CHANNEL-ADAPTIVE MODULATION

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Abstract

Packet Reservation Multiple Access (PRMA) assisted adaptive modulation using 1, 2 and 4 bit/symbol transmissions is proposed as an alternative to Dynamic Channel Allocation (DCA) in order to maximise the number of users supported in a traffic cell. The cell is divided in three concentric rings and in the central high Signal-to-noise ratio (SNR) region 16-level Star Quadrature Amplitude Modulation (16-StQAM) is used, in the first ring Differential Quaternary Phase Shift Keying (DQPSK) is invoked, while in the outer ring Differential Phase Shift Keying (DPSK) is utilised. A channel SNR of about 7, 10 and 20 dB, respectively, was required in order to maintain a bit error ratio (BER) of about 1 %, which can then be rendered error-free by the binary BCH error correction codes used. A 4.7 kbps Algebraic Code Excited Linear Predictive (ACELP) speech codec is favoured, which is protected by a quad-class source-sensitivity matched BCH coding scheme, yielding a total bit rate of 8.4 kbps. A GSM-like Voice Activity Detector (VAD) controls the PRMA-assisted adaptive system, which ensures a capacity improvement of a factor of 1.78 over PRMA-aided binary schemes.

1 Background and Motivation

Dynamic channel allocation [1] (DCA) and packet reservation multiple access [2] (PRMA) are techniques which potentially allow large increases in capacity over a fixed channel allocation (FCA) time division multiple access (TDMA) system. Although both DCA and PRMA can offer a significant system capacity improvement, their capacity advantages typically cannot be jointly exploited, since the rapid variation of slot occupancy resulting from the employment of PRMA limits the validity of interference measurements, which are essential for the reliable operation of the DCA algorithm. One alternative to tackle this problem is to have mixed fixed and dynamic frequency re-use patterns, but this has the disadvantage of reducing the number of slots per carrier for the PRMA scheme, thus decreasing its efficiency.

In this paper we propose adaptive modulation as an alternative to DCA. The cells must be frequency planned as in a FCA system using a binary modulation scheme. When adaptive modulation is deployed, the throughput is increased by permitting high level modulation schemes to be used by the mobiles roaming near to the centre of the cell, which therefore will require a lower number of PRMA slots to deliver a fixed number of channel encoded speech bits to the base station (BS). In contrast, mobile stations (MS) near the fringes of the cell will have to use binary modulation in order to cope with the prevailing lower signal-to-noise ratio (SNR) and hence will occupy more PRMA slots for the same number of speech bits. Specifically, our adaptive system uses three modulation schemes, namely binary differential phase shift keying (DPSK) i.e., one bit per symbol at the cell boundary, quaternary differential phase shift keying (DQPSK), i.e., two bits per symbol at medium distances from the BS, and 16 level star quadrature amplitude modulation [3] (16-StQAM), which carries four bits per symbol close to the centre of the cell.

2 PRMA-assisted Adaptive Modulation

The input speech is encoded by a 4.7 kbps Algebraic Code Excited Linear Predictive (ACELP) speech encoder [4, 5], which generates 142 bits/30 ms. These bits were source sensitivity-matched encoded using the following 63-bit long binary Bose-Chaudhuri-Hochquenghem (BCH) codes [6]: BCH(63,24,7), BCH(63,30,6), BCH(63,36,5) and BCH(63,51,2). The total number of bits generated becomes 252/30ms, which corresponds to a rate of 8.4 kbps. We added a fifth 63 bit BCH codeword with an extra parity bit to act as a header. These 316 bits long speech packets must be conveyed over the radio link using a PRMA frame length of 30 ms to multiplex the speech channels. A voice activity detector (VAD) similar to that of the Pan-European mobile radio system known as GSM [7] queues the active speech packets to contend for a PRMA slot reservation, while during passive speech spurts the slot is surrendered to other users, who are becoming active.

We have chosen channel bandwidths similar to those in the Pan-European GSM and the DECT sys-

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Parameter	GSM	DECT	Unit
Channel Bandwidth	200	1728	kHz
Symbol Rate	133	1152	kBd
Bursts per Frame	48	416	

Table 1: Parameters of the GSM like and DECT like adaptive modulation PRMA systems

tems, namely 200 kHz and 1728 kHz. When using Nyquist filtering with a 50% excess bandwidth, the corresponding signalling rates become 133 and 1152 kBd, respectively, as shown also in Table 1. Our simulations consider only the uplink performance, which is assumed to have two branch selection diversity.

If we consider the case of the 16-StQAM modem which uses four bits per symbol, the 316 bits to be transmitted may be encoded as 79 symbols. An additional pair of symbols will be used to encode the modulation type, which is repeted three times in order to facilitate majority logic decisions. A further pair of dummy symbols will be allocated for the power ramping, yielding a total of 83 symbols per 30ms speech frame. This corresponds to a single-user signalling rate of 83/30 ms $\approx$ 2.77 kBd, allowing us to create INT{133.33 kBd / 2.77 kBd} $\approx$ 48 time slots, where the INT{ } function represents the integer part of the bracketed expression. When the DQPSK mode of operation is selected in areas of somewhat lower signal strength, we have to use two traffic bursts in order to convey the 316 bits of information, and when the binary DBPSK mode is selected, four bursts are required. Accordingly, we select the appropriate modulation type within the traffic cell considered, as a function of the received signal strength.

In our simulations all but one users generated negative exponentially distributed speech spurts and were uniformly distributed across the traffic cell. The speech performance of the proposed scheme was investigated using a recorded real speaker, whose speech activity was detected by our VAD and when active, the speech packet was queued for transmission to the BS. Since the required SNR difference amongst the various modulation schemes used is compensated by the internal sub-division of the cell, in all areas of the cell a similar speech quality can be maintained.

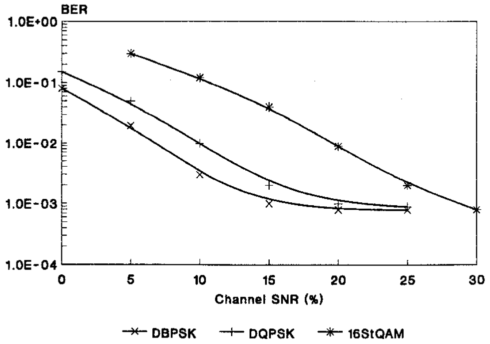

Figure 1: BER performance of our modulation schemes in Rayleigh fading with second order diversity at a symbol rate of 133kBd, carrier frequency 2GHz and mobile velocity of 15m/s

PRMA schemes have been documented for example in references [2, 3]. However, in the proposed PRMA-assisted adaptive modulation scheme mobile stations (MS) can reserve more than one slot in order to deliver up to four bursts per speech frame, when DPSK is invoked towards the cell edges. When a free slot appears in the frame, each mobile that requires a new reservation contends for it based on a permission probability, p. If the slot is granted to a 16-StQAM user, that slot is reserved in the normal way. If the slot is granted to a DQPSK user, then the next available free slot is also reserved for that user. Lastly, if the slot is granted to a DPSK user, then the next three free slots must also be reserved for this particular user. In this way, users that require more than one slot are not disadvantaged by forcing them to contend for each slot individually. If, however, there are less than three slots available, DQPSK or 16-StQAM users still may be able to exploit the remaining slots.

We found that the difference in signal to noise ratio (SNR) required for the different modulation schemes in order to maintain similar bit error ratios (BER) was approximately 3 dB between DPSK and DQPSK, and 12dB between DPSK and StQAM, when transmitting over Rayleigh-fading channels. The BER curves for these modulation schemes in narrow-band Rayleigh channels with second order diversity, a propagation frequency of 2 GHz and a vehicular speed of 15 m/s are shown in Figures 1 and 2 in case of the GSM- and DECT-type systems, respectively.

Thus, using an inverse fourth power pathloss law, DPSK was invoked between radii $0.84R$ and the cell boundary, R, which is one quarter of the cell area. StQAM was used between the cell centre and $0.5R$, which is a further quarter of the cell area and DQPSK in the remaining area, which constitutes half of the total cell area. Accordingly, considering the number of slots needed by the various modulation schemes invoked and assuming a uniform traffic density, we can calculate the expected number of required slots per call as

$$E(n) = \frac{1}{4}.4 + \frac{1}{2}.2 + \frac{1}{4}.1 = 2.25 \text{ slots.} \qquad (1)$$

Since a binary user would require 4 slots, this implies a capacity improvement of a factor of $4/2.25 \approx 1.78$.

System	Slots	Permission Probability	Simultaneous Calls	Normalised by cluster size K	Improvement over binary with PRMA	Improvement over binary without PRMA
DBPSK	12	0.5	19	19	-	58%
DQPSK	24	0.4	44	31.1	64%	159%
Adaptive	48	0.5	36	36	89%	200%

Table 2: Improvements in capacity possible with adaptive modulation PRMA with 48 slots

System	Slots	Permission Probability	Simultaneous Calls	Normalised by cluster size K	Improvement over binary with PRMA	Improvement over binary without PRMA
DBPSK	104	0.1	220	200	-	112%
DQPSK	208	0.1	470	332	51%	219%
Adaptive	416	0.1	400	400	82%	285%

Table 3: Achievable capacity improvements for the adaptive modulation PRMA with 416 slots

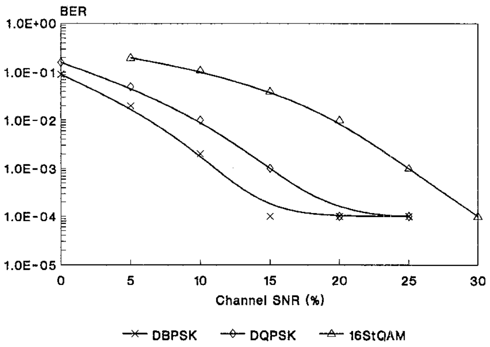

Figure 2: BER performance of our modulation schemes in Rayleigh fading with second order diversity at a symbol rate of 1152kBd, carrier frequency 2GHz and mobile velocity of 15m/s

3 Adaptive GSM-like Schemes

As mentioned earlier, when using the 133.33 kBd GSM-like adaptive PRMA schemes, we can create 48 slots per 30 ms speech frame. This is equivalent to 12 slots for a binary only system, since four slots are required for the transmission of a 30 ms speech packet. When the quaternary system is used, 24 pairs of slots can be created. Note that when fixed channel allocation is used, the adaptive scheme and the binary only scheme can use the same cluster size. A quaternary only system requires a 3dB greater SIR than the binary scheme. According to Lee [8],

$$\frac{D}{R} = \sqrt{3K} \tag{2}$$

where D is the distance to the closest interferer, R is the cell radius, and K is the cluster size. The prevailing Signal-to-Interference Ratio (SIR) can be expressed as

$$\mathrm{SIR} \approx \left(\frac{D}{R}\right)^{\gamma} \tag{3}$$

where γ is the path loss exponent and hence

$$K = \frac{1}{3}(\mathrm{SIR})^{\frac{2}{\gamma}}. \tag{4}$$

In this treatise we have used a pathloss exponent of $\gamma = 4$, and therefore increasing the SIR by 3dB requires that the cluster size be increased by a factor of $\sqrt{2}$.

The packet dropping versus number of users performance of the 12 slot binary scheme is shown in Figure 3 together with the 24 slot quaternary and the 48 slot adaptive scheme. For all schemes their associated optimum permission probabilty was used, which allowed us to support the highest number of users, assuming a packet dropping probability of 1%. It is clear from the Figure that a maximum of 19 simultaneous calls can be supported at a packet dropping probability of 1%, when using the binary scheme with a PRMA permission probability of 0.5. In contrast, the 24 slot quaternary scheme can support 44 simultaneous calls when using a permission probability of 0.4. Lastly, our 48 slot adaptive scheme can accommodate 36 simultaneous calls with a permission probability of 0.5. The capacity improvements attainable by the proposed GSM-like scheme are presented in Table 2.

4 Adaptive DECT-like Schemes

In our DECT-like schemes we have INT{1152 kBd/2.77 kBd}=416 slots per frame for the adaptive PRMA system. This is equivalent to 104 slots

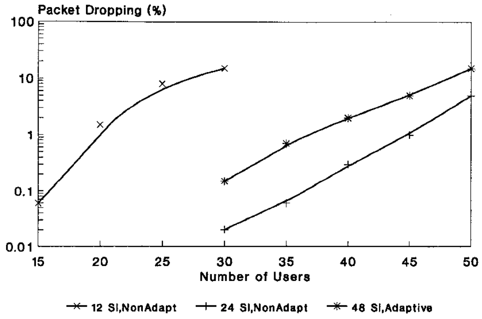

Figure 3: Packet dropping performance of the GSM-like PRMA schemes

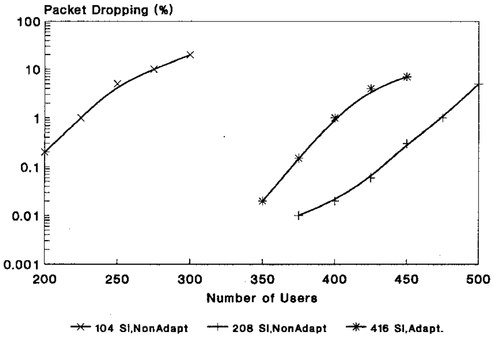

Figure 4: Packet dropping performance of the DECT-like PRMA schemes

for a binary only system and 216 slots for a quaternary only system. Note that when fixed channel allocation is used, the adaptive scheme and the binary only scheme can use the same cluster size. Again, a quaternary only system requires a 3dB greater SIR than the binary scheme and so the cluster size should be increased by a factor of $\sqrt{2}$.

The packet dropping versus number of users performance of the 104 slot binary scheme is portrayed in Figure 4 when using a permission probability of 0.1. Observe from the Figure that this scheme can support up to 220 simultaneous calls at a packet dropping probability of 1%. When opting for the 208 slot quaternary scheme, the packet dropping versus number of users performance curve reveals that this system can accommodate 470 simultaneous calls with a permission probability of 0.1. Finally, the packet dropping performance of the 416 slot adaptive scheme suggests that the number of supported simultaneous conversations is about 400, when opting for a permission probability of 0.1. The achievable capacity improvements for our DECT-like system are displayed in Table 3.

5 Conclusions

Adaptive modulation with PRMA gives the expected three- to four-fold capacity increase over the binary scheme without PRMA. Generally the greater the number of slots, the greater the advantage of PRMA over non-PRMA systems, since the statistical multiplexing gain approaches the reciprocal of the speech activity ratio. Furthermore, PRMA-assisted adaptive modulation achieves an additional 80% capacity increase over PRMA-assisted binary modulation. The speech performance of our adaptive system evaluated in terms of Segmental Signal-to-noise Ratio (SEGSNR) and Cepstral Distance (CD) is unimpaired by channel effects for SNR values in excess of about 8, 10 and 20 dB, when using DPSK, DQPSK and 16-StQAM, respectively.

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