A Jointly Optimised Subband Coding, BCH Coding, 16-QAM, Diversity and Post-Enhancement Scheme for Mobile Radio Speech Transmission

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1 16-QAM Performance via Gaussian and Rayleigh Channels

In 16-QAM schemes one signal constellation point is represented by two consecutive bits of the in-phase (i_1, i_2) and quadrature-phase (q_1, q_2) components, which are interleaved when transmitted via the channel to give the sequence i_1, q_1, i_2, q_2. Closer scrutiny of the 16-QAM constellation of Figure 1 shows that the i_2, q_2 bits are always at a 'protection distance' d from their decision boundaries, represented by the dashed lines. The i_1, q_1 bits on the other hand are half of the time at a distance of d, half of the time at a distance of 3d from their decision boundaries, constituted by the solid coordinate axis. Whence there exist two 16-QAM subchannels, CI and CII, with a higher and lower integrity, respectively [1].

Microcellular mobile radio channels of the future Public Personal Communications Network (PPCN), such as those, for example, inside office buildings, can usually be described by Rician channel models, but the best and worst cases are represented by the Additive White Gaussian Noise (AWGN) and the flat Rayleigh-fading channels, respectively. Therefore we have evaluated the CI and CII subchannel performances using both theory and simulations via our AWGN and flat Rayleigh-fading channel models in Figure 2. The Rayleigh-fading envelope used in our simulations has been sampled at 16 ksamples and stored for a vehicle travelling at 30 mph. Other vehicular speeds have been generated by up- and down-sampling the fading envelope. Observe that for both channel models there are considerable differences in terms of the CI and CII bit error rates (BER), but in the Rayleigh channel the BER discrepancy is more profound. For the Rayleigh channel at an SNR of 20 dB the difference between the CI and CII BERs exceeds an order of magnitude, and for the CII subchannel it is above 10^{-1}. Thence the CII subchannel is unsuited for digital speech transmission via Rayleigh-fading channels, while through AWGN channels the CI and CII BER is much lower than required for speech communications.

2 Average Locking AGC

From this experience we have concluded that a fade-tracking AGC has to be deployed. Several approaches have been tried and finally we have opted for a method, which we refer to as 'average-locking' AGC. The idea behind the average-locking AGC is that the average energy of the full 16-QAM constellation is $E=10d^2$ when a PRBS signal is transmitted, as computed from Figure 1, and any deviation from this is attributed to signal envelope fading. The envelope fading can be compensated for by multiplying the current QAM constellation with an appropriate gain factor. The CI subchannel's BER is unaffected by the average-locking AGC, but the CII BER is significantly reduced, as evidenced by Figure 3 for 20 and 30 dB channel SNRs, with vehicular speeds in the range of 15-120 mph, as a function of the averaging length k. For most SNRs and vehicular speeds an averaging length of k=4 is a good choice, thence in our further discourse we use k=4. Observe also that for an SNR of 30 dB also the CII subchannel's BER is below 10^{-2}, and it can be rendered suitable for the transmission of perceptually less significant subband coded (SBC) speech information bits, if forward error correction (FEC) is used.

3 Switched Diversity

In a further attempt to improve the system's performance we have investigated the effects of switched diversity on CI and CII BER at a vehicular speed of 30 mph and channel SNRs of 20, 22 and 25 dB via our flat Rayleigh-fading channel in Figure 4, as a function of the switched diversity order. While the CII BER is virtually independent from the SNR and diversity order, the CI performance is improved by more than an order of magnitude when second-order switched diversity is used.

4 Proposed SBC/BCH/16-QAM/Diversity Systems

The block diagram of our candidate systems is depicted in Figure 5. The bit-sensitivities of the SBC codec for a voiced speech segment are shown in Figure 6. The subband coded (SBC) bits are mapped according to their perceptual importance onto the CI or CII 16-QAM subchannels by the help of the block 'SBC MAP'. After Bose-Chaudhuri-Hocquenghem encoding (BCHE) and rectangular interleaving the bits are assembled in the block 'ASM QAM' for 16-QAM transmission via the Rayleigh-fading channel. After diversity reception, demodulation and deassembling in the block 'DASM QAM' the bits are deinterleaved and BCH decoded. Finally, bit demapping, subband decoding and speech postprocessing ensues to recover the original speech.

If no FEC coding is utilised, a 4 kBd system is resulted, since the 16 kbit/s SBC speech is transmitted via the 4 bits/sample 16-QAM modem. This system is used as a benchmarker in the comparison of our proposed systems. Its segmental SNR (SEG-SNR) performance is too low (4 dB) for toll-quality speech transmission even in excess of channel SNRs of 30 dB via the Rayleigh-fading channel at 30 mph, since the error-free SBC SEG-SNR=14 dB, as evidenced by Figure 7.

BCH block codes are powerful in correcting both random and bursty errors, and with the proviso of moderate blocklengths they have low decoding complexities, as well as confident error detecting capabilities. The error detecting capability can be advantageously exploited to invoke speech post-enhancement algorithms and to control handovers [2], [3]. Therefore we opted to use BCH codes.

Our first candidate system adds BCH coding to both subchannels so that their BERs are not only sufficiently low to carry SBC speech, but also nearly matched. This is achieved by using BCH(63,48,2) and BCH(63,24,7) codes in the CI and CII subchannels, respectively. This scheme does not require any special SBC mapping, therefore it is transparent to voice-band signalling, but does not fully exploit the potential benefits of the different CI and CII subchannels. The resulting transmission rate is 28 kbit/s, i.e., 7 kBd. Rectangular interleaving over eight BCH coded frames is used to randomise the bursty error statistics via the Rayleigh-fading channel. In summary, toll-quality SBC speech transmission is possible with a delay of 36 ms for channel SNRs in excess of 20 dB via flat, viz. non-dispersive Rayleigh-fading channels for a vehicular speed of 30 mph, as seen in Figure 7.

A more bandwidth-efficient system is derived, if the differing BERs of the subchannels are exploited. The SBC mapper maps the group of more important SBC bits onto the CI subchannel, having sufficiently low BER for their transmission in excess of 20 dB channel SNR. In the CII subchannel a shortened BCH(60,36,4) code with a depth-eight rectangular interleaver is used to sufficiently lower the BER for the transmission of the group of less significant SBC bits. The system's SEG-SNR curve is again depicted in Figure 7, characterised by its transmission rate of 5 kBd. Note that at the cost of 2 dB higher channel SNR significantly higher bandwidth efficiency is achieved when compared with the 7 kBd system.

When second-order diversity is deployed, the 5 kBd system outperforms the 7 kBd system and guarantees toll-quality speech for SNRs in excess of 18 dB with a system delay of 36 ms for a vehicular speed of 30 mph via flat Rayleigh-fading channels. For line-of-sight AWGN channels significantly lower channel SNRs guarantee extremely bandwidth efficient, toll-quality mobile speech transmission in the microcellular PPCN environment.

5 Speech Post-Enhancement

The BCH codec's error detection capability is also exploited to invoke a waveform substitution technique, which is best understood with reference to Figure 8. If the received speech is deemed to be seriously corrupted, since three consecutive BCH coded frames (18 ms) are erroneously decoded, the last correctly received 6 ms SBC speech segment is used as a template to find a highly correlated 18 ms speech segment in a buffer, storing 54 ms of the previous correctly decoded SBC speech history.

6 Conclusion

Using a jointly optimised SBC/BCH/16-QAM/Diversity system near toll-quality speech communication is possible within a bandwidth of less than 10 kHz in the microcellular PPCN mobile radio environment. Deploying CELP or RPE-LTP codecs further improves the bandwidth efficiency or the speech quality, respectively.

References

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[2] L. Hanzo, K.H.H. Wong, R. Steele: Efficien channel coding and interleaving schemes for mobile radio communications, Proc. of IEE Colloq., 22 Febr. 1989, London

[3] K.H.H. Wong, L. Hanzo, R. Steele: Channel coding for satellite mobile channels, accepted by Int. Journ. of Sat. Comms., John Wiley, Vol. 7, 1989

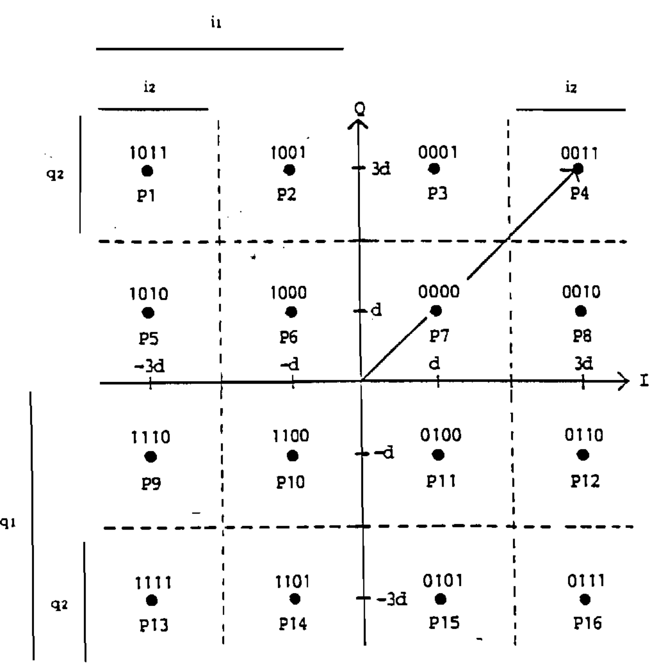


Fig.1: 16-level QAM constellation

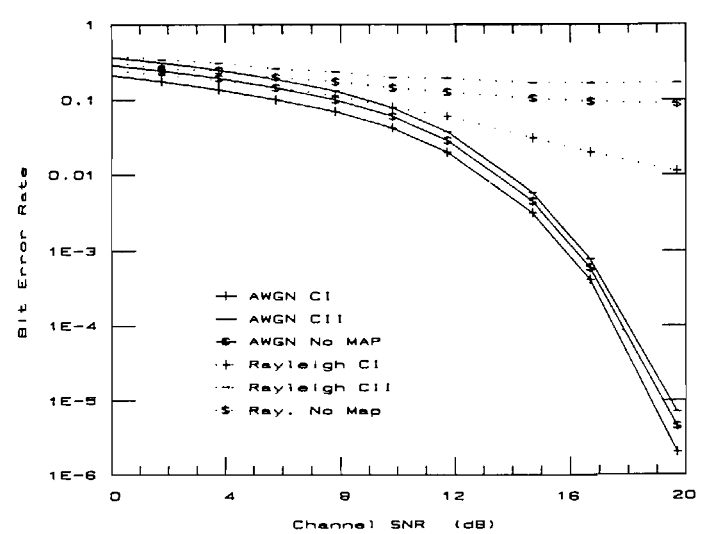
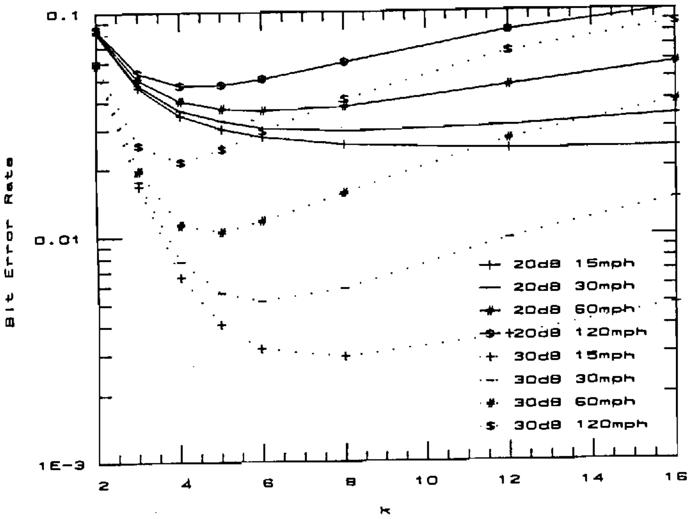


Fig.2: CI and CII BER variation vs. channel SNR



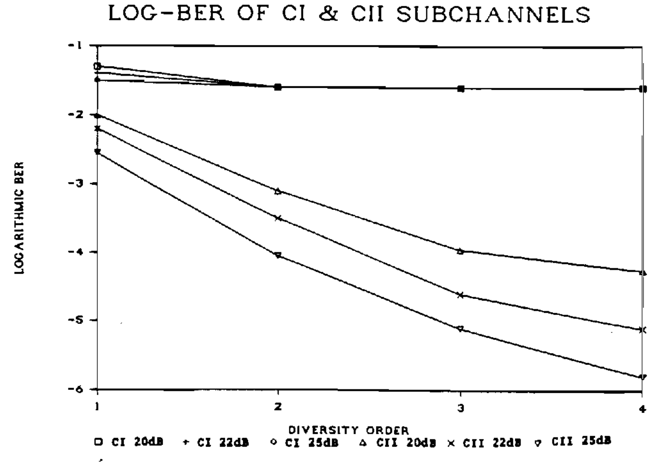


Fig.3: CII BER variation vs. averaging length k with AGC

Fig.4: CI and CII BER vs. diversity order

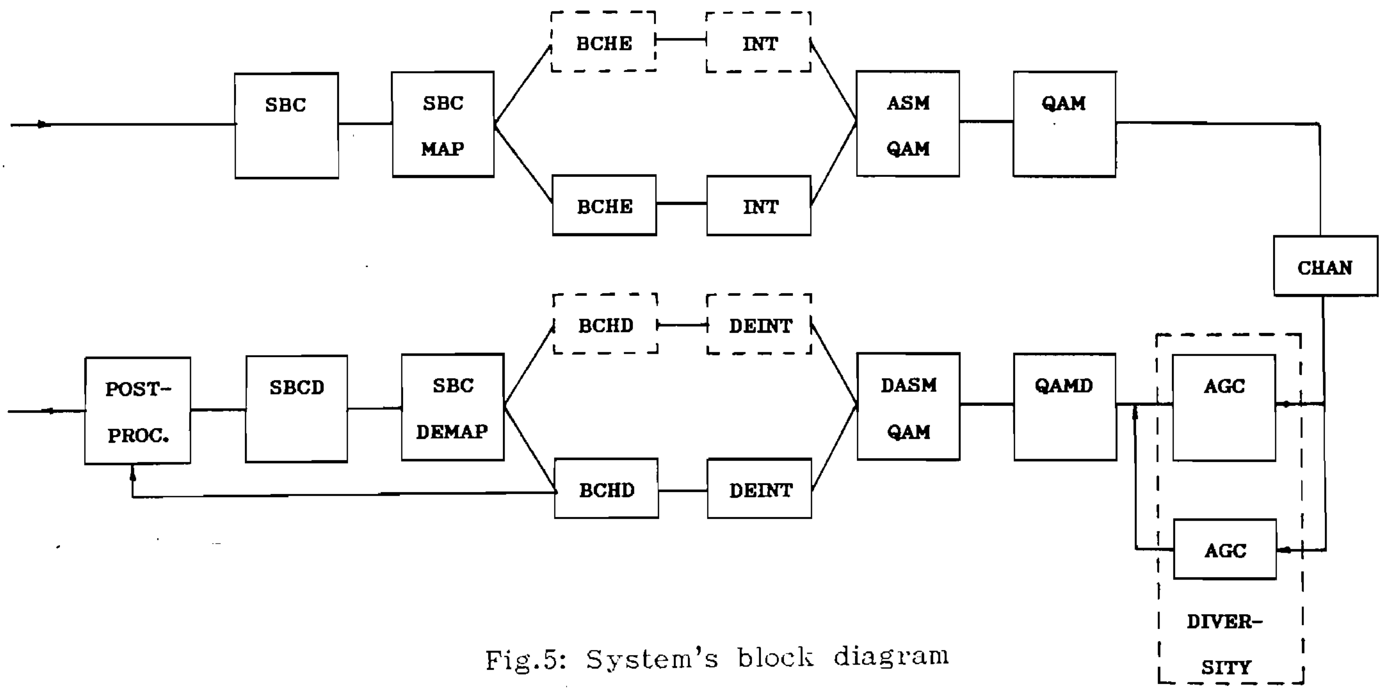
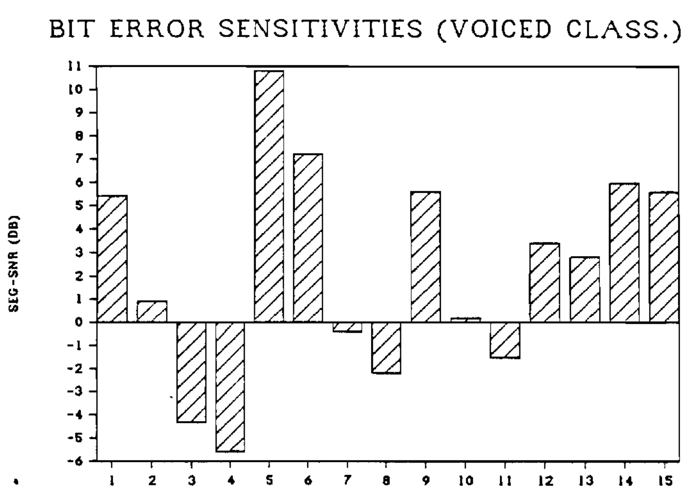


Fig.5: System's block diagram



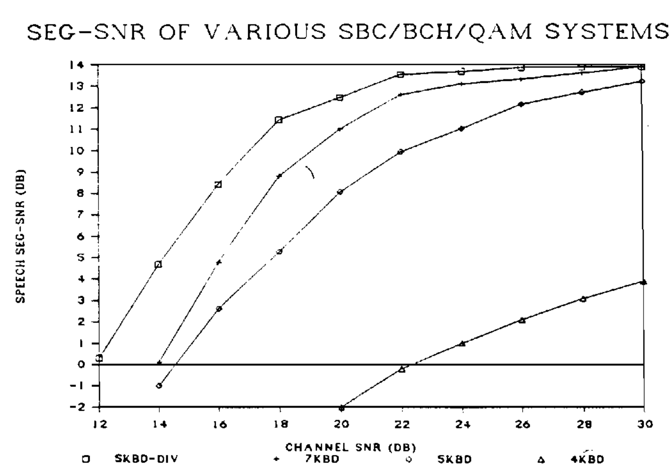
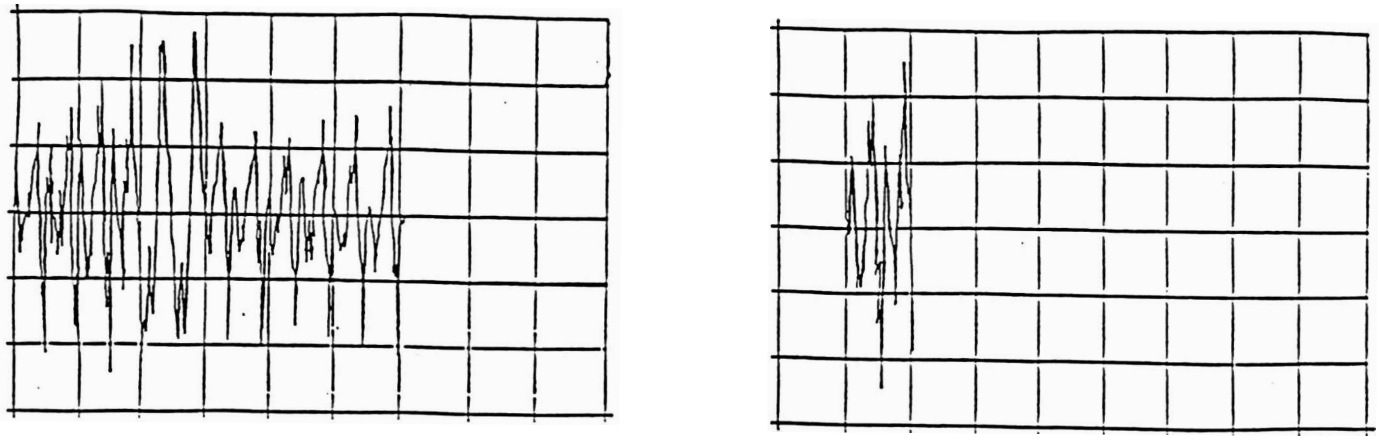
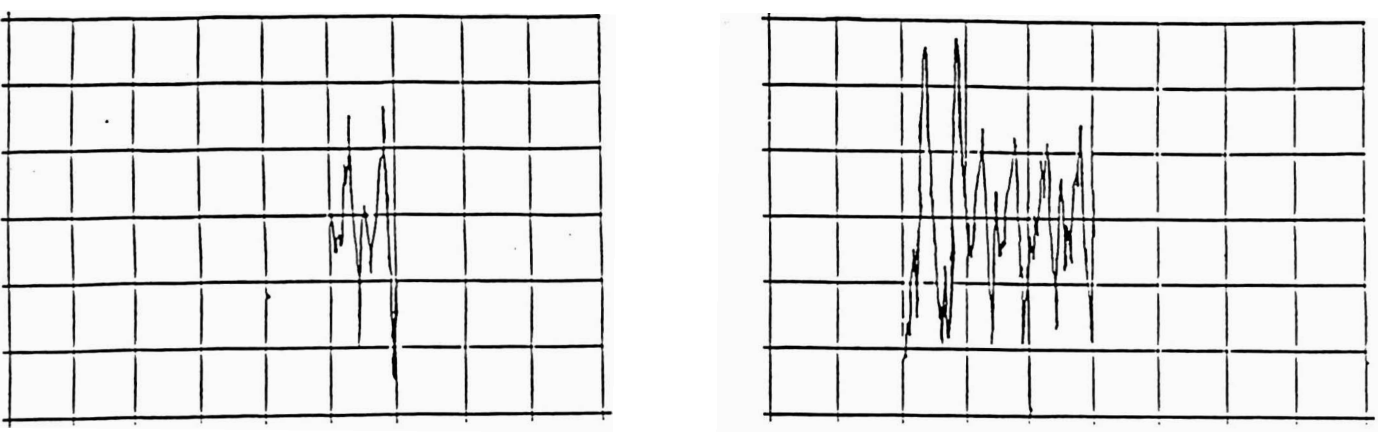


Fig.6: SBC bit-sensitivity vs. bit-index for voiced speech

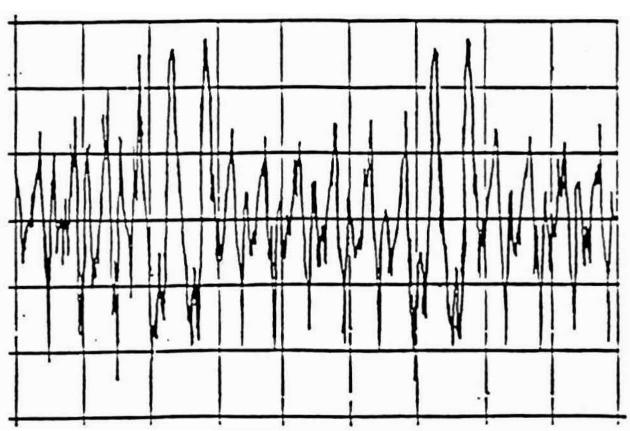
Fig.7: SEG-SNR of proposed SBC/BCH/QAM systems vs. channel SNR



(c)



(d)



(e)

Figure 8: Speech post-enhancement using waveform substitution technique