Robust H.263 Video Transmission over mobile channels in interference limited environments *†

P. Cherriman, L. Hanzo
Dept. of Electr. and Comp. Sc., Univ. of Southampton, SO17 1BJ, UK.
Tel: +44-703-593 125, Fax: +44-703-594 508
Email: pjc94r@ecs.soton.ac.uk, lh@ecs.soton.ac.uk
http://www-mobile.ecs.soton.ac.uk

July 19, 1996

Abstract

The cellular channel capacity of conventional cells is shown to vary dramatically as a function of the distance from the base station. An intelligent 7.3 kBaud adaptive videophone transceiver is contrived, in order to exploit the higher channel capacity of uninterfered cell areas and to satisfy the prevalent system optimisation criteria. The system employed an enhanced H.263-compatible video codec and it was capable of operating over a wide range of operating conditions. The proposed technique has the potential to support videotelephony over existing and future wireless systems using the H.263 video codec. The main system features are summarised in Table 1.

1 Channel Capacity and Co-channel Interference

The Shannon-Hartley law states that the channel capacity of a band-limited Additive White Gaussian Noise (AWGN) channel can be expressed as in Equation 1:

$$C = B\log_2(1+\gamma), \tag{1}$$

where B is the channel bandwidth, γ is the signal to noise ratio (SNR), and C is the channel capacity in bits/sec. The SNR γ is defined as $\gamma = \frac{S}{N}$, where S is the received signal power and N is the AWGN power within the channel bandwidth.

In most mobile radio systems, however, the channel exhibits Rayleigh fast fading, aggravated by typically log-normally distributed shadowing or slow fading, resulting in a time-variant channel capacity. Lee [1] derived an estimate of the channel capacity in Rayleigh fading environments and showed that when using diversity in a Rayleigh fading environment, the average channel capacity can approach that for a Gaussian channel. The normalised channel capacity can be expressed as in Equation 2:

$$\eta = \frac{C}{B} = log_2(1+\gamma), \tag{2}$$

an upper bound approximation, which has to be replaced by Lee's estimate [1] in case of Rayleigh channels:

$$\eta \approx \log_2 e \cdot e^{-1/\gamma}(-E + \ln\gamma + \frac{1}{\gamma}), \tag{3}$$

where $E \approx 0.577$ is the Euler constant. Evaluation of this formula shows a 32% channel capacity reduction in comparison to the Gaussian channel at an SNR of 10 dB.

In a cellular re-use structure the effect of co-channel interference must be included in the channel capacity estimate. Hence the definition of γ in Equations 1-3 must be modified by replacing the SNR

*This treatise is complemented by a demonstration package portraying video sequences at various bit rates, which is down-loadable from http://www-mobile.ecs.soton.ac.uk

†1st IEEE Wireless Video Communications Workshop, 4-5 Sept. 1996, Loughborough, UK

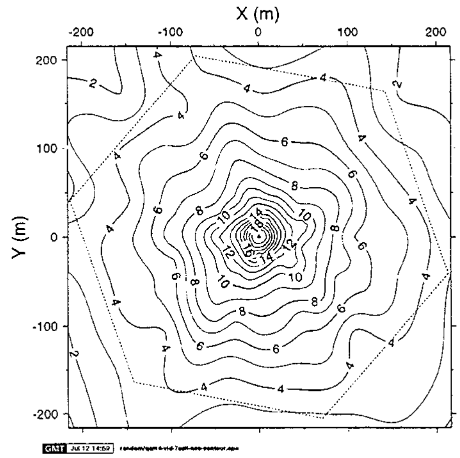

Figure 1: Simulated normalised channel capacity profile of a hexagonal cell, employing a reuse factor of 7, pathloss exponent of 3.5, slow-fading frequency of 1 Hz, standard deviation of 6 dB and random 4QAM video user positions within cell boundaries

by the signal to noise-plus-interference ratio (SINR). The SINR is defined below in Equation 4, where S is the received signal power, I is the received interference power and N is the AWGN power within the channel's bandwidth:

$$\gamma = \frac{S}{I+N}. \tag{4}$$

Therefore the normalised channel capacity for a band-limited, interference-contaminated Gaussian channel is defined in Equation 5:

$$\eta = \frac{C}{B} = log_2\left(\frac{S+I+N}{I+N}\right). \tag{5}$$

In a noise-limited radio system without power-control one would expect the SINR to reduce with distance from the transmitter, when using an omni-directional aerial. However in an interference-limited system the pattern of SINR is less regular. The normalised channel capacity for a typical hexagonal cell in a simulated system, with Rayleigh fast- and log-normal shadow fading having a standard deviation of 6 dB and a frequency of 1 Hz is shown in Figure 1. Let us now concentrate our attention on the effects of co-channel interference.

The co-channel interference performance and capacity of various cellular systems was investigated for example by Lee and Steele in Reference [2]. Our co-channel interference studies have mainly concentrated on the up-link of hexagonal cells with a reuse factor of 7, using an omni-directional antenna at the centre of each cell. This is a commonly investigated cellular cluster type, where each basestation has 6 so-called first-tier co-channel interferers. The average SINR profile of the previously used hexagonal cell characterised previously in Figure 1 in terms of normalised channel capacity is shown in Figure 2. Having characterised the propagation environment, let us now focus our attention on aspects of the proposed transceiver.

2 System Parameters

In order to realise the potentially high channel capacity of the central section of the propagation cell of Figure 1 and the associated higher SINR values of Figure 2, we contrived a multi-mode videophone transceiver, ensuring less robust, but higher quality video communications under favourable channel conditions, while invoking more robust, but lower video-quality modes under hostile channel conditions.

The system proposed uses embedded binary Bose-Chaudhuri-Hocquenghem (BCH) coding [3] combined with a re-configurable Pilot Symbol Assisted (PSA) Quadrature Amplitude Modulation (QAM)

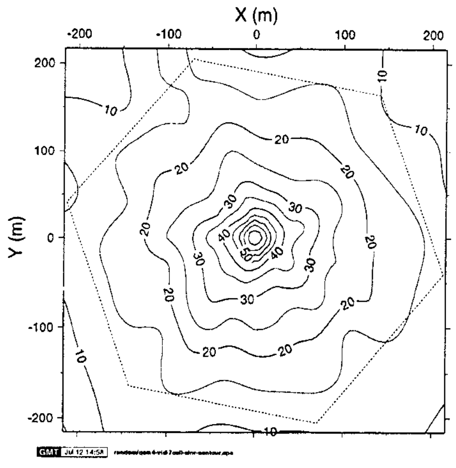

Figure 2: Simulated SINR contours of a hexagonal cell, employing a reuse factor of 7, pathloss exponent of 3.5, slow-fading frequency of 1 Hz, standard deviation of 6 dB and random 4QAM video user positions within cell boundaries

Features	Multi-rate System			
Modem	PSA-BPSK	4-PSAQAM	16-PSAQAM	64-PSAQAM
Bits/Symbol	1	2	4	6
Number of sub-channels	1	1	2	3
C1 FEC	BCH(127,85,6)	BCH(255,171,11)	BCH(255,191,8)	BCH(255,199,7)
C2 FEC	N/A	N/A	BCH(255,147,14)	BCH(255,163,12)
C3 FEC	N/A	N/A	N/A	BCH(255,131,18)
Source bitrate (kbit/s)	4.25	8.55	16.9	24.65
Min. AWGN SINR (dB)	4	10	15	20
Min. Rayleigh SINR (dB)	10	15	20	30
User Symbol Rate (kBd)	7.3			
No. of Users	9			
System Symbol Rate (kBd)	131.4			
System Bandwidth (kHz)	200			
Effective User Bandwidth (kHz)	11.1			
TDMA frame length (ms)	20			
Slots/Frame	18			
Vehicular Speed (m/s)	13.4			
Propagation Frequency (GHz)	1.8			
Fast Fading Normalised Doppler Frequency	6.2696×10^{-4}			
Log-Normal Shadowing standard deviation (dB)	6			
Pathloss Model	Power law 3.5			
Basestation Separation (km)	1			

Table 1: Summary of System features for Reconfigurable mobile radio system

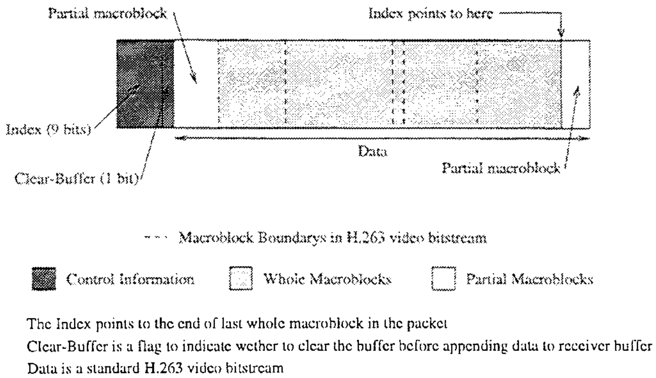

Figure 3: Structure of a packet generated by the modified H.263 video codec

modem [4]. The system can operate, under network control, in one of four modes, each mode corresponding to a different modulation scheme. This allows the system to span a wide range operating conditions in terms of video quality, bit rate, robustness against channel errors and implementational complexity, while exploiting the higher channel capacity of the central region of Figure 1. For example, the transceiver operates using highly bandwidth efficient 64-level Pilot Symbol Assisted Quadrature Amplitude Modulation (64-PSAQAM) in a benign indoors cordless environment, where high SNRs and SIRs prevail. The number of modulation levels is dropped from 64 to 16, when the portable station (PS) is handed-over to an outdoors street micro-cell, and can be further reduced to 4 or even 2 in less friendly propagation scenarios. The system parameters are summarised in Table 1.

Observe in the Table that the different QAM modes have different integrity sub-channels, where this number ranges from 1 to 3 [4]. In general these modulation subchannels can provide source-sensitivity-matched protection, however, in case of the H.263 scheme to be used in our transceiver all bits are very sensitive to transmission errors and hence have to be equally well protected. Therefore we adjusted the error correction power of the various subchannel codes, in order to equalise the different subchannel integrities, as suggested by the different BCH codecs of Table 1. The propagation conditions are also listed in Table 1.

The system was capable of operating over a bitrate range of 1-6, corresponding to the 1-6 bit/symbol QAM modem modes. Hence the forward error correction coded signalling rate became 7.3 kBaud in all modes. When opting for a modulation excess bandwidth of 50%, and a system bandwidth of 200 kHz, as in the Pan-European GSM system, the maximum signalling rate becomes 133.33 kBaud. At this signalling rate INT(133.33/7.3)=18 time-slots can be created, where INT indicates integer division. Assuming an identical speech signalling rate of 7.3 kBd, 9 videophone users can be supported by the proposed scheme in the GSM system's 200 kHz bandwidth. A range of further system aspects can be inferred from Table 1. Let us now consider the video aspects of our transceiver.

In order to support the robust, near-constant rate operation of the system, we contrived an adaptive packetisation algorithm. The transmission packets shown in Figure 3 incorporated some side-information for assisting the H.263 codec in resynchronising after the loss of packets. This side information contains an index and a buffer-clear flag. The index indicates the position of the last whole macroblock fully contained within the current transmission packet. The transceiver ensures that there are no errors in the output H.263 video stream, by only passing whole macroblocks to the H.263 decoder. Partially received macroblocks are buffered at the transceiver until the remainder of the partial macroblock arrives. If the remainder of a partial macroblock is lost due to packet corruption, the first part of the partial macroblock buffered at the transceiver, can be discarded by setting the buffer-clear flag in the transmission packet. Discarded partial macroblocks information is replaced by a codeword indicating no change to the macroblock.

In order to comply with the requirements of the above transmission scheme, the H.263 codec was modified in a standard-compatible fashion. Namely, macroblocks that have been coded but not yet transmitted successfully to the H.263 decoder, must be able to be re-encoded, if necessary. This requires a history of various macroblock parameters to be stored for each macroblock. This information is discarded when they are successfully transmitted. This modification allows macroblocks to be classified as not updated, when they are dropped by the receiver due to packet corruption. Furthermore, in a reconfigurable system, the system may have decided to switch to a lower order, but more robust modulation scheme, due to adverse channel conditions. In this case packets not yet transmitted, will have to be re-encoded at a lower resolution and bitrate for a smaller packet size.

3 Transmission of H.263 video over mobile radio channels

In recent years, there has been increased research activity in the field of mobile videophony, proposing proprietary [5] or standard H.261 and H.263 based schemes [6, 7]. Due to its inherent error sensitivity the H.261 and H.263 [8, 9] coded video stream requires an Automatic Repeat reQuest (ARQ) mechanism. Naturally, using ARQ introduces latency both due to the delay of the acknowledgement feedback information and due to the repeated transmission of the same packet, when the radio channel is particularly hostile.

We have developed a method for transmitting H.263 coded video over mobile channels, relying on a low delay, low bitrate feedback channel expected to be provided by the intelligent third generation mobile systems of the near future. This acknowledgement mechanism informs the transmitter as regards to which video packets were corrupted. The main advantage of the proposed technique is that it does not require the successful delivery of every packet. The transceiver can optionally drop any packet it wishes. This reduces the delay considerably in comparison to that of ARQ. In order to allow the dropping of a packet, some side-information is transmitted with each packet, which enables the transceiver to output an unimpaired H.263 video stream, where the macroblocks contained within lost or corrupted packets are not updated. Hence in this context packet corruption is equivalent to packet dropping. Since the H.263 encoder is informed by the feedback channel as regards to which macroblocks the decoder was unable to update due to corruption, the encoder can adjust the local decoder's buffer, so that the local decoder and decoder keep in synchronisation, thereby curtailing any long term image degradation.

When the video packet error rate or BCH-coded frame error rate (FER) is low, the lost macroblocks will normally be updated in the next video frame and any image degradation due to the error event will be removed. Generally macroblocks that are lost, but are consecutively updated during the next few frames are not noticeable, unless the motion activity in the frame is particularly high. However, as the FER increases, the lost macroblocks may not be updated for several frames, and the dropped macroblocks become more conspicuous. When the transceiver experiences degrading channel conditions, it can instruct the H.263 encoder to reduce its bitrate and invoke a lower quality, but more robust mode of operation, in order to improve the throughput of macroblocks.

Figure 4 shows the decoded video peak signal to noise ratio (PSNR) versus the video frame index performance of the system for various video packet dropping rates in its 4QAM mode of operation for transmissions over the standard fading channel characterised in Table 1. The different packet dropping rates were engendered by using various channel SINR values. In order to prevent excessive video degradations, it is advantageous to reconfigure the system in a more robust mode, before the packet dropping rate increases beyond some 5%. The associated subjective effects are characterised by the corresponding demonstrations that can be viewed on the WWW [1]. The PSNR versus channel SINR performance of the transceiver is portrayed in Figure 5 over AWGN channels, while the corresponding Rayleigh-fading channel results are depicted in Figure 6 without shadow fading and in 7 with shadow fading exhibiting a standard deviation of 6 dB. The effect of shadowing can be judged when comparing Figures 6 and 7.

4 Conclusions

The cellular channel capacity of conventional cells was estimated and an intelligent adaptive videophone transceiver was proposed, which exploited the higher channel capacity of un-interfered cell areas. The system employed an enhanced H.263-compatible video codec and it was capable of operating over a wide range of operating conditions, reconfiguring itself according to the prevalent system optimisation criteria. The proposed technique has the potential to support videotelephony over existing and future wireless systems using the H.263 video codec. The key system parameters are summarised in Table 1.

[1] http://www-mobile.ecs.soton.ac.uk/peter/robust-h263/robust.html

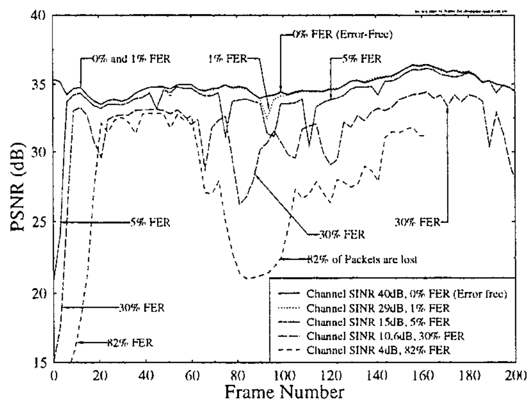

Figure 4: Decoded video PSNR versus video frame index for transmission over Rayleigh fading channels for various packet dropping (FER) rates

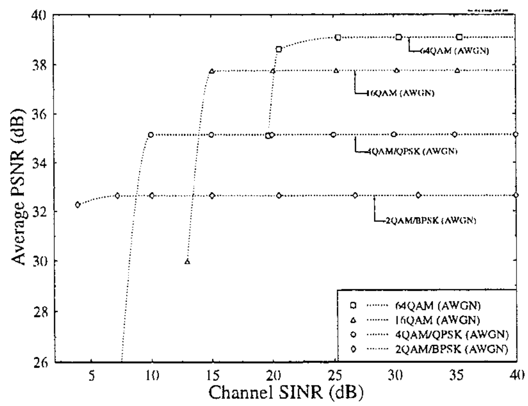

Figure 5: Decoded video PSNR versus channel SNR performance for transmissions over AWGN channels using BPSK, QPSK, 16QAM, 64QAM

5 Acknowledgement

The financial support of the EPSRC, UK in the framework of the contract GR/K74043 is gratefully acknowledged.

References

[1] W. C. Y. Lee, "Estimate of channel capacity in rayleigh fading environment," *IEEE Trans. on Vechicular Technology*, vol. 39, pp. 187–189, Aug 1990.

[2] C. C. Lee and R. Steele, "Signal-to-interference calculations for modern TDMA cellular communication systems," *IEEE Proc.Communication*, vol. 142, pp. 21–30, Feb 1995.

[3] R. Steele, ed., *Mobile Radio Communications*. IEEE Press-Pentech Press, 1992.

[4] W. Webb and L. Hanzo, *Modern Quadrature Amplitude Modulation: Principles and Applications for Wireless Communications*. IEEE Press-Pentech Press, 1994.

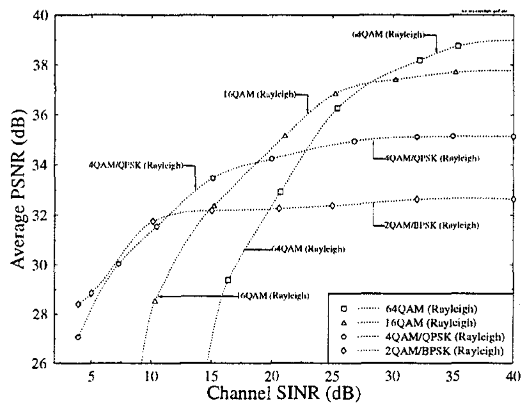

Figure 6: Decoded video PSNR versus channel SNR performance for transmissions over Rayleigh channels using BPSK, QPSK, 16QAM, 64QAM

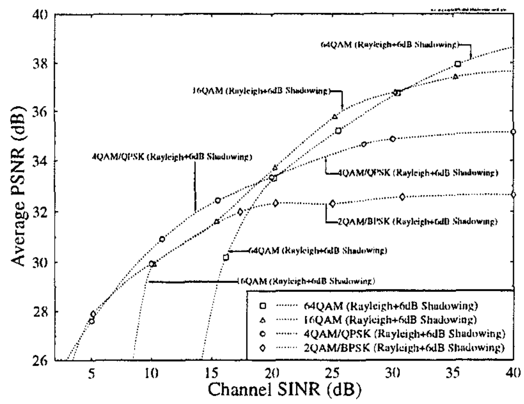

Figure 7: Decoded video PSNR versus channel SNR performance for transmissions over Rayleigh channels with 6dB Shadow fading using BPSK, QPSK, 16QAM, 64QAM

[5] L. Hanzo and J. Streit, "Adaptive low-rate wireless videophone systems," *IEEE Tr. on Video Technology*, Aug 1995.

[6] M. Khansari, A. Jalali, E. Dubois, and P. Mermelstein, "Low bit-rate video transmission over fading channels for wireless microcellular systems," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 6, pp. 1–11, February 1996.

[7] N. Färber, E. Steinbach, and B. Girod, "Robust H.263 video transmission over wireless channels," in *Proc. of International Picture Coding Symposium (PCS)*, (Melborne, Australia), pp. 575–578, March 1996.

[8] ITU-T, *Draft Recommendation H.263: Video coding for low bitrate communication.* Due to be approved 1995/96.

[9] M. W. Whybray and W. Ellis, "H.263 - video coding recommendation for PSTN videophone and multimedia," in *IEE Colloquium (Digest)*, pp. 6/1–6/9, IEE, England, Jun 1995.