Performance of Video Quality in Dual-Branch Diversity Based SR-ARQ over Rayleigh Fading Channel

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ABSTRACT

In this paper, we investigate the video quality performance in a dual-branch selection diversity receiver in time—varying channel environments. We consider the selective-repeat automatic repeat request (SR-ARQ) protocol in order to maximize effectively the quality of service in terms of throughput over Rayleigh fading channels. To achieve high video quality at the receiver, the extended ARQ (EARQ) scheme based packet combining strategy is considered. The simulation results show that a significant improvement in the performance can be attained when a retransmission of packet combining is used along with selection diversity at the client end. In addition, the selection combining based EARQ protocol outperforms that of only selection combining scheme based basic ARQ.

General Terms

Analysis, Model, Performance.

Keywords

ARQ**,** Diversity, Rayleigh Fading, Throughput, Video quality.

1. INTRODUCTION

Although the demand on multimedia applications such as real-time video streaming is widely increased over the wireless networks, the necessary Quality of Service (QoS) in terms of throughput, loss, and delay does not guarantee the support of video quality transmission [1-4]. Specifically, the performance of wireless links is severly degraded due to correlated channel fading, which limits the overall system throughput considerably relative to wireline altenatives. The video steaming over a noisy and/or deeply faded channel encounters bit errors causing packets corruption, which consequently leads to a remarkable degradation in the quality performance of the reconstructed video sequence. Therefore, robust transmission of real-time video over time-varying wireless channels is still critical problem to achieve good perceptual quality at the client terminal end [3-5]. To achieve this goal, there are basically two ways to fully utilize the channel capacity (throughput) in the presence of time-varying channel: adaptation [7-10] and diversity techniques [13-20].

In the adaptation mode, parameters such as transmission power [8], symbol rate [2], constellation size [12], and coding rate/scheme are changed in response to the time-varying channel conditions. This is called a channel-adaptive technique required in wireless communications. On the contrary, the diversity techniques use the channel variations by resolving several fully or partially de-correlated signals such as time, frequency and space diversity. These techniques have been pursued to increase the reliability of the time-varying wireless systems under the worst channel conditions [14-18].

Nevertheless, an alternative way to mitigate the channel fading is to rely on the automatic repeat request (ARQ) protocol at the data link layer, which requests retransmission for those packets received in error. Since retransmissions are activated only when necessary, ARQ becomes quite effective in improving system throughput especially in the time-varying wireless systems when the data transmitted blocks are equipped with error detection strategies such as a cyclic redundancy check (CRC) [9-11]. In general, there are three basic ARQ protocols: stop-and-wait (SW), go-back-N (GBN), and selective-repeat (SR). Among all ARQ schemes, SR is reported to show the best throughput performance [7**]** and thus it is interesting to analyze and investigate its behavior in order to have an upper limit on the throughput performance that any ARQ protocol can achieve in practice.

If the ARQ scheme has to be used over a mobile radio channel, the time-varying multipath fading characteristics introduce a certain amount of correlation between different ARQ packet (re)transmissions; that is, channel errors cannot be assumed to be independent from packet to packet. Therefore, many recent researches **[**12-20**]** have dealt with such ARQ schemes in different approaches for single channel system or route diversity system in order to increase and enhance the overall system throughput (quality of service) either by applying adaptive modulation and coding (AMC), e.g., [16-20], and/or by varying the packet size **[**9,17**]**, or by controlling, for example, the throughput efficiency of ARQ, HARQ I and HARQ II with code combining in the presence of feedback errors over multipath block fading channels as in [14].

On the other hand, an alternative diversity technique is also powerful tool used in wireless communication systems to mitigate

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fading effects [19-20]. The depth of the fades and/or the fade duration is reduced by supplying the receiver with multiple replicas of transmitted signal that have passed over independently fading channels. The simplest form of diversity combining is the selection diversity (SC). This system is so-called SNR-based SC [21] and its performance is evaluated under the assumption of continuous branch selection. The conventional selection diversity scheme generally selects, among the L diversity branches, the branch providing the largest signal-to-noise ratio (SNR) (or largest fading amplitude). Many recent schemes [15-18] have been proposed to provide significant power gains (channel gain) over existing selection diversity schemes in Rayleigh fading channels. For example, [22] has introduced that in very slow fading channels, the dual-branch switched diversity scheme at the transmitter can improve the throughput efficiency of the ARQ protocols significantly. More specifically, the diversity benefit obtained from this scheme can reduce the delay in transmitting the data packet and this will be an attractive goal in many applications such as audio, image and real-time video streaming. Moreover, Gogate and Panwar showed that alternating data transmission over two independent channels can improve the overall delay/throughput in a highly correlated Rayleigh fading environment, both for non-real time [23] and real-time data based multiple description coding (MCD) for compression of image and video signals [24]. Meanwhile, [17] investigated the potential merits of duplicate packet transmission over two independent channels and examine the delay/throughput performance under alternative ARQ protocols and compared the results with a single channel system. In fact, there was no analysis on video/image quality performance in their scenario.

In this paper, we investigate the considerable enhancements that dual-branch diversity receiver may offer in terms of throughput and quality of service (QoS) when the MPEG-4 video is streamed over Rayleigh fading channel. Two dual-branch selection receiver configurations are considered to evaluate the potential benefits of diversity. The extended automatic repeat request (EARQ) based packet combining strategy is considered to achieve high perceptual video quality at the client end. We introduce the selection combining based (EAQR) scheme to provide a significant improvement in the video performance as compared with the scheme based only a basic ARQ.

The paper is organized as follows. Section 2 describes a system model. Section 3 presents the performance analysis, and followed by Section 4 for simulation results and performance evaluation, and finally conclusions are summarized in Section 5.

2. SYSTEM MODEL

Let us assume a wireless communication system consisting of one transmit antenna and two receiver antennas. We assume a selective repeat automatic repeat request (SR-ARQ) protocol with perfect CSI is available at the receiver. CSI and feedback antenna information are sent back to the transmitter by using the feedback CSI channel, with a CSI sensing delay $\tau << D$ (round-trip delay of ARQ feedback); whereas the sensing delay can be artificially reduced by using prediction filter [13]. The channel is time-varying and frequency flat fading with instantaneous zero-error feedback. Error detection based on the usual cyclic redundancy check (CRC) is perfect, provided that sufficiently reliable error detection CRC codes. For numerical results, we use a typical CRC-16 in each packet and the effect is included in the throughput calculation. Since only finite delays and buffer sizes can be afforded in practice, the maximum number of ARQ retransmissions has to be bounded. This number can be specified by dividing the maximum allowable system delay over the round trip delay required for each retransmission [15,17]. Therefore, we adopt the maximum number of retransmission allowed per packet is $N_{\max}$. It means that if a packet is not received correctly after $N_{\max}$ retransmissions, we will drop it, and declare packet loss. This is very reasonable and can be afforded in video/image transmissions because the underlying bit streams represent highly correlated image contents. On the other hand, the error packets can also be utilized if the receiver declares to do so. Thereby, the probability of packet loss after $N_{\max}$ retransmissions is no longer than certain packet loss rate [12].

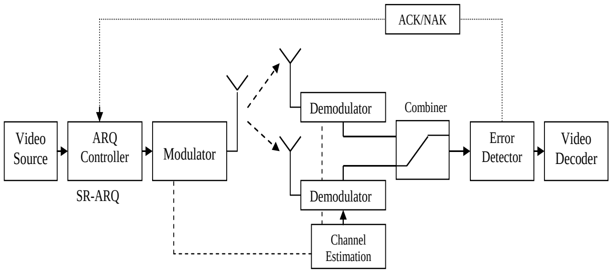

Figure 1. Block diagram of the dual branch selection diversity based ARQ post-reception scheme

In Figure 1, we present an ARQ scheme associated with two types of post-detection dual-branch receiver diversity: *(i)* a classical selection combiner (SC-ARQ) and *(ii)* a selection combiner based an Extended ARQ (SC-EARQ) [15,25]. For both receivers, positive (ACK) or negative (NACK) acknowledgements can be sent at the radio-data link layer neglecting a round-trip delay (latency). Here, individual receivers are associated with each antenna. The decision process after the receivers (demodulators) considers a reception as correct using CRC error detection, if it is correctly received over any of the diversity branches[1]. A correct packet hence is chosen to the output. In this model, we evaluate the video quality of MPEG-4 stream [4-5] over a dual-branch Rayleigh fading channels when a last hop is mobile device. A typical Group of Pictures (GoPs) structure of an MPEG stream is considered. Each GoP consists of three types of frames: I-, P- and B-frames. For simplicity sake, we identify a GoP pattern of MPEG-4 video as $G(N_P, N_{BP})$ where N_P corresponds to a number of P-frames in a GoP, and N_{BP} corresponds to the number of B-frames between I and P frames.

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[1] In both schemes, we assume packet errors are independent and there is no correlation effect of the spatial and frequency diversity.

2.1 SC-ARQ Scheme

In this scheme, the individual receivers are associated with each antenna (Figure 1). The two diversity branches are continuously mointered and the branch with the best signal-to-noise ratio (SNR) is chosen to the output of a received packet [25]. The decision process after receivers considers a correct packet reception, if it is correctly received over any of the diversity branches using SR-ARQ basic protocol. In fact, when diversity reception in the packet-by-packet fashion is considered, the advantages of this scheme are somewhat reduced. Moreover if the present antenna has incorrect reception, outputs of other antenna are neglected. On the other hand, the important aspect of such scheme is that even if all packets received over the diversity branches are corrupted, they can be combined in an attampt to resume the correct packet.

2.2 SC-EARQ Scheme

When ARQ scheme is used with packet combining (i.e., extended ARQ or EARQ), erroneous copies of the same packet are combined using bitwise modulo-2 sums (logical XORs) to locate errors in a combined copy [10,15, 26]. In this paper, we consider this SC-EARQ scheme for three reasons. Firstly, this appoach with a cyclic redundancy check (CRC) at every step can recover the correct copy in both in binary symmetric channels (BSC) and Rayleigh fading channel. Secondly, its performance has shown very closely to the upper bound of type-II hybrid ARQ schemes in particulare for BER values lower than 10^{-2}. Thridly, the EARQ scheme employs easy to implement the hard-decesion receivers for any modulation scheme (coherent and non-coherent) in selection combining compared to maximal ratio combining (MRC). Futhermore, since the EARQ uses hard decision, collection of the diversity branches is not requirement, therefore SC-EARQ can be used during soft handover of a CDMA system.

In SC-EARQ scheme in a time diversity system (Figure 1), if at least one of the received copies over a diversity branch is correct, it is accepted in the same way of SR-ARQ scheme. Otherwise, if both copies contain errors the bitwise modulo-2 sum of the copies is computed to locate the bit errors in a combined copy. The decision process involves bit-by-bit inversion and CRC check in an attempt to retrieve the correct packet. In fact, this process fails if there is at least one bit position where both copies have an error, i.e., double error, or the number of errors in the combined copy exceeds a predefined number $N_{\max}$. The term $N_{\max}$ is used to maintain the computational complexity within reasonable limits with truncated version. In this case, if the packet combining process fails for a pair of erroneous copies, then they are discarded and a retransmission is occurred according to the decision process [15].

3. PERFORMANCE ANALYSIS

3.1 ARQ Throughput

A protocol performance is usually characterized by many important parameters which are defined by the communication system requirements. These parameters are the probability of receiving a packet without errors and the protocol throughput efficiency. There are several definitions of the protocol throughput efficiency. Most frequently it is defined as the ratio of the mean number of information bits successfully accepted by the receiver to the number of bits that could have been transmitted during the same time interval [**7**]. To derive an expression for the throughput efficiency of the ARQ protocol, the assumption of an "optimal" ARQ protocol can be assumed in that only packets containing errors are retransmitted. The throughput efficiency of ARQ scheme in bit per second can be determined by [27]

$$\eta_s = R_s \left(\frac{K}{N} \right) \frac{1}{\overline{m}} \qquad (1)$$

Where the first term *K/N* represents the ratio of information bit to the total bits in a packet and *N-K* is being the CRC bits, and consequently $R_c = K / N$ can express the channel code rate. In fact, η_s denotes the effective received data rate, R_s indicates the source data rate, and the term $\overline{m}$ represents the average number of transmission attempts per packet. Assuming that the ARQ scheme retransmits a packet until the ACK of a successful reception, the average number of attempts required to successfully transmit one packet is given by,

$$\overline{m} = (1-p) + 2p(1-p) + 3p^2(1-p) + ... = \frac{1}{1-p}. \qquad (2)$$

where p is the average block or packet error rate (BLER or PER). Then, for a given p the throughput efficiency of ARQ is given by

$$\eta_s = R_s \left(\frac{K}{N} \right) (1-p) \qquad (3)$$

When a perfect retransmission algorithm is employed that can happen only when retransmit packets are in error and can continuously transmit new packets as long as no errors occur. Thus for a Selective Repeat (SR-ARQ) scheme, throughput is given by the well-known formula [7,12]

$$\eta_{SR} = R_s \left(\frac{K}{N} \right) \left(1 - P_b(\gamma_b)\right)^N \qquad (4)$$

where *N* is the packet size in bits including the number of over - head bits (e.g., CRC); and $P_b(\gamma_b)$ is being the channel bit error rate (BER) as a function of the channel SNR per bit (γ_b).

3.2 The Channel Performance

In practice, the signals in the diversity branches may not show completely independent fading. The envelope cross correlation ρ between these signals is a measure of their independence. Therefore [21],

$$\rho = \frac{E\left[[r_1 - \overline{r_1}][r_2 - \overline{r_2}]\right]}{\sqrt{E\left|r_1 - \overline{r_1}\right|}\sqrt{E\left|r_2 - \overline{r_2}\right|}} \qquad (5)$$

where r_1 and r_2 represent the instantaneous envelope levels for the normalized signals at the two receivers; and $\overline{r_1}$ and $\overline{r_2}$ are their respective means. For instance, if a cross correlation (correlation coefficient ρ) of 0.5 between signal envelopes is available this will be sufficient to provide a reasonable degree of diversity gain [21]. Depending on the type of diversity employed, these diversity channels must be sufficiently *separated* along the appropriate diversity dimension. More specifically, we ignore the correlation effect of the spatial diversity in terms of *coherence distance* as well as the frequency diversity in terms of *coherence bandwidth,* and the only time diversity is considered whereby the separation between channel reuse in time should be longer than the *coherence time*. The later coherence factor in turn depends on the channel characteristics and varies *inversely* as the Doppler shift spreads.

Accordingly, the statistical properties of fading signals depend on the field component used by the antenna, the vehicular speed, and the carrier frequency. Hence, for ideal case of a mobile surrounded by scatters in all directions, the covariance function, i.e., autocorrelation function of the received signal *x*(t) (not the envelope *r*(t)), can be shown as

$$\rho = J_o\left(2\pi\ f_d T_s\right) \tag{6}$$

where J_o is a Bessel function of the zero-*th* order first kind. In fact, T_s denotes the symbol time which is less than the coherence time T_c of fading period, i.e. correlation between two symbols over channel in case of slow fading, and the Doppler spread f_d of the signal represents a function of the mobile speed υ and the carrier frequency (1/λ). Note that the correlation properties of the fading process depend only on $f_d T_s$. When $f_d T_s$ is small (e.g. < 0.1), the process is much correlated ("slow" fading); on the other hand, for large values of $f_d T_s$ (e.g., > 0.2), successive samples of the channel are almost independent ("fast fading"). For high data rates (i.e., small T_s), the fading process can typically be considered as slowly varying, at least for the usual values of the carrier frequency (e.g., 2 GHz over UMTS standard) for cellular mobile networks and for typical mobile speeds.

If the coherent BPSK modulation is used in particular in a dual branch selection combining diversity receiver in Fig. 1, the average bit error probability of correlated Rayleigh fading channel with the average SNR equal to $\overline{\gamma}$ can be expressed in closed form as [25],

$$P_{b,SC} = \frac{1}{(1+\rho)}\left[\frac{1+\rho}{2} - \sqrt{\frac{\overline{\gamma}}{1+\overline{\gamma}}} + \frac{1-\rho}{2}\sqrt{\frac{(1-\rho)\overline{\gamma}}{2+(1-\rho)\overline{\gamma}}}\right] \tag{7}$$

where $\overline{\gamma}$ represents the average SNR of the first branch for equal average branch SNRs ($\overline{\gamma_1} = \overline{\gamma_2}$), and ρ is the power correlation coefficient between the estimated and actual fadings expressed in (6). In fact, $0 \le |\rho| \le 1$ denotes a measure of the quality of channel estimation defined in (6) in terms of time delay and the maximum Doppler frequency shift (e.g., in land-mobile communication systems).

Nevertheless, according to the system model in Fig. 1, since bit error is random in an AWGN channel, the packet loss (error) is also considered random. In the SC-ARQ post-reception scheme, the probability of successfully receiving a packet is that of a successful reception over either of the diversity branches, and this can be expressed as by

$$P_1 = 1 - \left(1 - (1 - P_{b,SC})^N\right)^2 \tag{8}$$

$P_{b,SC}$ is defined in (7), and consequently the effective throughput can be computed as,

$$\eta_{SC-ARQ} = R_s\left(\frac{N-C}{N}\right) P_1 \tag{9}$$

In the SR-EARQ scheme, when both copies are erroneous, a packet is retrieved correctly if the combined copy does not have a double error, and if the total number of errors in the combined copy is at most $N_{\max}$. The probability that both these conditions are satisfied is **[**15**]**

$$P_2 = \sum_{k=1}^{N_{\max}-1}\sum_{i=1}^{N_{\max}-k}\begin{pmatrix} n \\ k \end{pmatrix}\begin{pmatrix} n-k \\ i \end{pmatrix} P_{b,SC}^{k+i}\left(1-P_{b,SC}\right)^{2n-k-i} \tag{10}$$

and the expected throughput of the EARQ scheme is given by

$$\eta_{SC-EARQ} = R_s\left(\frac{N-C}{N}\right)\left(P_1 + P_2\right). \tag{11}$$

3.3 Video Quality

To estimate the number of playable frames at a receiver, random and stationary packet loss is considered over a time-varying Rayleigh fading channel in Figure 1. The system model designed for MPEG-4 video stream therefore can expressed in terms of the total playable frame rate as follows [5],

$$PFR = G.W_I \cdot [1 + \chi_P + N_{BP} \cdot W_B(\chi_P + W_I \cdot W_P^{N_P})] \tag{12}$$

where,

$$\chi_P = \left(W_P - W_P^{N_P+1}\right)\times\left(1-W_P\right)^{-1},\ W_i = \left(1-\varepsilon_s^*\right)^{S_i},$$

$$G = (\eta_s / N)/(S_I + N_P S_P + (1+N_P)N_{BP}S_B)\,. \tag{13}$$

W_i stands for the successful transmission probability of the *i-th* frame type (I, P, and B) in a GoP pattern and S_i denotes packet size of the *i-th* frame type. G corresponds to the number of GoPs per second. S_I, S_P, and S_B are the frames' sizes of the I, P, and B frames in GoP pattern (in packets), respectively. In this model, *N* (in bits) must be chosen as small value for the correlated Rayleigh fading channel corresponding to the estimation of CSI feedback, η_s is defined as the effective throughput received at the client in (bps), i.e. the maximum allocated bandwidth required to provide the desired video quality.

4. SIMULATION RESULTS

4.1 System Settings

The performance of dual-branch diversity receiver has been conducted using the simulation parameters given in Table 1. These parameters are based broadly on the UMTS cellular mobile system for MPEG-4 video streaming [1,5,17]. In numerical results, we use for example a typical GoP(2,3) "*I-BBB-P-BBB-P-BBB*" where N_P =2 and N_{BP} =3 streamed with channel data rate of 144kbps to evaluate the perceived play-out frame rate. Then the proposed scenario to achieve the maximum video quality performance in terms of playable frame rate (PFR) can be summarized as follows:

1. The video bitstream is encoded in a short packet size of 100 bits including 16 bits CRC error detection at the data link layer using SR-ARQ (or SR-EARQ) in order to ensure a desired quality of video streaming at client.
2. The video system at the receiver estimates the channel state (CSI) feedback to specify the average SNR per bit for each antenna branch. The bit-error rate $P_{b,SC}$ for *coherent* BPSK modulation scheme can be assessed for both schemes [25]. For typical channel performance, equal average SNR (γ) for each branch is assumed in (7) to evaluate the required BER for the two SC schemes and the corresponding packet or block error rate (BLER or PER) in (8) and (10).
3. At the receiver, when the SC-ARQ post-reception scheme is used, the successful reconstructed packet is that of a successful reception over either of the diversity branches. In this case there is only one retransmission, i.e., $N_{\max}$ =1, if an erroneous packet occurs.
4. To increase the effective throughput and the corresponding video quality (i.e., number of play-out frame rate), the SR-EARQ scheme combines the two erroneous packet copies and a packet is retrieved correctly if the combined copy does not have a double error, and if the total number of errors in the combined copy is at most $N_{\max}$ using (11).

4.2 Performace Evaluation

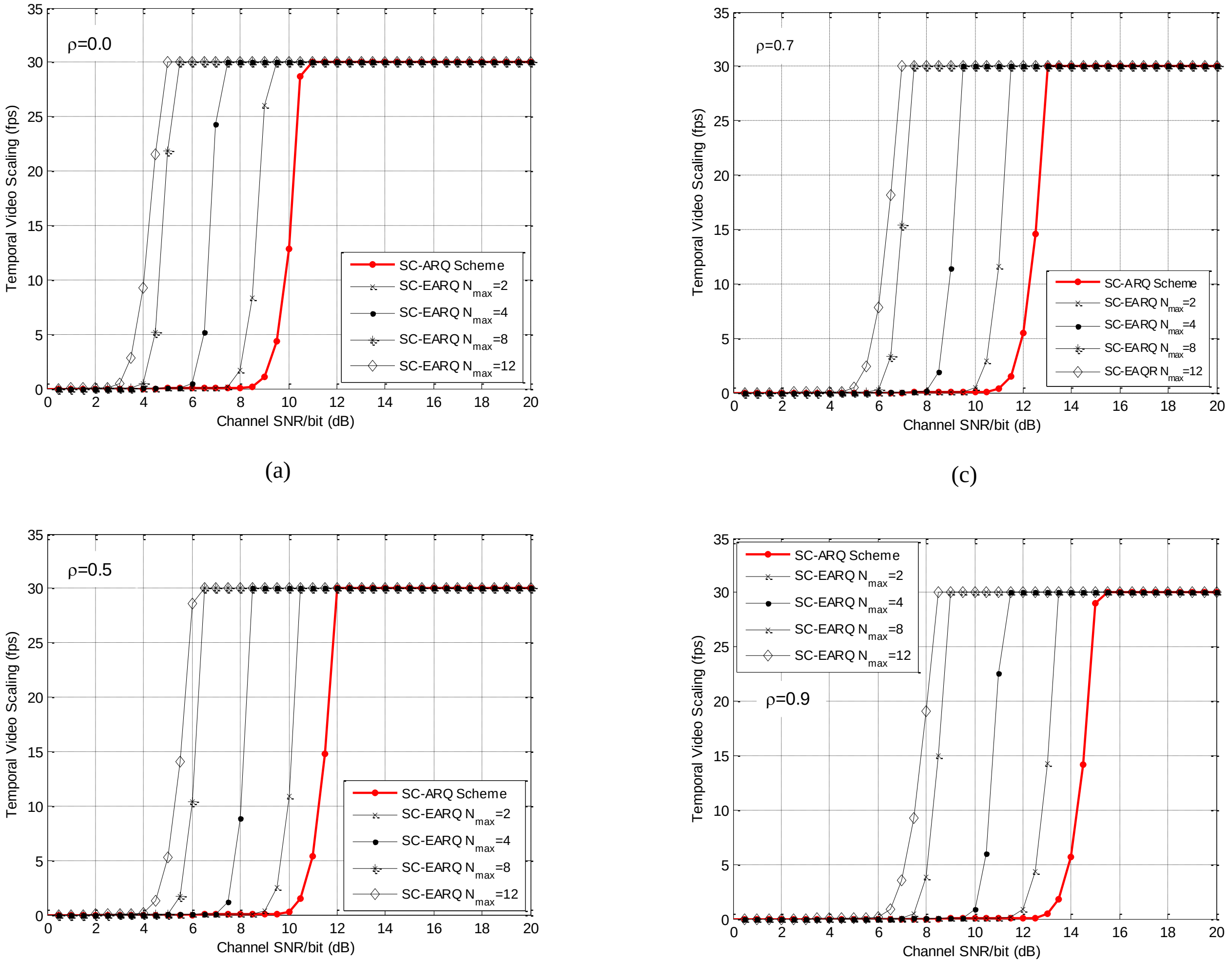
In this study, video quality in terms of the number of play-out frame rate is evaluated as the basic QoS performance in the two diversity schemes described in Section 2. The results are obtained using Matlab programming to verify the overall system performance. Figure 2 explains the temporal video scaling in terms of frame per second (fps) versus the average channel SNR in (dB) for both schemes. It is clearly noticed that SC-EARQ under various values of power correlation coefficient factor ρ (fading conditions) and with equal branch SNR ($\gamma_1 = \gamma_2$),outperforms the basic SC-ARQ scheme. A significant increase in the number of reconstructed video frames per second can be considerably attained when $N_{\max}$ increases in case of SC-EARQ scheme, in particular for low values of ρ . In other words, the power correlation coefficient will effectively degrade the video quality performance as far as this coefficient tends to be close to 1. For example, when $N_{\max}$ is achieving 12 retransmission attempts, a full video motion rapidly provides the upper-limit of 30 fps at the lowest channel SNR values of 4.5, 6.2, 7.0, and 8.2 dB for various power correlation coefficient ρ of 0.0, 0.5, 0.7 and 0.9, respectively. Meanwhile, there exits a clear channel gain of 0.5 dB to 3.0 dB in the range of SNR once the maximum retransmissions $N_{\max}$ becomes 2 or higher for correlated fading channel and uncorrelated channel as well.

Table 1. Simulation Parameters

Physical Channel	**Rayleigh fading channel**
SNR γ	1…20 (dB)
Channel data rate	144kbps UMTS standard
Carrier frequency	2 GHz
Mobile speed	1km/h-80km/h
Data-link Layer	CRC-16
Packet size	100 bit
Application Layer	MPEG-4 (base-layer)
F_o (video source)	30 (fps)
GoP(2,3)	*I-BBB-P-BBB-P-BBB*
(S_I , S_P , S_B)	Typical values (25,8,3) [packet]

Figure 3 draws the impact of the client mobility at the diversity receiver (mobile speed) on the perceptual video quality over the dual-branch Rayleigh fading channel for both schemes. It is shown that a video quality versus mobile speed (e.g., 1km/h-80 km/h) for various branch channel SNR and packet retransmissions can be improved whenever the received branch SNR increases. For example, low value of SNR below 7 dB can not achieve 15 fps (i.e., less than 50% of the full motion) despite the maximum retransmissions increases beyond 12. However, high values of SNR, for instance 12 dB, the full-motion play-out frame rate rapidly carries out for small and limited number of retransmissions but not exceeding four attempts [12]. In fact, truncated ARQ protocol is required to limit the maximum number of retransmission.

In similar manner, Figure 5 shows the impact of the normalized Doppler frequency on the video quality performance at the diversity receiver for various values of average SNR values and retransmissions. It is also found that the speed of the mobile (in Figure 4) will affect the performance of SC scheme when the correlated coefficient achieves a value equal or nearly close to 1 where $f_D T_s$ tends to be small enough less than 1×10^{-3}, i.e., "slow fading". That refers to the fact which states low values of f_D corresponds to highly correlated channels; and high values of f_D corresponds to a less correlated channel "fast fading", in which significant variations of the fading coefficients over short time periods may occur [7]. As a result, the expected video quality achieves a constant quality level along the increasing of mobile speed through the diversity gain obtained ($f_D T_s$ increases slightly) and that is provided a perfect CSI is available at the receiver. In addition, the high video quality will consequently achieve highest upper bound (30 fps) when the high SNR values are present at the dual-branch antenna receiver. Finally, we can conclude that the high values of SNR will guarantee a higher throughput and a higher video quality performance once a mobile speed arises but not beyond 200 km/h in practice at normalized Doppler shift not greater than 2.6×10^{-3} (f_D must not exceed 148Hz), in Figure 5. Moreover, it is found that short packet size allows low packet loss rate and it also provides an opportunity for wireless channel to operate at a lower range of channel SNR as compared to the SNR range of large values of *N*. Upon observations, the results obtained introduce a significant video quality in terms of temporal video scaling (in fps) as compared with other studies for *single channel* systems. In Table (2), for example, Basso *et al.* [4] evaluated MPEG-4 video quality over a time-varying EDGE wireless cellular network in terms of average PSNR up to 38 dB at only frame rate of 10 fps at 100 kbps. Furthermore, using SC-EARQ scheme explains a good predicted video quality performance as compared with the Mean Opinion Score (MOS) measure and video frame rate performance evaluated by Lo *et al* . [1] over a typical UMTS network for UDP using integrated tool environment. They achieved MOS score 5 (Excellent) with PSNR up to 37 dB at full video motion of 25 fps. Also, for only single Rayleigh fading channel in [5] it is noticed that the full video motion of 30 fps based on heuristic TCP throughput can be obtained only at high channel SNR values. High range of SNR values is between 25dB and 35 dB under different mobile speeds (1km/h-36km/h). On the contrary, ARQ scheme in [22] evaluated JPEG image transmission with switched antenna diversity over slow fading channels. A 4-DPSK modulation scheme is used for channel variations, $f_D T_s = 1.3\times10^{-5}$, carrier frequency 900 MHz, 1 km/h, data rate 64 kbps, and 128 bit packet size in the transmission of type-I and



(a)

(c)

(b)

(d)

Figure 3. Video quality versus average branch channel SNR for various values of retransmissions. (a) Uncorrelated channel (b), (c) and (d) Correlated fading channels ρ =0.5, 0.7, and 0.9. *N*= 100 bit, CRC=16 bit, channel rate 144 kbps and GoP(2,3)**.**

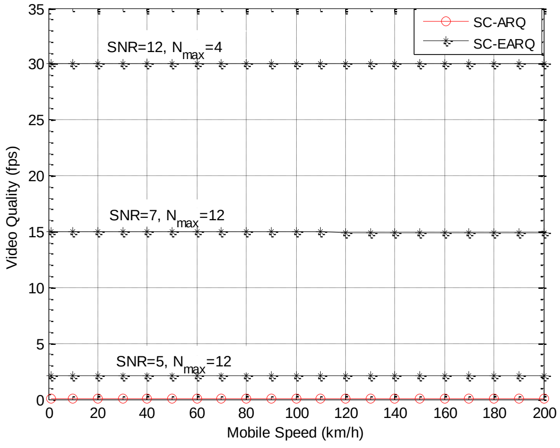


Figure 4. Video quality versus mobile speed for various branch channel SNR and retransmissions. *N*= 100 bit, CRC=16 bit, and Go(2,3).

type-II packets with a BER of 10^{-3} and consequently required SNR is about 28 dB. With two transmit antenna this decreases to 20 dB and in the presence of a large number of antennas the corresponding SNR is 15 dB. Moreover, simulation results in [17] showed only the effect of 50% reduction in maximum useful channel capacity for the two-branch diversity system using short data packet (96 bit) using two ARQ protocols (e.g., Go-back N and Stop-and-Wait); but without evaluating the video or image quality at the client end.

5. CONCLUSION

In this paper, we have dealt with the video quality performance in a dual-identical branch selection diversity receiver in time—varying channel environments. To improve the quality of service (QoS) in terms of throughput we consider the selective-repeat automatic repeat request (SR-ARQ) protocol over dual-branch Rayleigh fading channels. A high video quality at the receiver can considerably be achieved by applying the extended ARQ (EARQ) scheme of packet combining strategy. The SC-EARQ scheme outperforms the basic SC-ARQ because the expected throughput of EARQ is always higher than the only basic ARQ. As a result, a significant improvement in the video quality performance is obtained when the effect of a retransmission of packet combining is used efficiently along with selection diversity at the client end. The received video quality displays rapidly 30fps for only using small number of retransmissions at low values of channel SNRs. Further work can be extended to investigate channel-adaptation technique by combining adaptive modulation and coding (AMC) with truncated ARQ for Rayleigh or Nakagami-*m* fading in order to provide more channel gain in terms of the channel capacity (throughput), and consequently high perceptual video quality at the client end.

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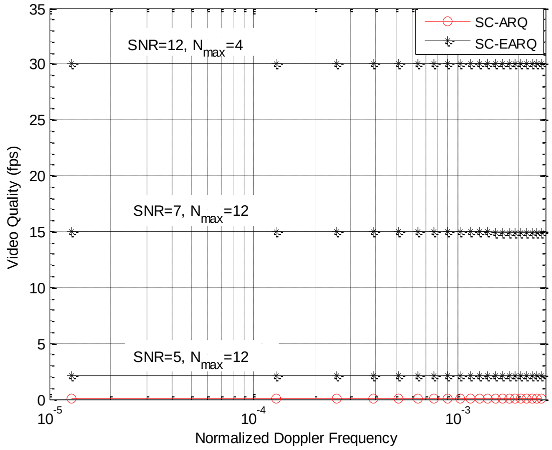

Figure 5. Video quality versus normalized Doppler frequency for various branch channel SNR and retransmissions. *N*= 100 bit, CRC=16 bit, and GoP(2,3).

Table 2. A Comparative Example for MPEG-4 Quality Performance over Rayleigh Fading Channel

Approach	**MPEG-4 Video Quality Measure**
Single channel based emulated EDGE cellular network [4]	PSNR up to 37.8-38dB (10 fps, 100 kbps)
Single Channel based heuristic TCP simulated WCDMA [5]	Play-out frame rate up to 30 fps (Channel SNR 25dB-35dB)
Single Channel - Integral Tool Based MOS-AM over UMTS [1]	MOS Score 5 (Excellent) (PSNR up to 37 dB, 25 fps)
Dual-transmit Switched Antenna Diversity based ARQ [22]	Channel SNR up to 20 dB for JPEG image (Type-I and Type-II packets)
Proposed SC-EARQ	Play-out frame rate up to 30 fps (lower SNR=12 dB, $N_{max} = 4$)

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