traffic (DECT and PHS together) per BS within this scenario could be enhanced from $6.4\,Erl/BS$ in simulations without this rule to $7.5\,Erl/BS$, see Figs. 10 and 11, both for a GoS of 2%. The reference simulation is performed with a mean traffic of $6.5\,Erl/BS$ at 2% GoS.

It can be concluded that PSDA is an effective method

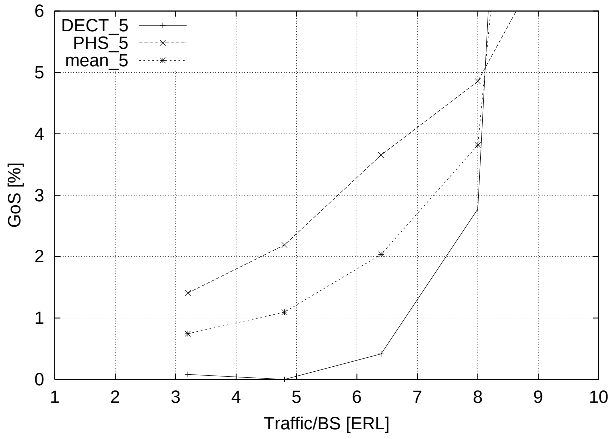

Fig. 10: PHS–CCs at heavily interfered positions

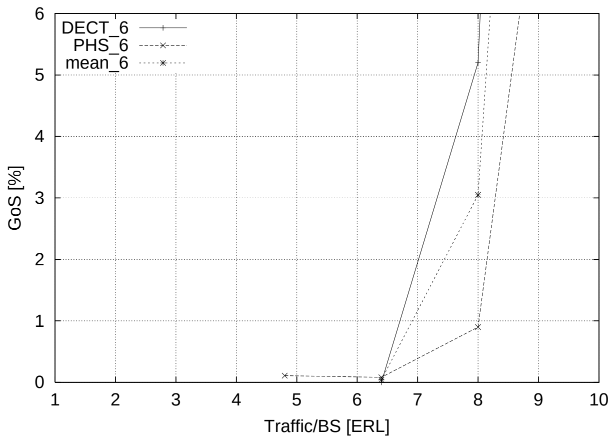

Fig. 11: PHS–CCs at less interfered positions

to enhance the spectral efficiency within a given scenario. Since it also results in an assimilation of the system performance of DECT and PHS, it fulfills the demand for fairness as well. In opposite to splitting of the shared band, PSDA makes use of existing diversities between DECT and PHS to protect the control channels of PHS. Thus it is not necessary to change the system behaviour of DECT, in order to increase the performance of PHS. This is particularly interesting, if PHS wants to enter a new market in an area where DECT is already well established.

VIII. Conclusion

This contribution focuses on improving the access to the radio channel being part of a shared frequency band, which is supposed to be simultaneously used by two different systems. This is investigated by minimising the number of blocked calls due to synchronisation errors. In order to estimate the effectiveness of several FSR, coexistence simulations with the two cordless telephone systems DECT and PHS are discussed. Therefore an existing simulator for DECT systems (called DESI) is enhanced to simulate protocols following the Japanese PHS standard.

A Frequency Sharing Rule (FSR), namely the Power Spectral Density oriented Assignment (PSDA) [12] is introduced. The idea is to make use of the different nature of two systems that are to operate in the same band. Thus, if one system needs a particular protection in some way, this can be achieved without wasting frequency resources as it happens with Minimum Frequency Separation (MFS). In this way, one system is able to use frequencies with less interference from the other and therefore the spectral exploitation is improved. It is also shown that under certain circumstances the system which is to be protected can also become predominant.

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. It is 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 the cost of any party. Additional investigations are useful to determine an optimised (self adapting?) strategy in order to warrant the fair coexistence of uncoordinated radio communication systems at a highest possible rate of exploitation of the shared frequency band.

IX. Acknowledgment

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