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Implementation of Intelligent Fuzzy Logic Scheme in Video Transmission Over 2.4GHz Wireless

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Abstract: *Video transmission over varying channels like wireless technology is unpredictable because of interferences caused by other wireless devices in the same Industrial, Scientific and Medicine (ISM) frequency band and/or general channel noises. Transmitting Moving Picture Expert Group (MPEG) video stream over wireless technology presents a challenge, as MPEG demands large bandwidth. Considering these issues of interference and bandwidth consumption, an intelligent transmission is introduced in this research work such that the controller adjusts itself to the current state of the wireless channel to sustain MPEG video quality during the communication process. A neural-fuzzy controller and a rule-based fuzzy controller are implemented in the design to monitor input - output of a traffic shaping buffer and offer suitable parameters for the MPEG encoder for video transmission over the network. This method reduces data loss and improves image quality as compared to traditional open-loop MPEG video transmission over wireless.*

Keywords: *Video transmission, Wireless Technology, fuzzy controller, MPEG encoder, bandwidth, channel congestion.*

1. INTRODUCTION

Video is part of human's life and has become essential source of entertainment. Video compression is essential in video transmission and its storage in lesser memory. Video transmission is the technology of electronically capturing, recording, processing, storing, transmitting and reconstructing a sequence of still images representing scene in motion. Nowadays, video transmission over wireless networks is considered the most interesting application in our daily life.

Wireless networks usually provide the last mile of connectivity to users in a communication network. Though these networks have advantages of deployment and user mobility, video communication over these networks faces severe challenges [1]. The wireless networks suffer interference, noise and bandwidth variation. Furthermore, there still exits challenges of improving the quality-of-service (QoS) of multimedia applications. Some of the conventional service architectures, network structures and protocols lack the capacity to provide a robust distribution medium since most of them are not designed considering the high data rate and real-time transmission requirements of digital video [2].

Wi-Fi networks generally use 2.4GHz and 5GHz, each with its advantage over the other. One of the major advantages of 2.4GHz is that it is cheaper to manufacture devices that use the frequency, thereby making it to become popular. The 2.4GHz waves easily penetrate solid objects such as walls and floors [3].

One of the major issues with wireless network is fading [4]. It occurs due to multipath propagation, in which the received signal consists of a series of attenuated, time delayed and phase shifted replicas of the transmitted signal. The resultant received signal is the vector sum of these individual signal components arriving from different paths. These components add either constructively or destructively depending upon their relative phase difference, thus giving random amplitude variation in the received signal. Another issue with wireless network is the limited and dynamically varying bandwidth. Although wireless network support high data rate, they usually provide limited capacity. Interference is another issue with the wireless channels. It usually degrades the quality and capacity of wireless links.

Wireless channels have limited bandwidth. Uncompressed video, however, possess very high bandwidth even as such networks are not suitable to transmit the video directly over them. A variety of solutions for reliable video communication over noisy channels have been proposed to cope with the challenges. These include forward error correction (FEC), joint source-channel coding (JSCC), adaptive modulation, retransmission using automatic repeat request (ARQ), adaptive source channel coding, robust source coding, scalable coding with transport prioritization and hierarchical modulation [5].

As mobile data rates continue to increase, and more people rely on wireless transmission, the amount of video transmitted over at least one wireless hop will likely continue to increase. However, this kind of application needs large bandwidth, efficient routing protocols, and content delivery methods to provide smooth video playback to the receivers. Current generation wireless networks are likely to operate on internet technology combined with various access technologies. Achieving effective bandwidth aggregation in wireless environments raises several challenges related to deployment, link heterogeneity, network congestion, network fluctuation and energy consumption. To this end, an intelligent transmission technique is implemented in this research so that the controller may adjust itself to the current state of the wireless channel to sustain MPEG video quality during the communication process. A neural-fuzzy controller and a rule-based fuzzy controller are implemented in the design to monitor input - output of a traffic shaping buffer and offer suitable parameters for the MPEG encoder for video transmission over the network.

The report is presented such that introduction is given in Section One, methodology and implementation procedures are given in Section Two, and the results are presented in Section Three. Conclusion is made in Section Four and some recommendations are also given.

2. METHODOLOGY AND IMPLEMENTATION

This section deals with the details of the research methodology and implementation. Few concepts are also explained for clarity and synchronization. For open-loop control, the decisions over when to accept new traffic, which packets to discard, and scheduling at various points in the network are made without consideration of channel condition. In contrast, closed loop solutions are based on the concept of a feedback loop. This approach has three parts when applied to congestion control [6]. It monitors the system to detect when and where congestion occurs, passes the information to places where action can be taken and adjusts system operation to correct the problem.

2.1 Intelligent Video Transmission

In Figure 1, an overview of video transmission with neural fuzzy scheme is shown. Spatial compression is applied to a single frame of video.

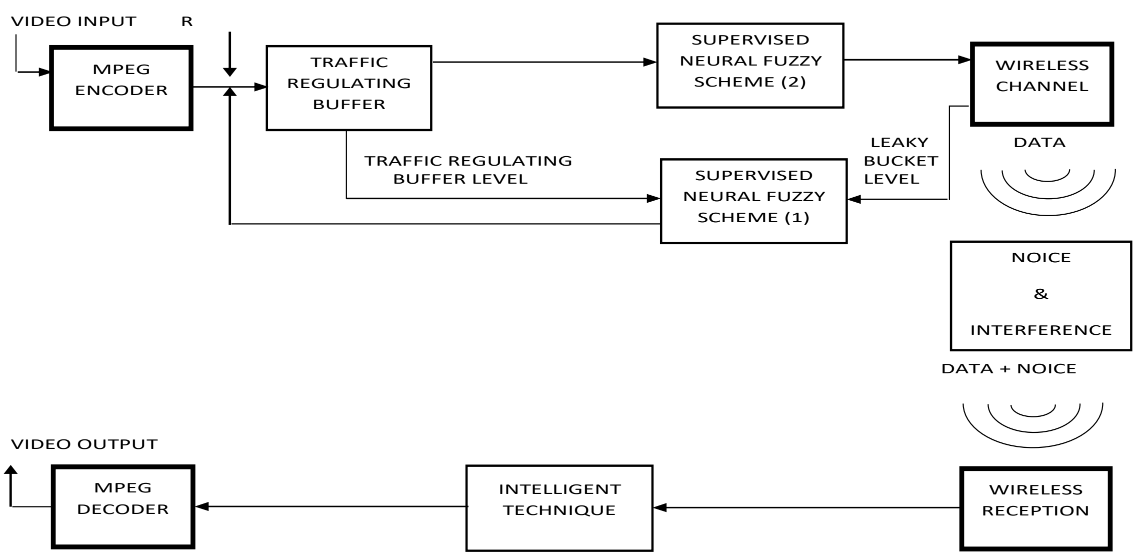

Figure 1: Overview of video transmission with neural fuzzy scheme

The degree of spatial compression affects the overall video quality, and this is the part where our design focuses to manipulate the video transmission speed. In general, the concern is to balance between the picture quality and compression degree. However, video transmission speed is a crucial factor in choosing suitable configuration for spatial compression as well as the picture quality and compression degree [7].

Discrete Cosine Transform (DCT) and Quantization are the main functions in spatial model. DCT is a method of compressing an N×N block of data into a weighted sum of spatial frequencies. The following equation represents a 2-D DCT for an N×N block [8-9].

$$Spq = \alpha p \alpha q \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} Txy \cos\left[\frac{\pi(2x+1)p}{2N}\right] \cos\left[\frac{\pi(2y+1)q}{2N}\right] \quad (1)$$

where p, q = horizontal and vertical frequency indices = 0,1, 2…, N-1.

αp and αq are given by;

$$\alpha p = \begin{cases} \sqrt{\frac{1}{N}} \; for\ p = 0 \\ \sqrt{\frac{2}{N}} \; for\ p \neq 0 \end{cases} \quad (2)$$

Inverse DCT can be calculated by using Txy where x, y = 0,1, 2…, N-1. Quantization takes the DCT coefficients and maps them into a quantized signal with a reduced range of values. A scalar quantizer is used here, where each coefficient is mapped to obtain an individual quantized value. In an entropy encoder process, probabilities of the symbols, which represent elements of video sequence are assigned. These probabilities are then used to produce a compressed bit sequence, which is ready for the transmission [7].

Figure 2 outlines the overall diagram of a rule-based fuzzy (RBF) Controller and a neural-fuzzy (NF) Controller for MPEG VBR video transmission over 2.4 GHz wireless technology. This research introduced a traffic shaping buffer to manipulate and co-ordinate the VBR encoding video prior to entering the wireless channel [10]. The shaper buffer's role is to smooth the video output traffic and to partially eliminate the burstiness of the video stream entering the network. An RBF controller regulates the average arrival rate to the traffic-shaper to prevent either overflow or starvation of the buffer on a Group of Picture (GOP) basis.

In this research work, MPEG is based on Phase Alternate Line and it is assumed that there are 24 frames. A GOP has 12 frames and there are two GOPs in one second. The arrival rate is controlled to prevent excessive back-to-back data being produced during the peak transmissions of MPEG VBR video sources.

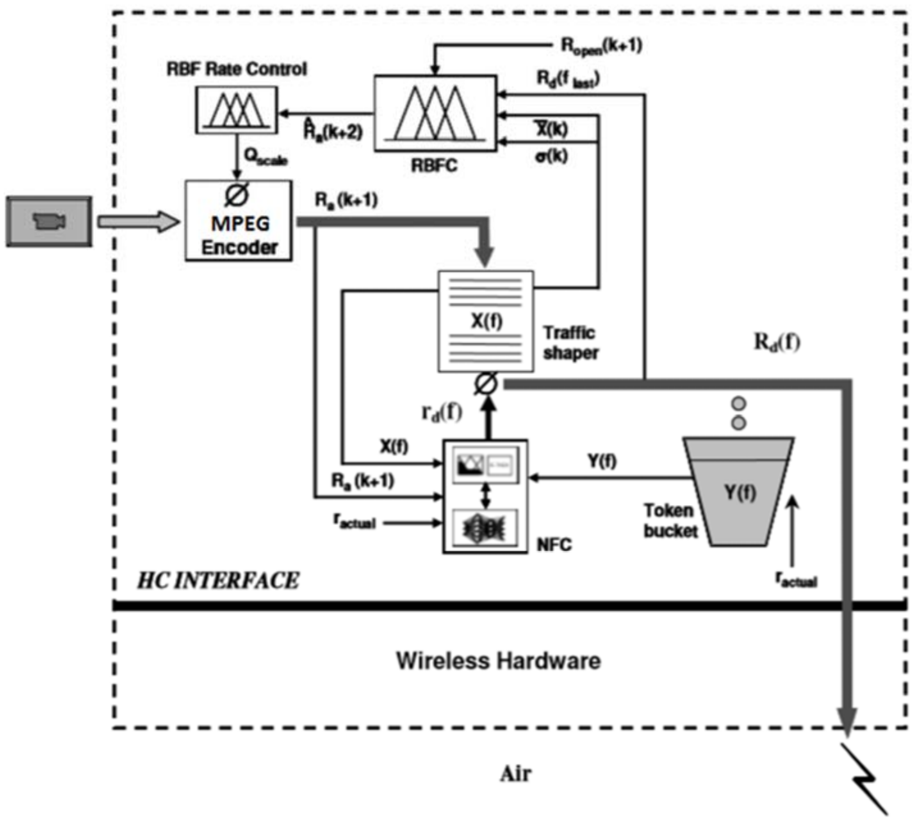

Figure 2: Intelligent video transmission in wireless technology

The inputs to the RBF controller are the fuzzified mean value $\overline{X}(k)$ and the fuzzified standard deviation σ(k) of the queue length from the traffic-shaping buffer and the output from the RBF controller is the fuzzified desired arrival rate $\hat{R}a\ (k+2)$.

The departure rate of the last frame $R_d\ (f_{last})$ and the estimated data-rate $R_{open}\ (k+1)$ for an open-loop algorithm are used to calculate the desired arrival rate $\hat{R}_a\ (k+2)$.

At any instant, the kth GOP is the group that has completely entered the network. The (k +1)'th GOP is the picture group which is in the process of passing through the model to reach the token-bucket and finally entering the wireless channel. The (k +2)th GOP is the picture group currently being encoded by the MPEG encoder.

This approach guarantees the traffic enters Bluetooth at an almost constant bit rate, while maintaining a relatively constant video quality. In effect, the burstiness of the VBR video is only suppressed and changed when the shaper buffer threatens to overflow. Therefore, this system maintains the benefits offered by the VBR encoding scheme while it controls the burstiness of the video stream entering the Bluetooth medium.

The inputs to the NF controller are the fuzzified queue length $X(f)$ from the traffic-shaping buffer and the fuzzified available tokens from the generic cell rate algorithm commonly known as token bucket $Y(f)$ [12-13].

It should be noted that token bucket or generic cell rate algorithm is usually associated with data transmission over most wired and wireless standards. However, token bucket rate policing method is largely inadequate to sufficiently regulate transmission of video data sources over wireless standards. The output from the NF controller is the fuzzified departure data rate $r_d(f)$. f is denoted for a frame. The range of the departure rate $R_d(f)$ is between the arrival rate $R_a(k+1)$ and the actual transmission (token) rate r_{actual}.

The rules associated with RBF1 controller are listed below, which are prewritten, and based on human experience and trial and error. The values of traffic-shaper departure rate $Rd(f)$ measured in kilobits per second, are generated from the output of the RBF1 controller [11]. The rule-based section of the integrated NF system and the RBF controller are based on Mamdani's min implication function. The inputs to the NF controller are the queue length in the traffic-shaping buffer X(f) and the available memory space in the token-bucket Y(f). X(f) and Y(f) are normalized using the capacities of the traffic-shaping buffer and the memory space of the token- bucket, respectively. The output from the NF controller is departure rate $r_d(f)$, measured in kilobits per second, using (3).

$$Rd(f) = 1/[i_d(f) \times (I_{d\_max} - I_{d\_min}) + I_{d\_min}] \quad (3)$$

where i_d represents the data inter-departure time from the traffic-shaping buffer. I_{d_max} and I_{d_min} are the maximum and minimum inter-departure time respectively. The values of I_{d_max} and I_{d_min} are determined by (4) and (5).

$$I_{d\_max} = \max\{1/R_a(k+1), 1/r_{actual}\} \quad (4)$$
$$I_{d\_min} = \max\{1/R_a(k+1), 1/r_{actual}\} \quad (5)$$

By keeping the values of the traffic-shaper departure rate $Rd(f)$ between the arrival rate $Ra(k+1)$ and the actual token-rate $ractual$, we ensure that there will always be a video stream flowing through the system as long as $Ra(k+1) \neq 0$. X(f) and Y(f) are calculated using

$$\mathrm{X}(f) = \frac{1}{K} \times \sum_{ki=0,fi=1}^{ki=k,fi=f-1} [Ra(ki+1) - Rd(fi)] \times \mathrm{T}f \quad (6)$$
$$\mathrm{X}(1) = 0, \quad 0 \le \mathrm{X}(f) \le 1$$
$$\mathrm{Y}(f) = \frac{1}{b} \times \sum_{fi=1}^{fi=f-1} [ractual - Rd(fi)] \times \mathrm{T}f \quad (7)$$
$$\mathrm{Y}(1) = \mathrm{b}, \quad 0 \le \mathrm{X}(f) \le 1$$

where b is the buffer size of the token-bucket, k is the buffer size of the traffic-shaper, and Tf is the time period of a video frame [13].

2.2 Implementation of MPEG Transmission Scheme in Matlab-Simulink

A Sugeno-Type Fuzzy (STF) controller is used to create a direct mapping from the inputs X(f) and Y(f) to the output of the NF controller. Each layer in the neural network is associated with a particular step in the fuzzy inference system. The first layer is the fuzzification layer. The activation function of a neuron is set to the membership function that specifies the neuron's fuzzy set [14]. In this research, each neuron in fuzzification layer has a bell activation function, which is defined in (8).

$$f(x) = \frac{1}{1+\left|\frac{x+c}{a}\right|^{2b}} \quad (8)$$

where the shape of the bell depends on parameters a, b and c; a and b both determine the shape of the membership function, while c (usually positive) locates the centre of the curve.

The values of these three parameters are decided through the training of ANFIS. Each neuron in the second layer corresponds to a single STF rule. A rule neuron receives inputs from the respective fuzzification neurons and calculates the firing strength or the truth-value of the rule it represents. The third layer is the defuzzification layer, which calculates the consequent value of each rule, weighted by the firing strength of that given rule. The NF scheme used in this work is a zero-ordered Sugeno-Type system, which means the activation function of each neuron in the defuzzification layer is equal to a constant. The exact values of these constants are determined through the training process of the NF system.

Finally, the output layer is represented by a single summation neuron [15]. This neuron calculates the sum of outputs of all defuzzification neurons and produces the overall ANFIS output. ANFIS is trained to approximate the mapping created by NF controller. Therefore, ANFIS has the same inputs and output as the integrated NF controller. The inputs X(f) and Y(f) are defined by four fuzzy sets and three fuzzy sets respectively. Since ANFIS is essentially a multi-layered neural network, the NF scheme is trained using the back-propagation algorithm; the standard training algorithm for multi-layered feed-forward neural networks.

An adaptive technique is incorporated into the control scheme through the use of a neural-fuzzy controller in Figure 2. First, a neural network represents a rule-based fuzzy controller. This network comprises of a three-layered architecture [15] and uses fuzzy sets (i.e. fuzzy membership functions) as its weights at the input and output layers. The nodes of the hidden layer embody the fuzzy IF-THEN rules. The conventional back-propagation procedure [16] for multilayer neural networks is utilized to train the fuzzy membership functions. The parameters associated with the membership functions change through the learning process such that the network interprets the desired input/output map of the controller as accurately as possible. Finally, the parameters attained from the training procedure are fed back into the fuzzy system to facilitate the best control performance.

The NF controller is based on Sugeno or Takagi-Sugeno-Kang method [17]. Therefore, the proposed adaptive scheme is a Sugeno RBF1 controller whose output membership functions are of a first-order. Sugeno method works well with optimization and adaptive techniques. This research introduces a novel rule-based fuzzy set to automate the rate control in the MPEG encoder. In Fig. 3.2, the RBF Rate Control is placed before the MPEG encoder. The desired $\hat{Ra}(k+2)$ is an input to the RBF Rate Control. In this approach, *Qscale* for I picture is attained first, followed by *Qscale* for P picture and then B picture. The process starts by using initial *Qscale* and find the difference between the offered *Ra* and the desired $\hat{Ra}(k+2)$. The result will determine the next *Qscale* to be tested. For example, if the offered *Ra* is higher than the desired $\hat{R}a\ (k+2)$, *Qscale* could be decreased. Hence the new *Qscale* to be tested is the minimum *Qscale.* The same process continues to find *Qscale* for P picture then B picture. Eventually, a set of *Qscale* for I, P and B is offered for the new GOP to be used in the MPEG encoder. The rules of this RBF Rate Control are reasonably straight forward yet effective. The input of the RBF Rate Control consists of 11 membership functions shown in Fig. 3.2.4 as level 1 to level 11. These levels represent 11 range of values between 0 to 1. The input arrived at the RBF Rate Control is then mapped into this membership function and passed through the rule-based fuzzy set to offer the output. The major advantage of this novel approach is the speed [18], which is one of the most important aspects in video transmission.

3. RESULTS AND DISCUSSION

This section presents the results and their discussion. The results obtained from the video transmission simulation using MATLAB Simulink are presented having implemented both the open-loop and the neural-fuzzy transmission schemes. Furthermore, the results of the open loop VBR encoding system are compared with the proposed intelligent NF scheme and are given in Table 1. When the NF scheme is applied, the percentage of dropped data decreases by more than 94% and the standard deviation of output rate of the wireless channel decreases by 74.9%. The numerical results of testing clips using intelligent fuzzy logic controller is shown in Table 1.

Table 1: Comparison of Simulation Results from Open-loop and Intelligent System

Video1	Open loop scheme	Intelligent Scheme
Width (pixel)	640	640
Height (pixel)	112	112
Average GOP size (kbits)	389.827	430.610
Total % of dropped data	9.431	0.561
Standard deviation of GOP size (kbits)	138.066	34.667
Video format	RGB24	RGB24
Frame rate	30	30

The MPEG encoder output variance rate for the open loop VBR system is higher than the NF scheme and RBF1 scheme. In noisy situation like combined noise, the intelligent fuzzy controller adapts itself to the actual channel condition, resulting in an increase in the variance of output rate from the traffic-shaper. The MPEG decoder developed here needs to be able to cope with missing information.

At some points in the simulation, when one or both buffers are full and data stream is still provided from the MPEG encoder, the excessive data will have to be dropped. In this research, only the B picture can be dropped as the loss of B picture will not affect other frames in the GOP. As a result, the MPEG decoder needs to be modified in order to cope with the loss of B picture. This is done by replacing the missing information with the default values to complete the stream for each component. The components are then ready to be decoded. Video clip, Video 1 is used in this research to simulate the proposed intelligent system. Simulations are carried out for both open-loop encoding system or VBR system and the proposed intelligent system to compare the results.

Table 1 gives summarized values for both plots showing that the standard deviation of the intelligent system is much lower than the standard deviation obtained for the open-loop encoding system, which results in reduction in burstiness and data loss. Also, in Table 1, the GOP size is averaged for both systems and there are more GOP sizes for the intelligent system than the open-loop system demonstrating more data for transmission resulting in better picture quality.

Figure 3 and Figure 4 summarize the results obtained from the conventional open-loop system and the implemented intelligent system respectively. By inspection, it can be seen that in terms of transmission rate regulation, the intelligent technique can manipulate the MPEG encoder as well as regulate the bit rate in order to keep the output bit rate R_d in line with the actual transmission speed, r_{actual}. Which proofs much better than the open-loop system. The burstiness of video data in Figure 4 is much better controlled for the departure rate R_d than the arrival rate R_a resulting in better image quality. The overall data dropped is much more for the open-loop system in Figure 3 than the intelligent system in Figure 4 because arrival and departure rates are controlled as much as possible. It was observed that the frames from the open-loop system display data loss and distortion. However, the original image could roughly be seen, and this is because of the advanced technique in spatial compression offered by MPEG scheme.

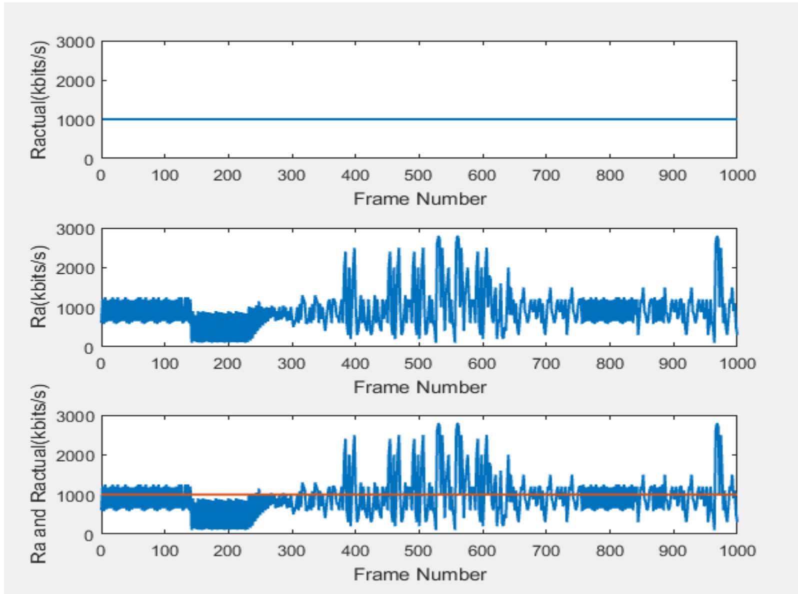

Figure 3: Video1 Open-loop encoding system results for arrival rate (R_a) and actual transmission rate (r_{actual}).

The motion vector is a very important part in reconstructing the image for the B picture, which was allowed to be dropped in this work. With full set or part of motion vector, the image can be reconstructed from the reference frame(s). Furthermore, the open-loop system experienced severe loss in many frames in fast moving events, while the images captured from the intelligent system showed no data loss. In this scenario, no data survives for the pictures in the open-loop system, and without motion vectors, the images cannot be reconstructed.

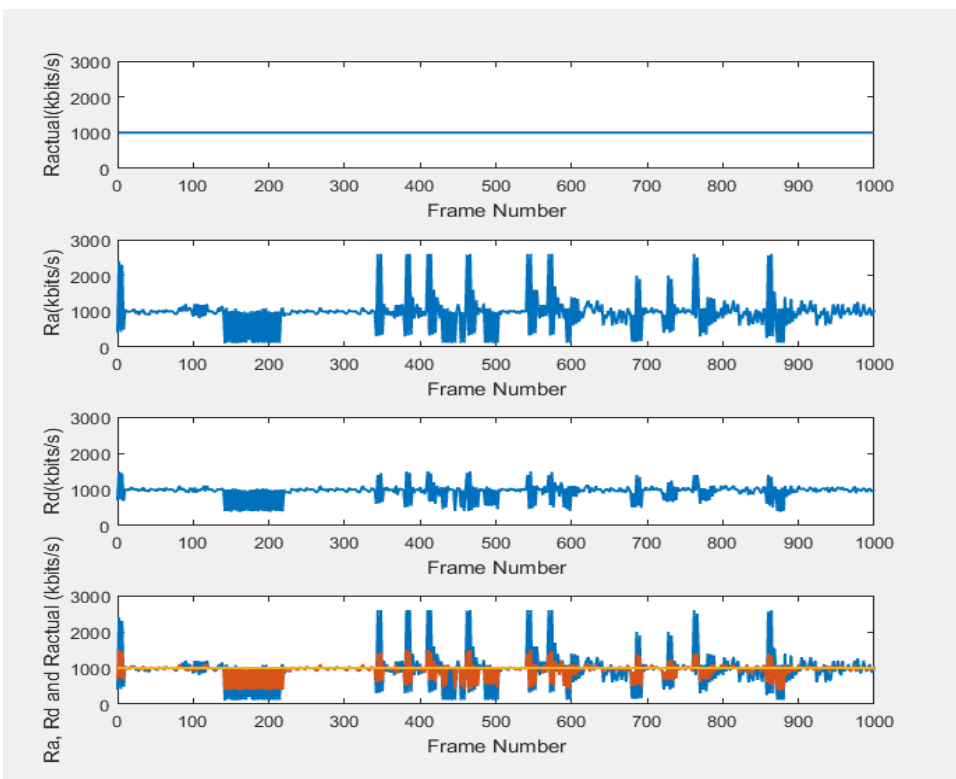

Figure 4: Video1 - Intelligent system results for traffic shaper arrival rate (R_a) and departure rate (R_d) and actual transmission rate (r_{actual}).

4. CONCLUSION AND RECOMMENDATION

Wireless video communication has to cope with time-varying channel conditions such as high error rates, burst error, link outage in case of severe fading, and capacity variations as well as limited power and low complexity issues.

Two intelligent schemes, a rule-based fuzzy controller and a neural-fuzzy controller were implemented to oversee the arrival rate to a traffic shaping buffer and the departure rate from the buffer respectively. This work reduced MPEG video data loss and standard deviation, while increasing the overall data distribution and the size of GOP of data transmission, which results in improving picture quality. Furthermore, the research work used a novel fuzzy approach to quantization level control, which sped up the transmission rate. The intelligent system is based on simple algorithms, which accommodate for the data loss at the receiving end and could be used for real-time implementations in delay-intolerant MPEG video services in wireless devices.

It is recommended that efficient error detection and correction technique could be used at the receiver to reduce the effect of noise and interference in the wireless channel. Use of large membership function can provide more accurate information as feedback to the traffic shaping buffer, and a trade-off can be made between video quality and compression degree to have a better transmission performance.

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Appendix

Rules in the RBF1 Controller

1. If (Mean $\bar{X}$ is small) and (Standard-deviation σ is small) then (Arrival-Rate $\hat{R}a$ is intermediate-large)
2. If (Mean $\bar{X}$ is small) and (Standard-deviation σ is intermediate) then (Arrival-Rate $\hat{R}a$ is large)
3. If (Mean $\bar{X}$ is small) and (Standard-deviation σ is large) then (Arrival-Rate $\hat{R}a$ is intermediate)
4. If (Mean $\bar{X}$ is intermediate) and (Standard-deviation σ is small) then (Arrival-Rate $\hat{R}a$ is intermediate)
5. If (Mean $\bar{X}$ is intermediate) and (Standard-deviation σ is intermediate) then (Arrival-Rate $\hat{R}a$ is small)
6. If (Mean $\bar{X}$ is intermediate) and (Standard-deviation σ is large) then (Arrival-Rate $\hat{R}a$ is intermediate-small)
7. If (Mean $\bar{X}$ is large) and (Standard-deviation σ is small) then (Arrival-Rate $\hat{R}a$ is very-small)
8. If (Mean $\bar{X}$ is large) and (Standard-deviation σ is intermediate) then (Arrival-Rate $\hat{R}a$ is very-small)
9. If (Mean $\bar{X}$ is large) and (Standard-deviation σ is large) then (Arrival-Rate $\hat{R}a$ is very-small)
10. If (Mean $\bar{X}$ is very-large) and (Standard-deviation σ is small) then (Arrival-Rate $\hat{R}a$ is intermediate-small)

11. If (Mean $\bar{X}$ is very-large) and (Standard-deviation σ is intermediate) then (Arrival-Rate $\hat{Ra}$ is very-small)
12. If (Mean $\bar{X}$ is very-large) and (Standard-deviation σ is large) then (Arrival-Rate $\hat{Ra}$ is very-small).

Rules in the NF Controller

1. If (Token Y is empty) and (Queue X is empty) then (Departure rate *Rd* is very-small)
2. If (Token Y is empty) and (Queue X is medium) then (Departure rate *Rd* is very-small)
3. If (Token Y is empty) and (Queue X is full) then (Departure rate *Rd* is very-small)
4. If (Token Y is empty) and (Queue X is very-full) then (Departure rate *Rd* is small)
5. If (Token Y is medium) and (Queue X is empty) then (Departure rate *Rd* is very-small)
6. If (Token Y is medium) and (Queue X is medium) then (Departure rate *Rd* is intermediate)
7. If (Token Y is medium) and (Queue X is full) then (Departure rate *Rd* is large)
8. If (Token Y is medium) and (Queue X is very-full) then (Departure rate *Rd* is very-large)
9. If (Token Y is full) and (Queue X is empty) then (Departure rate *Rd* is very-small)
10. If (Token Y is full) and (Queue X is medium) then (Departure rate *Rd* is large)
11. If (Token Y is full) and (Queue X is full) then (Departure rate *Rd* is very-large)
12. If (Token Y is full) and (Queue X is very-full) then (Departure rate *Rd* is very-large