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An Adaptive Fuzzy based FEC Algorithm for Robust Video Transmission over Wireless Networks

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Abstract: Forward Error Correction (FEC) is a commonly adopted mechanism to mitigate packet loss/bit error during real-time communication. An adaptive, Fuzzy based FEC algorithm to provide a robust video quality metric for multimedia transmission over wireless networks has been proposed to optimize the redundancy of the generated code words from a Reed-Solomon encoder and to save the bandwidth of the network channel. The scheme is based on probability estimations derived from the data loss rates related to the recovery mechanism at the client end. By applying the adaptive FEC, the server can predict the next network loss rate through the use of the reports, using a curve-fitting technique to generate the optimized number of redundant packets to meet specific residual error rates at the client end. Simulation results in the cellular system show that the video quality is massively adapted to the optimized FEC codes based on the probability of packet loss and packet correlation in a wireless environment.

Keywords: Fuzzy logic, Artificial Neural Network, Video Quality, Energy-Efficient, Forward Error Correction, Cellular System, Wireless Network, Forward Error Correction.

1. INTRODUCTION

IP-based wireless networks have become more popular due to their capabilities to be used within a broad range of applications. In the next generation networks, video transmission is expected to be the dominating applications of the network worldwide. With advances in multimedia technologies demand for transmission of high-quality videos over the wireless networks increases. However, existing wireless networks may not often guarantee the required video quality at the receiver side. Moreover, video transmission over wireless network using existing algorithms is subject to various kind of errors, which could significantly impact the quality of the delivered videos.

Furthermore, the errors in the wireless hop often occur due to the random bit errors (i.e. packet loss) caused by channel variations, such as noise, co-channel interference, mobility, and multi-path fading effects. Therefore, maintaining video quality when transmitting over the wireless network is challenging and requires strategic planning. The delivered video quality has been increased by reducing the effect of packet loss by using traditional error control solutions [1]. Automatic Repeat reQuest (ARQ) and Forward Error Correction (FEC) are widely used to improve the throughput of a wireless network and reduce the effect of the network error, improving the video Quality of Experience (QoE). There are advantages and disadvantages to each error-control mechanism when applied to the network. ARQ is simple and needs less bandwidth to improve the videos' quality as the sender re-transmits the erroneous packets. However, this re-transmission incurs considerable Round-Trip Time (RTT), which delays recovery of the lost packets in the network. FEC is more complex and incurs less RTT, since the erroneous packets are corrected using redundant packets. However, the use of FFC, incurs a bandwidth overhead [2]. Video quality adaption over mobile wireless networks has been reported in literature [3]. Khan et. al. proposed a Quality of Experience (QoE) prediction model for a H.264 based low bitrate Quarter Common Intermediate Format (QCIF) video transmission [3]. The proposed approach provides a measure of user-perceived quality without requiring time-consuming subjective tests. Intelligent wireless systems for video transmission have also been reported in the literature. In these systems, various intelligent control systems are used to control the network's errors, and the wireless systems are usually implemented using Fuzzy control, decision tree, neural network, genetic algorithms, or expert systems [4]-[6]. Adaptive FEC based techniques are mainly known to be suitable in improving

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the QoE of video transmitted over error-prone mobile wireless networks. In reference [4], Hameed et al. proposed an energy-efficient QoE support framework for wireless video communications. The proposed framework consists of; a perceptual video quality model to allow the real-time prediction of video quality in low computation cost and an energy-efficient application layer with a content-aware FEC scheme to prevent video quality degradation network packet losses. Their results show that the proposed model achieved prediction accuracies of 88.9% and 90.5% on 2 distinct testing sets, which improves the probability of high-quality video transmission over wireless networks. Reference [5] used a practical decentralized (albeit heuristic) scheme to calculate the pre-buffering adaptively and re-buffering time at each user node. The proposed system is forced to operate in a "smooth streaming regime," where the system uses a minimal playback buffer under a specific run rate. Moreover, Artificial Neural Network (ANN) has also been proved to be an excellent solution to address QoS of video streaming for the cellular clients in networks through an adaptive FEC approach based on ANN [6]. The proposed model presents the idea of recovering the corrupted packets in the video flow via a suitable redundancy mechanism using FEC codes addressed by the ANN. The FEC adaptation is based on predefined probability equations that are gathered from the data loss rates related to the restoration rates, where the latter were calculated at the client end. The client-side relays this information to the Base Station (BS) via a feedback channel (RTT of TCP Friendly Rate Control Protocol (TFRCP)). The neural network trained for each video. Immich et al. proposed a cross-layer adaptive video aware FEC and Fuzzy Logic based mechanism (View FECz) in [7]. The proposed method combines the database knowledge and human experience about the intrinsic video content in addition to network characteristics by defining several Fuzzy rules over the Fuzzy sets. This method improves the quality of the delivered videos without adding any unnecessary redundancy to the video bitstream at Playback Frame Rate (PLR) below 20%. The knowledge of an expert can also be used to develop a rule-based decision-making algorithm for video transmission over a wireless network. To enhance the FEC efficiency in the network, Shih proposed integrating the FEC scheme and the packet-size control mechanism [8]. The proposed scheme uses the packet-level FEC to protect video streams. The packet-size control is integrated into the FEC redundancy control mechanism to achieve the user-specified delivery quality whilst also minimizing the total bandwidth overhead. Shih suggested a method that incorporates the Packet Size Control (PSC) mechanism with the optimal packet-level FEC to enhance the efficiency of FEC over wireless networks. According to the minimum bandwidth consumption strategy, both the degree of FEC redundancy and the transport packet size were simultaneously adjusted [9]. Jebarani and Jayanthy proposed an adaptive error control mechanism that employs a cascaded Fuzzy inference system to combat the high packet drop rates and low-power communication unreliability [10]. To improve the QoE in video streaming over a wireless network, Jammeh and Fleury proposed a Fuzzy logic-based mechanism to deliver robust video quality and control congestion [11]. Bezerra et al. presented a collaborative routing-based video streaming protocol, in vehicular ad hoc networks to reduce the video content sharing. The authors assume the vehicles as infrastructures for communication, which uses a cooperative multitude of end-user clients to establish the communication. The proposed collaborative model uses a cluster architecture, along with a routing table, which is generated by considering the location, speed and recording angle of each vehicle, to reduce the exchange of video data between vehicles. The authors reported superior performance in terms of availability for end-to-end communication, in comparison to other protocols [12]. Aliyu et.al. reported a vehicle selection technique for multi-path video streaming, over a junction area in a vehicular network. The proposed method studies the vehicle before, inside and after the junction area. In this network, all vehicles exchange a "Hello Message" with their neighbouring vehicles, where the hello message contains: vehicle ID, road ID, vehicle direction and a message time stamp. The proposed method is then employing an adopted greedy algorithm to select the best vehicle for forwarding the video, considering: the strength of hello message- in terms of the Signal to Interference Plus Noise Ratio (SINR), density of vehicles in the junction area, distance of vehicle to the base and state of the vehicle in the junction. The authors reported significant improvement on video packet loss over the state-of-the-art techniques [13].

This paper presents an adaptive Fuzzy control-based algorithm to recover error-corrupted video data packets. The proposed method can be used to determine optimal FEC for different channels states. The adaptation process of the Reed-Solomon FEC scheme is based on the probability measures derived from the data packet loss rates related to the recovery rates at the client end. The framework is based on the principle of taking inputs from the wireless channel subject to Fuzzy arithmetic and obtaining a crisp value of the FEC code. The proposed Fuzzy Logic-based Adaptive FEC Control (FL-AFEC) system demonstrates the ability to predict the next FEC code in which the Playable Frame Rate (PFR) is maximized over a highly correlated packet loss over the wireless channel. The rest of this paper is organized as follows: Section 2 introduces the proposed video transmission system, including the analytical model of the FL-AFEC system. Section 3 details the system scenario, system settings, simulation results, and performance comparison of the proposed technique. Conclusions and outlines of the future works are given in Section 4.

2. SYSTEM MODEL

In this paper, consideration of video flow in a point-to-point network has been shown in Fig. 1, which is utterly composed of one Base Station (BS) in a wireless network and a single user end. The last wireless link is connected to a wired Internet via the BS [14] and the transmission protocols are UDP/RTP/IP, which underplaying TCP-Friendly. Within this scenario the key network assumptions are:

1. MPEG-4 is the video traffic transmutation.
2. No congestion established at the Base Station (BS) node due to other cross-traffics has been defined for the wire link. Hence, it assumes that there will be no video packets loss between the server and BS.
3. Only the effect of the wireless link is taken into account to draw the end-to-end Packet Loss Rate (PLR) caused by the wireless channel errors during transmission. Thus, packet loss is assumed to be random and stationary.
4. Packet Size (S) for all connections of one application is the same, unless otherwise stated.
5. T denotes the streaming rate, where throughput is considered to be TCP-Friendly flow.
6. Two wireless channel models are considered to describe the burst error pattern as follows: (i) Gilbert-Elliot Channel and (ii) Extended Gilbert Channel to be the wireless virtual channels. Both models were derived for wireless video transmission, as explained in [15].

Therefore, the normalized available bandwidth of a TFRC video session concerning TCP packet size can be expressed as [16]:

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

where S is the TCP packet size in 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. RTT stands for Round-Trip Time in second, and RTO is the TCP Re-transmission Time Out (RTO) value in second.

Video frames are encoded and transmitted in Group of Pictures (GoP), where the first frame in each GoP is always an I-frame. An Intra-frame (I-frame) is the basis for prediction of all other frames within each GoP. The selection of number of frames within a GoP depends on the quality of the transmission channel. A size of 12 to 15 is usually used for wireless transmission. Since information within I-frame is used to reconstruct both P- and B-frames within the GoP. Any losses occurred in I-frame data packets could significantly affects the quality of the decoded frames. Information in Predicted-frames (P-frames) are also used for predictions, which has less effect on the quality of the decoded video frames. The third type of frames within a GoP named Bidirectional frames (B-frames), information in B-frames are not used for prediction. Therefore, loss of B-frame data packets just affects the quality of its reconstructed frame and does not propagate to other frames. Equation (1) provides an expression for T as TFRC throughput, the GoP rate can be written as [16]:

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

where N_p and N_B represent the number of P- and B-frames in a GoP, respectively. The total Playable Frame Rate (PFR) is determined using equation 3 [16]:

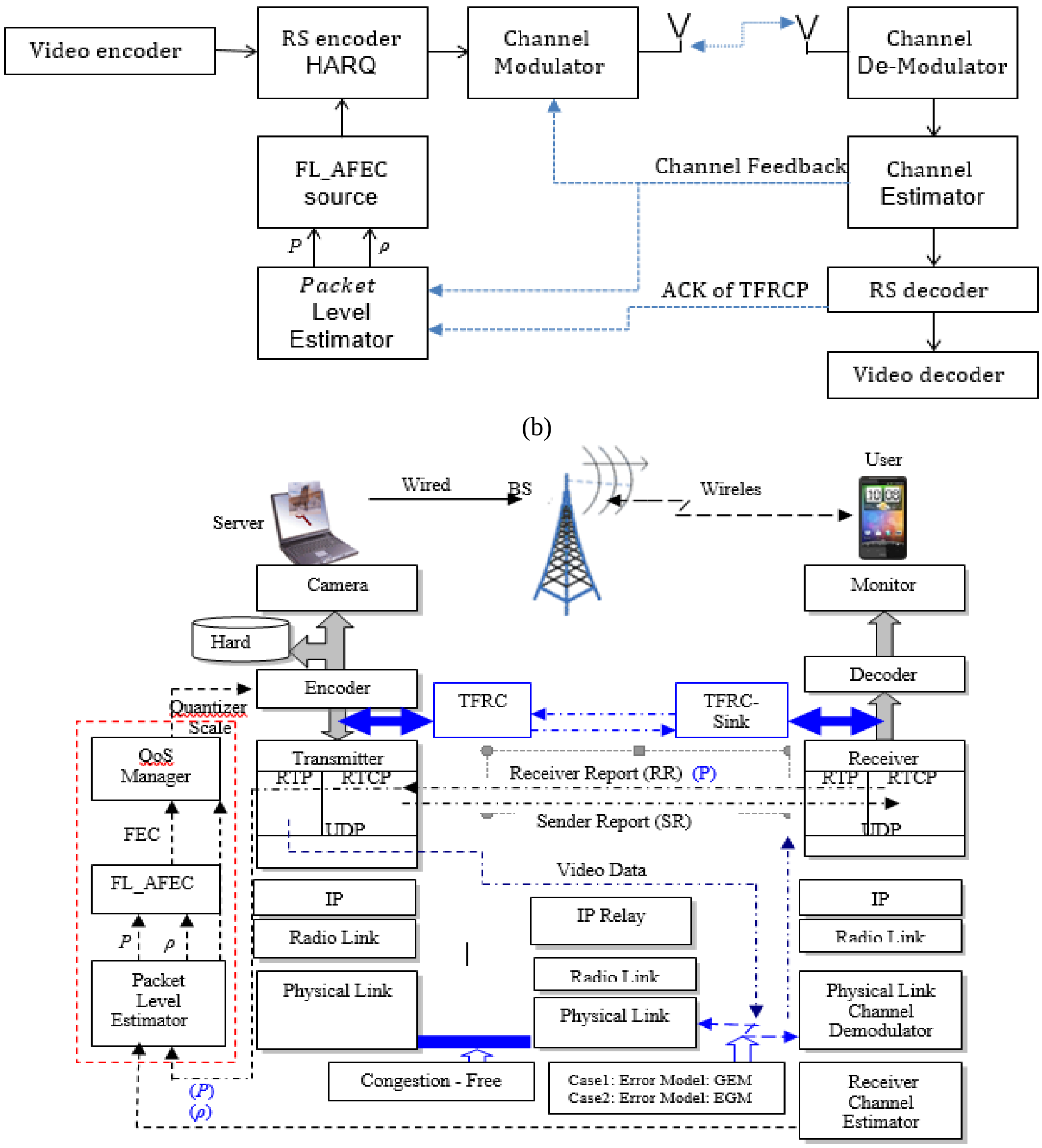
$$PFR = G.P_{SI}.(1 + \frac{P_{SP}-{P_{SP}}^{N_P+1}}{1-P_{SP}} + N_{BP}.P_{SB}.(\frac{P_{SP}-{P_{SP}}^{N_P+1}}{1-P_{SP}} + P_{SI}.{P_{SP}}^{N_P})) \tag{3}$$

where P_{S1}, P_{SP} and P_{SB} are the probabilities of successful transmission of I-, P-, and B-frames. To improve video quality, it is assumed that P_{S1}, P_{SP} and P_{SB} are the probabilities that the sender transmits N packets over two models of Gilbert channel and the receiver correctly receives K-packets. Moreover, as indicated in [17] that the models' probability can be expressed in the form of Equation (4):

$$\mathrm{P_{avg}} = \mathrm{P_0}\Pi_0 + \mathrm{P_1}\Pi_1 \tag{4}$$

where P_{avg} is the average packet loss rate product by the Gilbert Eliot model (GE), $\pi_1$andπ_0 steady state probability being in a good or bad state:

$$\varphi(N,K) = \pi_0(\varphi_{G_0G_K}(N) + \varphi_{G_0B_K}(N)) + \pi_1(\varphi_{B_0G_K}(N) + \varphi_{B_0B_K}(N)) \tag{5}$$


(a)

(b)

Figure 1. (a) System process; (b) video streaming architecture in which Fuzzy logic is considered to control the FEC.

where $\phi(N,K)$is the average packet loss probability using the Extended Gilbert Eliot Model (EGM). The detail of the derivation of this equation is outlined in [2].

3. THE PROPOSED APPROACH MODEL

A. Max-min optimization

The Max-min decision theory was the first method, which was used to find the optimum Forward Error Correction (FEC) for the network. An obvious requirement of a good Playable Frame Rate (PFR) search is to make the interval of uncertainly as large as possible. Therefore, PFR can be written in the form of Equation (6):

$$PFR_{max-GEM} = max_{0sPECsi}(PFR_{GEM\ FEC}(FEC,P,\rho)) \quad i = 0, 1, 2, 3 \qquad (6)$$

$$PFR_{max-EGM} = max_{0sPECsi}(PFR_{EGM\ FEC}(FEC,P,\rho)) \quad i = 0, 1, 2, 3 \qquad (7)$$

$$PFR_{max} = \max\,(PFR_{GEM-FEC}, PFR_{EGM-FEC}) \quad i = 0, 1, 2, 3 \qquad (8)$$

where $PFR_{max-GEM}$ denotes the maximum PFR of GEM model. When choosing one of its three FEC code sets (i.e., small, medium and large codes) for i = 1, 2, and 3, $PFR_{GEM-FEC}$ represents the PFR for GEM for one FEC code, ρ is the packet correlation. Similarly, $PFR_{max-EGM}$ is the maximum PFR for EGM model for the ith FEC code; and consequently PFR_{max} becomes the maximum PFR between both models.

B. Fuzzy Logic Adaptive FEC (FL_AFEC) method

Fuzzy Logic Controllers (FLC) [17], which mimic a human’s perception in defining level of belongings and importance of Fuzzy sets members and decision-making have been used in the development of the proposed method. In a Fuzzy set, each member is defined by two values: membership value and possibility, which they could have a value in the range of [0, 1], independently. Besides, a member of one Fuzzy set can be a member of other Fuzzy sets at the same time with the same or different possibilities. Fuzzy controllers usually use “if-then” rules to make inferences, for instance, x, y, z are linguistic variables (names for known data values), if x is high, and y is low, then z is normal, where high, low, and normal are membership functions of the Fuzzy matching subsets. In this paper, the concept of Fuzzy Logic Controllers (FLC) developed an FLC’s based method to determine network Forward Error Correction (FEC) weights. Changes to the number of packet loss and the correlation experienced by video stream packets crossing the wireless network are calculated in the receiver side and are sent to the sender. The sender uses the concept of the FLC to calculate suitable network FEC weights. Existing controllers usually select an error model when making a decision. However, in our experiments the selected error model is used to estimate the video Playable Frame Rate (PFR). Fig. 1 shows a block diagram of the system and its FLC based FEC weights calculation.

1) System Scenario

The proposed method uses to adaptively determine optimum Forward Error Correction (FEC) codes for video transmission over wireless network:

a) For each set of the system variables, the proposed method uses equation 8 to calculate $PFR_{max-GEM}$ and $PFR_{max-EGM}$, while existing methods calculate $PFR_{max-GEM}$ and $PFR_{max-EGM}$ using equations 1-4 and 6 and equations 1-4 and 7, respectively.

b) It proposed 3 rules based on the network parameters and achievable max PFR.

2) System Settings

To generate simulation results, network parameters of a typical network that is widely used in the literature, as tabulated in Table I, are used [2, 16, 18]. MPEG-4 video codec uses the following parameters to generate video bit stream: GoP = 6, and number of P- and B-frames are set to 3 and 2, respectively, and P_{00} , P_{11} and P_0 are set to 0.96, 0.94 and 0.001, respectively. The packet error rate range is set to 0.001 to 0.1 with increasing step of 0.001 [2] and the packet correlation range is set to 0.1 to 0.9 with incurring step of 0.1. In this paper, Forward Error Correction weighting factors for I-, P- and P-frames for different level of protection, presented in [16], and tabulated in Table II are used. As it can be seen from Table II, I-frames packets always have higher FEC weights than P- and B-frames data packets and P-frames data packets have larger FEC weight than B-frames. Therefore, FEC weights are in a range 1 to 10 with 1 interval.

TABLE I. SYSTEM SETTINGS

Parameter	**Value**
t_{RTT}	168ms
t_{RTO}	$t_{RRT} * 4$
N_P	3
N_{BP}	2
S_I	24.64 KB
S_P	7.25 KB

TABLE II. FEC WEIGHTS FOR I-, P- AND B-FRAMES

Code	**FEC weights**	S_{IF}	S_{PF}	S_{BF}
0	None	0	0	0
1	Small	1	1	0
2	Medium	4	2	0
3	Large	8	4	1

C. Performance Evaluation

This section describes the Playable Frame Rate (PFR) of an MPEG-4 Video streaming over wireless channel using two packet loss models named GEM and EGM. Simulation results were generated using codec and network parameters introduced in Tables 1 and 2 and considering that the maximum allowed frame rated over Internet is 30 frames per second (fps).

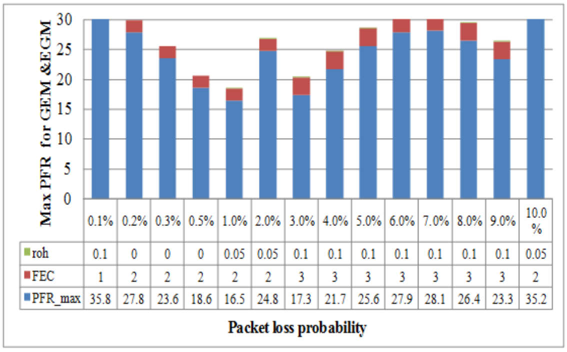


Figure 2. Maximum PFR vs the probability of packet loss and packet correlation.

Fig. 2 shows the maximum PFR versus the probability of packet loss and packet correlation, which are determine using Equation 8. Regardless of the first and the last values in Fig. 2, simulation results clearly show that PFRs of both GEM and EGM have significantly improved; it shows lowest PFR is above 16 fps, while the least acceptable value for PFR at high bitrate transmission for a moving picture is 5 fps. The improvement in PFR implies that the proposed method delivers video sequences of significantly higher quality. The proposed compound model also mitigates the PFR fluctuation due to use of different FEC weights for I-, P- and B-frames. In reference [19], the authors showed that video PFR improves more, when light FEC weights, (1, 1, 0), and small packet loss probability setting is used. The Video PFR performance deteriorated when FEC weights are increased. For probability measures greater than the threshold value, the use of medium FEC weights improves the PFR performance. The comparative resolute rules for the best PFR can be written as:

a) Rule 1: if $P \leq 0.05\%$, then application of GEM model along with small FEC weights.

b) Rule 2: If $0.05\% < P < 3\%$ and $\rho \leq 0.1$ then application of EGM model along with small FEC weights.

c) Rule 3: if $P \geq 3\%$ and $\rho \leq 0.1$ then application of EGM along with Medium FEC weights.

D. Proposed FL_AFEC Performance Evaluation

1) Experiment 1

Rule 1 is defined on a low memory channel, where ρ could have any value. Referred to Roles 2 and 3, the system presented in Fig. 1 can be modified by adding a memory element to represent ρ, where $\rho \leq 0.1$. The resulting system is shown in Fig. 3. This paper focuses on FEC weights, which are embedded in the wireless network. Hence, the model does not take into consideration all of the FL_AFEC outputs. However, server uses an error model as a part of its process. The input variables are fuzzified using a triangular-shaped membership function. Table III shows labels of input and output variables. Moreover, values of the input variables: ρ, FEC and P are normalized in the ranges given in Tables 1 and 2. MATLAB Fuzzy toolbox was used to perform the experiments. Fig. 4 illustrates the details of the proposed Fuzzy-Logic based Adaptive FEC system using Mamdani's Fuzzy–Logic. The memberships of the linguistic variables P, FEC and ρ are adjusted based on the wireless network environment to introduce the resulting Fuzzy Logic system decision surface.

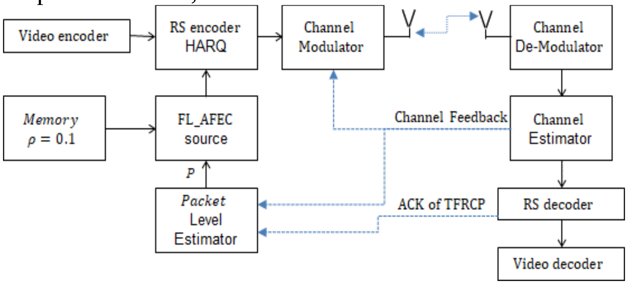


Figure 3. FL_AFEC Processing Bocks.

TABLE III. (A) LINGUISTIC VARIABLES' PROBABILITY (P) AND (B) THEIR RESPECTED FEC ASSIGNMENT RULES

(A)

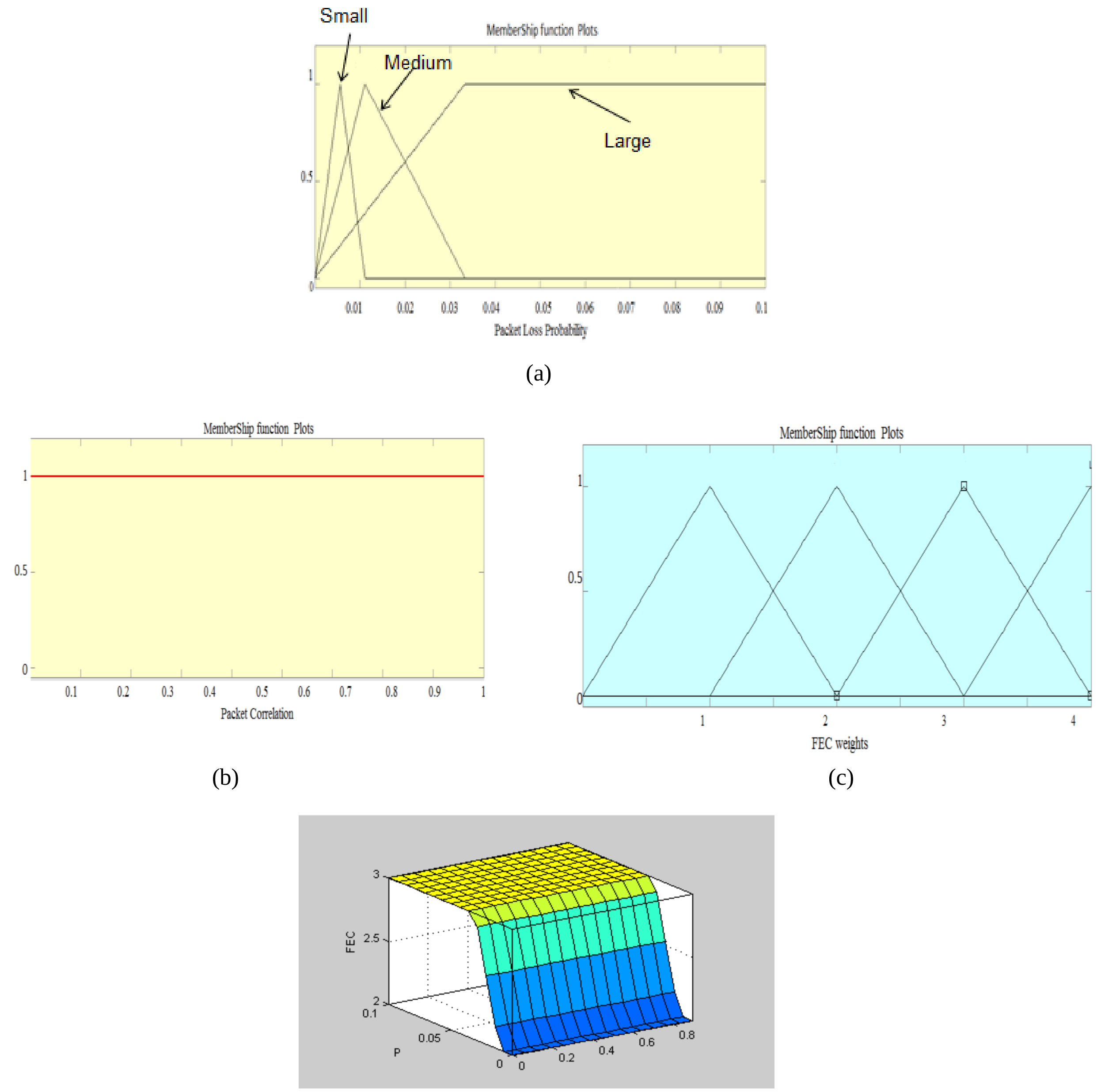
	Small	**Medium**	**Large**
P	$P \leq 0.05\%$	$0.05\% < P < 3\%$	$P \geq 3\%$

(B)

P	**Small**	**Medium**	**Large**
FEC	Small	Small	Medium

2) Experiment 2

Let both P and ρ values vary randomly. The input variables are fuzzified using the triangular-shaped membership method. Table IV shows the input and output variables' labels and values of the input variables, ρ, FEC and P are normalized in the ranges given in Tables 1 and 2. Fig. 5 shows the resulting decision surface using Mamdani Fuzzy–Logic method for single output value when General triangular-shape is considered, where experiment was conducted in MATLAB platform using its Fuzzy control toolbox.



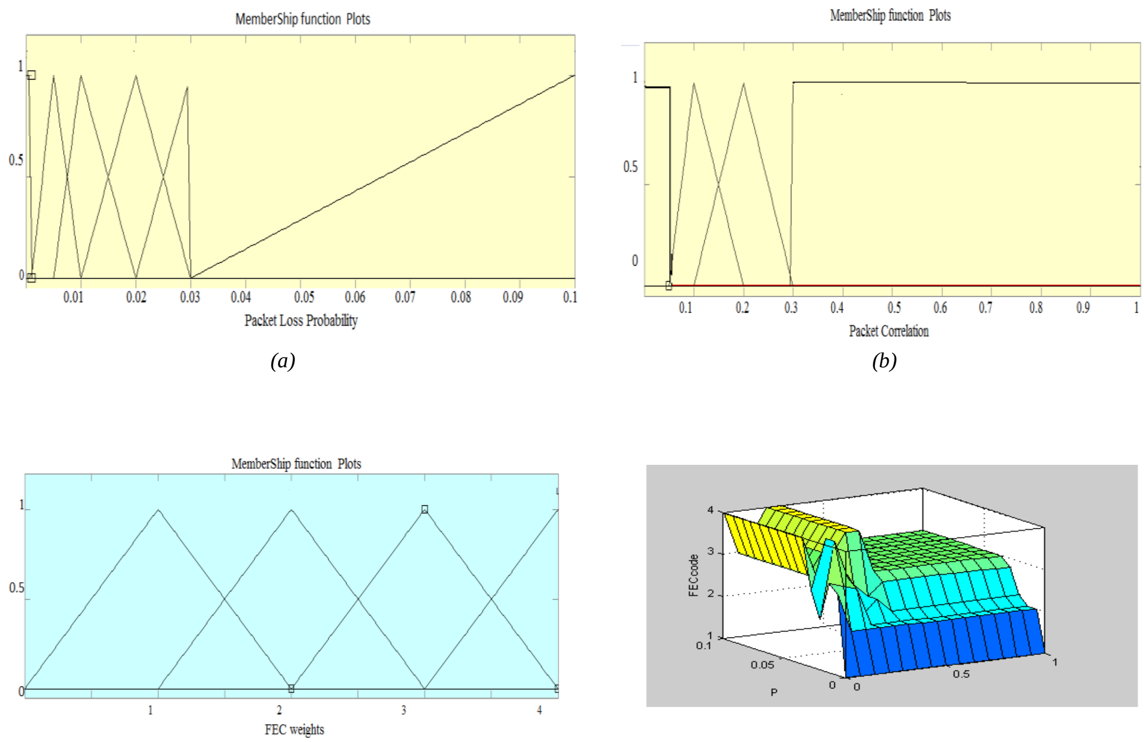
(a)

(b)

(c)

(d)

Figure 4. FL_AFEC: Mamdani Fuzzy–Logic based on triangular-shape: (a) membership of linguistic variable P, (b) membership linguistic variable ρ, (c) membership of output FEC, and (d) Fuzzy Logic system decision surface.



(a) *(b)*

(c) *(d)*

Figure 5. FL_AFEC: Mamdani Fuzzy –Logic Based on Triangular-Shape; (a) Membership of Linguistic Variable P; (b) Membership Linguistic Variable ρ; (c) Membership of Output FEC; and (d) Fuzzy Logic System Decision Surface.

TABLE IV. (A) P INPUT LABELS, (B) P INPUT LABELS, AND (C) OUTPUT LABELS.

(A)

Z	0.001	≤ 0.001
VS	0.002	≤ 0.005
	0.003	
	0.005	
S	0.01	≤ 0.01
M	0.02	≤ 0.02
L	0.03	≤ 0.03
V.L	0.04 to 0.1	>0.03

(B)

V.S	**S**	**M**	**L**
0.05	0.1	0.2	0.03 to 0.9
≤ 0.005	≤ 0.1	≤ 0.2	≥ 0.03

(C)

P/ρ	**V.S**		**S**		**M**		**L**	
	Model	**FEC**	**Model**	**FEC**	**Model**	**FEC**	**Model**	**FEC**
Z	GEM	0	GEM	0	GEM	0	GEM	0
V.S	GEM	1	GEM	1	GEM	1	GEM	1
S	EGM	3	GEM	1	GEM	1	GEM	1
M	EGM	1	EGM	3	GEM	1	GEM	1
L	GEM	2	EGM	3	GEM	2	GEM	2
V.L	GEM	2	EGM	2	EGM	3	GEM	2

CONCLUSION

This paper proposed an effective scheme, called FL_AFEC, to improve the QoS over wireless network environment. The maximum optimization method is used to determine the maximum PFR. The concept of Fuzzy Logic Controllers is used to determine FEC weights for I-, P- and B-frames, where the system uses a feedback channel to send packet loss probability and packet correlation measures to the sender. Experimental results demonstrate promising improvements in terms of PFR. Results also show that the proposed scheme achieves PFR higher than 16fps, while the least acceptable PFR for transmitting moving pictures at high data rate is 5 fps. The advantage of Fuzzy based systems is that in these systems the knowledge can be represented in comprehensible linguistic rules. Moreover, its systems implementation is much simpler.

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