APPLICATION OF PACKET RADIO MULTIPLE ACCESS IN DIGITAL ENHANCED CORDLESS TELECOMMUNICATIONS

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ABSTRACT

Digital Enhanced Radio Telecommunications (DECT) is a general radio access technology for short range wireless telecommunications. It provides telephony quality voice services and a broad range of data services. Packet Radio Multiple Access (PRMA) is a variation of r-Aloha technique adjusted to use for speech services. Basic DECT system does not discriminate between kind of data it transmits and does not adjust its behaviour to existing conditions. Indeed, DECT uses circuit switched commutation to establish a connection independently form data type. In this paper a characteristics of speech transmission is taken into account and improvement of DECT is discussed. The circuit switched network for voice transmission utilizes effectively about 40% of channel capacity, as people listen for approximately half of phone call time and only during the other half, they produce [1]. This results in wasting radio resources, because a signal comprising 'silence' is being transmitted. The idea of applying a packet transmission into DECT radio interface facilitates maintenance of the speech connection only when speech signal is available to be sent. The investigations in applying the PRMA into DECT has show that the substantial gain can be achieved. This paper discusses the concept of applying PRMA to DECT and disseminates the simulation results.

INTRODUCTION

Radio signal carrying the information between portable part and fixed part decays due to propagation attenuation, therefore the signal can be reused if the sufficient distance is kept. From this idea, the whole area can be divided into cells of a certain radius where none of available frequencies is used more than once. This division of frequency bands assignment could be forced by the system architecture, which is the case in GSM or could be dynamically-runtime allocated. The DECT resource management and frequency band assignment schema consists in Dynamic Channel Selection (DCS). This means that the must of planning the resource coverage was eliminated thanks to the automatic self-configuration of the network. This hugely simplifies the network planning and allows the co-existence of many service providers who could share the same frequency band without any agreement. For that DECT is called self-adapting network [3].

PRMA is a variation of R-Aloha protocol, which is facilitated to use in voice services by a fixation of packets length and a fixation of reservation slot position. PRMA frames are divided into at least two types of slots: many transmission slots and at least one reservation slot. When data to be transmitted arrives, terminal uses Aloha protocol to obtain a permission for a transmission. Each frame has a particular slot dedicated for the purpose of reservation (r-slot). In case, when two terminals logged to the same base station try to send their request at the same time, they cause a collision whereupon both of them fail to get the permission and have to retry their request. To not drive to the collision in the following time-frame they cannot both transmit again in the next turn. Instead, the terminals draw weather they will retry immediately or wait the time of duration of one frame. This gives chance to omit the collision in subsequent time-frame.

The parameter ruling the process of re-transmitting the reservation request is a *permission probability* which indicates how probable the retransmission after collision is. Technically this problem is solved by drawing the number form the range of 0 to 1 and comparing it to the *permission probability* value. If the drawn number is smaller, then retransmission will occur. Otherwise, the terminal waits a turn.

The terminal which failed to establish the transmission channel has to store packets in buffer, which should be capable of keeping postponed packets for 40 ms. The buffer length of 40 ms is the time of maximal delay, which is still unnoticeable for people. Packets deferred for more time would cause an uncomfortable feeling, hence they are dropped. From user point of view, problems in obtaining a reservation results in front-end-clipping, that is that the beginning of voice signal is cut out. This phenomenon is unacceptable, when the number of lost packets exceeds 1% of total number of packets transmitted. Otherwise, it is acceptable.

TECHNICAL ISSUES

From technical point of view, the introduction of PRMA into DECT should be applicable without introducing expensive changes into DECT core infrastructure. It just needs minor changes in radio equipment.

Elements that should be added, are a Voice Activity Detector (VAD) and a Control Unit, whose placement in the terminal is shown in the Figure 1. VAD detects weather user speaks or not, so it is in fact a 'filter of silence'. This device allows to find out when the radio channel may not be used and therefore can be released.

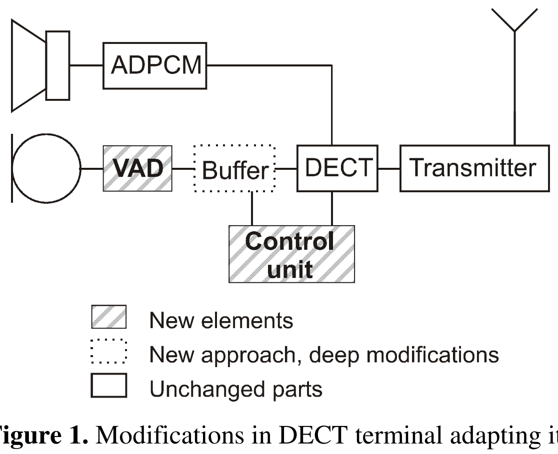

Figure 1. Modifications in DECT terminal adapting it to PRMA-DECT

Control Unit would be responsible for driving the DECT radio part during the periods of activity detected by VAD. The matters of reserving the radio channel (including dealing with collisions) are also up to Control Unit. Buffer should automatically take care of the packets: store them for sufficient amount of time and dispose those too old to be send. Other modules remain unchanged in the terminal. The cost of contemporary electronic components sold as 'commercials-off-the-shelve' is relatively low and prospective mass production of PRMA-DECT terminals may not be burdened with greater cost than DECT terminals.

SIMULATION MODEL

Point of reference

DECT application scenarios are widely studied by European Telecommunication Standardisation Institute (ETSI) in ETSI Technical Report (ETR) number 310, while the results of numerical simulations of DECT and scenarios of DECT applications were presented in ETR 042.

The research agenda is divided into two stages. First one is designing 'not interfered single PRMA-DECT' model related to 'basic DECT scenario'. Second one deals with interference scenarios identified by ETSI in their Technical Report (ETR) 310 and 42.

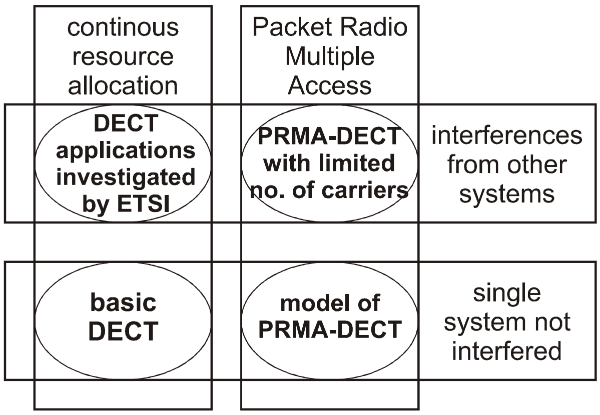

Figure 2. The domains in which DECT and PRMA-DECT are seated regarding this paper.

The early stage simulations refering to DECT without interferences consider one cell only. The speech model taken into account is common for all of mobile stations. Power control and capture effect are not simulated there. The second stage is fully developed.

Interferences considered there are modelled on the basis of the 'ETSI interferences model' presented in [3]. At the Figure 2 the relations between DECT and PRMA-DECT are illustrated. Ellipses on the left depict base protocol researched by ETSI and those on right are subject to investigation in this paper.

Basic DECT system characteristics are taken form the DECT specification. DECT can utilize 120 radio channels in a particular, small area concurrently, which means that according to Erlang B Formula, the system can put through 100 E traffic. A single DECT base station can maintain 12 transmissions in 12 slots at a moment.

Implementation of DECT-PRMA model

The voice traffic is modelled in the simulator as a real-time traffic. The model for single source (a terminal) consists of two states: speaking (ON) and silent (OFF) with a transmission rate σ from ON and γ from OFF. The ON period in model used in simulations in this paper is 43% of total call time. The model represents an instance of two-state Marcovian process as shown in the Figure 3. The symbols: σ and γ are probabilities of shifting from one state to another.

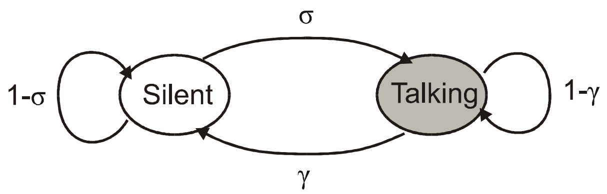

Figure 3. The speech model as a Markovian process

The exact duration of both: the talk spurt and the silence time is drawn before each series of OFF-ON during the simulation and has negative exponent distribution. Four different sets of parameters for speech models are tested. The speech model producing the greatest amount of data to be sent is taken into account in further investigations. The typical values of silence time and talk spurts time are [5]:

- talk spurt mean time: 1.00 s,
- silence duration mean time: 1.35 s.

The values of main DECT technical parameters having impact on the radio resources utilisation are defined as shown in the Table 1.

Table 1. **DECT technical parameters**

Parameter	*Value*
Signal Sensitivity [dBm]	-83
Maximal Input Noise [dBm]	-112
Signal-To-Noise-Ratio [dB]	29
Maximal Power [dBm]	24

Grade of service (GoS) is modelled in the simulator as the rate showing how many packets are dropped due to lack of free transmission channels. The system works at acceptable level of quality until the total number of lost packets does not exceed the GoS level. The GoS is therefore defined as follows [4]:

$$GoS = \frac{no.of\ lost\ packets}{total\ no.of\ \ packets} * 100\%$$

The acceptable values of GoS for PRMA system range form 0.5% to 1.5%. In this paper 1% GoS is assumed.

For the multiple systems environment simulations (see Figure 2), the radio propagation model is introduced. The signal attenuation models used in the simulator are taken form the [3],[4]. The default model in typical scenario assumes a propagation exponent accounting for the path loss equal to 3.5. The attenuation between floors is assumed 15 dB per floor. According to the ETSI, the formula for this signal attenuation model is:

$$I(d) = 38 + 35\log(d) + 15\,x\,(number\ of\ \ floors)$$

Interferences were modelled as an influence of radio devices on a particular radio resource. An interfered channel is the one, which has unacceptably high level of signal form outer source. The threshold of interferences and threshold of signal legibility are specified in the Table 1.

NUMERICAL RESULTS

The research consists of few simulations containing different scenarios: a single cell in ideal environment, a group of cells interfering with each other and a group of cells experiencing limited number of carriers.

Permission Probability

The first stage of research aim at broad investigation in single PRMA-DECT cell to obtain information on how PRMA behaves in simple DECT application and to determine the base parameters for use in further research.

The impact of PRMA on the capacity of basic DECT is investigated in the *permission probability* domain. The most favourable parameters determined this way are then implemented in more complex scenarios.

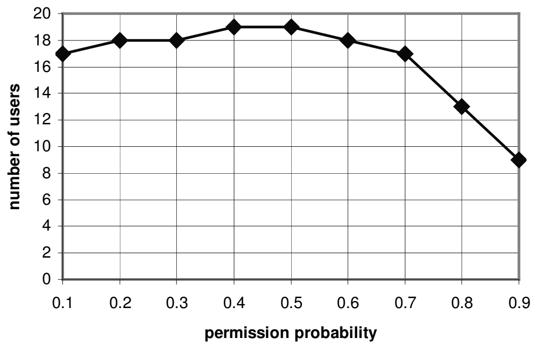

Figure 4. Capacity of the system regarding permission probability

The congestion in PRMA system occurs at the level of 18-19 users for permission probability between 0.3 and 0.6. The results for that range does not depend on the random numbers generator (RNG) entry point (random seed), while for border values of permission probability the simulation is RNG seed sensitive.

For lower permission probabilities the chance for retransmission in case of collision is so slight, so the delay is caused by waiting for the opportunity to retransmit. For the highest values of permission probability the re-occurrence of collision in the following turns obstructs the reservation process several times one by one, which was direct cause of low capacity.

Mean Access Delay

The duration of mean access delay of establishing the connection in PRMA is at least one frame. This comes from the architecture of PRMA protocol, as the reservation process takes one or more turns in case of collision.

In the beginning of talk spurt, terminals send a reservation request, which occupies first frame. The reservation has to be successfully received following the assignment of transmitting channel. This generates the delay of 10 ms. After this terminal can start sending speech packets. When it comes to dealing with the collisions the delay increases. As this can be seen in the Figure 5, mean access delay does not reach 30 ms at Grade of Service equal to 1%. The delay greater than 40 ms is unacceptable.

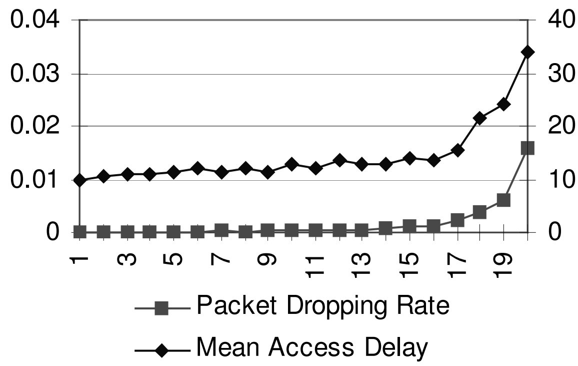

Figure 5. Mean Access Delay [ms] (right y-axis) and the Packet Dropping Rate (left y-axis) in DECT-PRMA over the number of users per base station

Limited access to the radio resource

In this experiment the PRMA is contrasted with the TDMA system to measure the gain of packet switching using PRMA protocol over circuit switching.

The influence of unavailability of slots in the frame results in a loss of gain of PRMA over TDMA and in the situation of extremely poor accessibility to the most of slots, the PRMA performs worse than pure TDMA system. Following from the simulation results presented in the Figure 6, a conclusion on number of issues is drawn. Firstly, PRMA performs well even at the partially available frame. As shown in the figure, the capacity gain ramps down as more of the slots are unavailable. Secondly, the influence of devoting one of the slots to be the r-slot is noticeable for number of available slots less than 5. The whole gain in this case is consumed by the missing transmission slot (which is turned into r-slot). This goes hand in hand with the results presented in the literature, for example [5]. The conclusion from this scenario is, that PRMA is advantageous over TDMA when a lot of slots is available.

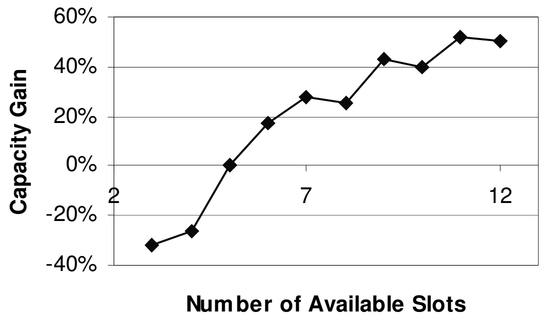

Figure 6. Capacity Gain of PRMA over TDMA

Reservation strategies

Two reservation strategies dealing with the collision by drawing a permission probability were identified. The so-called "Always" strategy implies drawing at any time a terminal is going to obtain a reservation. The second strategy named "After collision" assumes that drawing weather to transmit or not is not performed at the first try of obtaining the reservation also. The simulation revealed that the "Always" strategy is extremely beneficial for permission probability up to 0.3, while "After collision" works well for permission probability higher than 0.7. In the range between 0.3 and 0.7 the strategies display similar efficiency, but "After collision" has one-user advantage over "Always" strategy. "After collision" is used in further investigations.

Speech model

The voice source is modelled as a two-state Markovian process with states 'being active' (ON) and 'being silent' (OFF). The values of silence and talk spurt duration are drawn and their mean values are given as the parameters of the simulation. Four different sets of parameters are considered, as shown in the Table 2.

Table 2. Speech generator parameters

Param-s set	*Mean Talk Spurt Time*	*Mean Silence Time*	*Talk Ratio*
A	1.000	1.350	42.6%
B	1.187	1.646	41.9%
C	1.200	1.800	40.0%
D	1.400	2.300	37.8%

Those sets of parameters are commonly used by other authors [5]. The maximal gain of the most favourable (D – favourable in terms of talk ratio) and the least favourable (A) set is about 10% (19 users in one cell in contrast to 21 users in one cell).

Capture effect

In case of collision, the stronger of signals, (only if it is strong enough) could be recovered form the received bunch of noise. For the simulation, the perfect capture effect is taken into account, which means, that each collision ends up with successful recovering of one of the signals. The simulation of such case revealed, that the capture improves the capacity by one user per base station. Hence the influence of the capture effect on PRMA is about 6%.

Summary for basic PRMA-DECT

Research show that PRMA systems depend crucially on the permission probability parameter, whose value between 0.4 and 0.6 guarantee stable work of the system and maximal capacity.

The reservation process consumes one-frame-time in the best case, so terminal generates at least 10 ms of delay. This is a PRMA inevitable feature.

The reservation strategy 'After collision' does not deteriorate the delay, while 'Always' strategy does. The second one is not applied due to worse results.

PRMA offers substantial gain when there are over 5 slots available. The fact, that in a PRMA frame there is one transmission slot less in comparison to DECT frame is a reason for such state of matters. This missing slot in PRMA plays a role of reservation-slot.

Other factors which influence the PRMA-DECT capacity are: speech model (about 10% variation depending on mean talk spurt and mean silence times assumed) and capture effect (about 6% in ideal environment).

Office application of PRMA-DECT

The assumptions of simulation scenario are that terminals are randomly positioned in the building 100m x 100m in which 16 base stations are regularly spaced. The simulation covers 400s of real system performance.

The speech model considered is the A from Table 2, permission probability 0.5 and technical details concerning DECT radio protocol, like in Table 1. The ETSI propagation model is assumed. Grade of service equal to 1%.

The results of simulation and comparison to ETSI results are presented in Table 3.

Table 3. The capacity of PRMA-DECT in comparison to DECT capacity determined by ETSI.

No. of available carriers (channels)	*Average traffic per base station (by ETSI)*	*Average no. of users (at 0.2 E) per base station*	*Gain over DECT*
4 (48)	4 E (3.2 E)	20	20%
6 (72)	6 E (4.5 E)	30	30%
8 (96)	9 E (5.3 E)	45	70%
10 (120)	13 E (5.6 E)	65	130%

It can be seen from Table 3 that the system is interference limited (C/I limited) up to 6 carriers. This is the case also in pure DECT. For higher number of carriers the capacity becomes trunk limited (maximum number of slots – 11 transmission slots – are used to transmit the data. In PRMA-DECT this means that more, than 11 simultaneous calls per base station is being made).

The maximum capacity of simulated system is 23 000 E per km^2 (ETSI simulated 10 000 E per km^2)

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