Unequal protection using adaptive burst profile selection for WiMAX video streaming

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It is proposed that in a compact urban region fixed WiMAX (IEEE 802.16d) burst profiles can be adaptively selected according to the picture type of packets from an arriving encoded video stream. Because additional protection of anchor picture packets reduces the data rate, an algorithm dynamically selects less favourable burst profiles for less important packets. Under the stringent Stanford University Interim channel model, this simple scheme achieves as much as 10 dB gain in video quality at the receiver.

Introduction: Fixed WiMAX, IEEE 802.16-2004 or IEEE 802.16d [1] provides several non-line-of-sight (NLOS) modulation modes, namely BPSQ, QPSK, 16QAM and 64QAM, with various error coding rates for distances between 2 and 4 km. Each of these data burst profiles may be supported within a single frame. This Letter considers the possibility of a simple but effective scheme offering unequal protection (UP) of video according to picture type. By monitoring the input video bitrate, a burst profile is selected that offers a lower rate than the arrival rate to more important anchor picture packets. If intra-coded (I) picture data is protected then the less important P- and B-picture data rates must compensate, which occurs through selection of one or more burst profiles offering higher data rates. In the scheme, the allocation depends on the WiMAX congestion level indicated by transmit buffer fullness. For example, low buffer fullness may allow some P-picture packets to be protected while high buffer fullness requires some P-picture packets to be allocated to a still higher data rate. The public nature of WiMAX, in which a video stream must coexist with other traffic means that the UP system cannot be too elaborate. However, in justification of UP, our experiments have determined up to 10 dB improvement in received video quality for moderate SNR using the Stanford University Interim (SUI) channel model [2], used with the NIST WiMAX simulation module [3] for the well-known ns-2 (v. 2.31) simulator.

Methodology: In the Standard (IEEE 802.16d) there are seven burst profiles [4] (with the most robust profile 1 reserved for burst mapping data), with the change of modulation and coding rate achieved by puncturing on an inner non-recursive convolution code (with symbol-level protection from a fixed outer Reed Solomon code).

The input video rate is monitored through a linear predictive filter over 50 groups of pictures (GOPs). This moving average acts as an estimate of an appropriate burst profile, M, to fulfil the current rate. Upon determination of M, the profile $M-1$ is invariably selected for all I-picture packets, as profile $M-1$ gives improved error protection at a cost of a lower sending rate. Relative allocation of P- and B-picture data to the different burst profiles is now decided by the normalised buffer fullness, B, where 1 signifies a full buffer. Assume an available capacity index (ACI) initially set to 1 within a range [0, 1]. In general, ACI is decreased with an increase in B (and vice versa) and to avoid excessive fluctuations in the burst profile selection policy, changes to the ACI are made only if B either exceeds a high threshold (set to 0.8 in this Letter) or drops below a low threshold (0.2 herein). If B falls below the low threshold, implying that there is buffer capacity to absorb sending at a slower but more robust rate, ACI is additively increased by α (set to 0.05 herein), which has the effect of increasing the number of packets sent at a lower rate. If B rises above the high threshold, implying that buffer capacity is reducing, then ACI is multiplicatively reduced by a factor β (1.25 herein), which correspondingly increases the sending rate to avoid packet loss from buffer overflow.

Detailed control is determined by dividing the ACI range into four evenly-spaced zones. Consider if ACI falls within the smallest zone [0, 0.25), then all B-picture packets are sent at a higher data rata, $M+1$, i.e. a less robust burst profile, and even some P-picture packets are transmitted in this way. In fact, the ratio of P-picture packets transmitted using the higher profile should decrease linearly with an increase of ACI, because the buffer capacity is then greater and thus it is possible to send packets at a lower, more robust rate. To achieve this (refer to the pseudo-code in Fig. 1), the normalised offset of ACI within a zone, F, is first calculated. Set the zone indicator $D = \text{ceil (ACI} \times 4)$ and then $F = \text{ACI} \times 4 - \text{D} + 1$. (The operator ceil (Y) rounds the value of Y to the nearest integer greater than or equal to Y.) For example, if ACI = 0.125 and thus falls midway within the range of the zone [0, 0.25) then F is set to 0.5. F would also be set to 0.5 if ACI fell midway in value within the range of one of the other zones. F is now compared with a uniformly distributed random variable $R \in [0, 1]$. Finally, a P-frame packet will be transmitted using the profile $M+1$ if $R > F$ or profile M is selected otherwise. The reason for the comparison is to ensure a fair long-term distribution of packet allocation between profiles $M+1$ and M.

```
D=ceil (ACI × 4 );
F=ACI × 4 − N + 1;
R=rand ();
Select Case N
 Case D=1
     B_pic→M+1; P_pic→(R>F)?M + 1:M ;
Case D=2
     B_pic→(R>F)?M+1:M; P_pic→ M ;
Case D=3
     B_pic→M; P_pic→(R>F)?M:(M−1) ;
Case D=4
     B_pic→(R>F)?M:(M−1); P_pic→M−1 ;
End
```

Fig. 1 *Algorithm for B- and P-picture packet selection of burst profile*

As the ACI's value rises into the next zone, [0.25, 0.5), indicating that the buffer is becoming less full, then it becomes possible to send some B-picture packets at the rate given by burst profile M. As the buffer empties out and the ACI is in the range [0.5, 0.75) then some P-picture packets are offered protection by the $M-1$ burst profile and so on, according to Fig. 1.

For this Letter's example, SUI channel two was selected out of six empirical channels designed to cover terrain in the USA. SUI-2 models a flat terrain with light tree density and low Doppler spread. The cell radius is assumed to be 6.4 km. Antenna height at the BS is 15.24 m, beamwidth 120° and at the SS is 3.048 m, beamwidth 50°, with vertical polarisation only. The settings for a 7 MHz licensed bandwidth were selected from the Standard, for which we chose to simulate the 5 ms frame duration. Appropriately to SUI-2, a cyclic prefix of 1/32 was subsequently selected in simulations for a relatively limited delay spread of 0.2 μs.

Experiments were carried out with input from three SIF-sized, 25 frame/s MPEG-2 video clips, all encoded at a variable bit-rate at a target rate of 2.5 Mbit/s for 40 s with a GOP structure of $N = 12$ and $M = 3$. 'News' contains some motion, showing a newsreader and changing backdrop. 'Friends', an excerpt from the well-known situational comedy, is more complex, with scene cuts and moderate motion. Finally, 'Football' contains considerable motion and is of higher complexity.

Results: Fig. 2 compares the bit error rate performance of different burst profiles under the SUI-2 channel model with the orthogonal frequency division multiplexing cyclic prefix set to 1/32. The Figure clearly shows the superiority of lower profiles in terms of error robustness. Fig. 3 shows packet loss rates for the 'News' clip under the SUI-2 channel model at several different average SNR settings (Lower SNRs result under this model result in unacceptable video quality and are not presented.) Owing to the adaptive profile scheme, not only does the total packet loss rate considerably reduce but also the proportion of lost B-picture packets increases, resulting in preservation of the vital I-picture packets.

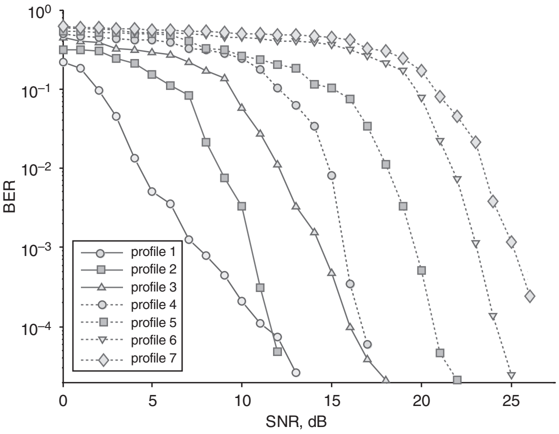

Fig. 2 *Bit error rate performance of differing burst profiles under SUI-2 channel model*

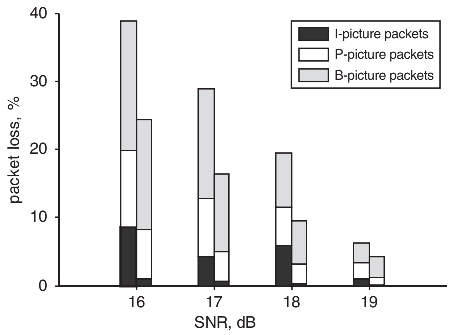

Fig. 3 *Comparison of average packet loss rates for (left-hand) non-adaptive burst profile selection; and (right-hand) adaptive selection for 'News' clip under SUI-2 channel model*

Fig. 4 compares the video quality (luminance PSNR) between non-adaptive and adaptive selection of profiles with UP. At 16 dB, with non-adaptation all clips would be unwatchable, while the UP scheme quality verges on the acceptable by virtue of an almost 10 dB improvement. At an SNR of 17 dB, the video quality is good when UP is applied but is poor otherwise. As might be expected, when SNR improves the relative advantage of UP declines. However, UP at 19 dB SNR still contributes to several dB improvement in video quality.

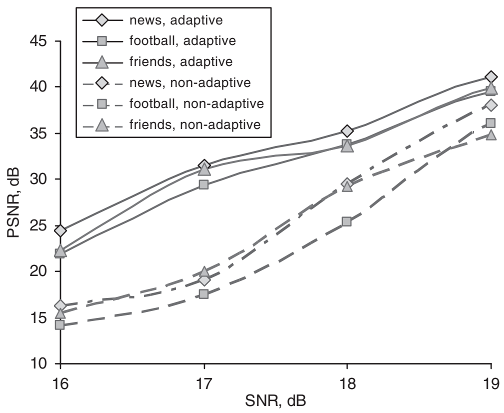

Fig. 4 *Comparison of video quality for three video clips of increasing complexity using adaptive and non-adaptive burst profile selection under SUI-2 channel model*

Conclusions: Applying an additive increase and multiplicative decrease algorithm to selection of burst profile, according to arriving packet picture type importance, results in many dB of gain in delivered video quality. In principle, the algorithm can be transferred to Mobile WiMAX (IEEE 802.16e), though currently it is Fixed WiMax that has been deployed in the UK.

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