Practical Considerations of Using Antenna Diversity in DECT

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Abstract: Performance of different antenna diversity techniques which can be applied in DECT is investigated. Test-equipment that complies with the DECT physical-layer (radio interface) has been developed in order to do measurements under real conditions. Diversity measurements were performed in three office buildings and two industrial buildings. We have concluded that antenna diversity (of a kind) must be employed in DECT to mitigate the effect of both fast fading and time dispersion.

I. INTRODUCTION

Cordless equipment made according to the Digital European Cordless Telecommunication (DECT) standard is already commercially available from a number of manufacturers. The cost of deploying a DECT based telephone system in a large business area with multiple Radio Fixed Parts (RFP) will be strongly affected by the coverage range of each RFP. In addition to the costs of RFP equipment, also expenses for wiring, installation, and cellular planning must be considered. The coverage range of DECT equipment is often mentioned to be in the range of 50 to 100 meters. However, professional users are very demanding and will *not* only require 100 percent coverage (disregarding the quality), but 100 percent coverage with a speech quality equivalent to the wired telephones. This paper is concerned with the *useful* coverage range of DECT in a business application, and the potential improvement by employing antenna diversity.

There has been some skepticism about the coverage range of DECT. The transmitted power is fixed to 250 mW (+24 dBm) peak during a TDMA-packet, and the receiver sensitivity is specified to -83 dBm. Hence, the maximum path loss L_{static} for a non-fading radio channel is 107 dB (antenna gains are disregarded). Because of multipath propagation a large fading margin must be subtracted from the static link budget, and in practice the maximum tolerated mean path loss L_{faded} is much smaller than L_{static}. Antenna diversity is a well-known method to reduce the short-term fading probability and consequently the required fading margin. The theoretical diversity gain in terms of signal distribution is thoroughly analyzed in e.g., Jakes [1] for narrow band Rayleigh-distributed signals.

In DECT the Bit Error Rate (BER) is not only affected by multipath propagation in terms of signal fading, but also in terms of time dispersion, which leads to Inter Symbol Interference (ISI). The Data rate in DECT is 1.152 Mbit per second (corresponding to a bit duration of 868 ns). Impulse response measurements in typical DECT business environments have indicated that rms delay spread values in the order of 100 ns may often be present, and values higher than 250 ns can be found in extreme situations. DECT link-simulations have shown that rms delay spread values of more than 80-100 ns will severely limit the BER for a standard DECT receiver [7][8]. From previous indoor radio channel investigations, we have found that antenna diversity not only reduces the fading probability, but it also mitigates the effect of time dispersion for a *quasi-narrowband* radio channel (BT ≤ 0.1). This is due to a correlation (approx. -0.5) between instantaneous power and instantaneous rms delay spread [2]. The following section gives a brief description of the DECT radio interface as a background for understanding the dedicated antenna diversity solutions for DECT.

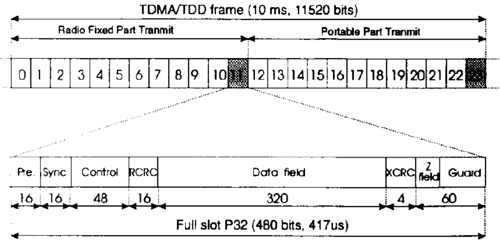

Fig. 1: The DECT TDMA/TDD structure and the DECT full-slot packet.

II. THE DECT TDMA/TDD STRUCTURE

The allocated radio frequency band for DECT is 1880-1900 MHz. In this 20 MHz band there are 10 RF carriers with a channel separation of 1.728 MHz. The data transmission rate is 1152 kbit/s, and the modulation method is Gaussian Frequency Shift Keying (GFSK) with a bandwidth bit period product (BT) of 0.5. A RF channel is time divided into TDMA frames of 10 ms duration. Each TDMA frame is sub-divided into 24 full-slots, where the Radio Fixed Part (RFP) normally transmits during the first 12 time slots, and the Portable Part (PP) transmits during the last 12 time slots. A duplex transmission (e.g., for voice data) uses a pair of timeslots on the same RF-carrier separated by 12 full-slots (5 ms) for downlink and uplink transmission respectively. The access technique is a combination of Frequency Division and Time Division Multiple Access, and Time Division Duplex (FD-TDMA/TDD). The transmitted power during a TDMA-packet is +24 dBm for both RFPs and PPs. The receiver sensitivity is specified to -83 dBm for a static channel at a BER of 10^{-3} [4].

The DECT full-slot (e.g., used for voice data) has a duration of 480 bit intervals, see Fig. 1. It includes: A Synchronization (S)-field (32 bits), which aids clock and packet synchronization, an A-field (64 bits) for signaling and control information, which includes a R-CRC field (16 bits) from a Cyclic Redundancy Code, a B-field (324 bits), where the first 320 bits are available for user data (e.g., voice data) and the last 4 bits (X-field) are used for a parity check on some defined bits in the data-field, a Z-field (4 bits), which is a duplication of the X-field aimed for detecting sliding collision, and lastly a guard space of 56 bit intervals [3][4].

III. ANTENNA DIVERSITY TECHNIQUES

DECT is well-suited for antenna diversity implementations. Because of the TDMA/TDD access scheme described in the previous section, antenna diversity shall only be implemented at the RFP to obtain the full advantage for both up and downlink transmission. A pair of TDMA/TDD-packets in a duplex connection use the same RF-carrier only separated in time by 5 ms. As the spatial movement of a PP during this time interval is small compared to the wavelength, the radio channel is considered reciprocal (time-invariant). Applying e.g., selection diversity at the RFP, the antenna branch, which was selected (according to a given criteria) for reception, shall be used for transmission 5 ms later. Switch diversity can be implemented in a similar manner, but here the switching delay can be found to 10 ms for the PP to the RFP transmission. The validity of the approach that the radio channel is time-invariant during a TDMA-frame depends on the user speed. A time varying channel will degrade the antenna diversity performance significantly. Simulations have shown that for user speeds faster than 1 m/s, the gain for switch diversity has nearly disappeared, whereas the gain for selection diversity remains nearly unaffected for user speeds up to a couple of meters per second [8].

For true narrowband systems (BT<<0.1) the Received Signal Strength Indication (RSSI) is often used as a selection or switching criteria, because it is a good measure for the signal quality. Due to the relatively high bit rate in DECT, the link quality may however often be limited by time dispersion, and the RSSI criteria will only to some extend reflect the signal quality [2]. It seems therefore obvious to use the CRC-check fields provided in the DECT TDMA-packet for a selection or switching criteria. This criteria will include both types of channel impairments. However, there is a complexity versus performance trade-off, which has to be taken into account. We therefore consider three different diversity implementations of various complexity:

- CRC-controlled Switch diversity is the simplest type of diversity, which is used in most commercial DECT equipment. The additional complexity of the RFP is limited to a second antenna and two RF-switches, see Fig. 2(a). The RFP will choose an antenna branch for transmission and reception by default, and continue using that branch until a CRC error occurs, whereupon both the transmitter and receiver will switch to the other branch for use in the succeeding TDMA/TDD frame, and so on. At least one CRC error must occur before a switching takes place !

- CRC-controlled Selection diversity requires two full receiver branches and is the most complex of the three suggested diversity techniques, see Fig. 2(b). The received signal from both antenna branches is demodulated, and a branch selection takes place controlled by the CRC-check. The selected antenna branch is used for transmission in the succeeding TDMA/TDD frame. Apart from the costs of the second receiver there is an additional drawback of this diversity technique: It requires a dedicated diversity Burst Mode Controller (BMC), which is able to handle two Rx input-signals and perform the branch selection. We are not aware of such BMC's, though they should be simple to produce.

- Delayed RSSI-controlled Selection diversity is a hybrid between selection and switch diversity. The second receiver branch is only implemented to the point where RSSI is measured, see Fig. 2(c). The RFP receives only from one of antenna branch at a time, while the RSSI from both of the branches is measured simultaneously. If the RSSI from the antenna branch selected for the moment goes below the monitored branch, an antenna switching takes place, which is used in the following TDMA/TDD frame.

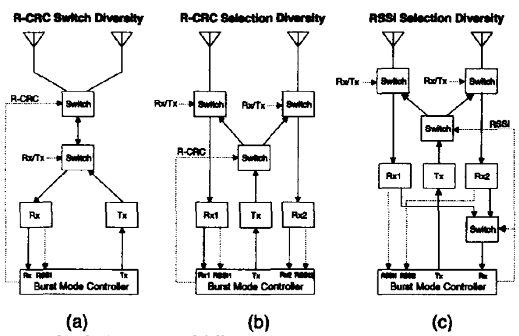

Fig. 2: Block diagram of different diversity configurations for DECT

IV. HARDWARE TEST BED

In order to investigate the performance of DECT under real conditions, we have developed a real-time DECT test bed that complies with the DECT physical-layer (radio interface). In addition to propagation and diversity studies the test bed is also used for developing advanced DECT data-receivers. The test bed consists at present of one transmitter and two receivers. The RF-technology for DECT has been outside the field of our interest, and all RF-parts have been implemented by using standard modular components.

The data-transmitter and data-receiver including modulation or demodulation, TDMA-timing, clock and packet synchronization, CRC-checks, scrambling, and etc., were implemented in an ADSP-2111 Digital Signal Processor (DSP) by means of firmware. The digital to analog conversion of the GFSK modulated signal in the transmitter, and visa versa in the receiver, was performed at an IF of 4.608 MHz ($4 \cdot r_b$), and the sampling frequency f_s was 18.432 MHz ($16 \cdot r_b$). The implementation method has been described in Sollenberger [6]. As the used DSP could not make data transfer at the sampling rate f_s, an external buffer was used for intermediate storage of the GFSK modulated TDMA-packet. The type of demodulator, which was implemented for the diversity measurements, was a non-coherent differential detector [5]. The receiver sensitivity was measured to approx. -89 dBm at a BER of 10^{-3}.

V. MEASUREMENT SETUP AND SITES

The DECT test-transmitter was put on a trolley together with battery power-supply and a turntable. The Tx antenna was mounted on the turntable in a radius of 0.6 m, and in a height of 1.8 m. During measurements the turntable rotated with a steady speed of 10 seconds per round (i.e., the Tx antenna speed was 0.38 m/s). The two DECT test-receivers were put on another trolley, where the antennas were mounted with a 0.2 meter horizontal separation and in a height range of 1.8 to 2.5 m. Both the Tx and Rx antennas were vertically polarized dipoles. For each *Tx*, *Rx* position, 6000 TDMA-packets (spaced by 10 ms) were recorded simultaneously for both receivers, and they were stored on a PC for later post-processing. In order to minimize the amount of collected data, the important information was compressed to only four bytes per TDMA-packet. The stored information included: Packet synchronization error, R-CRC error, X-CRC error, RSSI, number of bit errors in the data-field, etc. Evaluation of the different antenna diversity techniques was performed later off-line.

The sensitivity requirements in DECT is specified to -83 dBm at a BER of 10^{-3}. From DECT link simulations we found that the bit errors mostly appear in bursts for a Rayleigh faded signal. As there is no error protection of the data field when transmitting voice data, we believe that a packet failure rate is a more appropriate performance criteria. We have therefore utilized the powerful R-CRC check provided in the DECT TDMA-packet as a performance criteria. Simulations have shown that a BER of 10^{-3} approximately corresponds to a R-CRC failure rate of 10^{-2} [7][8]. In order not to measure with a receiver, which have a much better sensitivity level than what can be expected of commercial DECT equipment, a 5 dB attenuation in front of the receiver was in-calibrated.

Three office buildings and two industrial buildings were used for diversity measurements. The office buildings were NOVI, AUC, and JTAS, and the two industrial buildings were Sanistål and Silvan. In this paper, due to the limited space, we have decided mainly to show detailed results from one of the buildings, Sanistål.

VI. RESULTS

Sanistål is a steel company. The site is a large warehouse for steel and sanitary items. The building is 60 meters wide and 75 meters long with an internal wall at the x position, -55 meters, see Fig. 3. Rows of steel shelves raised to the roof carrying heavy pallets are situated in the hall. The walls are made of reinforced concrete, some with a steel facade. The numerous gateways are made of aluminum with only a few small windows. As described the hall is very closed with respect to radio waves, which should give basis for severe time dispersion. The test-receivers were situated at the *x,y* position (-32.5 , 15.0), see Fig. 3. The Tx trolley was in a systematic manner placed at 52 different positions both inside and outside the hall. The measured Tx positions are in Fig. 3 shown with a symbol, where the gray scale of the symbol indicates the measured signal quality (Frame Error Rate, FER = R-CRC-failure rate).

At the office building NOVI we compared the measured R-CRC failure rates achieved from the DECT test-equipment with the voice quality of a commercial DECT product. From the comparison we made the coarse relationship shown in Table I. A more thorough analysis of the speech quality is made in [10].

TABLE I.
RELATION BETWEEN R-CRC FAILURE RATE AND SPEECH QUALITY

Measured R-CRC Failure Rate (FER)	Log (FER)	Voice Quality
> 0.1	> -1	No Connection
0.03 - 0.1	-1.5 to -1	Poor /Unacceptable Quality
0.01-0.03	-2 to -1.5	Acceptable/Poor Quality
0.003-0.01	-2.5 to -2	Good/Acceptable Quality
< 0.003	< -2.5	Very good Quality

In Fig. 3(a) the measured failure rate is shown for *No diversity*. We estimate in this case that there will be full DECT coverage (i.e., connection can be established) inside the hall, but the speech quality will be unacceptable. If *R-CRC Switch Diversity*, is applied, see Fig. 3(b), we estimate that the hall is covered with a poor to an acceptable speech quality. For *RSSI Selection Diversity*, see

Fig. 3(c), we estimate that the hall is covered with an acceptable to good speech quality, and if using *R-CRC Selection Diversity*, see Fig 3(d), the entire hall and most of the outside positions are covered with a very good speech quality.

In Fig. 4 the R-CRC failure rate is shown versus received signal strength. The two individual receiver branches are shown with triangles. It can be observed that the R-CRC failure rate crosses the 1 percent level at approx. -60 dBm, and that the failure rate remains just below 1 percent even for very high signal strengths. For *R-CRC Switch Diversity* the 1 percent level is reached at app. -65 dBm, and the error floor for high signal strengths is reduced to approx. 0.3 percent. For *RSSI Selection Diversity* the performance is slightly better than for R-CRC switch diversity, but there is no significant improvement. For *R-CRC Selection Diversity* the failure rate cross the 1 percent at approx. -75 dBm, and the failure rate declines fast down to 0.01 % or better for higher signal strengths. Note that the diversity gain is negligible for signal strengths below -80 dBm. Fig. 5 shows a very severe position from the NOVI site, where the DECT link-quality is limited by time dispersion. The R-CRC failure rate is measured versus transmitted power for a fixed (*Rx, Tx*) position.

The x-axis is the transmitted power in dB relative to 24.5 dBm, which was full power, and the Y-axis is the measured R-CRC failure rate. Due to ISI the failure rate reaches an irreducible error floor of 8 percent if not applying diversity, but if using *R-CRC Selection Diversity*, the error floor is well below 1 percent. *R-CRC Switch Diversity* and *RSSI Selection Diversity* give similarfailure rates in an ISI limited situation, though, it should be mentioned that the failure patterns are different, which may have impact on the subjective speech quality [10]. Similar types of measurements at other locations have shown that RSSI controlled selection diversity perform equivalent to R-CRC controlled selection diversity in situations, where the link quality is dominated by lack of signal strength.

When antenna diversity is applied to DECT, the coverage range will mostly be limited by the received

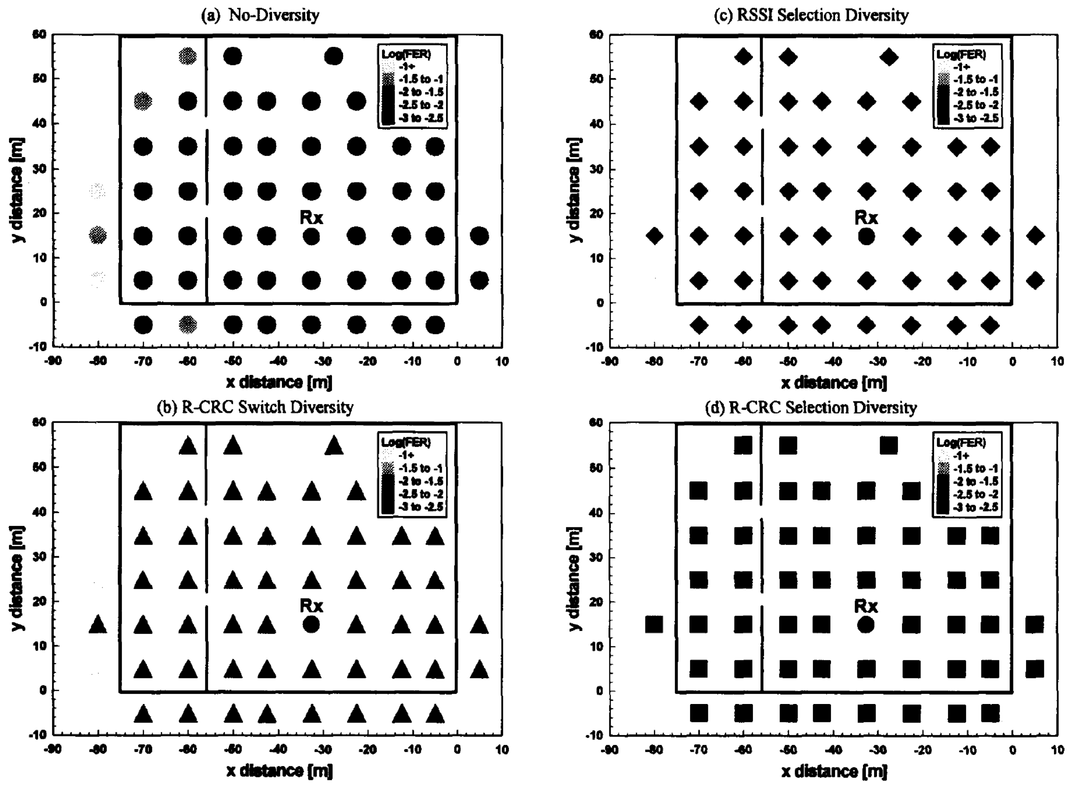

Fig. 3: Measured R-CRC Failure Rates (FER) at the test site Sanistål shown for different antenna diversity techniques. The Building layout is shown by thick solid lines.

signal strength, as diversity combat the affect of time dispersion at nearly all the measured positions. A simple path loss model can therefore be a useful tool for planning a DECT cellular layout. Different indoor path loss models have been proposed in the literature. In the model proposed by Devasirvatham [9] the path loss is modeled by free-space propagation plus a linear attenuation factor a, which can be adjusted depending on the building structure and materials:

$$L_0 = K_f + 20 \log d + a \cdot d \qquad (1)$$

K_f is a frequency dependent constant and d is distance. In Fig. 6 this model has been applied to the measured data, shown for various a values. Except for some of the 'outside' Tx positions, the model with an a value of 0.7 gives a good lower bound for the measured signal strengths.

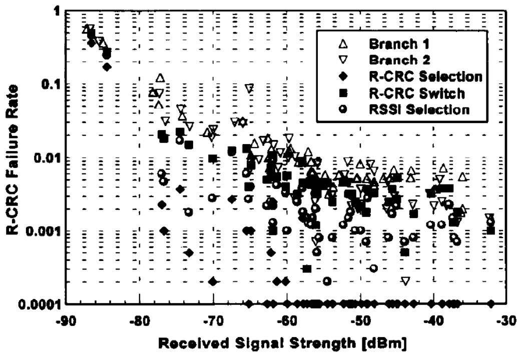

Fig. 4: Measured R-CRC failure rate versus received signal strength for various antenna diversity techniques.

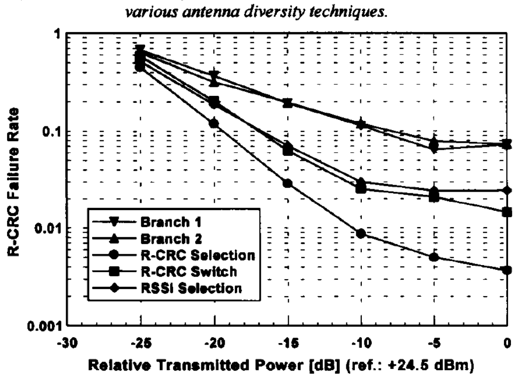

Fig. 5: Measured R-CRC failure rate versus transmitted power for a fixed Rx and Tx position

If *R-CRC Selection Diversity* is used, a mean signal strength of approx. -75 dBm is required (9 dB fading margin), and the coverage range in this type of building can be predicted to be in the order of 40-45 meters. If no diversity is applied the coverage range where an acceptable speech quality can be achieved, will be less than 25-30 meters. These coverage range predictions agree very well with results measured at the other industrial site, Silvan. For the three office building sites the coverage range is even shorter.

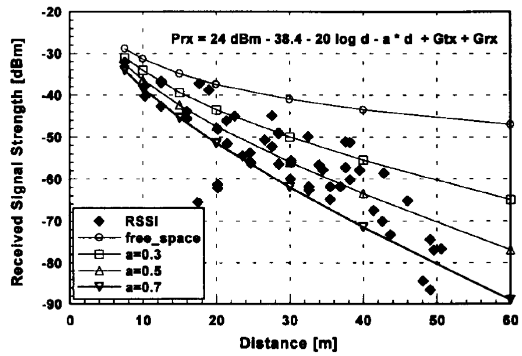

Fig. 6: Measured RSSI compared to the prediction model in Eq. (1)

VII. CONCLUSIONS

Based on the measurement results shown in the paper together with similar results from the other measured sites we conclude the following:

- Antenna diversity (of some kind) must be applied in DECT; otherwise the range where a solid coverage can be expected, will be less than 15-25 meters in an indoor business environment. This range can be extended up to 30-45 meters by applying *CRC Selection Diversity*.
- In a business application, seen from a performance versus price criteria, we believe that the optimum choice of diversity technique is *CRC Selection Diversity*, as the performance gain over both fast fading and time dispersion is superior. We do not find it worthwhile to apply *RSSI Selection Diversity*, compared to using the simple *CRC Switch Diversity* technique as the gain difference is marginal.

VIII.. REFERENCES

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