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Transmission of MPEG-2 Encoded VoD Services over Wireless Access Networks using Type-II Hybrid ARQ Schemes with RCPC Codes

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ABSTRACT

In this paper, we investigate the effectiveness of applying type-II hybrid ARQ schemes to the transmission of MPEG-2 encoded video streams over fixed wireless links in broadband fixed wireless access networks (B-FWANs) for video-on-demand (VoD) services. Rate compatible punctured convolutional (RCPC) codes are used. Simulations were conducted to evaluate the overall system performance. The fixed wireless channels are modeled by a specific finite-state Markov model in conjunction with the K-factor Rician fading model. Important metrics relevant to the broadband video services are analyzed, including the error rate of the original information cells, the quality of the reconstructed video sequences, and channel throughput.

1. INTRODUCTION

1.1. Broadband Fixed Wireless Access Networks (B-FWANs)

During the past years, there has been an increasing demand for broadband services such as video on demand (VoD) and fast Internet access, etc., which require higher bandwidth both in the backbone networks as well as in the local access network. In addition, the 1996 Telecommunication De-regulation Act, which allows different service providers to compete in each other's territory to provide broadband services to potential residential and business customers, has propelled the emergence and development of promising wireless infrastructures, such as wireless access networks (WANs) and satellite networks.[1] For most of the practical and marketable broadband services, such as VoD, digital broadcast TV, tele-education, and home shopping, mobility is not a top-priority consideration. Therefore, fixed wireless access networks (FWANs), especially broadband FWANs (B-FWANs) have attracted a lot of attention.

B-FWANs, using wireless access loops connecting a fixed customer premise or terminal to the broadband network, provide an effective solution for new competitors to capture the local access market because of their fast deployment capability, cost effective infrastructure and overall low maintenance cost of the system. Currently, one promising B-FWAN candidate for broadband services to the home or business is Local Multipoint Distribution/Communication System (LMDS/LMCS). LDMS is proposed to offer two-way digital wireless services, including high quality digital video distribution and fast Internet access services, by using low power, high frequency ($28GHz$ band) radio signals over short to medium distances (1 to 3 miles depending on terrain and antenna placement).[1–3]

In this paper, we investigate the effectiveness of transmitting MPEG-2 encoded video streams of VoD services over B-FWANs using type-II hybrid automatic repeat request (ARQ) schemes in conjunction with rate compatible punctured convolutional (RCPC) codes, because RCPC codes can provide an incremental and accumulative error correction capability as the retransmission proceeds. In the rest of this section, the system architecture for providing MPEG-2 encoded VoD sequences over B-FWANs is described briefly. The concept of the type-II hybrid ARQ schemes are also described. In Section 2, the concept of RCPC codes is introduced. In Section 3, a hidden Markov model (HMM), or, a discrete finite state Markov model, is described, which is specifically designed to capture the characteristics of the high frequency fixed wireless channel in B-FWANs. The fixed wireless channel experiences Rician fading since a line-of-sight (LOS) propagation path is usually required between the transmitter and the receiver. In Section 4, the simulation system to evaluate the overall performance is described briefly. The performance results of applying type-II hybrid ARQ schemes with RCPC codes to MPEG-2 encoded video sequences over fixed wireless channels are then presented. Finally, we summarize the simulation results in Section 5.

1.2. MPEG-2 Encoded VoD Services over B-FWANs

MPEG (Motion Picture Expertise Group) is a broadband video compression standard. CATV companies are using MPEG-2 as the standard for the distribution and broadcasting of video services. Direct Broadcast Satellite (DBS) and HDTV use MPEG-2 video for direct broadcast. Digital Video Disk (DVD) has also defined in its specification that the video decoding standard would be MPEG.[4] Most likely, major broadband video services provided over B-FWANS, such as VoD, pay-per-view (PPV) and digital TV will also adopt the MPEG-2 standard.

In Figure 1, the system architecture of providing VoD services over B-FWANs is illustrated. A cellular service structure is usually adopted in B-FWAN system, i.e., the service area is divided into small service cells, and users within each cell communicate with the base stations via fixed wireless channels. Multiple base stations are connected to one central office, which functions as the gateway to the broadband network. The broadband network is assumed to be an ATM network, and a wireless ATM (WATM) infrastructure is adopted in the wireless service cells, since a variety of services will be provided over B-FWANs. For VoD services, the users have the freedom to select a video program from a large selection. When the VoD server receives a request for a certain video program, the request will be granted upon the availability of the computational and network resources. Once the request is approved, a virtual connection will be set up from the VoD server to the end user, and the MPEG-2 encoded video stream will be delivered from the VoD server to the base station in a stream of ATM cells, which will be encapsulated into WATM cells and be forwarded to the end user.

1.3. Type-II hybrid ARQ scheme

Wireless channels are time-varying and have a high bit error rate (BER). Error protection or error control is mandatory in order to guarantee quality of service (QoS). Generally, there are two basic error control strategies, which are usually adopted in wireless networks or systems: *Forward Error Correction (FEC)* and *Automatic Repeat Request (ARQ)*.

FEC schemes maintain constant throughput and time delay. However, for a non-stationary and error-prone wireless channel, a powerful error correction code must be used in the FEC scheme to guarantee a certain QoS requirement for the worst channel conditions. As a consequence, FEC schemes are associated with unnecessary overhead that reduces throughput when the channel is relatively error free. ARQ is simple and achieves reasonable throughput levels if the error rates are not very high. However, ARQ schemes result in variable delay, which may not be acceptable for real-time services.

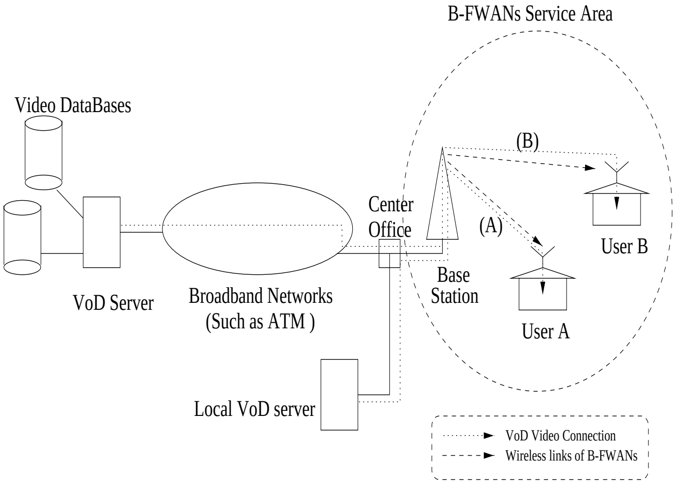

Figure 1. System architecture for VoD over B-FWANs.

In order to overcome their individual drawbacks, the combination of these two basic approaches, called hybrid ARQ schemes, have been developed over the past years.[7–11] In type-II Hybrid ARQ schemes, any packet that could not be successfully decoded is saved. Simultaneously a retransmission is requested. All received copies of a packet are used in the decoding process. (Note that it is not necessary that the same packet be retransmitted, often a parity packet is sent instead.) The above process is repeated until the packet is successfully decoded or the maximum number of allowed retransmission attempts is exhausted. In Figure 2, the procedure of how a type-II hybrid ARQ scheme works is illustrated. Di represents the original packet, and Di_1, Di_2, ... represent the retransmitted redundant packets of the information packet Di.

In some earlier work, we investigated how to effectively transport MPEG-2 encoded video streams over wireless channels in B-FWANs for broadcast or multicast services (one-to-multiple services).[5] The VoD service is a point-to-point video service that incorporates simple VCR functionality, such as fast forward, rewind, pause, etc. Therefore, the performance of each individual channel can be utilized in the implementation of the error control scheme. On the other hand, a set-top box (STB) with a certain amount of memory (client buffer) is usually installed at

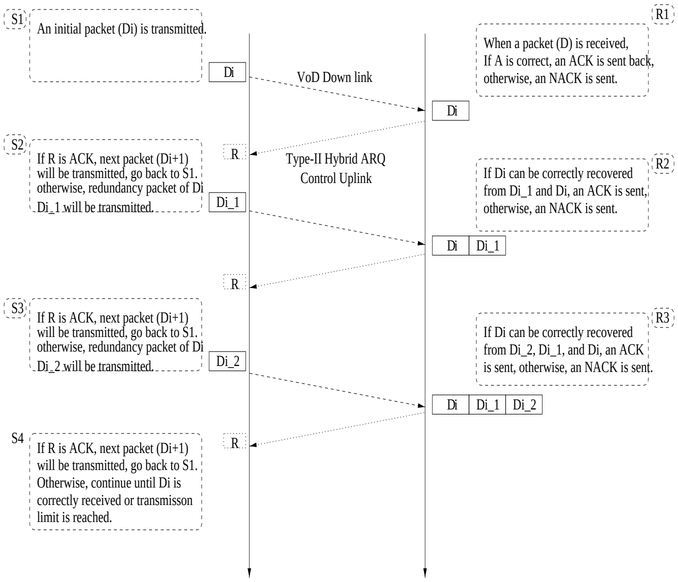

Figure 2. An illustration of the operation of a type-II hybrid ARQ scheme using RCPC codes.

the destination, and the received MPEG-2 video data is usually stored temporarily before decoding. Therefore, the real-time requirement for VoD services is not as critical as it is for real-time interactive video services. In order to use the channel resource more effectively, we investigate the efficiency of using ARQ or hybrid ARQ schemes for the transmission of MPEG-2 encoded VoD video streams over these fixed wireless channels. Earlier research showed that the conventional ARQ scheme when applied properly offered a feasible solution.[6] In this paper, we investigate the effectiveness and the performance improvement when using type-II hybrid ARQ schemes in conjunction with RCPC codes. To our knowledge, the work presented in this paper is the first time that results related to applying type-II hybrid ARQ schemes (with RCPC codes) to MPEG-2 video transmission over wireless networks are being presented.

2. RATE COMPATIBLE PUNCTURED CONVOLUTIONAL (RCPC) CODES

2.1. Convolutional Codes

For an (n, k) block code, the n output symbols of the encoder depend only on the current k input symbols. Therefore, block codes are memoryless since successive information blocks are encoded or decoded independently. Convolutional codes were first introduced by Elias.[12] They are also called trellis codes. In contrast with the block codes, trellis encoders generate code symbols utilizing a sequential finite state machine driven by the input information symbols. For an (n, k, m) convolutional code, the output of the encoder at any given time depends not only on the k input symbols at that time, but also on the m previous input symbols. Typically, n and k are small integers with $k < n$, and m (the memory order) must be made large enough to achieve low error probability. The decoders for convolutional codes are usually based on the Viterbi algorithm, which is known to be an optimal algorithm, although the decoding complexity increases exponentially with memory length.[13]

2.2. Punctured Convolutional Codes

In practice, convolutional codes of a certain desired rate are of interest for bandwidth-constrained applications, such as wireless channels. Generally, a change in coding rate will cause a fundamental change in the decoding structure. In order to solve these problems, a process of puncturing was first introduced by Cain, Clark and Geist.[11]

The puncturing process is easy and effective. By deleting certain (puncturing) code symbols from a lower-rate code, while keeping the parameter k fixed, a higher rate convolutional code is obtained. This puncturing process is performed periodically. For example, if we adopt an $R = \frac{1}{2}$ code and consider a period of P, the encoder produces $2P$ output symbols over the interval. Suppose that we read these symbols into an array of size $2 \times P$, and delete $D <= P-1$ of these symbols from the transmission queue. Then the effective code rate will be $R' = \frac{P}{2P-D}$. By choosing the period P and the number of deleted symbols D appropriately, a convolutional code at the desirable rate can be obtained. Specifically, for a P punctured code derived from a parent code with rate $R = \frac{1}{n}$, the effective rates are[14]

$$R' = \frac{P}{P+l}, l = 1, 2, 3, ..., (n-1)P.$$

We now illustrate code puncturing with the help of an example. The puncturing matrices of a family of RCPC codes generated from a rate $\frac{1}{2}$ mother code with $P = 8$ are given in Table 1.[15] Each matrix has 8 columns and 2 rows, corresponding to the puncturing period of $P = 8$ and the branches at the output of the rate $\frac{1}{2}$ coder, respectively. The elements of puncturing matrices are only *zeros* and *ones*. A *zero* in a puncturing matrix means that the corresponding code bit will not be transmitted, a *one* means that it will be inserted in the channel bit stream. For example, to generate a $\frac{8}{14}$ code, puncturing matrix $p(\frac{8}{14})$ is used. Encoding of 8 information bits with the two generator polynomials results in $2 \times 8 = 16$ bits at the two output branches of the encoder. Every fourth and eighth output bit of the second row are deleted. Instead of transmitting 16 bits, only 14 bits are transmitted per 8 information bits. Therefore, a rate $\frac{8}{14}$ code is generated.

The encoder for a punctured code can be fabricated using the original low-rate convolutional code (mother

Table 1. Example of a puncturing table for a family of RCPC codes (mother code rate = $\frac{1}{2} = \frac{8}{16}$, P=8)

Effective Code Rate	$\frac{8}{9}$	$\frac{8}{10}$	$\frac{8}{12}$	$\frac{8}{14}$	$\frac{8}{16}$
Puncturing Matrix p	11110111 10001000	11111111 10001000	11111111 10101010	11111111 11101110	11111111 11111111

Table 2. Example of a puncturing matrix for a family of RCPC codes (mother code rate = $\frac{1}{3} = \frac{8}{24}$, P=8)

Effective Code Rate	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{3}$
Puncturing Matrix	11111111 00000000 00000000	11111111 11111111 00000000	11111111 11111111 11111111

code) encoder followed by a bit selector which deletes specific code bits according to a given puncturing rule. Only the bit selection rule is changed to generate different rates of codes. At the receiver end, the punctured codes are de-punctured by following the same bit selection rule. That is, the bits which were punctured out at the transmitter are replaced with '0's. Then, the resultant codes are decoded by a Viterbi decoder based on the mother code. To decode different rate codes, only the matrixes are changed. Obviously, the same puncturing matrix must be used at both the encoder and the decoder.

2.3. RCPC codes and type-II hybrid ARQ

The concept of puncturing can also be modified to generate a family of RCPC codes by adding a rate-compatibility restriction to the puncturing rule.[15,11] Two punctured convolutional codes, obtained from the same parent code, are said to be rate-compatible if all the code bits in the higher rate code are used in the lower rate codes. Let $p(r_1)$ and $p(r_2)$ be the puncturing matrices of two rate-compatible codes ($r_1 > r_2$). If an element in $p(r_1)$ is equal to one ($p_{ij}(r_1) = 1$), then the same element in $p(r_2)$ is also equal to one ($p_{ij}(r_2) = 1$). Given a high-rate punctured convolutional code with puncturing matrix $p(r_1)$, a lower rate-compatible punctured convolutional code can be generated if we replace some *zeros* of $p(r_1)$ with *ones* and retain the previous *ones* in $p(r_1)$. For example, if we replace the fifth *zero* of the first row in the puncturing matrix of a rate $\frac{8}{9}$ code ($p(\frac{8}{9})$) given in Table 1 with a *one*, the puncturing matrix of a rate $\frac{8}{10}$ compatible code will be obtained.

RCPC codes have been shown to offer nearly equivalent performance when compared with the best previously known codes of the same rate. However, they are much simpler to decode than the conventional convolutional codes. For their simplicity and effectiveness, RCPC codes are ideal for type-II hybrid ARQ schemes, in which incremental transmission of additional redundancy in the subsequent retransmissions is required to enable decoding of a packet correctly. In general, if the retransmission limit is RL, the rate of the mother code of the RCPC codes is chosen to be $\frac{1}{RL+1}$. For example, as shown in Figure 2, Di could be a rate $\frac{1}{1}$ code, and Di and Di_1 together form a rate $\frac{1}{2}$ code, and Di, Di_1 and Di_2 together form a rate $\frac{1}{3}$ code, where Di_1 and Di_2 are redundant packets of packet Di. If the total retransmission limit is 2, then the mother code is chosen to have a rate of $\frac{1}{3}$. If we assume the puncture period $P = 8$, the corresponding puncturing matrixes could be as those shown in Table 2.

3. THE HIDDEN MARKOV MODEL OF FIXED WIRELESS CHANNELS

3.1. Hidden Markov Model

Hidden Markov models, or probabilistic functions of Markov chains, have been used extensively in various systems, including speech and image recognition, telecommunications, and queuing systems. The major reasons for the model's popularity is its ability to approximate a large variety of stochastic processes and its relative simplicity.[16]

Digital signal transformations in the presence of noise and fading when combined with other channel impairments lead to bursty errors on the channel. HMMs are widely used to describe the bursty nature of communication channel errors.[17] For digital wireless channels, a Markov chain can model the channel states. At the receiver, received symbols (errors as well as correct transmissions) are observed. However, the channel state in which an error has occurred is unobservable, or "hidden". By allowing error probabilities to be state-dependent, we can model states (or bursts) with different error probabilities. In a Markov model, a set of channel states and the matrix of transition probabilities among states are defined. As an example, the popular and classical Gilbert's HMM,[18] models the channel with two states: G (for good) and B (for bad or burst). There are no errors in state G, while errors occur in state B with a certain probability. The channel state switches between state G and state B according to the state transition probability matrix.

3.2. HMM for Fixed Wireless Channels

In order to investigate the performance of different ARQ-based error control schemes when they are applied to MPEG-2 video transmission over broadband fixed wireless channels, a specific finite state Markov model is designed to simulate the wireless links.

The short term variance of a high frequency (millimeter wave) fixed wireless channel in B-FWANs can be modeled as a K-factor Rician fading model.[19] In the K-factor Rician model, the received signal power consists of the waves coming directly from the transmitter along the LOS path (the direct component, E_d) and a number of small waves scattered from adjacent houses, leaves or other scattering objects (the scattered component, E_s). Since the scattered waves have random phase, the summation of the scattered signal waves will produce a complex Gaussian process whose amplitude is Rayleigh distributed. When the constant direct wave is included, the resultant amplitude should follow the Nakagami_Rica distribution.[20] A tuple is used to describe the state of the channel (K, SNR), in which the ratio $K = \frac{E_d}{E_s}$ is the K factor, and the SNR is the signal to noise ratio at the receiver. The K-factor fading model becomes a Rayleigh fading model when $K \ll 1$.

Since the short-term characteristics of the channel can be specified by the tuple, (K, SNR), it is reasonable to define a channel state by the (K, SNR) tuple in the HMM. In addition, we assume that K and SNR are independent, due to the fact that K describes the relationship between the direct and indirect components of the received signals, while SNR describes the relationship between the total signal power to the channel noise. The transitions in K of the channel can be modeled by a discrete Markov chain with N_K finite states, and the transitions in SNR by another discrete Markov chain with N_{SNR} finite states. The HMM of the channel state is then the combination of the two independent Markov chains.

For now, we assume that the Markov chain of K and that of SNR are two independent Gilbert two-state HMMs. That is, $N_K = 2$ and the two K states are specified by $K0$ and $K1$ as in Figure 3 (a), and $N_{SNR} = 2$ and the two SNR states are specified by $SNR0$ and $SNR1$ as in Figure 3 (b). In Figure 3 (c), we show how the two independent Markov chains are combined together to form the HMM for the wireless channel with states CS, where $CS0, CS1, CS2, CS3 = CS(0,0), CS(1,0), CS(0,1), CS(1,1)$ respectively, and the resultant channel states are illustrated in Figure 3 (d).

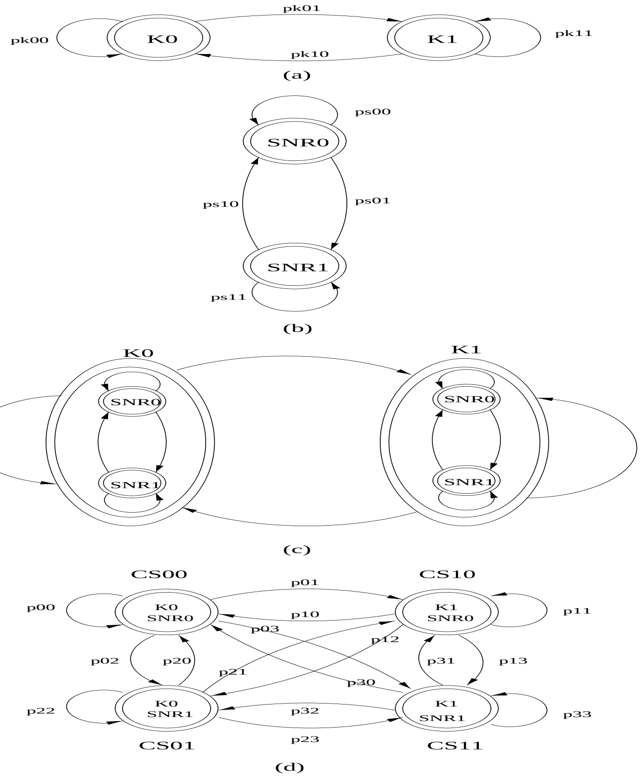

Figure 3. A finite state hidden Markov model of the channel states for the fixed wireless channel ($N_K = 2, N_{SNR} = 2$), (a) the Markov chain for K, (b) the Markov chain for SNR, (c) combining the two Markov chains to form the channel state HMM, (d) the resultant channel state Markov model.

The probability of the channel state changing from state i into state j is $p_{i,j}$, and the matrix of transition probabilities is $P = \{p_{i,j}\}$, where $i,j = 0,1,2,3$. Let $P_K(0)$ and $P_K(1)$ be the probabilities that the K state is in K_0 and K_1 states respectively. Then,

$$P_K(0) + P_K(1) = 1. \tag{1}$$

When the equilibrium condition is applied,

$$P_K(0) \times pk_{01} = P_K(1) \times pk_{10}. \tag{2}$$

and

$$\begin{aligned} pk_{01} &= 1 - pk_{00}, \\ pk_{10} &= 1 - pk_{11}. \end{aligned} \tag{3}$$

So that,

$$\begin{aligned} P_K(0) &= \frac{1-pk_{11}}{(1-pk_{00})+(1-pk_{11})}, \\ P_K(1) &= \frac{1-pk_{00}}{(1-pk_{00})+(1-pk_{11})}. \end{aligned} \tag{4}$$

Similarly, the probabilities that the SNR state is in SNR_0 and SNR_1 states, $P_{SNR}(0)$ and $P_{SNR}(1)$ are

$$\begin{aligned} P_{SNR}(0) &= \frac{1-ps_{11}}{(1-ps_{00})+(1-ps_{11})}, \\ P_{SNR}(1) &= \frac{1-ps_{00}}{(1-ps_{00})+(1-ps_{11})}. \end{aligned} \tag{5}$$

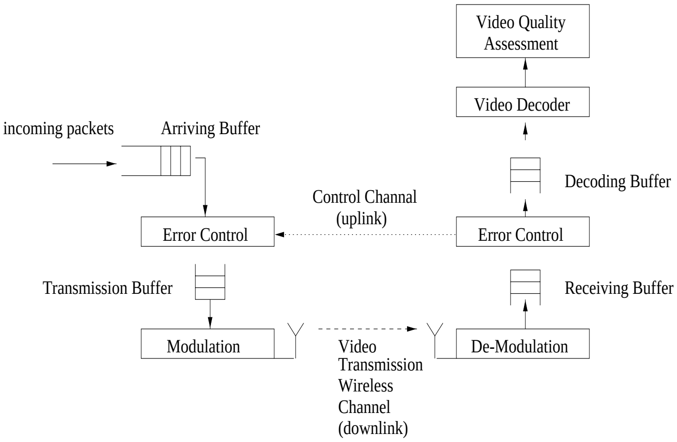

Figure 4. The block diagram of the simulation system for MPEG-2 encoded VoD service over B-FWANs using type-II hybrid ARQ schemes.

With the assumption that K and SNR are independent, we have

$$\begin{aligned} P_{CS(0,0)} &= P_K(0) \times P_{SNR}(0), \\ P_{CS(0,1)} &= P_K(0) \times P_{SNR}(1), \\ P_{CS(1,0)} &= P_K(1) \times P_{SNR}(0), \\ P_{CS(1,1)} &= P_K(1) \times P_{SNR}(1). \end{aligned} \tag{6}$$

4. PERFORMANCE EVALUATION

4.1. Simulation System

Figure 4 shows the block diagram of the system which simulates the transmission of MPEG-2 encoded video streams for VoD services over wireless channels in B-FWANs, when a type-II hybrid ARQ scheme with RCPC codes is used to combat channel errors. The ATM cells containing the MPEG-2 stream of the video or movie program arrive at the base station (BS) through the virtual connection, where they are converted into WATM cells and the type-II hybrid ARQ scheme is applied to combat channel errors. Each WATM cell contains a payload field of $48 \times 8 = 384$ bits, an error control field (ECF) of 16 CRC bits for error detection, and a tail field for the proper termination of the block convolutional encoder and decoder.

To increase the throughput of the wireless channels, a truncated (i.e., we limit the number of retransmissions) type-II hybrid selective repeat ARQ (SR-ARQ) scheme with RCPC codes is used. We also assume that the uplink control channel is error-free, and the bandwidth needed by retransmission is granted whenever it is requested.

A clip (about 1000 frames) of the well-known action movie *IndianaJones II*, which contains several car chase scenes and frequent scene changes was used. The movie clip is a progressive NTSC video sequence of 30 frames per second and has a frame size of 512×480 pixels. The encoding frame pattern is "IBBPBBPBBPBB". In Figure 5, the number of bits allocated to each frame of the VBR encoding of the video clip is given. As we can see, I-frames (the spikes) generate more bits than P-frames and B-frames.

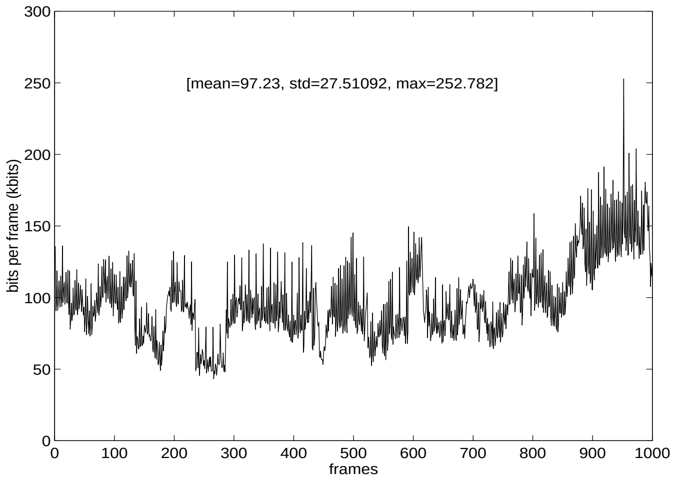

Figure 5. Trace of the bits/frame for *Indiana Jones (II)*

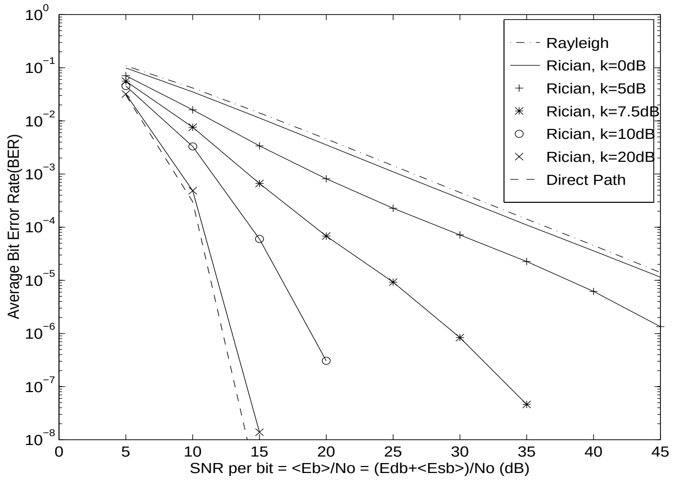

Figure 6. The BER curve of the 28GHz fixed wireless channel (K Factor Rician fading Model, $\pi/4$-shifted DQPSK).

4.2. Simulation Conditions

An evaluation of the performance of the fixed wireless channel by using the K-factor Rician fading model has been conducted.[5] Figure 6 shows the simulation results of the bit error rate (BER) for the TDMA fixed wireless channel in the $28GHz$ frequency band under different (K, SNR) conditions using the K-factor Rician fading model. The service radius is $5km$. The modulation scheme used is $\pi/4$-shifted DQPSK.

In the simulations to study the performance of the type-II hybrid ARQ scheme, the fixed wireless channel is modeled by the combination of the two-state K Markov chain and the two-state SNR Markov chain, as in Figure 3 (d). The BER of the resultant 4 states: $CS(K = 5dB, SNR = 10dB)$, $CS(K = 10dB, SNR = 10dB)$, $CS(K = 5dB, SNR = 30dB)$, and $CS(K = 10dB, SNR = 30dB)$, are approximately 2×10^{-2}, 4×10^{-3}, 10^{-4}, and 10^{-11} respectively. For broadband video services, the channel state with BER of 10^{-11} can be treated as error-free.

In order to simplify the choices of different channel statistics, we assume that $pk_{00}+pk_{11} = 1andps_{00}+ps_{11} = 1$. That is, when the K or the SNR of the channel state is more likely to stay in a good state, it is less likely to be in a bad state. Therefore, equation (6) can be simplified as follows

$$\begin{aligned} P_{CS(0,0)} &= (1 - pk_{11}) \times (1 - ps_{11}), \\ P_{CS(0,1)} &= (1 - pk_{11}) \times ps_{11}, \\ P_{CS(1,0)} &= pk_{11} \times (1 - ps_{11}), \\ P_{CS(1,1)} &= pk_{11} \times ps_{11}. \end{aligned} \tag{7}$$

¿From equations 7, the distribution (or statistics) of the channel states can be specified by the pk_{11} and the ps_{11} values. When pk_{11} or ps_{11} increase, the channel is more likely to stay in a state with better BER performance, (note, the BER of state 1 is lower than that of state 0).

For the simulations, the range for the pk_{11} and the ps_{11} are chosen to be $[0.7 - 0.99]$. Although K and SNR are not dependent, we also assumed that $pk_{11} = ps_{11}$ in order to reduce the number of simulation variables and present the results more conveniently. Note that the effect of changing pk_{11} or ps_{11} is similar - it either improves or deteriorates the average BER of the channel. Under these simplifications, the range for the probabilities of the state $P_{CS(0,0)}$ and the state $P_{CS(1,1)}$ are approximately $[9\% - 0.01\%]$ and $[49\% - 98\%]$ respectively, while the range for the states $P_{CS(1,0)}$ and $P_{CS(0,1)}$ combined are approximately $[42\% - 2\%]$. Hence, the average BER range is approximately $[3 \times 10^{-3} - 4 \times 10^{-5}]$.

4.3. Performance Results

Simulations were conducted to evaluate the overall performance of the type-II hybrid ARQ scheme in conjunction with RCPC codes, when they are used in the transmission of MPEG-2 encoded video sequences for VoD services over fixed wireless channels. In this subsection, the simulation results are summarized and compared to those obtained when using conventional SR-ARQ schemes.

4.3.1. Error rate of the original information cells

In the conventional ARQ scheme, the original information cells will be sent when a retransmission is requested, until the retransmission limit is exhausted. In the type-II ARQ scheme using RCPC codes, redundant cells are sent in the retransmissions as shown in Figure 2, in which additional redundancy in the subsequent retransmissions increases the probability of correctly decoding the original cells.

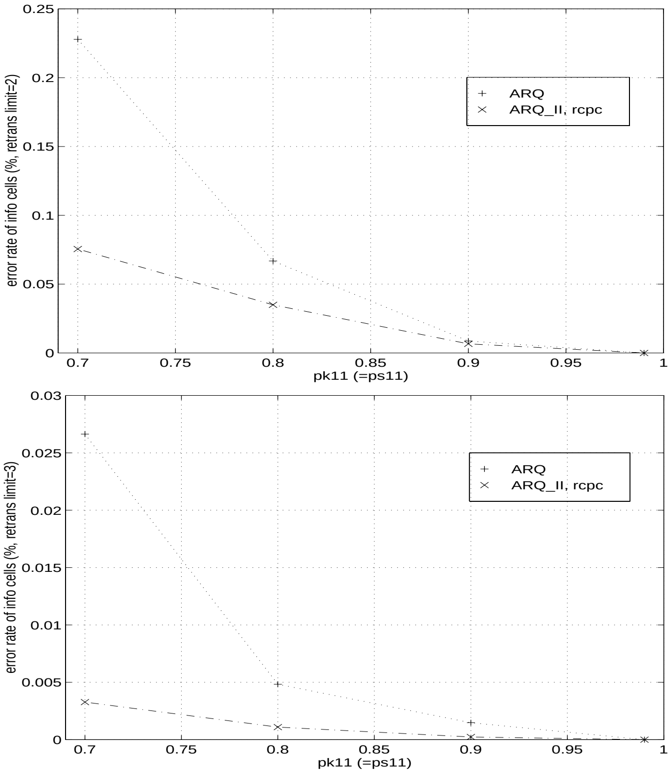

Figure 7. A comparison of the error rate of the original information cells, when the retransmission limit is (upper) 2, (lower) 3.

We define the error rate of the original information cells as the ratio between the number of the original information cells received which are not correct when the retransmission limit is exhausted, to that of the total original information cells. In Figure 7, the error rates of the original information cells under different ARQ schemes and different retransmission limits are compared. As shown in Figure 7, when the type-II hybrid ARQ with RCPC codes is used, the error rates drop substantially due to the error correction capability provided by the redundancy cells. Within the range of the channel statistics used in the simulations, when the retransmission limit is 3, the cell error rates become very small. We note that in order to let the type-II hybrid ARQ scheme work effectively, the retransmission limit has to be chosen to be large enough, bassically no less than 2.

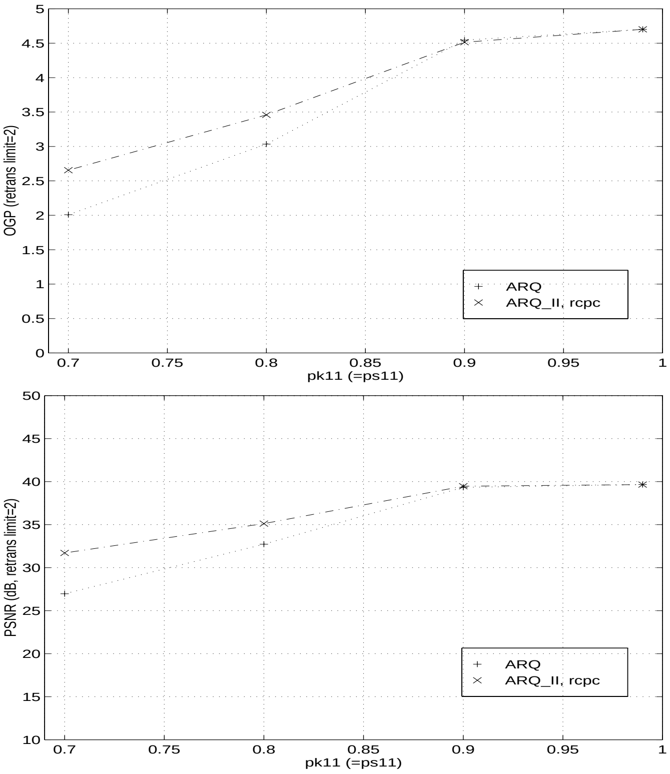

Figure 8. A comparison of the video quality in OGP (upper) and in PSNR (lower), when the retransmission limit is 2.

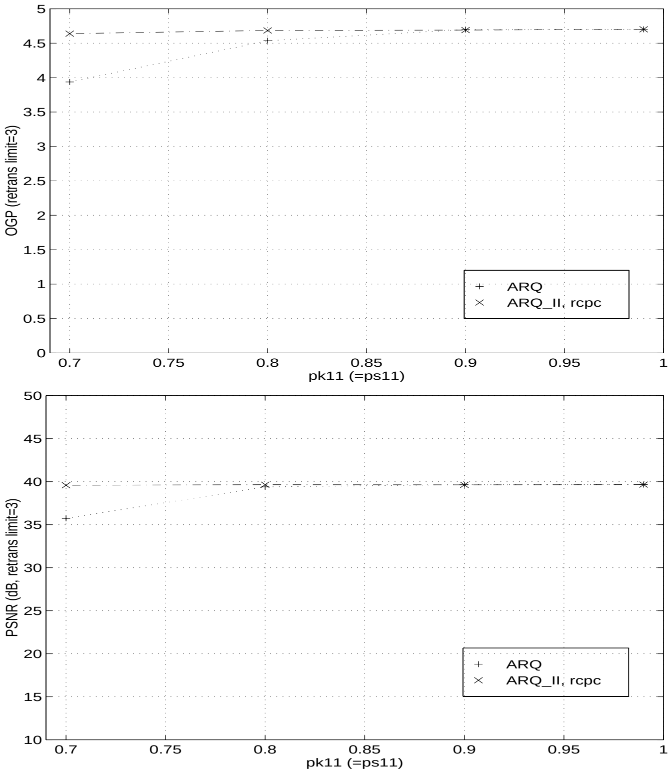

Figure 9. A comparison of the video quality in OGP (upper) and in PSNR (lower), when the retransmission limit is 3.

4.3.2. Quality of the reconstructed video sequences

The *objective grade point (OGP)*[21] and the *peak signal to noise ratio (PSNR)* are used to assess the quality of the reconstructed video sequences. The PSNR only measures the spatial distortion between the original frames and the reconstructed frames; while the OGP measures both the spatial and the temporal distortions. Another objective video quality assessment scheme used in our simulation was proposed by the Institute for Telecommunication Sciences (ITS). In subjective assessments, a panel of selected human viewers are shown the video clips and subjective grade points (SGPs), in the range from 1 to 5, are given by the viewers. In objective assessments, a set of parameters are calculated based on the video clips and an OGP is derived which should match closely that of subjective assessment.

The quality of the reconstructed video sequences when using the conventional and the type-II hybrid ARQ schemes with different retransmission limits are compared in Figure 8 and 9 respectively. Under the same retransmission limits, the quality of the reconstructed video sequences using the type-II hybrid ARQ scheme outperform those using the conventional ARQ scheme when the channel condition is poor. This is a direct result of the improvement of the error rate in the original information cells (Figure 7). When the retransmission limit is 3, the quality of the reconstructed video sequences when using the type-II hybrid ARQ scheme is quite satisfactory, as the error rates are negligible as shown in Figure 7.

4.3.3. Retransmission ratio

The retransmission ratio is defined as the total number of retransmission cells to the total number of original information cells. The simulation results on the retransmission ratios for the conventional ARQ and the type-II hybrid ARQ schemes with different retransmission limits are compared in Figure 10 respectively. The results show that the type-II hybrid ARQ scheme has a lower retransmission ratio under the same channel statistics and the same retransmission limit, especially when the channel condition is poor, which is attributed to the error correction capability provided by the redundant cells.

Since the retransmission ratio is largely determined by the number of first time retransmitted cells, the discrepancy in the retransmission ratio of the conventional ARQ and the type-II hybrid ARQ schemes are relatively small, as there is no error correction capability associated with

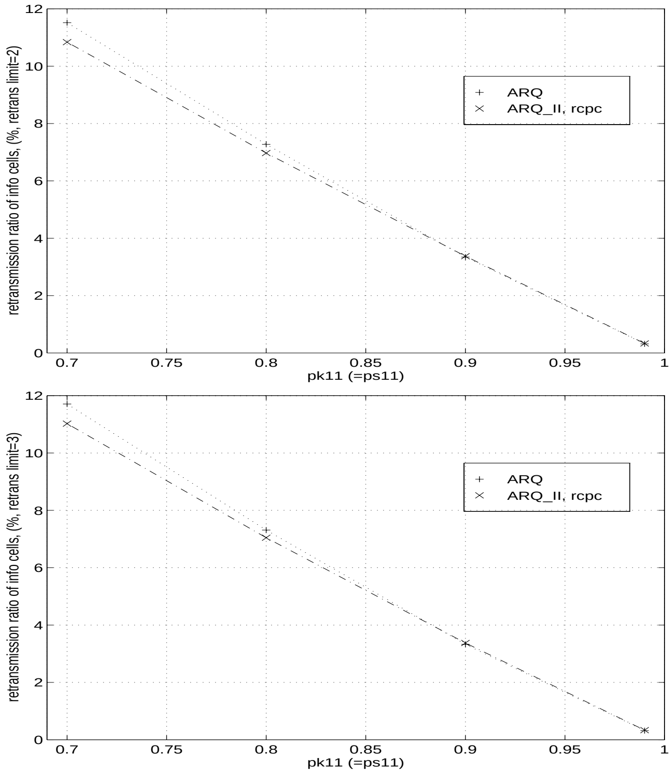

Figure 10. A comparison of the retransmission ratios, when the retransmission limit is (upper) 2, (lower) 3.

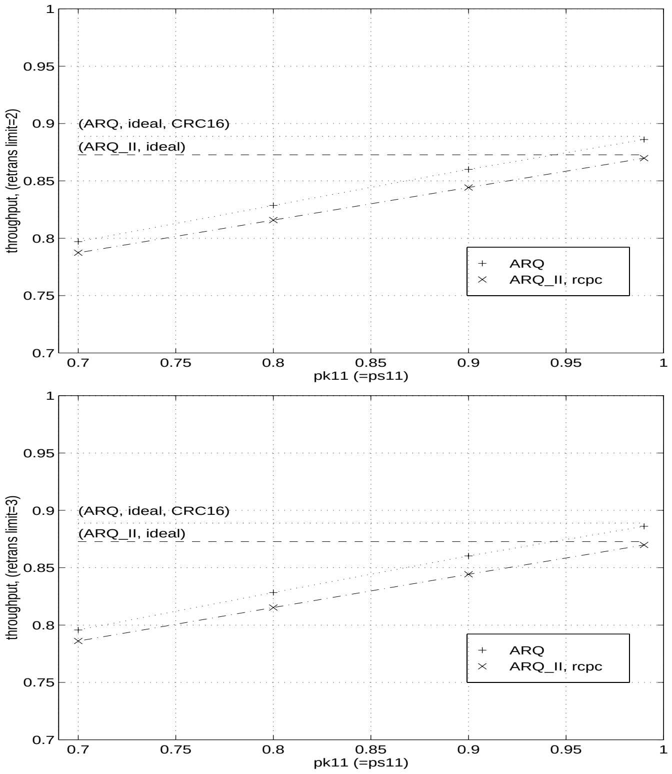

Figure 11. A comparison of the channel throughput, when the retransmission limit is (upper) 2, (lower) 3.

the initial attempt in the type-II hybrid ARQ scheme. We also observe that when the retransmission limit increases from 2 to 3, the retransmission ratio just increases very slightly.

4.3.4. Channel throughput

The channel throughput (or utilization) is defined as the ratio of the number of information bits to the total number of bits transmitted over the wireless channel, which consists of the information bits, the necessary overhead related to the operation of ARQ-based schemes and the retransmitted bits. The channel throughput is determined by the combination of the overhead and the retransmission ratio. Figure 11 shows the simulation results of the channel throughput for the conventional and the type-II hybrid ARQ schemes. In Figure 11, the horizontal lines represent the ideal channel throughput of the corresponding ARQ schemes; while the sloping lines represent the actual channel throughput obtained via simulations.

Due to the tail bits (1 octet) used in the type-II hybrid ARQ scheme for the proper operation of the convolutional decoder, the ideal channel throughput of the type-II hybrid ARQ scheme is slightly lower than that of the conventional ARQ scheme. Therefore, a certain portion of the channel resource is wasted when the channel is good. When the channel statistics worsen, the difference in the channel throughput between the two schemes is reduced slightly. This is attributed to the error correction capability associated with the type-II hybrid ARQ scheme, which reduces the retransmission ratio as shown in Figure 10.

5. SUMMARY

In our previous studies,[6] we investigated the feasibility of applying ARQ schemes to the transmission of MPEG-2 encoded video streams over fixed wireless links in B-FWANs for VoD services. In this paper, we studied the effectiveness of using type-II hybrid ARQ schemes in conjunction with RCPC codes in the transmission of MPEG-2 encoded video streams over wireless channels for VoD services. Simulations were conducted to evaluate the overall system performance. The variations in the quality of the fixed wireless channel used in a B-FWAN system are modeled by a finite state Markov model, which consists of two independent Markov chains, the two-state K Markov chain and the two-state SNR Markov chain. Important metrics relevant to broadband video services are evaluated, including the error rate of the original information cells, quality of the reconstructed video sequences

(OGP and PSNR), and the excess bandwidth used by the retransmissions.

When the channel has low BER for approximately 50% of the time, (a reasonable assumption for the fixed wireless channels in B-FWANs), the simulation results show that the error rate of the type-II hybrid ARQ scheme is much lower than that of the conventional ARQ scheme. In order to let the type-II hybrid ARQ scheme work efficiently, the retransmission limit has to be greater than 1. As a direct result, the quality of the reconstructed video sequences when using the type-II hybrid ARQ scheme, is improved substantially when compared to those using the conventional ARQ scheme under the same channel statistics and the same retransmission limits.

The cost of the improvement in the video quality for the type-II hybrid ARQ scheme consist of the computational complexity due to the Viterbi algorithm used in the decoding of the convolutional codes, which are the mother codes for the RCPC codes, and the slight drop in the channel throughput due to the tail bits. However, when properly applied, RCPC codes are much simpler to decode than the conventional convolutional codes. In order to guarantee satisfying the QoS requirement at a reasonable computational complexity, the constrain length of the mother code used for the RCPC codes has to be chosen properly.

In this paper, the average fading duration of the wireless channel is relatively short (about 1 to 2 cells). Currently, we are investigating the performance of the different ARQ-based error control schemes when the wireless channel experiences longer fades. The preliminary results indicate that the discrepancy in the channel throughput when using the type-II hybrid ARQ scheme is further reduced and becomes negligible when the channel experiences relatively long fades, while the type-II hybrid ARQ scheme can guarantee a more consistent video quality.

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