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Efficient Low Bit-Rate Low-Latency Channelization in DECT

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In a TDMA standard such as DECT, low bit-rate transmission is feasible either at the cost of efficiency (shorter slots with fixed overhead per slot) or increased latency (longer frames). This paper proposes a new scheme for low bit-rate low-latency channelization in the DECT standard, in which data can be efficiently transmitted at rates as low as 10 kbps. This could be useful for sending acknowledgments for a high-speed data communication link, or for vocoder/VoIP traffic. The proposed scheme enables efficient low bit-rate transmission by dividing a DECT channel into four subbands, and by employing a new slot structure wherein TDMA overhead is kept to a minimum. It is shown that the proposed scheme can coexist with the DECT system and can be implemented using existing IMT-2000 DECT hardware with minor modifications. A comparison is also made of the proposed scheme with existing options for low bit-rate channelization in DECT.

1. MOTIVATION

In today's scenario, advanced voice coding algorithms enable the transmission of toll quality voice at a bit rate as low as 6–8 kbps [1]. Instant messaging and always-on Internet connectivity are also very popular. Low bit-rate channels are needed to enable efficient scheduling of internet traffic in high-speed shared downlinks such as HSDPA and HDR [2], and for sending acknowledgments (*ack*) for downlink packets. The uplink *ack* traffic for IP packets is of the order of few kilobits per second when the downlink is of the order of 500 kbps. Further, link-layer ARQ may be implemented to improve the efficiency of the radio link. This will necessitate link-layer *acks* in every frame or two. Thus, low bit-rate low-latency channels are also required in addition to the channels with ever higher data rates.

For example, the IMT-2000 digital enhanced cordless telecommunications (DECT) standard [3] can support a bit rate of 500 kbps per user (with 64-QAM as modulation scheme). The high data rates offered by the standard could be used to offer a shared downlink. With this data rate, transmission of an average IP-packet size of 5000 bytes for a file download will take 80 ms. With the DECT frame size of 10 ms, an *ack* will have to be transmitted every 8 to 16 frames. Now, it requires a minimum of two frames in DECT to establish/tear down a bearer connection. Hence it is not practical to set up/tear down the uplinks and transmit *acks* in bursts. It is also not possible to delay the *acks* unduly. There is thus a need to create an efficient low bit-rate low-latency channel in this case.

In this paper, we propose modifications to the IMT-2000 DECT standard to provide low bit-rate low-latency channels by dividing a DECT channel into four subbands, and by employing a new slot structure. The proposed scheme called *modified DECT with subbands* (mDECT-SB) can coexist with the DECT system, and can be implemented using existing IMT-2000 DECT hardware with minor modifications.

2. BACKGROUND

DECT is used to provide wireless-in-local-loop (WLL) based telephony in many developing countries. In India, about one million telephone connections are currently provided using corDECT [4], a system based on the DECT standard. The system is now upgraded to provide broadband services. DECT employs TDMA-TDD to provide multiplexing among users. In any TDMA system, since the data is transmitted in bursts, a receiver has to perform the essential tasks of carrier/clock acquisition in the beginning of every slot. Additionally, each slot may carry a fixed amount of signalling/control information. The guard symbols, which account for the propagation delay between the portable part (PP) and the radio fixed part (RFP), and allow time for power ramping, further add to the overhead of each slot. Thus, the fixed overhead per slot in TDMA makes the provision of low bit-rate channels inefficient. For example, in a DECT half-slot [3], the payload (80 bits) is only 33% of the total (240 bits).

An alternative for creating low bit-rate channels without the inefficiency associated with the use of short bursts, is to increase the frame duration. This, however, increases latency. For example, with a DECT full slot and QPSK modulation, the frame duration should be extended by 8 times to 80 ms, if an 8 kbps channel is desired. Such high latency cannot be tolerated for applications such as telephony or for sending acknowledgments in a TCP link. There is an option of creating the low bit-rate channels by reducing the high TDMA overhead by sharing it across multiple users in consecutive frames. This option also introduces latency in the system. There is a related but less appreciated problem associated with increasing the frame duration. If the duty cycle of a TDMA channel is α, and the required energy/bit is E_b, the peak transmit power is $(E_b/\alpha) \cdot R_f$, where R_f is the frame rate. As α goes down, the peak power goes up. Thus, there is a problem in providing low bit-rate TDMA channels having link performance comparable with FDMA or CDMA systems.

In principle, therefore, while providing for low bit-rate channels, one should simultaneously employ as little bandwidth as possible without increasing the latency. The efficient utilization of uplink bandwidth could thus increase the system capacity for asymmetric traffic as proposed in the DECT packet radio service [5]. A scheme has been proposed in [6], wherein four OFDM subcarriers in one of DECT channels are used by one user in a DECT time slot. Here, OFDM is employed to improve the receiver performance in a multipath channel. However, to maintain symbol synchronization, all subcarriers have to be transmitted by one user. Thus this scheme cannot be used for multiple users to create multiple low bit-rate channels in one DECT channel, as in the scheme proposed here.

3. IMT-2000 DECT PHYSICAL LAYER

As mentioned above, DECT uses a TDMA-TDD radio transmission method. A basic DECT TDMA frame consists of 24 slots over 10 ms, with each frame divided into two halves of twelve contiguous slots, one half each for the uplink and downlink directions. Each full slot is of 480 symbols, with a 32-symbol S-field for synchronization, 64-symbol A-field for signaling, 320-symbol B-field for payload, 8-symbol Z-field for the CRC, and 56-symbol guard time. DECT also defines a half slot to provide low bit-rate services [3].

DECT operates in the 1880–1935 MHz band with a carrier spacing of 1.728 MHz. In DECT, a dynamic channel selection procedure (DCS) [7] is used to select a channel from the set of available channels, based on the received signal strength indication (RSSI) measurements. For example, with 10 carriers and 12 slots, there are 120 channels to choose from.

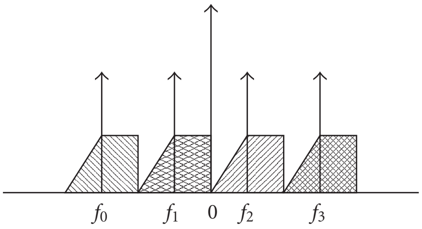


Figure 1: Spectrum of four subbands at baseband.

4. mDECT-SB PRINCIPLES

In the proposed mDECT-SB scheme, a DECT channel of 1.728 MHz is divided into four equal subbands, as shown in Figure 1. The subbands so obtained each have 1/4th of the bandwidth of a DECT channel. Correspondingly, the symbol duration in the subband is elongated by a factor of four. The frame structure of DECT, that is, the frame duration, number of slots, and slot durations, is kept unchanged. With the increase in symbol duration, the number of symbols in one full slot comes down by a factor of four (i.e., 480/4) to 120. With the new slot format proposed in Section 7, it will be shown that the new scheme enables the efficient transmission of rates as low as 10 kbps in one slot by using BPSK/QPSK modulation as specified in the IMT-2000 DECT standard.

With the slot and frame durations unchanged, there is no increase in latency. However there is the over-arching issue of how mDECT-SB can coexist, and inter-operate, with existing DECT systems. Even if mDECT-SB cannot inter-operate, it must at least be benign towards other DECT systems. Benignity is maintained by preserving the existing slot and frame boundaries, and crucially, by suitably modifying the DECT channel selection algorithm for the subbands, as discussed next.

The slot and frame boundaries of DECT are maintained in mDECT-SB, so that it can coexist with existing DECT systems. *The presence of a signal in one or more subbands of a DECT channel will result in any DECT-compliant receiver showing RSSI as if a conventional DECT signal is occupying the full channel, as far as the DCS procedure is concerned*. Thus if one or more mDECT-SB subbands in a DECT channel are occupied in a time slot, the DCS algorithm in a DECT system will treat the entire DECT channel as being occupied in that time slot. This is as it ought to be for correct functioning of DCS in the DECT system. The RSSI measurement thus gives the level of interference seen by the DECT system, irrespective of whether an entire DECT channel, or only one or more subbands, is occupied.

As for the mDECT-SB system, its DCS algorithm needs the RSSI in each subband in a particular time slot, if an individual low bit-rate mDECT-SB channel has to be selected. As we will see in Section 6, the RSSI in a subband in a particular time slot can be estimated by combining the RSSI measurement of the full channel obtained from the transceiver, with relative energy estimates of the subbands obtained after subband separation in the digital domain.

If a DECT channel is occupied in a time slot by a DECT system, the mDECT-SB system will see all the four mDECT-SB channels in the DECT channel as being occupied during that time slot. If, on the other hand, one or more subbands is not being used by another mDECT-SB links in the vicinity, the RSSI for the subband estimated as described will make this apparent. The system implementing mDECT-SB can thus select this low bit-rate subband for a user who needs such a link.

5. ARCHITECTURE OF THE mDECT-SB SCHEME

5.1. Uplink channelization

In a time slot, any PP transmits only one of the four available subbands, or the full channel as in DECT. At the RFP, the subbands received in the same time slot belongs to different PPs. Depending on the distances between the RFPs and the PPs, the received subband signals can have significantly different power levels. Since the channel selection filter (Figure 3) selects a full channel, the input to the analog to digital converter (ADC) will consist of the desired subband in the presence of possibly much stronger interferers in the other subbands. The ADC should provide adequate resolution for the desired, but possibly weak, subband.

In an IMT-2000 DECT receiver, the ADC resolution needed is around 5 bits (for a signal-to-quantization-noise ratio of ~ 30 dB). However, when the channel selection filter selects more than one subband and different subbands are received with different power levels, the resolution needed is higher. If the resolution of the samples of the desired subband is to be of the order of 5 bits as before, the ADC resolution required depends on the level of adjacent channel interference (ACI) the RFP is expected to tolerate. For example, with an 8-bit ADC, 18 dB ACI can be tolerated for the subbands put together.

ACI at RFP is controlled by introducing power control for the subbands at the PPs. Since the channel selection filter provides the necessary suppression for adjacent DECT channels, it is enough if the power control is applied to the subbands belonging to the same DECT channel. Since DECT is a TDD system, it is easy to estimate the desired transmit power level from the received signal level and implement the power control. This control needs be only with a resolution of 1-2 dB.

The received signal level varies due to shadowing and fading. Transmit power control at PPs compensates for the shadowing loss. Increased ADC resolution (by about 3 bits) would still be needed to account for fading (~10–15 dB). Since a PP has to estimate the desired transmit power level from the signal it receives from the RFP (on the same carrier), *it is necessary that the PPs using the subbands in a time slot should be communicating with the same RFP, as shown in Figure 2.*

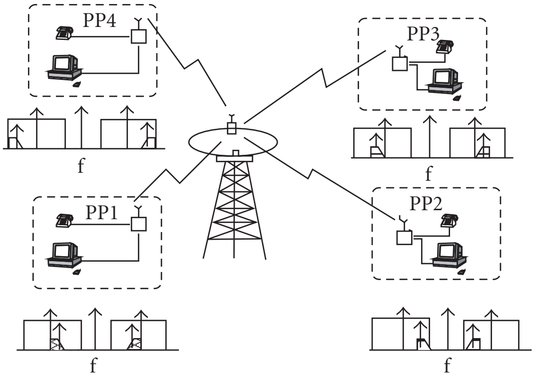


Figure 2: Uplink architecture for the mDECT-SB scheme.

Now, the received signal is the sum of four subbands centered at different frequencies. The channel selection filter used in DECT receivers has a sharp cutoff with a bandwidth of 1.152 MHz. In a normal IMT-2000 DECT system, distortion caused by the transition band of the filter is equalized by designing a suitable equalizer. For mDECT-SB, the distortion caused in the subbands towards the edges of the channel selection filter will be higher and the equalizer performance will be poor.

In order to avoid this distortion for the subbands along the edge, the desired subband must be first translated to the passband of the channel selection filter. The synthesizer used in the IMT-2000 DECT receivers normally generate carrier frequencies in the steps of 1.728 MHz (DECT channel spacing). The synthesizer stepsize now needs to be suitably modified as discussed below.

With a synthesizer stepsize of 864 kHz, the subbands centered at f_1 and f_2 (Figure 1) can be translated to the passband of the filter. With this stepsize, when translating the subbands at the channel edge (f_0/f_1), an undesired subband (f_A) belonging to the adjacent DECT channel (possibly being used by another RFP) will also translate into the passband of the filter, as shown in Figure 4(a). The power of this subband may be far greater than that of desired subband, as power is controlled only by the RFP under consideration for subbands belonging to the same DECT channel. In order to avoid this ACI problem, the mDECT-SB system should employ a synthesizer stepsize of 432 kHz. With this stepsize, a desired subband at the channel edge is translated only by 432 kHz, and the undesired subband from the adjacent DECT channel is partially filtered out by the transition band of the DECT filter, as shown in Figure 4(b). A synthesizer stepsize of 432 kHz thus reduces the uncontrolled ACI, compared to a stepsize of 864 kHz.

In order to have similar link margins on the up- and down-links, the power amplifier (PA) transmit power at the PP must be decreased by a factor of four. DECT specifies maximum transmit power of 24 dBm. Thus, for the mDECT-SB option, the maximum output power of the PA at PP must be 18 dBm in time slots in which mDECT-SB is employed.

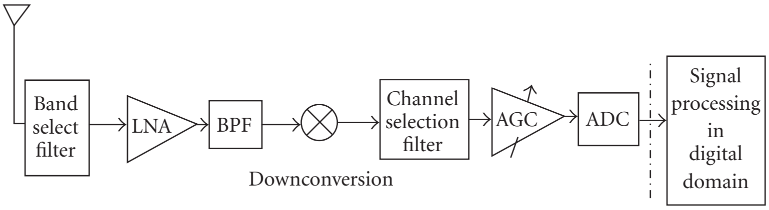
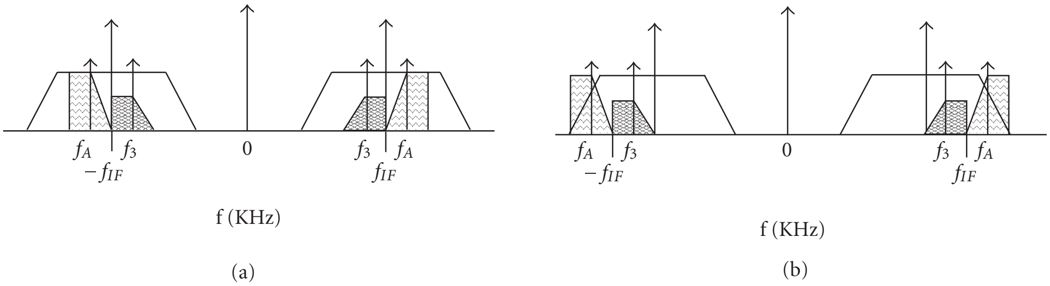


FIGURE 3: Block diagram of a generic IMT-2000 DECT receiver.



(a)

(b)

FIGURE 4: Downconversion of subbands using synthesizer stepsize of 432 kHz.

5.2. *Downlink channelization*

The differential modulation schemes specified by IMT-2000 DECT standard [3] have restricted envelope variations. The PA on the transmitter needs to be thus linear for a limited range. The transmission of more than one subband in a time-slot at the RFP will lead to large envelope variations and will necessitate the use of a higher PA backoff. This can be avoided by eschewing mDECT-SB in the downlink. Instead, an IMT-2000 DECT full slot at normal symbol rate is time-multiplexed among four users, as shown in Figure 5. *A necessary condition for this architecture is that all the four PPs should be connected to the same RFP*.

The *A*-, *B*-, and *Z*-fields of a time slot are considered as one field and partitioned into four different subslots for different users. Each sub-slot will have separate A_k- and B_k-fields, as shown in Figure 6. The four PPs receive a common time slot and each selects the data meant for itself.

6. RSSI CALCULATION FOR THE INDIVIDUALS SUBBANDS

The ADC samples the received signal amplified by an automatic gain control (AGC) amplifier (Figure 3). The AGC amplifier amplifies the received signal to a predetermined power level, independent of the received signal power. This implies that only relative energy estimates of the individual subbands can be determined in the digital domain. These relative energy estimates can be combined with RSSI measurement of the full channel (obtained from the transceiver) to determine the absolute energy levels as shown next.

Let E_c be the RSSI measurement of the full channel as obtained from the transceiver. Also, let E_k be the RSSI estimates of the individual subbands. Therefore,

$$\sum_{k=0}^{k=3} E_k = E_c \quad \text{for } k = 0, 1, 2, 3. \tag{1}$$

Define $E_k = m_k * (E_0)$, with $m_0 = 1$. That is, m_k is the relative energy of the kth subband with respect to the first subband. Thus,

$$E_0\left(\sum_{k=0}^{k=3} m_k\right) = E_c. \tag{2}$$

Now, m_k, $k = 1, 2, 3$, can be determined in the digital domain after subband separation. The RSSI E_0 can be solved from (2), and hence E_k, $k = 1, 2, 3$.

7. SLOT STRUCTURE FOR MDECT-SB

7.1. *Uplink*

As mentioned earlier, the number of symbols in mDECT-SB in a full slot is reduced by a factor of four, from 480 to 120 symbols. The efficiency of TDMA can be poor if the TDMA overhead is not carefully kept to a minimum. In this section, we propose a new slot structure for mDECT-SB by reducing the overhead associated with *S*-, *A*-fields and guard symbols.

7.1.1. *Signalling field*

DECT employs an adaptive channel allocation procedure called DCS. For DCS to work, a fair amount of fast signalling is needed between the PP and the RFP. Due to this, DECT has generous signalling capacity, with an *A*-field of 64 bits/slot

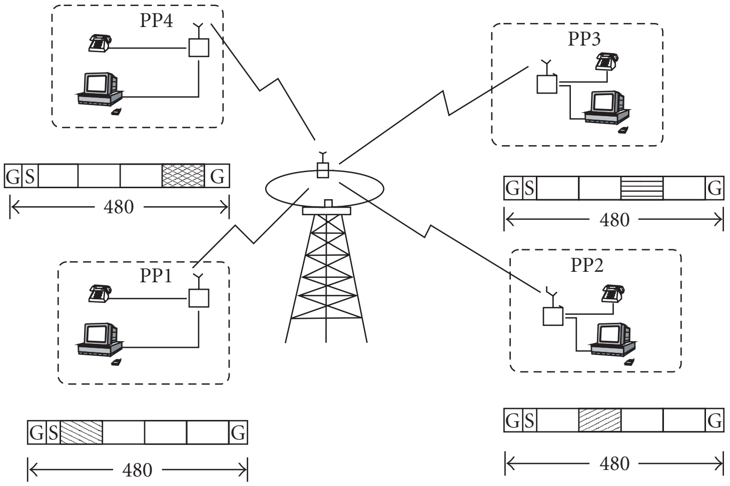


Figure 5: Downlink architecture for the mDECT-SB scheme.

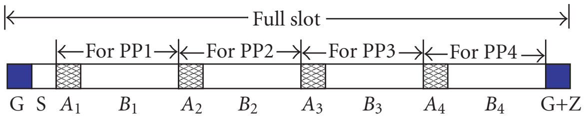


Figure 6: Time-multiplexed full slot for the downlink.

(irrespective of half, full, or double slot). It is proposed to use DQPSK for the *A*-field, instead of DBPSK as in IMT-2000 DECT [3]. We then need only 32 symbols for the *A*-field as shown in Figure 7.

7.1.2. Guard symbols

The guard time between time slots in a TDMA system is meant for power ramping and differential propagation delay between the PPs and RFP. In existing DECT systems, out of 56 symbols guard time, 12 symbols are required for power ramping. In mDECT-SB, the same guard time as in DECT would now correspond to 56/4 = 14 symbol duration. With autoranging [8] and timing advance as in GSM [9], the required number of guard symbols can be reduced to 8 symbols. The active portion of the slot can therefore be 112 symbols.

7.1.3. Synchronization field

DECT systems use a 32-symbol synchronization field, out of which 16 symbols are used by the preamble and 16 symbols for synchronization. In the pre-IMT-2000 DECT systems, hardware clock acquisition and data detection circuitry are commonly employed, in which the signal can be processed in one pass itself. The settling time of the clock recovery phase locked loop (PLL) necessitates the use of a 16-symbol long preamble for initial acquisition and synchronization. In IMT-2000 DECT and mDECT-SB, where the entire demodulation is done in digital domain, the length of preamble can be reduced from 16 to 8 symbols without significantly degrading the performance of the carrier frequency offset, carrier phase offset, and sampling clock phase estimation algorithms. Further, in mDECT-SB, instead of a 16-symbol binary synchronization word, a new 8-symbol complex synchronization word (see Section 8) is proposed. A second pass can be made, if required, to refine the clock estimate using the synchronization word. Thus in the mDECT-SB system, we use only 16 symbols for the *S*-field, out of the available 112 symbols, thereby reducing the overhead. With $\pi/4$-DQPSK modulation, the remaining 96 symbols will give between 192 bits per slot, of which 64 bits will be the *A*-field. This implies

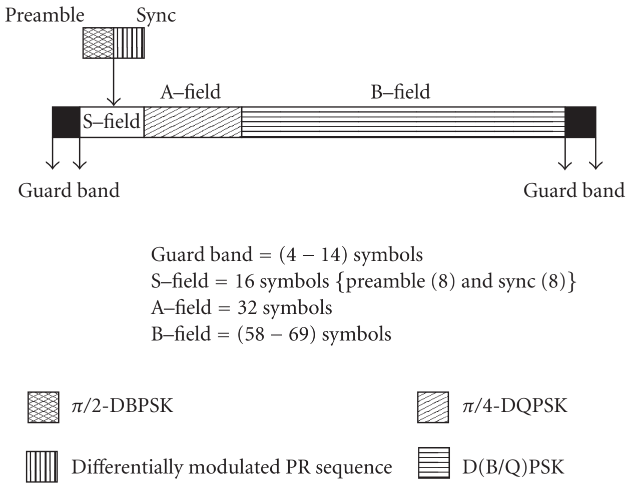


Figure 7: Uplink slot structure for mDECT-SB.

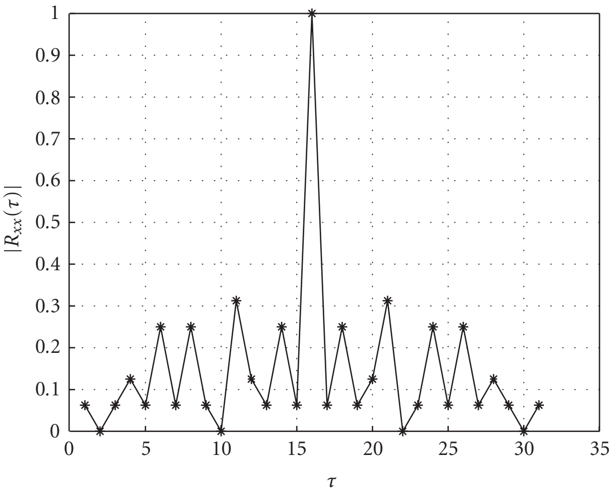


Figure 8: Autocorrelation function of present DECT synchronization word.

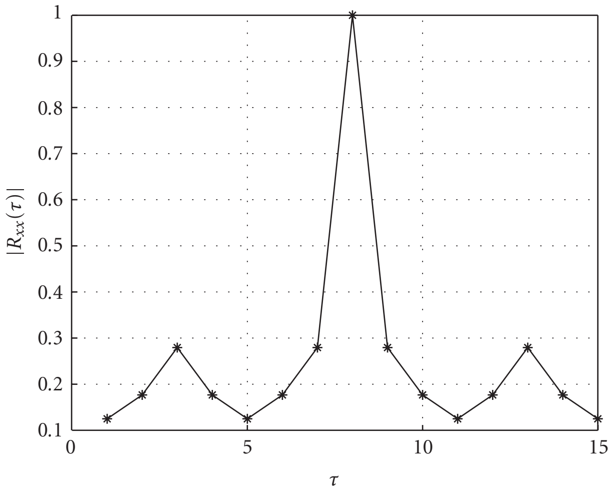


Figure 9: Autocorrelation function of new sequence.

that a bit rate of 12.8 kbps can be made available for user payload.

7.2. Downlink

As discussed in Section 5 (Section 5.2), we typically do not employ subbands in the downlink, but use the conventional IMT-2000 DECT channel. We also retain the *S*-field as in IMT-2000 DECT in order to make the PP receiver common for all bit rates. In a DECT full slot, the guard field and the CRC field are common, as shown in Figure 6, and the *A*-, *B*- and *Z*-fields constitute $64 + 320 = 384$ symbols out of the total of 480 symbols. These 384 symbols are partitioned for four different users. Each user now has $384/4 = 96$ symbols. The *A*-field for each PP is QPSK modulated as on uplink, requiring only $64/2 = 32$ symbols. The remaining $96 - 32 = 64$ symbols can provide a bit rate of 12.8 kbps/user

8. COMPLEX SYNCHRONIZATION WORD FOR mDECT-SB

In the present DECT system, a 16 bit word ($0X1675$) is used as the synchronization word [3], and it has an equal number of ones and zeros. The autocorrelation ($R_{xx}(\tau)$) of this PRN sequence is plotted in Figure 8. It can been be seen that $R_{xx}(\tau)$ gives a sharp peak for $\tau = 0$ and small side lobes for any other τ.

The IS-54 standard [10] defines 14-symbol long differentially-encoded complex synchronization words. A simulation study was done to study the autocorrelation of a synchronization word obtained by truncating the 14-symbol synchronization word to 8 symbols (by dropping 3 symbols on either side). The peak magnitude of $R_{xx}(\tau)$ of either of the synchronization words, thus measured for $\tau \neq 0$ (Figure 9), is nearly the same when compared with $R_{xx}(\tau)$ for $0X1675$. Any of the above-mentioned complex sequences suitably truncated can be used as a synchronization word for mDECT-SB

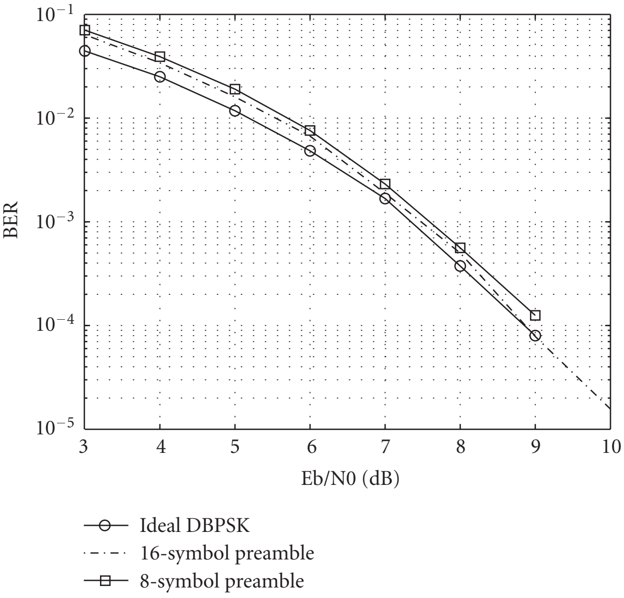


Figure 10: BER performance.

9. PERFORMANCE OF RECEIVER ALGORITHMS

To study the effect of reduction in preamble length, the performance of the mDECT-SB system for $\pi/2$-DBPSK modulated signal was evaluated for 16-symbol and 8-symbol preambles for a frequency offset of 10 kHz. The frequency offset of 10 kHz is chosen because with the presently available low-cost crystal oscillators, it is easy to ensure an offset of less than 10 kHz. In these simulations, it is assumed that the clock phase estimation algorithm gives the best sampling phase. In Figure 10, where BER results have been plotted for 16- and 8-symbol preambles, respectively, it is clear that performance

Table 1: Comparison between IMT-2000 DECT and mDECT-SB.

Bit rate (kbps)		Options		NOU		TDMA efficiency (%)	
IMT-2000	mD	IMT-2000	mD	IMT-2000	mD	IMT-2000	mD
8	6.4	1 HS(B)	1 FS(B)	2	4	33.33	53.33
16	12.8	1 HS(Q)	1 FS(Q)	2	4	50	70

degradation for the 8-symbol preamble is only 0.1 dB, when compared to the 16-symbol preamble. This deterioration is due to the fact that noise is now averaged only over 8 symbols. This gap can be further reduced if the synchronization word is also used for refining the estimate.

10. COMPARISON OF mDECT-SB WITH IMT-2000 DECT

In Table 1, improvements obtained by using mDECT-SB instead of IMT-2000 DECT for data rates between 6.4–12.8 kbps are presented. In this table, NOU is number of users per full slot and HS/FS is half/full slot with BPSK/QPSK (B/Q) as modulation scheme. The use of $\pi/8$-D8PSK in a full slot mDECT-SB will provide 19.2 kbps/user, which is an intermediate bit rate not normally available in DECT. The only application for bit rates higher than 8 kbps is Internet access, for which the higher the bit rate, the better. Since IMT-2000 DECT provides a range of much higher bit-rates, this mode is not expected to be useful.

It can be seen from Table 1 that a low-latency 12.8 kbps channel is supported by mDECT-SB with a TDMA efficiency of 70%. This is a little higher than the efficiency of conventional GFSK-based DECT for a 32 kbps channel. At 12.8 kbps, an mDECT-SB channel can easily support vocoded voice traffic at 6 to 8 kbps with sufficient excess capacity for coding. Coding greatly improves link reliability for vocoded voice and IP traffic; and is part of modern air-interface standards. The lowest bit rate supported by mDECT-SB is 6.4 kbps, using spectrally inefficient BPSK modulation. Although the TDMA efficiency at 53% is higher than for an 8 kbps channel in IMT-2000 DECT, it is not recommended for widespread use.

In an IMT-2000 DECT transmitter, the baseband signal is generated by storing precalculated samples in a read-only memory (ROM) and then using a digital-to-analog converter (DAC) to reconstruct the analog signal. A higher capacity ROM (to store the samples for four subbands at the PP) can be used to generate the transmit signal for mDECT-SB without any other hardware modifications. As mentioned in Section 5, the synthesizer stepsize for an mDECT-SB receiver should be reduced to 432 kHz. The minor hardware modifications required to implement the mDECT-SB on a IMT-2000 DECT platform has been summarized in Table 2.

Table 2: Hardware modifications for mDECT-SB.

Hardware	mDECT-SB	IMT-2000 DECT
ROM	Increased size	—
Synthesizer stepsize	432 kHz	1728 kHz
ADC resolution	8–14 bits	8 bits

11. CONCLUSIONS

In summary, mDECT-SB when combined with low bit-rate voice coding can provide much higher voice traffic capacity with minimal modifications to the existing IMT-2000 DECT hardware. It can also provide efficient low bit-rate feedback channels for acknowledgments in asymmetric data links. An example of this is the G_F channel, which is used to carry acknowledgments for asymmetric connections in the DECT packet radio service [5]. As shown in Table 2, the mDECT-SB scheme can be implemented using an IMT-2000 DECT transceiver with only baseband software modifications and minimal hardware modifications. The same platform thus allows low bit rates with mDECT-SB, in addition to the high bit rates specified in the IMT-2000 DECT standard. The mDECT-SB scheme thus provides a simple and efficient way to provide low bit-rate channels in addition to the high bit-rate channels of IMT-2000 DECT without increasing the latency.

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