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Video quality based link adaptation for low latency video transmission over WLANs

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Abstract: Wireless Local Area Networks (WLANs) such as IEEE 802.11a/g and Hiperlan/2 utilise numerous transmission modes, each providing different throughputs and reliability levels. Many link adaptation algorithms proposed in the literature either maximise the error-free data throughput based on channel conditions or are based on the number of failed transmissions. However, these algorithms do not take into account the content of the data stream and strongly rely on the use of Automatic Repeat Requests (ARQs). Low latency video applications such as real-time video transmission may require no retransmission, or only a limited number of retransmissions. Moreover, completely error-free communication is not essential, especially if robust video compression techniques are applied. In such scenarios, improved decoded video quality can be obtained with a video stream transmitted at a higher bit rate using a higher link speed but with some degree of transmission error, rather than an error-free video stream at a lower bit rate using a lower link speed. In this work, we investigate a link adaptation scheme that improves the Quality of Service (QoS) for video transmission, based on the overall received video quality (Peak Signal to Noise Ratio, PSNR), rather than by maximising the error-free throughput. We also study a practical link adaptation approach that uses PER thresholds at the PHY layer. An empirical study showed that thresholds for switching from one mode to another are much lower (almost error free) than those currently used by throughput based schemes. We show that traditional link adaptation strategies are not appropriate for real-time video transmission with no retransmission. Simulation results using the H.264 video compression standard over IEEE 802.11a are presented.

Key words: Link adaptation, Wireless LAN, Video quality, Peak Signal to Noise Ratio (PSNR), Packet Error Rate (PER)
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INTRODUCTION

Low latency video transmission is very demanding in terms of the performance of all layers in the protocol stack. Over the last decade, research has focused on enhancements of each individual layer without considering cross-layer interactions. Adapting video coding to the channel/network conditions and technologies (and vice versa) (Girod *et al*., 2002) via the cross-layer exchange of information has only recently been investigated. van der Schaar *et al*.(2003) developed a cross-layer optimisation scheme that combines application layer FEC, adaptive MAC retransmissions and adaptive video packet size for video transmission over an IEEE 802.11b network. van der Schaar and Shankar (2005) discussed the challenges and principles of a cross-layer optimised multimedia transmission. The choice of optimal modulation using Application/MAC/PHY interactions for video over an IEEE 802.11b network was discussed as well as the choice of modulation scheme for optimal power consumption. Moreover, the authors stressed that an optimal solution for throughput may not be appropriate for multimedia transmission. Setton *et al*.(2005) detailed the basis of a cross-layer framework where packet size is dynamically adapted for a given link layer and channel condition. For a given packet length, the proposed scheme optimises the link layer parameters, such as the constellation and the symbol rate, in order to optimise the throughput. However, apart from (Setton *et al*., 2005) and (van der Schaar and Shankar, 2005), adaptive link and MAC layer techniques, such as coding rate and modulation scheme, have rarely been considered in the design of cross-layer systems.

When considering the PHY layer of COFDM-based WLANs at 2.4 GHz and 5 GHz, such as IEEE 802.11g (IEEE 802.11g, 2001) and IEEE 802.11a (IEEE 802.11a, 1999) respectively, numerous modes are available, each providing different throughput and reliability levels. Table 1 summarizes the different operating modes available for the IEEE 802.11a/g PHY layer. They range from BPSK 1/2 rate (Mode 1), which provides a nominal bit rate of 6 Mbps to 64 QAM 3/4 rate (Mode 7), with a nominal bit rate of 54 Mbps. The BPSK 1/2 rate mode provides a more reliable transmission link than the 64 QAM 3/4 rate mode for a given receive power. Fig.1 shows the PER performance of the 7 main modes of IEEE 802.11a/g with a PHY packet length of 376 bytes. A received Carrier to Noise Ratio (C/N) of 17 dB provides error free transmission if Mode 1 is used, whereas Mode 7 presents a *PER* of 0.8 at this C/N value. The choice of the operating mode (link speed) is therefore crucial to system performance.

Table 1 Mode dependent parameters for IEEE 802.11a/g

Mode	Modulation	Coding rate	Nominal bit rate (Mbps)	Ratio/ Mode 1
1	BPSK	1/2	6	1
2	BPSK	3/4	9	3/2
3	QPSK	1/2	12	2
4	QPSK	3/4	18	3
5	16 QAM	1/2	24	4
6	16 QAM	3/4	36	6
7	64 QAM	3/4	54	9

Due to the numerous operating modes available at the PHY layer, each with their own unique characteristics, the ability of the system to adapt to the fluctuations of the environment (mobility, interference and congestion) is critical to ensure overall performance optimisation. Many parameters can be varied at the MAC and PHY levels; examples include the maximum number of MAC level retries, the packet size, the mode (modulation and coding rate) and the type of antenna. Neither IEEE 802.11 (IEEE 802.11 MAC, 1999) nor IEEE 802.11a/g specifies an algorithm for dynamic rate switching. The IEEE 802.11 MAC only defines rules for the mode selection of the management frames and declares dynamic rate selection beyond the scope of the specifications (Haratcherev *et al*., 2002; Haratcherev and Langendoen, 2004; IEEE 802.11 MAC, 1999). It is therefore up to manufacturers to implement their own algorithms.

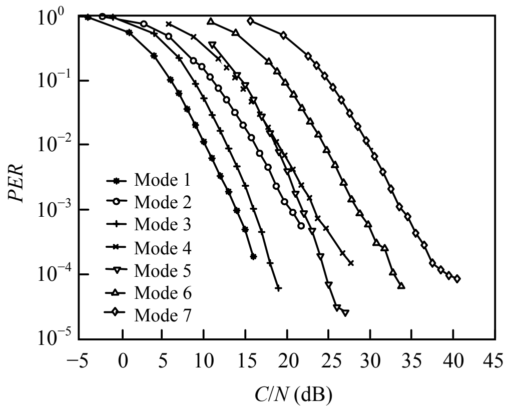

Fig.1 IEEE 802.11a/g PER performance of ETSI BRAN Channel A with 376 bytes per packet

The link adaptation mechanism enables the system to adapt the transmission mode according to a quality metric, with common examples including throughput, PER and delay. The ability to change modes is used to control the reliability of the system and provides the radio with the capability to adapt to a better configuration to improve the QoS of the transmission. Common link adaptation algorithms have focused on maximising the error-free throughput at the higher application layer (Ferré *et al*., 2003). These do not take into account the nature of the application data. Moreover, they strongly rely on the use of retransmission and therefore do not take into account transmission delays. Real-time video applications are time-bounded and require a strictly low latency transmission. In addition, completely error-free communication is not essential, especially if robust video compression techniques are applied. In such scenarios, improved decoded video quality can be obtained with a video stream transmitted at a higher bit rate (using a higher mode), but with some degree of transmission error, rather than an error free video stream at a lower bit rate (using a lower mode), as long as the level of errors allows the codec to lie within its operating range. Existing algorithms are not designed for low latency video sequences and are generally not suitable for such applications.

This work investigates heuristic link adaptation mechanisms appropriate for the transmission of real-time video. Simulations are performed in order to evaluate the viability of such mechanisms as well as to present a specific algorithm designed to optimise the perceptual video quality at the receiver via the exchange of information between the MAC and application layers. This paper is organised as follows. In Section 2, existing link adaptation algorithms are reviewed. A video quality based scheme is presented in Section 3. Comparison with existing algorithms is carried out in Section 4. Implementation issues are discussed in Section 5. Finally, Section 6 concludes the paper.

EXISTING LINK ADAPTATION ALGORITHMS

In this section, existing link (or rate) adaptation algorithms are discussed. A simple way to adapt the rate is to collect and maintain statistics on the transmitted data. Such schemes are classified as Statistics-based Automatic Rate Control algorithms (Haratcherev and Langendoen, 2004). Packet collision is not considered here and packet loss (or missing ACKs) due to channel distortion and additive white Gaussian noise. This assumption is made because a collision is representative of the network status (congestion), rather than the PHY layer conditions. Down-scaling the modes would not improve the QoS of the transmission if two stations collide. The rate adaptation algorithm should not therefore be influenced by collision and congestion statistics.

Packet Error Rate (PER)-based Control: In this algorithm, the PER of the transmitted data is used to select the mode. The PER can be determined by counting the ACKs of the IEEE 802.11 MAC frame received at the transmitter during a sliding decision window (a missing ACK means that the corresponding packet has not been correctly received). If the PER exceeds a certain threshold, then the current mode is switched to a lower mode. Up-scaling is performed if the PER falls below a second threshold and the system then switches to a higher mode. This algorithm was not initially designed for video transmission and instead it optimises the PER for an improved throughput.

Retry-based Control: In these algorithms, the decision metric used is the number of failed ARQs. If a transmission is unsuccessful after a certain number of retries N_{fail}, the mode is down-scaled. A simple version would implement up-scaling after a certain number of successful contiguous transmissions, N_{success}. Up-scaling can also be implemented with a PER-based control scheme using a decision window. This was developed under the name of AutoRate Fall Back (ARF) (van der Vegt, 2002; Manshaei *et al*., 2004) and designed to optimise the application throughput (Lacage *et al*., 2004).

SNR-based Control: In this method, the Carrier to Noise Ratio (C/N) or the Signal to Noise Ratio (SNR), which is directly linked to the PER, is used to determine the transmission rate. The throughput at the PHY layer can be expressed as a function of the PER and can be estimated as in (Doufexi *et al*., 2001; 2002; Lin *et al*., 2000) using:

$$Throughput=R\times(1-PER), \tag{1}$$

where R is the nominal bit rate of the link (Table 1). Link adaptation based on SNR-throughput is presented in Fig.2 for a MAC packet length of 376 bytes for the 7 operating modes of the IEEE 802.11a/g PHY layer. For such algorithm, the mode decision is as follows:

$$Mode_{\mathrm{T}}(C/N)=m\in M,$$

with

$$Throughput(m,C/N)=\max_{i\in M}(Throughput(i,C/N)),$$

with $Mode_{\mathrm{T}}$ being the winning mode and $M=\{1,2,3,4,5,6,7\}$. The crossing points of the curves define the switching points (in terms of C/N) at which the system should up-scale or down-scale.

A simple SNR-based algorithm would search in look-up tables (made available at the MAC) for the best throughput for a given C/N. These tables could theoretically be generated prior to any transmission with different packet lengths for all the different modes, C/Ns and different channel conditions. It should be noted that the formula assumes that ARQ is used for retransmitting packets until the packet is received correctly, or the maximum retry count is reached (whichever comes first). Data are therefore received error-free and this method does not take into account the nature of the data or the delays incurred. The C/N switching levels can be converted into equivalent PHY PER thresholds in the adjacent modes, defining therefore an acceptable level of channel error before changing mode. This then defines a hybrid throughput-based algorithm with the PHY PER being used as a metric.

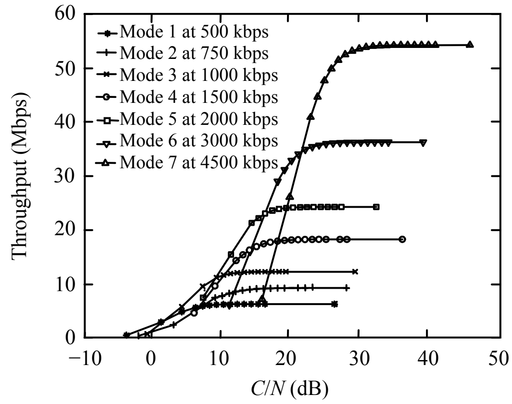

Fig.2 Link adaptation based on throughput, IEEE 802.11a/g, 376 bytes per packet

Other Algorithms: Other rate adaptation algorithms combining different techniques have been presented in the literature. Qiao *et al*.(2003) developed a power-based control algorithm, the MiSer (Minimum Energy Transmission Strategy) scheme, which minimises the communication energy consumption in an IEEE 802.11a PHY layer extension (IEEE 802.11h) by combining Transmit Power Control (TPC) with PHY rate adaptation. Holland *et al*.(2001) designed a Receiver-Based AutoRate (R-BAR) protocol in order to optimise the application throughput, where the choice of transmitting rate is made at the receiver based on its own stored statistics (Lacage *et al*., 2004; Manshaei *et al*., 2004). The information on the chosen rate is then transfered back to the transmitter via the CTS frame of the handshaking RTS/CTS exchange. Haratcherev *et al*.(2004; 2005) developed a hybrid automatic rate controller, combining a throughput-based rate controller with an SNR-based approach. By dynamically adjusting RSSI-look up tables, the algorithm selects the more appropriate rate. This scheme aims at improving throughput and reducing delay and PER, and can adjust the transmitted video rate. Variations of the above algorithms can be found in many papers, among which (Ci and Sharif, 2002; Yuen *et al*., 2002; Qiao and Choi, 2002; Hoffman *et al*., 2005) are notable.

Almost all the reported link adaptation algorithms are designed to provide throughput and/or PER performance improvements (Zhu *et al*., 2004; van der Schaar and Shankar, 2005) and/or to reduce power consumption. They do not take into account the low delay requirements of the application. Their reliance on retransmission does not permit their implementation for applications requiring time bounded delay. Moreover, in the case of multimedia transmission, they do not optimise the perceived video quality (van der Schaar and Shankar, 2005).

LINK ADAPTATION BASED ON VIDEO QUALITY

Scenarios

In this work, H.264 (H264 Software, 2005) video transmission over an IEEE 802.11a/g based WLAN is investigated. A unicast link with an RTP/UDP/IP protocol stack is considered on top of the IEEE 802.11 MAC layer. Traditionally, this PHY technology provides a data link for PDAs and laptops. In this paper, a relatively low bit rate of 250 kbps to 9000 kbps is used for real-time (i.e. live) video transmission. Several handheld devices share the same channel, and low latency unicast transmission is assumed to be without reliance on layer 2 (MAC) ARQ. Note, the maximum number of ARQ allowed in the MAC is variable, with 32 being commonly used by most 802.11 manufacturers. Broadcast transmission is not considered in this paper and this is left for future investigations.

Motivations

The work in this paper is motivated by the fact that previously presented algorithms do not take into account the nature of the transmitted data. Moreover, they strongly rely on retransmission and cannot be deployed for video applications requiring very low latency. They were designed to provide the highest throughput and to maximise error-free data transfer without regard for delay and retransmission. For multimedia, a strong reliance on ARQ is not desirable and completely error-free communication is not essential, especially if robust video compression techniques are applied. In such scenarios, better decoded video can be obtained with a video stream transmitted at a higher bit rate but with some degree of error, rather than an error-free video stream at a lower bit rate, as shown in Fig.3. The overall quality of the received video sequence depends on a trade-off between video bit rate and BER/PER. For a given C/N of 18 dB, Mode 1 provides error-free transmission at low video bit rates (700 kbps with a *PSNR* of 37.07 dB), whereas Mode 5 provides a transmission with a PER of 10^{-2} with a higher video bit rate (4235 kbps). However, Fig.3b shows better resolution and presents a better *PSNR* (44.85 dB) than Fig.3a (37.07 dB). Impairments due to errors are insignificant and cannot be noticed visually (Ferré *et al.*, 2003).

(a) Mode 1, 700 kbps, *PER*=0, *PSNR*=37.07 dB (b) Mode 5, 4235 kbps, *PER*=0.04, *PSNR*=44.85 dB

Fig.3 Foreman sequence, Frame 30, *C/N*=18 dB

This study is also motivated by the fact that the various operating modes of IEEE 802.11a/g WLANs support different link speeds. For example, video encoded at 10 Mbps cannot be transmitted on the lower modes, which allows only 6, 9 and 12 Mbps at the PHY layer. Limiting the transmission to the higher modes is undesirable since it reduces reliability and coverage of the transmission. It is therefore preferable to adapt the video bit rate depending on the transmission link.

Video rate, WLAN mode and packet length

At a given bit rate, the received video quality depends highly on the PER. The PER performance of IEEE 802.11a/g is PHY packet length dependent. For a given mode, a larger packet is more likely to be corrupted. Thus, one way of modifying the perceptual quality is to vary the packet length at the PHY layer at a given operating mode. However, changing the mode instead of the PHY packet size has a more dramatic effect on the PER performance at a given C/N level, as shown in Fig.4. Therefore, to vary the PER, it is proposed to switch between operating modes rather than to vary packet lengths. The main idea of this investigation is that each mode will carry one video bit rate and will therefore support better video quality if the PER is sufficiently low. Whenever the MAC layer adapts its link speed, the application layer also adapts its encoding video bit rate.

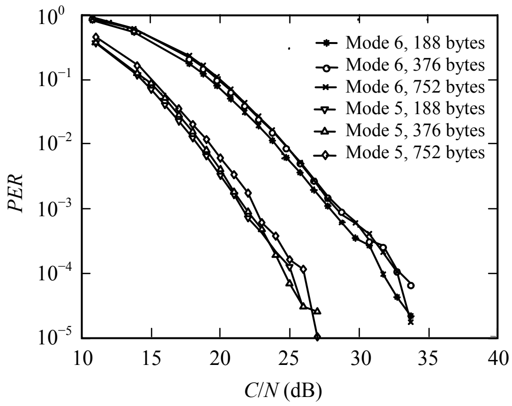

Fig.4 Influence of packet sizes and modes in PER performance

For the simulations reported in the following sections, two main assumptions apply:

(1) The ratios between the bit rates *BR* carried on each mode follow the ratios of the nominal bit rates available at the PHY layer for each mode as shown in Table 1.

(2) The maximum size of the video packet generated at the encoder is not modified. A non adaptive packet-size assumption is the most realistic case for such systems.

Simulation setup

All results were obtained using error patterns generated by our own fully compliant and validated (by performing the waveform tests of the standard and by comparing PER/BER curves) IEEE 802.11a simulator (Doufexi *et al.*, 2002; Khun-Jush *et al.*, 2002), which supports all the standardised operating modes and variable PHY layer packet lengths. The channel model conforms to ETSI-BRAN channel A specifications (Non Line-of-Sight office environment), with an rms delay spread of 50 ns.

For our simulations, we have encoded the Foreman sequence with 300 video frames (with an Instantaneous Decoder Refresh (IDR) frame every 12 frames) at CIF resolution (352×288 pixels) and at a frame rate of 30 Hz using the H.264 reference software (Version 10.1) (H264 Software). At the encoder, the RTP format and a fixed maximum NAL unit size were chosen. Generated slices are encapsulated into UDP/IP packets and passed to the IEEE 802.11 MAC layer. At the decoder, missing slices are concealed using the advanced error concealment algorithm of the reference software (Wang *et al*., 2002). For a range of C/N power levels, the video sequence is sent 100 times in order to create statistical results. The *PSNR* values of the decoded sequences are then averaged. The 100 video sequences are generated using different initialisation points in the error pattern file. We assume that the sequence and picture parameter sets, which contain critical video information, are transmitted error-free using TCP.

Empirical study

To determine the chosen mode, the following procedure is applied:

(1) For each mode, the *PSNR* curve of the received sequence is calculated over a large range of *C/N* levels.

(2) For each value of *C/N*, the mode that optimises the *PSNR* is chosen:

$$Mode_{vq}(C/N)=m\in M,$$

with

$$PSNR(m,C/N)=\max_{i\in M}(PSNR(i,C/N)),$$

where $Mode_{vq}$ is the winning mode and M={1,2,3,4, 5,6,7}.

(3) The crossing points of the *PSNR* curves define the switching points in term of the *C/N* value at which the system operating mode changes.

Fig.5 shows the *PSNR* curves of the Foreman sequence for different *C/N* levels, with *BR*=500 kbps and with a maximum video packet length of 376 bytes, and with no MAC retransmission (no ARQ). Following the rule of Table 1, Modes 1~7 carry video encoded at 500, 750, 1000, 1500, 2000, 3000 and 4500 kbps respectively. As the *C/N* increases, changing to higher modes with a higher bit rate provides a better *PSNR*. For example, from Fig.1, a higher *PSNR* is obtained with Mode 5 at a *C/N* of 22 dB, than with Mode 3. Mode 5 operates with some errors, whereas Mode 3 can operate error-free as shown in Fig.1, but delivers a lower *PSNR*. A natural and empirical switching point would therefore be based on *PSNR*; effectively selecting the mode with the highest *PSNR* at any time and for any *C/N* level. Note that Mode 2 (BPSK 3/4 rate) and Mode 4 (QPSK 3/4 rate) will never be chosen for transmission, because these modes have worse PER performance than Modes 3 and 5 respectively, and transmit using lower video bit rates.

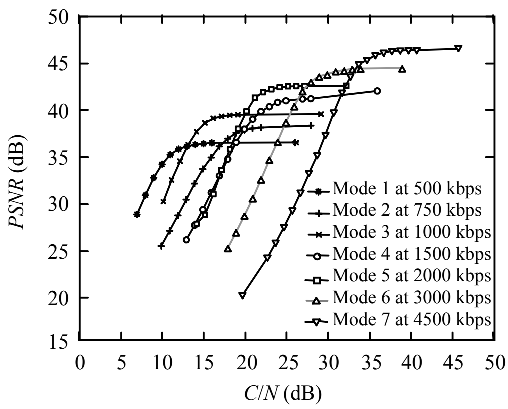

Fig.5 Video quality algorithm, Foreman, no ARQ

It should be noted that switching on *PSNR* is not a practical method, firstly because the video quality is only perceived at the receiver. The *PSNR* calculation requires the original sequence in order to compute the Mean Square Error (MSE). In a realistic transmission, the receiver does not have access to the original sequence and cannot compute the received *PSNR*. Also, the transmitter does not have knowledge of the received quality. Secondly, the generation of curves similar to Fig.5 as look-up tables at the transmitter is not possible since these curves depend on the content, the bit rate, the packet length, and the concealment techniques employed.

Practical switching scheme

Since PSNR and PER are closely linked, a more practical approach would be to employ the PER at the PHY layer as the decision metric. The transmitter can have knowledge of the C/N and the PER either by using the feedback channel, or by using look-up tables, or by simply checking the number of acknowledged packets (received ACK frames). The following procedure applies for the choice of the operating mode:

(1) $PER(m,C/N)\leq PER_u(m)$: upscale, if $m\neq 7$;

(2) $PER_d(m)\leq PER(m,C/N)$: downscale, if $m\neq 1$;

(3) $PER_d(m)\leq PER(m,C/N)\leq PER_u(m)$: stay in the current mode.

Where $PER(m,C/N)$ defines the PHY PER with the current operating mode m at a given C/N level, and $PER_u(m)$ and $PER_d(m)$ define the PER thresholds to up-scale to a higher mode and down-scale to a lower mode respectively. The PER thresholds can be obtained by converting the C/N values of the crossing points into PER values using the curves of Fig.1.

COMPARISON OF ALGORITHMS

In this section, the presented algorithm is compared with two existing link adaptation algorithms commonly implemented in IEEE 802.11 cards. The SNR (C/N) and Throughput-based algorithm, extensively uses the MAC layer ARQ (Fig.2 shows this algorithm applied with a PHY packet size of 376 bytes). The PER-based algorithm is also studied, with a PHY PER threshold of 10% being used for down-scaling.

PHY PER thresholds comparison

Table 2 compares the PHY PER thresholds. Fig.6 and Fig.7 give a graphical view of the different PHY PER threshold points. In Fig.7, the x-coordinate defines the PHY PER level at which switching occurs. The y-coordinate defines the current mode.

Table 2 PHY PER thresholds comparison

(a) PER Thresholds—Up Scaling

From Mode	1 to 3	3 to 5	5 to 6	6 to 7
VQ	1.82e-03	2.78e-05	2.12e-05	8.37e-05
Throughput	5.03e-01	8.33e-02	5.08e-02	4.75e-02
10%	2.11e-02	2.85e-03	4.90e-03	7.51e-03

(b) PER Thresholds—Down Scaling

From Mode	7 to 6	6 to 5	5 to 3	3 to 1
VQ	1.39e-03	1.99e-03	4.09e-03	8.99e-03
Throughput	3.43e-01	3.07e-01	6.45e-01	7.05e-01
10%	0.1	0.1	0.1	0.1

By comparing the PHY PERs, up-scaling and down-scaling are seen to occur at high and very high PHY PERs when the 10% PER-based approach and the throughput-based approach are used respectively. Switches occur at lower PHY PERs for the video quality based algorithm as shown in Fig.7. These figures show that a video application which is constrained to use no retransmission, would up-scale from Mode 3 to Mode 5 when the PHY PER on Mode 3 reaches 8.33×10^{-2} (Throughput-based) and 2.85×10^{-3} (10% PER-based).

The empirical study showed that switching should occur when the PHY PER on Mode 3 reaches 2.78×10^{-5}. On the other hand, down-scaling from Mode 5 to Mode 3 occurs when the PHY PER reaches 6.45×10^{-1} and 0.1 for the throughput and 10% PER-based schemes respectively. The studies also showed that down-scaling should occur at a PHY PER of 4.09×10^{-3} for an application using MAC ARQ. It can be seen that the algorithm based on video

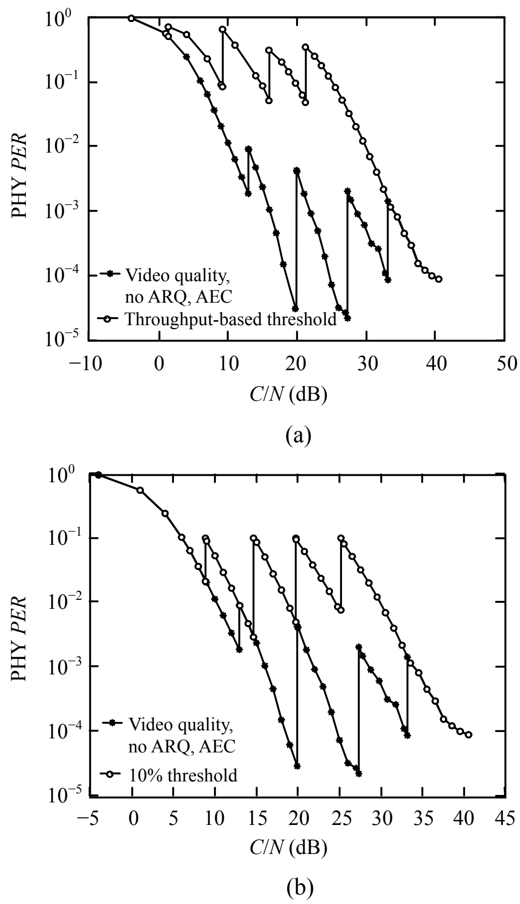

Fig.6 Link adaptation PER comparison. (a) Throughput-based comparison; (b) 10% PER-based comparison

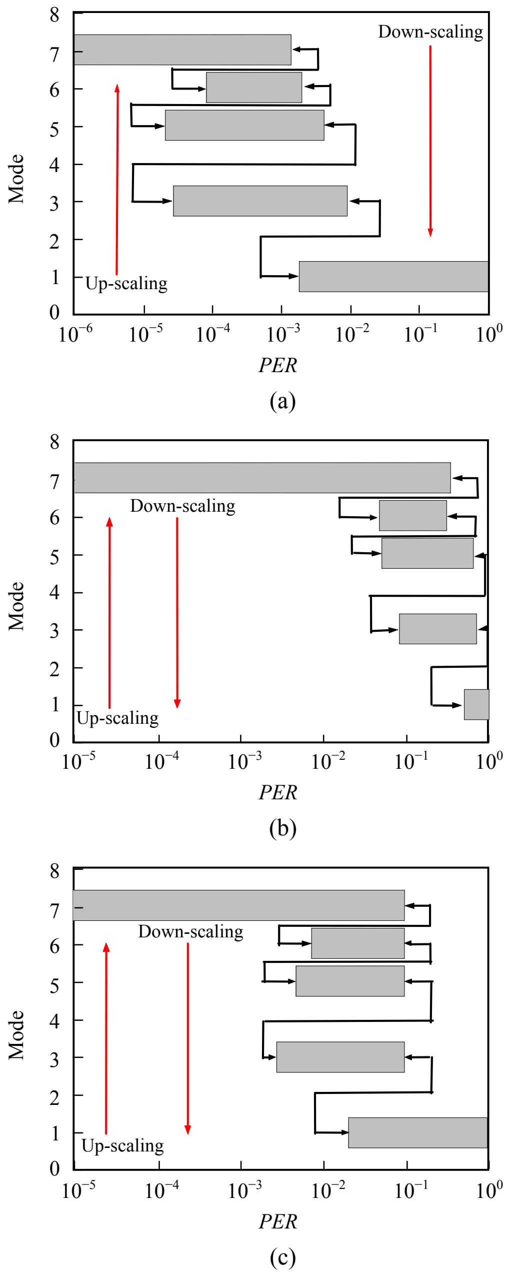

Fig.7 Switching points comparison, Foreman. (a) Video quality-based (no ARQ); (b) Throughput-based; (c) 10% PHY PER-based

quality operates at lower *PER* than the throughput-based and the 10% PER-based algorithms. These two mechanisms were not designed for such applications, and their thresholds are independent of the application or data type.

PSNR comparison

If one considers the case of unicast video transmission with a limited number of retransmissions, the driver of the card or access point would apply its original algorithm with its pre-built PER thresholds as explained in the previous section. These schemes are developed for general data, and not for real-time video transmission. Fig.8 compares the *PSNR* of the received sequence for the 10% PER-based algorithm with the empirical study conducted optimising the video quality with no retransmission, along with picture snapshots.

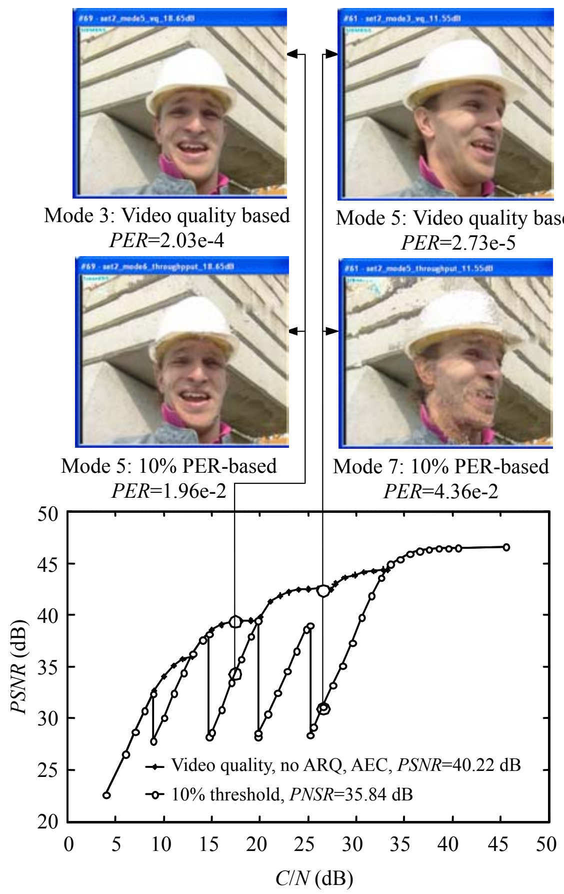

Fig.8 Algorithm *PSNR* comparison

For the two schemes, for a high *C*/*N*, Mode 7 is chosen to provide the highest video quality. However, as the receive power decreases and the PHY *PER* increases, the 10% PER-based algorithm remains on this mode, whereas the proposed algorithm switches earlier (at a lower *PER*) to a lower mode to maintain the video quality.

The results of Fig.8 show that a 4 dB gain in average *PSNR* is possible when the PER thresholds are well chosen. Because the thresholds of the throughput-based algorithm are even higher than the 10% PER scheme, performance of the throughput-based algorithm is therefore worse. Clearly, the high PHY PER thresholds proposed by the throughput and the 10% PER-based schemes do not allow good video quality reconstruction at the decoder. Lowering the PER thresholds puts the switching points in the operating range of the video codec for real-time applications that require low latency (and therefore use a low number of ARQs). The choice of these thresholds is therefore critical. Algorithms currently implemented in PC cards and APs are not suitable for real-time video applications with a limited number of retransmission.

IMPLEMENTATION ISSUES

The proposed approach uses PHY PER thresholds that have been shown to be much lower than traditional mechanisms. Results are shown in an empirical manner, stressing the need for an appropriate algorithm designed to optimise the received video quality rather than the throughput. The derivation of rigorous *PER* thresholds with an optimising algorithm is not in the scope of this paper and is left for future investigations. In the case of a low latency system, per-packet adaptation is possible since feedback information is available for each packet (Lacage *et al*., 2004). This is however neither realistic nor necessary for video transmission. The estimation of *PER* is critical. It is either estimated at the transmitter or alternatively at the receiver with the information being sent back to the transmitter. One solution is the use of C/N-based look-up tables. The main drawback of this method is the reliability of the *C*/*N* value and the variation of *PER* with channel type (Doufexi *et al*., 2001). Another solution is to estimate the *PER* through a sliding decision window. For example, acknowledged packets at the transmitter are counted during this decision window and the *PER* is then computed. For a slowly changing radio channel where users are not moving, fast adaptation is not required. In this case, adapting the operating link mode at a rate of around once every few seconds is reasonable. The proposed system requires a cross-layer exchange of information between the MAC and the application layer. This could be achieved using a Cross-Layer Bus to carry information from layer to another.

CONCLUSION

In this paper, a link adaptation strategy designed for high quality H.264 video transmission over the IEEE 802.11 MAC and IEEE 802.11a/g PHY layer was investigated and characterised. Emphasis was placed on robust transmission with no (or limited) retransmission. Previous algorithms focused on maximising the error-free data throughput. This study was motivated by the fact that these algorithms do not take into account the nature of the content and the low delay requirements for time-bounded applications. Since each transmission mode allows different nominal bit rates with different reliability, the investigated algorithm transmits the video sequence at different video bit rates for each mode. Our proposed strategy optimises the overall received video quality rather than the data throughput. This requires the application and MAC layers to exchange information. A practical approach was proposed, based on PER thresholds. Empirical results showed that the throughput-based and traditional PER-based algorithms switch-down for PHY error rates greater than or equal to 0.1, whereas the proposed algorithm down-scales the mode for a *PER* of around 10^{-2}. Similarly, the throughput-based algorithms switch up for a *PER* of around 5×10^{-2}, whereas the presented scheme up-scales the operating mode for a *PER* of around 10^{-3}. Since they use inappropriate thresholds, our results showed that traditional link adaptation mechanisms deliver poor video quality when applied to a time-bounded video transmission requiring no (or limited) retransmissions. A gain of 4 dB in *PSNR* was observed when the investigated algorithm was compared to the traditional 10% PER-based algorithm. The choice of up and down-scaling thresholds is therefore very critical. Link adaptation mechanisms implemented in PC cards and access points do not adapt optimally for video transmission, while our scheme is designed for low latency video transmission without strong reliance on ARQ. The influence of various parameters, such as the number of MAC level ARQs, the content of the video sequence, the initial video bit rate (on Mode 1), the packet size, and the error resilience tools on the switching thresholds are currently under investigation.

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