2 MONZON, J. C.: 'Radiation and scattering in homogeneous general biisotropic regions', *IEEE Trans.*, 1990, **AP-38,** (2), pp. 227–235
3 LINDELL, I. V.: 'Methods for electromagnetic field analysis' (Clarendon Press, Oxford, 1992)
4 CHEN, H. C.: 'Theory of electromagnetic waves: A coordinate-free approach' (McGraw-Hill, New York, 1983)

EFFECTS OF PRMA ON OBJECTIVE SPEECH QUALITY

J. C. S. Cheung, L. Hanzo, W. T. Webb and R. Steele

Indexing terms: Speech intelligibility, Digital communication systems

When transmitting 32kbit/s adaptive differential pulse (ADPCM) speech using Reed–Solomon error correction coding and 16 level quadrature amplitude modulation (16-QAM), our 20 slot packet reservation multiple access (PRMA) assisted cordless telecommunications (CT) scheme supported 36–38 speech users with negligible objective and subjective speech degradation. The average number of users per slot was nearly doubled due to deploying PRMA and toll quality speech was transmitted in a user bandwidth ~11·6kHz. For a channel signal-to-noise ratio (SNR) in excess of 25dB, a Rayleigh fading channel and mobile speeds above 2mph the speech segmental SNR degradation was less than 0·3dB.

Introduction: Packet reservation multiple access (PRMA), originally proposed by Goodman *et al.* [1], improves the spectral efficiency of time division multiple access (TDMA) links by surrendering previously reserved time slots during inactive speech segments to other users who are becoming active. Speech packets are encoded and queued for transmission, if active speech is deemed to be present by the voice activity detector (VAD) [2] and permission to contend is granted. The packet delay due to queueing must be below 32ms and the packet dropping probability P_{drop} due to contention for free slots must be less than 1% to maintain low subjective speech degradation. The effects of PRMA parameters on throughput have been documented in Reference 1 using a negative exponential speech spurt length and silence duration distribution model.

In our contribution, we are proposing a PRMA-assisted cordless telecommunications (CT) scheme and embarked on the investigation of the effects of PRMA on objective and subjective speech quality using real speech signals. This allowed us to portray speech degradations due to PRMA packet dropping in comparison to channel impairments.

System description: In our proposed system the 4 bit/sample 32kbit/s adaptive differential pulse code modulation (ADPCM) encoded speech data are protected by a matching 4 bit/symbol, $R = 2/3$-rate Reed–Solomon RS (12, 8, 2) codec operating over the finite Galois field (GF16). The benign microcellular channel features allow us to deploy bandwidth efficient 4 bit/symbol 16 level quadrature amplitude modulation (16-QAM) [3]. We assume that the radio channel is essentially flat Rayleigh for our 264kBaud transmissions at 1·9GHz when the pedestrian speed is 2mph. The bandwidth requirement is 440kHz. No equaliser is deployed but second-order diversity reception is used.

If speech is deemed to be present by the VAD [2] and permission to contend is also granted, the portable station (PS) transmits its 640 bit ADPCM-coded speech packet plus 64 header bits to the base station (BS). If the BS can decode the received PRMA packet without errors, it allocates the time slot that was temporarily used by the PS for its future up-link communications. However, when several PSs transmit their packets in the same slot, collisions occur, resulting in erroneous decoding at the BS, resulting in no reservation being given. In this case the PSs have to keep contending for future slots with a given permission probability, until either a reservation is granted or the maximum tolerable speech delay expires, when the packet is dropped. The PRMA system parameters used in our experiments are listed in Table 1.

Table 1 PRMA PARAMETERS

PRMA parameter	
Channel rate	264kBaud
Source rate	8 ksymbol/s
Frame duration	20ms
No. of slots	20
Slot duration	1ms
Speech frame length	20ms
Header length	64 bits
Maximum speech delay	32ms
Permission probability	0·3

Results and discussion: Using our proposed system we focus our attention on the objective degradation of ADPCM coded speech as a function of the number of PRMA users. For this experiment a perfect channel was used; one of the users was transmitting a pre-recorded telephone conversation, whereas the remaining users were modelled by the negative exponential speech distributions described in Reference 1. To ensure the consistency of our speech quality assessment we used both the segmental signal-to-noise ratio degradation (SEGSNR-DEG) and the cepstral distance degradation (CD-DEG) measures [4]. Our results are plotted in Fig. 1. Observe that both

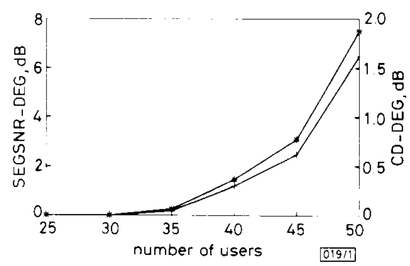

Fig. 1 *Objective speech degradation with PRMA against number of users*

—✶— SEGSNR-DEG
—+— CD-DEG

the SEGSNR-DEG and CD-DEG curves exhibit nearly zero degradation for less than 36–38 users, whereas for more than 40 users the curves become increasingly steep. For $P_{drop} = 1\%$ we have an SEGSNR degradation of ~0·5dB, while the CD degradation is ~0·1dB. In agreement with our expectations and subjective speech quality assessments, the objective speech degradations due to $P_{drop} = 1\%$ are minor.

To evaluate these objective degradations in relative terms, in our next experiment we restricted the number of PRMA users to $N = 20$, to maintain $P_{drop} = 0$, and evaluated the SEGSNR-DEG and CD-DEG objective measures as a function of the channel SNR for transmissions over Rayleigh fading channels, when the pedestrian speed was 2mph. Our results are shown in Fig. 2. Observe that for SNRs in excess of ~25dB our diversity assisted PRMA scheme has virtually no objective speech degradation. As the channel SNR is decreased, the curves become steeper and the speech degradation due to channel impairments rapidly becomes more dominant than that caused by PRMA packet dropping, as demonstrated in Figs. 1 and 2.

The joint effects of channel impairments and those due to PRMA packet dropping become more explicit in Fig. 3, where the overall combined system performance is characterised with the aid of the SEGSNR against channel SNR curves, parametrised with the number of users supported in the 20 PRMA slots. Virtually unimpaired speech quality is experienced for channel SNRs above 25dB, if the number of users is below 38. If either the channel SNR is decreased below 25dB, or the number of users is increased above 38, the speech performance begins to degrade significantly. It is interesting to note that the SEGSNR-DEG due to supporting 42 users instead of 38 is comparable in objective terms to that due to reducing the channel SNR from 25 to 23 dB.

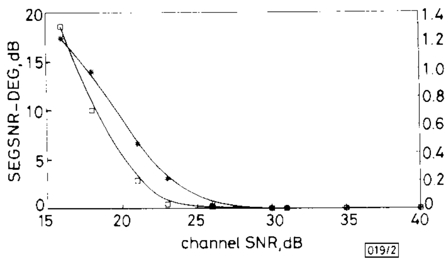

Fig. 2 *Objective speech degradation against channel SNR via Rayleigh fading channels*

—∗— SEGSNR-DEG
—□— CD-DEG

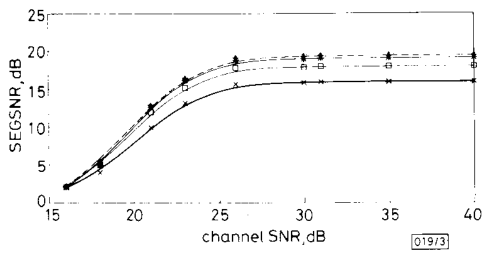

Fig. 3 *Overall system performance*

··■·· 30 users
—+— 34 users
—∗— 38 users
—□— 42 users
—×— 46 users

Summary: A spectrally efficient diversity- and PRMA-assisted CT scheme has been proposed using 4 bit/sample speech coding, 4 bit/symbol error correction coding and 4 bit/symbol modulation. The 264 kBaud, 20 slot PRMA system is capable of supporting 38 users with $P_{drop} < 1\%$. The average number of PRMA users per TDMA time slot is $38/20 = 1{\cdot}9$, which nearly doubles the TDMA bandwidth efficiency. The PRMA user bandwidth is given by 440 kHz/38 users $\simeq 11{\cdot}6$ kHz. Using a propagation frequency of 1·9 GHz and a mobile speed of 2 mph, a channel SNR of ~ 25 dB is required for unimpaired speech quality over Rayleigh fading channels. If either the channel SNR is reduced or the number of PRMA users is increased, the speech quality is degraded, but the impairments introduced by PRMA packet dropping are more modest than those due to channel effects.

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References

1 NANDA, S., GOODMAN, D. J., and TIMOR, U.: 'A packet voice protocol for cellular systems', *IEEE Trans.*, 1991, **VT-40**, (3), pp. 584–598
2 BACS, E., and HANZO, L.: 'A simple real-time adaptive speech detector for SCPC systems'. Proc. ICC '85, Chicago, Illinois, USA, pp. 1208–1212
3 WEBB, W., HANZO, L., and STEELE, R.: 'Bandwidth efficient QAM schemes for Rayleigh fading channels', *IEE Proc. I*, 1991, **138**, (3), pp. 169–175
4 WONG, K. H. H., HONZO, L., and STEELE, R.: 'Channel coding for satellite mobile channels', *Int. J. Satellite Commun.*, 1989, **7**, pp. 143–163

LINEARISATION OF HIGH-RATIO, WIDE-RANGE BIPOLAR CURRENT MIRRORS

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Indexing terms: Current mirrors, Integrated circuits, Bipolar devices

A new design strategy for implementing bipolar current mirrors with a high input to output ratio and a wide current range is presented. The strategy is based on a known area efficient topology. The new strategy improves the linearity of the current mirror at high currents.

Introduction: When designing high input to output ratio bipolar current mirrors, an EFA mirror [1] using one of the following three scaling methods is normally used: emitter area scaling, emitter degeneration, or insertion of a voltage source to increase V_{BE} [1, 2]. Emitter area scaling is not suited when the mirror ratio is high (e.g. > 100), and emitter degeneration is not suitable when the current range is wide and the maximal current is high; both due to a large area. The voltage source topology is area efficient and is therefore often used.

Traditional approach: Inserting a voltage source (V_{source}) in the mirror loop as shown in Fig. 1 results in the following modification of the input to output current ratio:

$$V_{source} + V_{BE,Q1} - V_{BE,Q2} = 0$$

$$\Updownarrow$$

$$V_{source} + V_T \ln\left(\frac{I_{C1}}{I_{S1}}\right) - V_T \ln\left(\frac{I_{C2}}{I_{S2}}\right) = 0 \qquad I_{Sx} = \frac{qD_n n_i^2}{W_a N_A} A_x$$

$$\Updownarrow$$

$$\frac{I_{C2}}{I_{C1}} = \frac{A_2}{A_1} \exp^{V_{source}/V_T}$$

Assuming a current mirror with ratio 1 : 1000 and an emitter ratio of 1 : 100 then V_{source} must have the value of 59·6 mV at 25°C ($I_{C2} = 1000 I_{C1}$, and $A_2 = 100 A_1$).

Normally, the voltage source is implemented by a resistor and a current source (see Fig. 1*b*). To implement a good

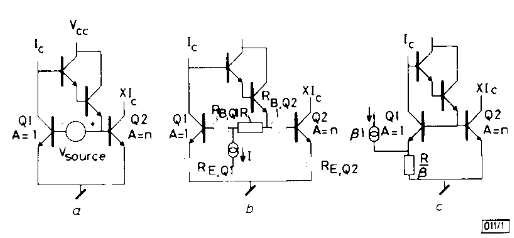

Fig. 1 *EFA topologies using voltage source insertion*

voltage source, the traditional approach has been to make the current I through the resistor much greater than the corresponding signal current. Therefore, the voltage source is normally inserted between the bases of the two transistors to keep I small.

As V_T is proportional to absolute temperature (PTAT), V_{source} must also be PTAT to ensure stable operation over temperature. If a current source I_{PTAT} is used, then V_{source} will be PTAT if the resistor used to implement the I_{PTAT} and the resistor used in V_{source} are fabricated in the same material. Furthermore, the accuracy of V_{source} using this implementation is determined from the matching between the two resistors.

A simulation of a current mirror using the traditional design strategy ($I \gg I_{B,Q1}$) is shown in Fig. 2(i). The mirror is implemented using the above mentioned specifications and the topology shown in Fig. 1*b*. At low currents (up to $\sim 5\,\mu$A