

## **Estimating MPEG-4 Video Transmission over Gilbert Wireless Channels**

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### **Abstract**

In this paper, the aim is to propose an analytical packet loss models to estimate the video quality for MPEG-4 video transmission over error-prone correlated wireless channels. Two packet loss models are considered at the packet level in the network layer using TCP-Friendly protocol: (i) Gilbert-Elliott Model (GEM) and (ii) Extended Gilbert Model (EGM). The resultant video quality in terms of playable frame rate (PFR) is estimated at the end client over wireless cellular network. The obtained results point out the effect of packet correlation factor on the perceived video quality under different conditions of packet loss probability. It is found that the proposed EGM model outperforms in estimating the perceived video quality.

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**Keywords**— Gilbert-Elliott, Extended Gilbert, MPEG-4 Video, TCP-Friendly, Wireless Network

### **Introduction**

The IP packet-based wireless cellular systems, like Universal Mobile Telecommunications Systems (UMTS) and High-Speed Uplink/Downlink Packet Access (HSUPA/HSDPA) technologies are recently developed for high data rate transmission [1][2][3]. However, a packet-loss process in such networks is still a crucial issue in estimating the probability of

correctly received video packets at the clients.

The real-time video transmission over the internet and wireless channel in heterogeneous packet networks is subject to various errors types. In wired networks (such as the Internet), packets are lost mainly due to buffer overflows (congestion) at the routers, meanwhile in the wireless hop, packets are often lost due to random bit errors caused by channel variations

like noise, co-channel interference, mobility, and multi-path fading effects. Thus maintaining video quality in wireless environment is very challenging and it requires more strategic planning and robust video transmission which is adaptable to the network and channel conditions [4][5].

More specifically, understanding the packet-loss process in IP-based packet networks and providing an accurate mathematical model to describe it are of great importance for the design and performance analysis of network applications (real-time applications). One way of describing the packet-loss process is to concentrate on the observed packet loss by itself without considering explicitly the causes that lead to such process [5] [6]. Thus, Markov process (chain) based models are classified in this category. In  $k$ -th order Markov chain model characterizing a loss process, the loss of every packet is assumed to be dependent only on the loss status of the previous  $k$  packet transmissions. The simplest Markov chain model is the case  $k=0$ , known as the Bernoulli model. In this model, the packet loss probabilities are independent of each other [7][8]. Another simple Markov chain model is the case  $k=1$ , known as the Gilbert model [9], which has been widely used to model end-to-end packet loss processes for real-time applications [6]- [8]. The former model has also been extended to Gilbert-Elliott model [10].

Although these low-complexity Markov chain models have been frequently used to model such processes [7][8], the accuracy of these Markovian models in capturing the correlation characteristics of real-world packet-loss processes needs to be investigated. Sanneck et al. [11] develop a different Markov chain model, called the extended Gilbert model. There are two categories of extended Gilbert models; those which describe reception run-lengths (RRL) and those which describe loss run-lengths (LRL). In our approach, we concentrate on RRL extended Gilbert models which is derived by Wu and Radha [12] to be applied for MPEG-4 video packet loss process over wireless channel.

On the other hand, many researches [13]-[18] have devoted on video streaming based on TCP/UDP protocols in different wired/wireless IP-packet networks. Specifically, TCP has become popular protocol because of its easy handling and deployment. TCP features in order delivery and reliable end-to-end transport, which makes additional tools like error concealment, unnecessary at the clients. In low-latency networks, TCP introduces good throughput performance and low end-to-end delays, which makes TCP-based interactive services possible. In [18], for example, they propose a client-driven video transmission scheme by utilizing multiple HTTP/TCP streams. In [3], they evaluate video streaming

based on TCP-Friendly Rate Control (TFRC) using Bernoulli packet loss model for a single and Multiple TFRC flows over a 1xRTT CDMA in UMTS network.

In this paper, we focus on video traffic controlled by TCP-Friendly protocol over cellular

network for the advantages of this protocol: (i) it does not cause network instability and avoid congestion collapse. (ii) it is fair to TCP flows, which is the dominant source of traffic on the internet, and finally (iii) this protocol has lower fluctuation compared to TCP. That makes TCP more appropriate for Real time applications, which requires a constant video quality [3]. To our best knowledge, the studies [13]-[18] did not investigate the extended Gilbert model for TCP video transmission over wireless channel. Therefore, we propose an approach to introduce the two packets loss models: Gilbert-Elliot Model (GEM) [7]-[10] and Extended Gilbert Model (EGM) [12]. The models employ TCP-Friendly Rate Control for MPEG-4 video

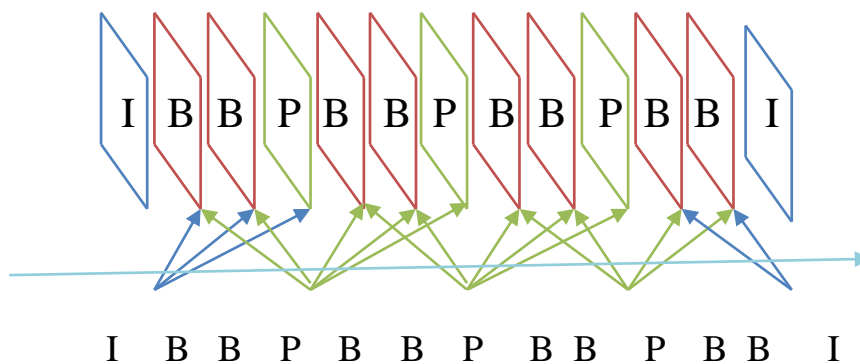
transmission, and then estimate the resultant video quality in terms of playable frame rate at the client end.

### Network Preliminaries

#### MPEG Standard

In the last years, several video standards have been developed for 3G mobile multimedia communications like H.263, MPEG-4, and H.264/AVC [8]. MPEG video is one of the most commonly used video compression standard which is encoded into three different types of frames- I (Intra-coded), P (Predictive-coded), and B (Bi-directional Predictive coded) frames.

In this standard, I-frame is independently coded, while P-frame is coded based on the prediction of object movement of the previous I or P frame. The B-frame is coded based on the differences between the previous I or P frame and the next I or P frame. Thus, there is a certain dependency relationship between I, P, B frames as shown in Fig. 1 [13][17].



**Figure1. Frame dependency**

### TCP-Friendly Throughput

We consider a video flow in a point-to-point network which is simply composed of one base station (access point) in UMTS and a single user end. This last wireless link is connected to a wired Internet via this base station [3][14]. By adjusting the sending rate to the desirable rate determined by an underlying TCP-Friendly Rate Control (TFRC), one can achieve the required quality of service (QoS) of video applications over a wireless link. Thus the normalised available bandwidth of a TFRC video session with respect to TCP packet size can be expressed as,

$$T = \frac{S}{t_{RTT} \sqrt{\frac{2P}{3}} + t_{RTO} (3\sqrt{\frac{3P}{8}}) P(1+32)} \quad (1)$$

S is the TCP packet size [byte], P stands for the average packet loss probability, i.e., loss event rate due to only the channel bit errors and there is no buffer overflow effect at the base station. The  $t_{RTT}$  is the round-trip time [sec], and is the  $t_{RTO}$  TCP retransmit time out value [sec].

### GOP Rate

Since (1) provides an expression for T as TFRC throughput, then GOP rate can be written as;

$$G = \frac{T/S}{(S_I + S_{IF}) + N_P(S_P + S_{PF}) + N_B(S_B + S_{BF})} \quad (2)$$

where is the size of I-frame, is the size of P-frame, is the size of B-frame, represents the number of P-frame in a GOP, represent the number of B-frame in a GOP [13].

### Playable Frame Rate

The total PFR by Wu et al.'s, technique is given by [13,14];

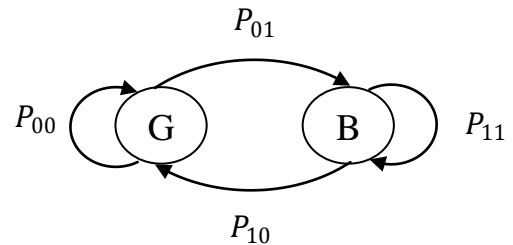
$$PFR = G \cdot P_{SI} \cdot (1 + \frac{P_{SP} - P_{SP}^{NP+1}}{1 - P_{SP}} + N_{BP} \cdot P_{SB} \cdot (\frac{P_{SP} - P_{SP}^{NP+1}}{1 - P_{SP}} + P_{SI} \cdot P_{SP}^{NP})) \quad (3)$$

Where  $P_{SI}$ ,  $P_{SP}$  and  $P_{SB}$  are the probabilities of success transmission of I, P, or B frame. The detail of the derivation of this equation is outlined in.

### The Proposed Approach

#### GEM-TFRC Video Model

Recently many studies used the measurements of burst error over a wireless channel by the well known Gilbert-Elliot model (GEM) [7][10]. In the present work, we further assume GEM as virtual channel with two nodes, to improve the video quality by estimating the playable frame rate. The state diagram of the model is shown in Figure 2, the model represents two states; the good state (good packet  $P_0$ ) and the bad state (bad packet  $P_1$ ).



**Figure 2. Gilbert Elliot state diagram for packet level**

The  $P_{01}$  is the state probability for the transition from good to bad, and  $P_{10}$  is the state probability from the transition from bad to good. The  $\pi_1$  and  $\pi_0$  study state probability being in state  $P_1$  and  $P_0$  and  $\pi_1 = \frac{P_{01}}{P_{01} + P_{10}}$ ,  $\pi_0 = \frac{P_{10}}{P_{01} + P_{10}}$  respectively. The average packet loss rate product by the GE model is [7]-[10];

$$P_{avg} = P_0\pi_0 + P_1\pi_1 \quad (4)$$

The GEM is memory less model, where Packet error is produced by a sequence of independent trial. Each packet has  $P_{avg}$  being flipped and  $1 - P_{avg}$  being successfully transmitted,  $P_{avg}$  is then the packet loss probability for the wireless channel. The network throughput becomes;

$$T = \frac{S}{t_{RTT} \sqrt{\frac{2P_{avg}}{3}} + t_{RTO} (3\sqrt{\frac{3P_{avg}}{3}}) P_{avg} (1+32)} \quad (5)$$

Giving N packet being transmitted over a Gilbert Elliott channel, with K packet received, the probability of successful transmission is;

$$P_{suc} = \sum_{i=K}^N \binom{N}{i} (1 - P_{avg})^i P_{avg}^{N-i} \quad (6)$$

With a specific I, P, and B frame sizes, Equation (5) can be used to compute the probabilities of successful transmission for each frame type as following;

$$GEMPS_I = \sum_{i=K}^{S_I} \binom{S_I}{i} (1 - P_{avg})^i P_{avg}^{S_I-i} \quad (7)$$

$$GEMPS_P = \sum_{i=K}^{S_P} \binom{S_P}{i} (1 - P_{avg})^i P_{avg}^{S_P-i} \quad (8)$$

$$GEMPS_B = \sum_{i=K}^{S_B} \binom{S_B}{i} (1 - P_{avg})^i P_{avg}^{S_B-i} \quad (9)$$

The total PFR using GEM-TFRC is expressed as

$$PFR_{GEM-TFRC} = G * GEMPS_I \cdot \left(1 + \frac{GEMPS_P - GEMPS_P^{N_P+1}}{1 - GEMPS_P}\right) + N_{BP} * GEMPS_B \cdot \left(\frac{GEMPS_P - GEMPS_P^{N_P+1}}{1 - GEMPS_P} + GEMPS_I * GEMPS_P^{N_P}\right) \quad (10)$$

### EGM-TFRC Video Model

The Second proposed model for packet loss probability is a model which was derived by Wu and Radha [12] have been used, where the

authors extends the two-state Gilbert model using the number of correctly received packets as a indexes for Gilbert states.

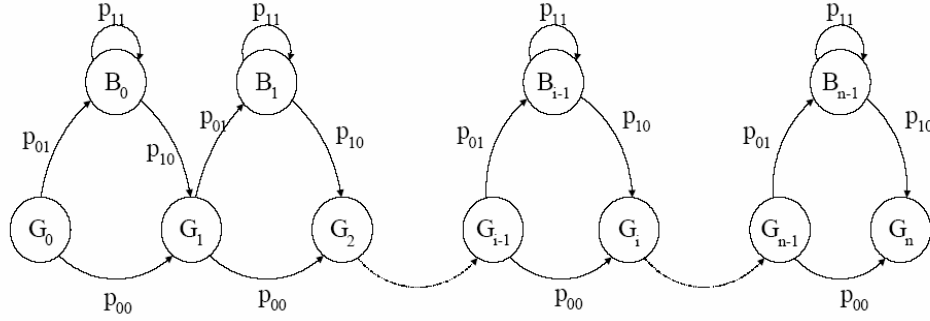


Figure 3. The state transition diagram of Extended Gilbert Model (EGM) [12].

The Extended Gilbert model is build on the probability of receiving correctly K packets among N packets transmitted over Gilbert is giving by [12];

$$\phi(N, K) = \pi_0(\phi_{G_0 G_K}(N) + \phi_{G_0 B_K}(N)) + \pi_1(\phi_{B_0 G_K}(N) + \phi_{B_0 B_K}(N)) \quad (11)$$

Where

$$\phi_{G_0 G_K}(N) = \begin{cases} \sum_{m=1}^K \binom{K}{m} \binom{N-K-1}{m-1} P_{01}^m P_{10}^m P_{00}^{K-m} P_{11}^{N-K-m} & 0 < K < N \\ 0 & K=0 \\ P_{00}^N & K=N \end{cases} \quad (12)$$

$$\phi_{G_0 B_K}(N) = \begin{cases} \sum_{m=0}^K \binom{K}{m} \binom{N-K-1}{m-1} P_{01}^{m+1} P_{10}^m P_{00}^{K-m} P_{11}^{N-K-m-1} & 0 < K < N \\ 0 & K=N \end{cases} \quad (13)$$

$$\phi_{B_0 G_K}(N) = \begin{cases} \sum_{m=1}^{K-1} \binom{K-1}{m} \binom{N-K}{m} P_{01}^m P_{10}^{m+1} P_{00}^{K-m-1} P_{11}^{N-K-m-1} & 0 < K < N \\ 0 & K=0 \end{cases} \quad (14)$$

$$\phi_{B_0 G_K}(N) = \begin{cases} \sum_{m=0}^{K-1} \binom{K-1}{m} \binom{N-K}{m+1} P_{01}^{m+1} P_{10}^{m+1} P_{00}^{K-m-1} P_{11}^{N-K-m-1} & 0 < K < N \\ P_{11}^N & K = \\ 0 & K = \end{cases} \quad (15)$$

The state probability  $P_{01}$  and  $P_{01}$  (or  $P_{00} = 1 - P_{01}$  and  $P_{11} = 1 - P_{10}$ ) are the effective parameters on the evaluation of  $\phi(N, K)$ . More useful parameters can be involved to improve the performance. In [12], the author used the average loss rate  $P$ , and the packet correlation

$\rho$ , to give another perception to the state transition probabilities, where packet correlation is the correlation between two errors symbols  $P_{00}$  and  $P_{11}$ , which can be expressed as;

$$P_{01} = P(1 - \rho) \quad (16)$$

$$P_{10} = (1 - P)(1 - \rho) \quad (17)$$

The computation of the successful transmission probabilities for a specific  $I$ ,  $P$ , and  $B$  frame sizes can be written as;

$$EGMP_{S_I} = \phi(S_I, K) \quad (18)$$

$$EGMP_{S_P} = \phi(S_P, K) \quad (19)$$

$$EGMP_{S_B} = \phi(S_B, K) \quad (20)$$

Then the total PFR using EGM-TFRC can be written as;

$$PFR_{EGM-TFRC} = G \cdot EGMP_{S_I} \cdot \left(1 + \frac{EGMP_{S_P} - EGMP_{S_P}^{N_P+1}}{1 - EGMP_{S_P}}\right) + N_{BP} \cdot EGMP_{S_B} \cdot \left(\frac{EGMP_{S_P} - EGMP_{S_P}^{N_P+1}}{1 - EGMP_{S_P}} + EGMP_{S_I} \cdot EGMP_{S_P}^{N_P}\right) \quad (21)$$

## Simulation Results

### Methodology

Based on the above assumption, we develop the following illustrative steps to find the optimal

playable frame rate based on the given models GEM-TFRC video model, and EGM-TFRC video model) mentioned in Section II.

1. Giving a specified state probability one can determine the from equation 3. For each set of other system variables, compute the PFR using equations 4 and 12. For EGM-TFRC, assign specific average loss rate  $p$ , and packet correlation, determine PFR using (4) and (21). We characterize the variation of the PFR in both Models in term of two dimensions; Packet loss Probability and PFR dimension, to find the optimal PFR.
2. Used the four different cases of transmitted and received packet with a certain probability of packet loss, to find the optimal PFR.
3. Giving a combination of packet correlation, and a set of an average loss probability, compute the PFR using (21). Characterize the variation of the PFR in term of two dimensions: packet correlation and PFR. To investigate the effect of packet correlation on the PFR, in four different cases transmitted and received packet.

### System Settings

Table 1 describes network characteristic of many typical network connection.[2] in

which we used in our simulation. Encoded video is transmitted as a repeating sequence of GOP ( $N_P, N_{BP}$ ) pattern, where  $N_P=3$  and  $N_{BP}=2$ . The  $P_{00}, P_{11}$  and  $P_0$  are set at 0.96, 0.94 and 0.001 respectively. The packet error rate is set between 0.001 to 0.1 with 0.001 intervals. Also, the packet correlation is set between 0.1 to 0.9 with 0.1 intervals.[13][12][17]

Table 1: Network Settings [3][13][12]

Parameter	Value
$t_{RTT}$	168ms
$t_{RTO}$	$t_{RTT} \times 4$
$S_I$	24.64KB ~ 25 packet
$S_P$	7.25KB ~ 8 packet
$S_B$	2.45KB ~ 3 packet

Table 2 MPEG Sending, Receiving Frames Size

	Sending	Receiving
	( $N_I, N_P, N_B$ )	( $K_I, K_P, K_B$ )
1	(25,8,3)	(25,8,3)
2	(25,8,3)	(20,6,1)
3	(25,8,3)	(25,6,1)
4	(25,8,3)	(24,6,1)

### Performance Evaluation

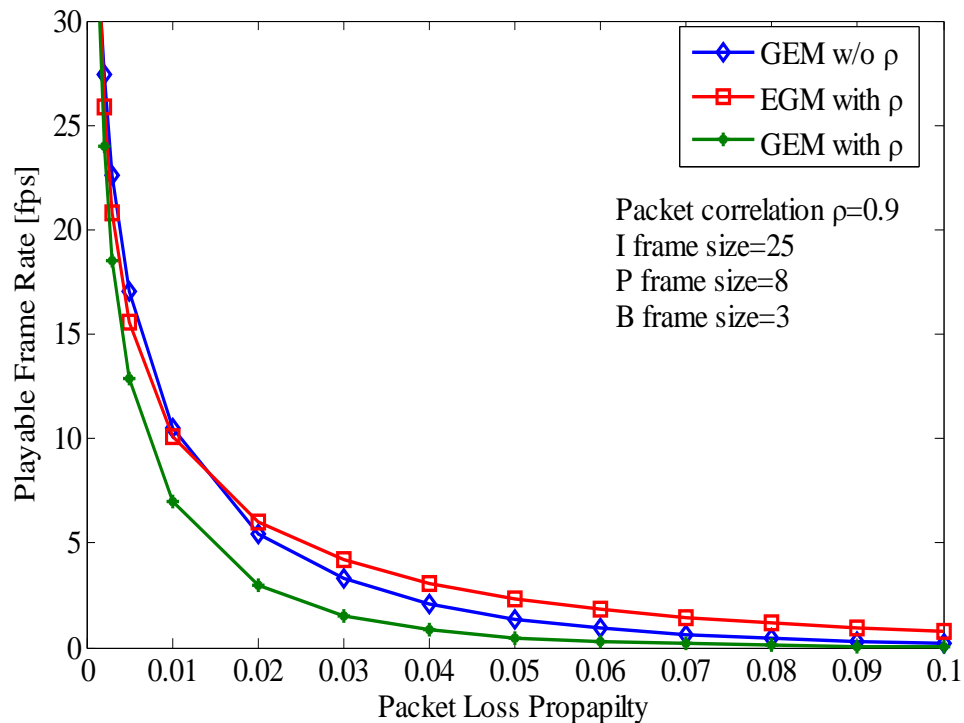
This section describe the PFR of an MPEG4 Video streaming over wireless channel using two packets lost models; the GEM-TFRC video model and EGM-TFRC video



model. The performance evaluation is carried out by considering the parameters in Tables 1, 2 and 3 for the fact that maximum frame rate allowed over internet is 30fps. Result was conducted using Matlab programming.

Figure 4 shows the PFR over the effect of packet error rate, using proposed models.

The PFR clearly indicates better performance in the range from 0.02 to 0.1 packet loss probability. Meanwhile, the GEM-TFRC becomes closer to the EGM-TFRC at packet loss probabilities below 0.02. However, the special case of the GEM-TFRC for which the correlation parameter had been added, gives us a poor performance in comparison with the other.



**Figure 4 The Playable Frame Rate comparison using GEM-TFRC without memory, GEM-TFRC with memory, and EGM-TFRC models**

Table 3 summaries different sending and receiving packets that are applied in the two models for video streaming. It is clearly noticed that there are two effects as follows:

dependency relationship between frames in GOP, and packet correlation factor. The PFR achieves the highest value at  $P=1\%$  and in contrary there is a clear degradation in video

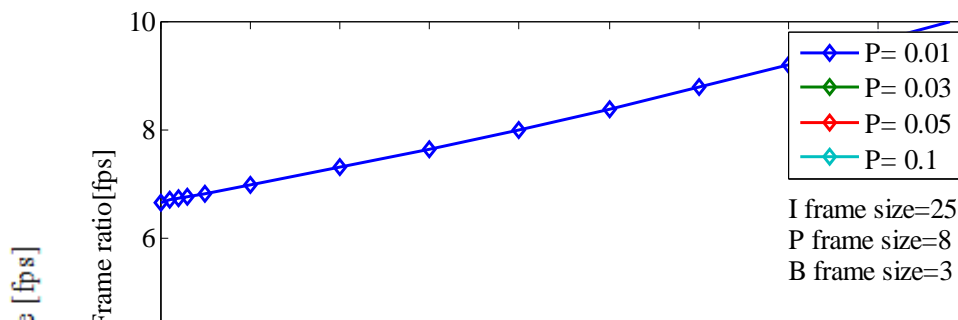
quality when packet loss increases to 5%. However, EGM-TFRC model introduces nonzero values of PFR when sending (25,8,3) and receiving (20,6,1); and this result obtained is caused due to the packet correlation factor.

Figure 5 shows the PFR over the effect of correlation factor in EGM-TFRC, when sending (NI=25, NP=8, NB=3) and receiving (KI=25, KP=8, KB=3) packets, when the packet correlation is low, it will produce low PFR; but this is not always the case when the `correlation

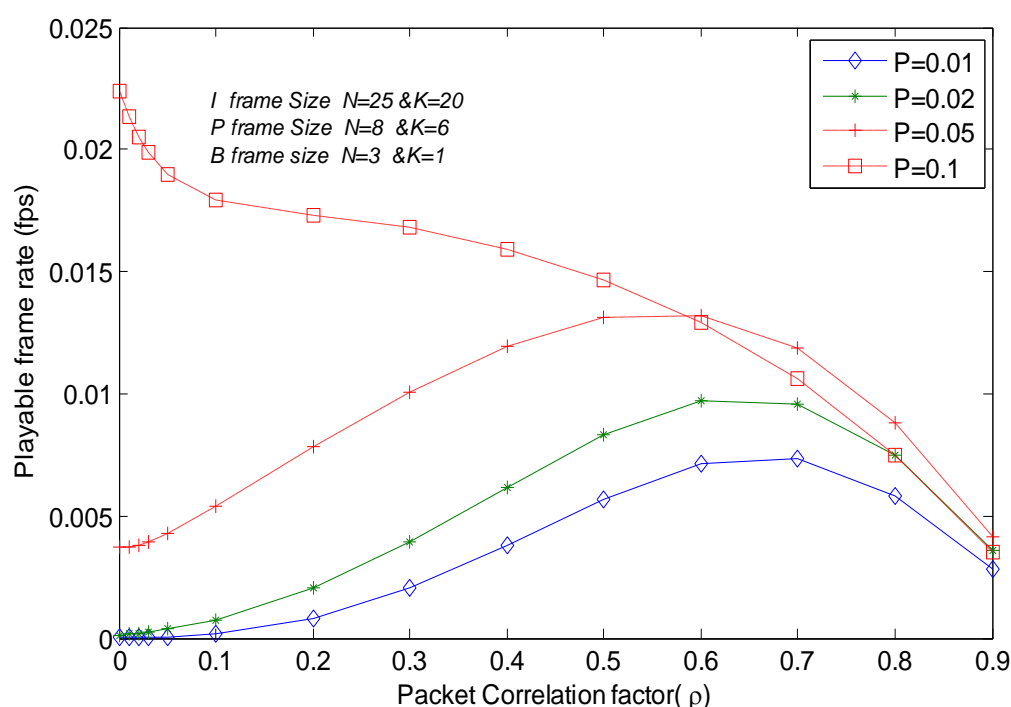
increase. In Fig. 5 we consider a case where a packet loss occur, where sending packet sizes are (NI=25, NP=8, NB=3), receiving packets (KI=20, KP=6, KB=1), as shown in Fig. 6 it is clearly shown that when  $P$  set to 1% we have got higher PFR at  $\rho = 0$ . The fluctuation in PFR values is also clearly noticed when  $\rho$  increases to 0.9. The PFR has approximately constant value over a combination of  $P$ ; as the correlation  $\rho$  is strong. Once the process initially starts in bad or good state, it has the inertia to stay at that state.

**Table 3: The MPEG4 sending and receiving Frame sizes and PFR for  $P=1\%$  and  $P=5\%$ .**

GEM-TFRC			
Sending	Receiving	PFR P=1%	PFR P=5%
( $N_I, N_p, N_B$ )	( $K_I, K_p, K_B$ )		
(25,8,3)	(25,8,3)	10.5119	1.37873
(25,8,3)	(20,6,1)	0.00	0.0005
(25,8,3)	(25,6,1)	1.4404	0.3022
(25,8,3)	(24,6,1)	0.0044	0.0062
EGM-TFRC			
Sending	Receiving	PFR	PFR
( $N_I, N_p, N_B$ )	( $K_I, K_p, K_B$ )	P=1%	P=5%
(25,8,3)	(25,8,3)	10.0929	1.3787
(25,8,3)	(20,6,1)	0.0028	0.0042
(25,8,3)	(25,6,1)	1.2677	0.3022
(25,8,3)	(24,6,1)	0.2366	0.2416



**Figure 5. The playable frame rate over the effect of correlation factor in EGM-TFRC video model when sending (NI=25, NP=8, NB=3) and receiving (KI=25, KP=8, KB=3)**



**Figure 4.b The playable frame rate over the effect of correlation factor in EGM-TFRC video model when sending (NI=25, NP=8, NB=3) and receiving (KI=20 ,KP=6 ,KB=1)**

## Conclusion

In this paper, we have proposed analytic packet loss models to estimate video quality over wireless channels with highly correlated errors

using TFRC protocol for MPEG-4 streaming. The models are based on Gilbert Elliot and Extended Gilbert model of packet loss probability. The results of GEM-TFRC video

model show good performance in high packet loss probability; meanwhile GEM and EGM both show reasonable performance as well but in the range of average packet loss rate below 2%. As a result, we conclude that these proposed models can be helpful to predict the video quality using packet loss models over wireless channels. The Future work can be extended to involve the FEC techniques the two to improve the performance of video quality under different conditions of wireless channels.

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## تقييم إرسال الصورة المرئية نوع MPEG-4 في قنوات جلبت اللاسلكية

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### الخلاصة

في هذا البحث، الهدف هو اقتراح نماذج تحليلية لفقد الرزمة لغرض مقارنة جودة الصورة المرئية من نوع MPEG4 المرسل عبر القنوات اللاسلكية ذات الاخطاء المترابطة. تم اقتراح نموذجين من فقدان الرزمة عند مستوى الرزمة في طبقة الشبكة باستخدام بروتوكول النقل TCP-Friendly; نموذج جلبت - البوت (2) نموذج جلبت الموسع. يتم تقييم جودة الصورة الناتجة بدلالة معدل الفريم العامل عند نهاية المستخدم في الشبكة الخلوية اللاسلكية. النتائج المستحصلة تبين تأثير معامل ترابط الرزمة على جودة الصورة المرئية المحسوسة تحت ظروف مختلفة من احتمالية فقدان الرزمة. وقد وجد أيضاً ان نموذج جلبت الموسع قد تفوق في مقارنة جودة الصورة المستلمة.

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