Proceedings of the 2007 IEEE Symposium on Computational
Intelligence in Image and Signal Processing (CIISP 2007)

An Integrated Neuro-Fuzzy Approach to MPEG Video Transmission in Bluetooth

H. B. Kazemian *Senior Member, IEEE*, and S. Chantaraskul
London Metropolitan University
Computing, Communications Technology and Mathematics Dept
100 Minories, London EC3N 1JY, UK

***Abstract*— This paper presents an integrated Neuro-Fuzzy (NF) scheme and a Rule-Based-Fuzzy (RBF) scheme applications to Moving Picture Expert Group (MPEG) video transmission in Bluetooth. In a Bluetooth network, transmission rate is unpredictable due to interferences by other wireless devices or general Bluetooth channel noises. MPEG Variable Bit Rate (VBR) video transmission is also unreliable and presents long delay and excessive data loss, due to variations in bit rate. It is therefore almost impossible to transmit MPEG VBR video over a Bluetooth channel, without data loss, excessive time delay or image quality degradation. In this work, a traffic-shaping buffer is introduced before the Host Controller Interface (HCI) of the Bluetooth protocol stack. An integrated NF scheme reduces the burstiness of the traffic-shaper output rate to enable the MPEG VBR video to comply with the generic cell rate algorithm contract before entering the Bluetooth channel. The computer simulation results show that the application of the proposed scheme reduces excessive time delay and data loss at the HCI, as compared with a conventional video transmission in Bluetooth.**

***Index Terms*— Bluetooth, MPEG VBR Video, integrated Neuro-Fuzzy scheme, Rule-Based-Fuzzy scheme.**

I. INTRODUCTION

Bluetooth is a short-range radio signal, which replaces the cables connecting electronic devices. Bluetooth permits high-quality, high-security, high-speed and low-power, voice and data transmission [1]. In Bluetooth networks, the bandwidth is significantly variable, as results of interferences in radio-frequency environments and portability of Bluetooth hosts. Furthermore, the maximum bandwidth supported by Bluetooth wireless is very limited. MPEG VBR video transmission adds more uncertainty and complexity to Bluetooth wireless. MPEG VBR video is data-hungry and requires a very large bandwidth for a successful transmission with a constant video quality. Therefore, there are many challenges to be overcome to allow video to be transmitted over the wireless network. To avoid these problems and to provide a good quality of service to the customers of the network, this research recommends using a new approach by implementing a Neuro-Fuzzy traffic control at the point of transmission.

Neural networks and fuzzy logic have been applied to many video / multimedia transmissions over wired and wireless networks. For example, Hopfield neural network has recently been applied to Connection Admission Control (CAC) for multimedia transmission over wireless networks providing Quality of Service (QoS). Simulation results show that the algorithm can maximize resource utilization and maintain fairness in resource sharing, while maximizing the statistical multiplexing gain in providing acceptable service grades [2]. Fuzzy logic deals with uncertainty inherent within processes and has been widely used in many control problems, such as MPEG VBR [3]. Furthermore fuzzy logic has been used for multimedia flow control over IEEE 802.11b wireless to provide QoS using CAC [4], Usage Parameter Control (UPC) [5] mechanisms. The real-time experimental results have been very successful providing faster response time and throughput, while requiring insignificant processing power.

Research has also been conducted in transmission of video in Bluetooth and wireless channels with some degree of success [6-8]. Furthermore, the Rule-Based-Fuzzy (RBF) controllers have been applied to MPEG VBR video transmission in Bluetooth [9-10]. The initial computer simulation results demonstrate that the RBF controllers can reduce data loss, time delay and image quality degradation. This research takes the application of fuzzy controllers to video transmission in Bluetooth further by using a novel Neuro-Fuzzy approach, where the controller trains and adjusts the parameters of membership functions of the rule-base to enable smoother and more stable throughput over Bluetooth. Furthermore, the Neuro-Fuzzy approach deals with oversubscription of MPEG VBR video data over the Bluetooth channel during the transmission period.

II. CONSTRUCTION OF NEURO-FUZZY SCHEME FOR VIDEO TRANSMISSION IN BLUETOOTH

Fig. 1 outlines the overall input-output diagram of the Neuro-Fuzzy controller and the Rule-Based Fuzzy (RBF) controller for MPEG VBR video transmission over a Bluetooth ACL link. In this research, a temporary storage

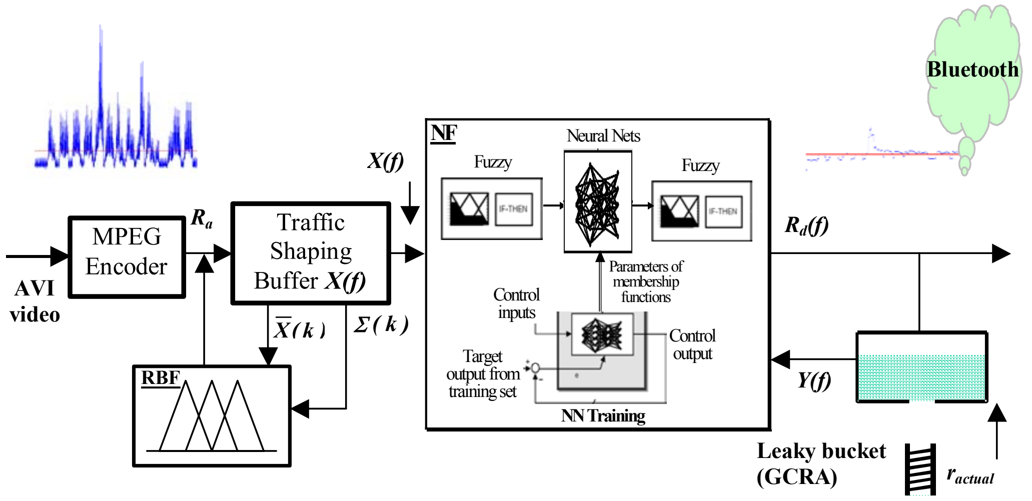


Fig. 1. The integrated NF and RBF schemes for MPEG VBR video transmission in Bluetooth.

area is developed, entitled traffic-shaping buffer $X(f)$. The buffer's role is to smooth the video output traffic and partially eliminate the burstiness of the video stream entering Bluetooth wireless. An integrated NF controller monitors the output rate or departure rate $R_d(f)$ of the traffic-shaping buffer frame by frame to co-ordinate the video traffic entering Bluetooth, where f represents a frame. A RBF controller regulates the average arrival rate $R_a(k+1)$ to the traffic-shaper to prevent either overflow or starvation of the buffer on a Group Of Picture (GOP) by GOP basis. In this research, MPEG is based on Phase Alternate Line and it is assumed that there are 24 frames, as oppose to 25 frames, per second [11]. A GOP has 12 frames and there are two GOPs in one second. The arrival rate $R_a(k+1)$ is controlled to prevent excessive back-to-back data being produced during the peak transmissions of MPEG VBR video sources. The inputs to the RBF controller are the mean $\overline{X}(k)$ and standard deviation $\Sigma(k)$ of queue length in the traffic-shaping buffer. The output from the RBF controller is the desired arrival rate $R_a(k+2)$. Traffic-rate policing is carried out by means of the Generic Cell Rate Algorithm (GCRA) – a rule by which video streams can be judged to be complying with the terms of the traffic contract, GCRA is commonly known as 'leaky bucket' or 'token-bucket'. In Fig. 1, the token-bucket is located prior to the HCI and measures the departure rate against the contracted mean rate. The actual token-rate r_{actual} varies according to the level of interferences in the Bluetooth channel and its environment. The contracted token-rate is the maximum bandwidth for a Bluetooth ACL link, which is set around 650 kb/s with 32 kb/s for the sound and 618 kb/s for the video images [1].

In Fig. 1, the rule-based section of the integrated NF system and the RBF controller are based on Mamdani's min implication function [12]. 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 (1).

$$R_d(f) = 1\Big/\left[\tau_d(f)\times(\mathrm{T}_{d\_\max}-\mathrm{T}_{d\_\min})+\mathrm{T}_{d\_\min}\right] \quad (1)$$

where τ_d represents the data inter-departure time from the traffic-shaping buffer. $\mathrm{T}_{d\_\max}$ and $\mathrm{T}_{d\_\min}$ are the maximum and minimum inter-departure time respectively. The values of $\mathrm{T}_{d\_\max}$ and $\mathrm{T}_{d\_\min}$ are determined by (2) and (3).

$$\mathrm{T}_{d\_\max} = \max\{1/R_a(k+1), 1/r_{actual}\} \quad (2)$$

$$\mathrm{T}_{d\_\min} = \min\{1/R_a(k+1), 1/r_{actual}\} \quad (3)$$

In Fig. 1, the basic diagram of the integrated NF controller is also presented. A Sugeno-Type Fuzzy (STF) controller [12] is used to create a direct mapping from the inputs $X(f)$ and $Y(f)$ to the output $R_d(f)$ 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. In this research, each neuron in fuzzification layer has a bell activation function, which is defined by (4) [13].

$$f(x) = \frac{1}{1 + \left| \frac{x-c}{a} \right|^{2b}} \tag{4}$$

The shape of the bell depends on parameters a, b and c, where the parameters a and b both determine the shape of the membership function, and the parameter c locates the center of the curve. The parameter c is usually positive. 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 paper 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. 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 [14]. Figs. 2-3 present the membership functions of the inputs of the NF controller. At one instance, the rules associated with the NF controller are listed in Table I. The training of ANFIS is performed off-line to minimize computation load.

III. MATLAB-SIMULINK COMPUTER SIMULATION RESULTS

Bluetooth provides two types of links – Synchronous Connection Oriented (SCO) link and Asynchronous Connection-Less (ACL) link [1]. ACL may support up to 723.2 kb/s downlink using DH5 packets and with 57.6 kb/s uplink, or symmetrically 433.9 kb/s in both directions. In this research the ACL link is used for video transmission over a Bluetooth channel. The Bluetooth specification provides flow control for the HCI, so that data transport across the HCI slows down when the HC buffer is overloaded, while it runs at full speed the rest of time. The host can only send data when there is space available in the HC buffer. That is to say, although the Bluetooth link may be set up with a certain token-rate in mind, the actual data-rate at which the host sends data varies according to the space left in the HC buffer at the time of transmission. To reflect this in the computer simulation, it is assumed that the collective interferences in the Bluetooth channel to be Gaussian. A normally Gaussian distributed noise to the contracted token-rate is introduced to simulate the actual data-rate at which the host sends IP packets to the Bluetooth module.

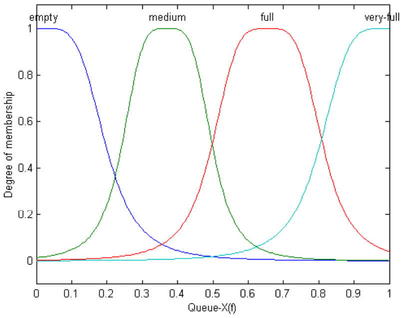


Fig. 2. Membership functions of fuzzy variable X(f) in NF control scheme.

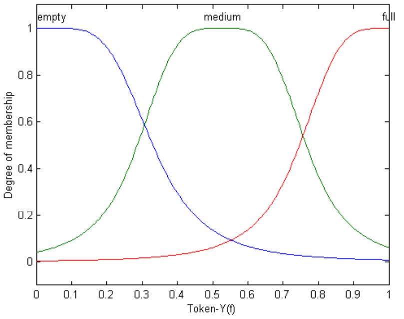


Fig. 3. Membership functions of fuzzy variable Y(f) in NF control scheme.

TABLE I

RULES IN THE INTEGRATED NF CONTROLLER

I. If (Token-Y(f) is empty) and (Queue-X(f) is empty) then (R_d is R_{dI})
II. If (Token-Y(f) is empty) and (Queue-X(f) is medium) then (R_d is R_{dII})
III. If (Token-Y(f) is empty) and (Queue-X(f) is full) then (R_d is R_{dIII})
IV. If (Token-Y(f) is empty) and (Queue-X(f) is very-full) then (R_d is R_{dIV})
V. If (Token-Y(f) is medium) and (Queue-X(f) is empty) then (R_d is R_{dV})
VI. If (Token-Y(f) is medium) and (Queue-X(f) is medium) then (R_d is R_{dVI})
VII. If (Token-Y(f) is medium) and (Queue-X(f) is full) then (R_d is R_{dVII})
VIII. If (Token-Y(f) is medium) and (Queue-X(f) is very-full) then (R_d is R_{dVIII})
IX. If (Token-Y(f) is full) and (Queue-X(f) is empty) then (R_d is R_{dIX})
X. If (Token-Y(f) is full) and (Queue-X(f) is medium) then (R_d is R_{dX})
XI. If (Token-Y(f) is full) and (Queue-X(f) is full) then (R_d is R_{dXI})
XII. If (Token-Y(f) is full) and (Queue-X(f) is very-full) then (R_d is R_{dXII})

In the Matlab-Simulink computer simulation, N(E, v^2) is utilized as a Gaussian distribution, where, E is the mean value, and v is the standard deviation. The mean value of the Gaussian interference noise is always zero [15]. Low-level rapid-changing noise has a standard deviation of $50/3 = \sqrt{278}$, such that 99.8% of the actual data-rates are within the range of [600-650] kb/s. 50 is the difference between 600 and 650, and 3 is the maximum allowable frame delay in the token-bucket. The low-level rapid-changing noise represents the total effect of low-level interference in the Bluetooth channel. High-level slow-changing noise represents the situation where 99.8% of the actual data-rates are within the [550-650] kb/s range. For high-level noise a standard deviation of $100/3=\sqrt{1111}$ is used. The high-level slow-changing noise represents the situation where an interfering device like microwave switches on and off from time to time.

TABLE II
COMPUTER SIMULATION RESULTS FOR THE PROPOSED SYSTEM FOR 'CHICAGO'.

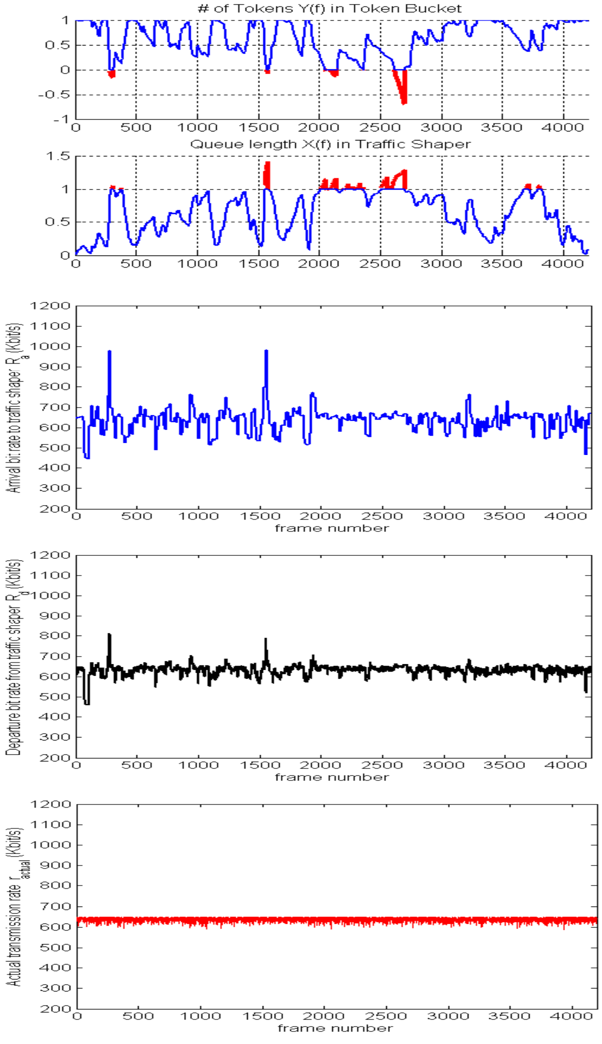
Experiment	NF and RBF controllers - Simulated interference $\lvert N(E, v^2)\rvert$ (kb/s)	
	Low-level $\lvert N(0, 278)\rvert$	High-level $\lvert N(0, 1111)\rvert$
Standard deviation of output rate from MPEG encoder (kbps)	58.11	53.70
Standard deviation of output rate from traffic-shaper (kbps)	27.80	29.23
% of Dropped-data at token-bucket	0.082	0.339
% of Dropped-data at traffic-shaper	0.308	0.719
Total % of dropped-data	0.390	1.059
Average Quantization Parameters $[Q_i, Q_p, Q_b]$	[8.62, 9.14, 8.93]	[8.79, 9.23, 9.06]

TABLE III
COMPUTER SIMULATION RESULTS FOR THE OPEN LOOP MPEG VBR ENCODING SCHEME

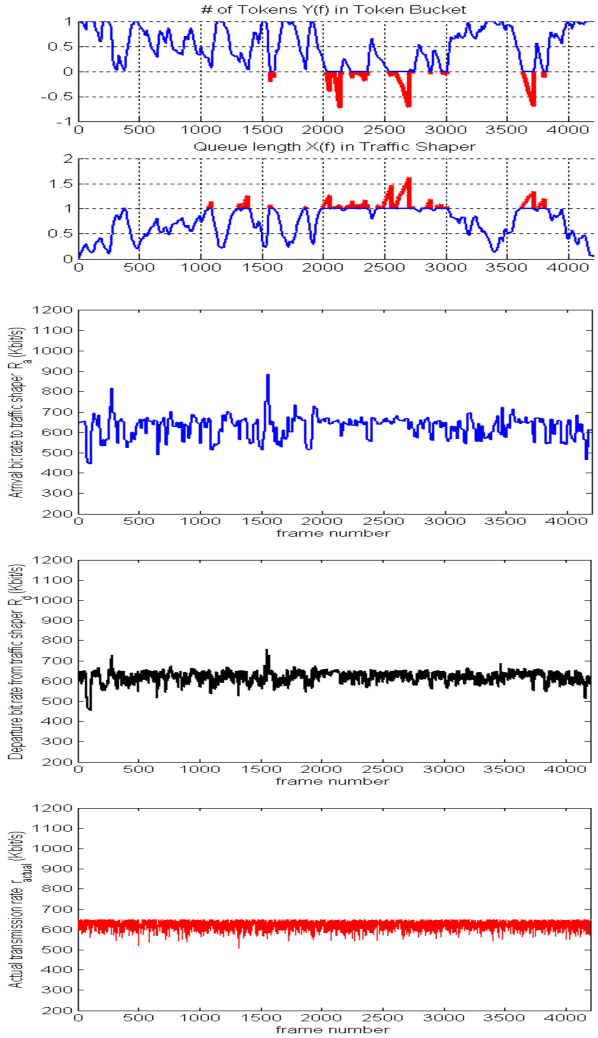
Clip Name	Resized Chicago	
Noise	Low-level $\lvert N(0, 278)\rvert$	High-level $\lvert N(0, 1111)\rvert$
Standard deviation of output rate from MPEG encoder (kbps)	188.1	
% of Decrease in standard deviation of encoded video output rate using NF + RBF controllers	85.22	84.46
% of Dropped-data	9.08	7.95
% of Decrease in # of dropped-data using NF + RBF controllers	95.7	86.7
Average Quantization Parameters $[Q_i, Q_p, Q_b]$	[9, 10, 9]	

A video clip called 'Chicago' [16] is used to implement the proposed NF control scheme and the first 350 GOPs of the clip are utilized for the computer simulation. The frame size of the clip is 240 (width) x 180 (height) pixels. Table II shows the numerical results of Chicago testing clip using the NF and RBF controllers. In Table II, the standard deviation of output rate from the traffic-shaper is much less than the standard deviation of output rate from MPEG encoder, demonstrating the output traffic to the Bluetooth channel is much smoother, resulting to a reduced data loss. Table III presents some of the results obtained for the open loop MPEG VBR encoding scheme and compares the results with the integrated NF scheme. Table III demonstrates a considerable decrease, a minimum of 84.46%, in the standard deviation of output rate to the channel by the proposed system, without presence of the noise. The percentage of dropped-data also decreases substantially when the integrated NF scheme is utilized; it is more than 86.7%. Furthermore, the standard deviation of output rate from the MPEG encoder for the open loop VBR scheme in Table III is noticeably higher than for the integrated NF scheme in Table II. Finally in Table II, the percentage of dropped-data at the token-bucket is less than the percentage of dropped-data at the traffic-shaping buffer. This is deliberate as the data is mainly lost by the integrated NF scheme only when it is necessary, while maintaining image quality. Nevertheless, the total percentage of the dropped-data is still very negligible. Tables II and III also outline average quantization parameters $[Q_i, Q_p, Q_b]$. Quantization parameters are concerned with controlling the size and bit rate of the MPEG video stream. The values of quantization parameters determine the degree of fine details of the moving images that could be lost. In MPEG the GOP is a group of pictures or frames between successive I- (Intra) frames, and the others being P- (Predicted) and/or B- (Bi-directional) frames. I- holds data to construct a whole picture, P- considers at the difference between the present and the previous frames, and B- measures the difference between the previous and the next frames. Quantization parameters therefore can be determined independently for each frame. High quantization parameters mean inferior quality of picture. The quantization parameters in Tables II-III are the mean values for I-, P-, and B- frames. Each of the quantization parameters is averaged over the whole testing clip. In VBR the image quality is fixed, therefore the user specifies the quantization parameters. The quantization parameters are fixed to $[Q_i, Q_p, Q_b] = [9, 10, 9]$ for low and high level noise for the open loop systems in Table III. For the integrated NF scheme in Tables II, the average quantization parameters are slightly smaller that the open loop VBR encoding system, demonstrating improvements in picture quality.

Fig. 4 presents the Matlab-Simulink computer simulation results for 'Chicago'. Fig. 4 has two sets of results for low level noise and high level noise, respectively. From above, each subsection such as (a), shows the normalized number of used tokens $Y(f)$, normalized queue length or capacity of the traffic-shaper $X(f)$, arrival bit rate to the traffic-shaper $R_a(k+1)$, departure bit rate from the traffic-shaper $R_d(f)$, and actual transmission rate r_{actual}. The token-bucket size is an indication of how much storage will be available in the stack for the data. The $Y(f)$ graphs show where the data sources are dropped and when the token-bucket contract is surpassed. The graphs for $X(f)$ indicate the degree of overflow or starvation of the buffer. Fig. 4 shows that as noise increases less token would be available in the token-bucket and the size of buffer in the traffic-shaper would decrease. In Fig. $4_{a\ \&\ b}$, the burstiness of the departure bit rate R_d from the traffic-shaper is reduced as compared with the arrival bit rate R_a to the traffic-shaper, which results to a smoother data transmission over the Bluetooth channel. The presence of the noise for the integrated NF scheme at all two levels has a little effect over the departure bit rate R_d. In Fig. $4_{a\ \&\ b}$, as the noise is increased, the changing rate in R_d is increased, and the burstiness variation in R_d is kept within the required contract, hence resulting in video stability and maintaining the overall image quality. In Fig. 4, the integrated NF scheme also ensures that the departure bit rate R_d is always between the arrival bit rate R_a and the actual token (transmission) rate r_{actual}. By maintaining the departure bit rate R_d between the arrival bit rate R_a and the actual token rate r_{actual}, the novel NF scheme decreases the standard deviation of the output bit rate and the number of dropped-data.



(a) The NF and RBF system with a noise of N(0, 278).



(b) The NF and RBF system with a noise of N(0, 1111).

Fig. 4. Chicago – Output bit rate using the integrated NF and RBF schemes.

IV. CONCLUSION

This work is concerned with reduction of oversubscribed MPEG VBR video transmission over a Bluetooth ACL link. A novel integrated Neuro-Fuzzy (NF) control scheme is utilized to reduce the burstiness of the traffic-shaping buffer output rate to enable the VBR encoded video to enter the Bluetooth network reducing time delay, data loss and image quality degradation.

The proposed NF scheme considerably reduces the standard deviation of the output bit rate to the Bluetooth channel and the number of dropped-data, which ultimately result to data transmission stability, while maintaining image quality at the receiving end. The NF control scheme also improves and maintains the quality of service with noise interferences over the Bluetooth channel. In conclusion, as the integrated NF and RBF schemes are both based on simple algorithms, the overall control system only requires an acceptable processing power, which could be used for real-time implementations in delay-sensitive MPEG VBR video services in mobile devices.

ACKNOWLEDGMENT

This work was funded by the Emerald Grant UK. The work was carried out at London Metropolitan University, UK.

REFERENCES

[1] https://www.bluetooth.org/spec/. Core_1.2_and Profile_1.2.

[2] C. W. Ahn and R. S. Ramakrishna, "QoS provisioning dynamic connection admission control for multimedia wireless networks using a Hopfield neural network," *IEEE Trans. on Vehicular Technology*, vol. 53, no. 1, pp. 106-117, Jan. 2004.

[3] Q. Liang and J. M. Mendel, *Modeling MPEG VBR Video Traffic using Type-2 Fuzzy Logic Systems*, Physica-Verlag GmbH Heidelberg, Germany, pp. 367 – 383, 2001.

[4] D. Soud and H. B. Kazemian, "A fuzzy approach to connection admission control in 802.11b wireless systems," in *The 29th Annual Conference of the IEEE Industrial Electronic Society (IECON'03)*, Roanoke, USA, Nov. 2nd – 6th, 2003, pp. 1914-1919.

[5] D. Soud and H. B. Kazemian, "A fuzzy approach to active usage parameter control in IEEE 802.11b wireless networks," *Expert Systems: The Int. Journal of Knowledge Engineering and Neural Networks*, Blackwell publishers Ltd., vol. 21, no. 5, pp. 269-278, Nov. 2004.

[6] C. Scheiter, R. Steffen, M. Zeller, R. Knorr, B. Stabernack, and K.-I. Wels, "A system for QOS-enabled MPEG-4 video transmission over Bluetooth for mobile applications," in *IEEE Int. Conference on Multimedia and Expo*, Baltimore, Maryland, July 2003.

[7] I. Ahmed, T. Arslan, and S. Khawam, "Video transmission through domain specific re-configurable architectures over short distance wireless medium utilizing Bluetooth IEEE 802.15.1," in *Proc. of IEEE SOC Int. Conference*, Edinburgh UK**,** Sept. 12th –15th, 2004, pp. 7- 10.

[8] L. Galluccio, G. Morabito, and G. Schembra, "Transmission of adaptive MPEG video over time-varying wireless channels: modeling and performance evaluation," *IEEE Trans. On Wireless Communications*, vol. 4, no. 6, pp. 2777-2788, Nov. 2005.

[9] H. B. Kazemian and L. Meng, "A fuzzy approach to video transmission over Bluetooth ACL links," in *IEEE 2004 Consumer Communications and Networking Conference (CCNC 2004), Las Vegas, NV, USA*, January 5th-8th, 2004.

[10] H. B. Kazemian and L. Meng, "A fuzzy control scheme for video transmission in Bluetooth wireless." *INS – Information Sciences, Elsevier Journals*, vol. 176, issue 9, pp 1266-1289, May 2006.

[11] B. Pank, *The Quantel Digital Fact Book*, A reference manual for the television broadcast & post production industries, http://www.quantel.com/domisphere/infopool.nsf/html/DFB, 11th ed. 2003.

[12] User's guide, *Fuzzy logic toolbox, for use with Matlab*. The Math Works Inc, 2005.

[13] M. Negnevitsky, *Artificial Intelligence – a guide to intelligent systems*, 1st ed., Addison Wesley, 2002.

[14] S. Haykin, *Neural Networks, a comprehensive foundation*, 2nd ed., Prentice Hall International, Inc., 1999.

[15] R. E. Ziemer and W. H. Tranter, *Principles of Communications – systems, modulation and noise*, 5th ed., John Wiley & Sons, Inc., 2002.

[16] http://www.movie-list.com/nowplaying.shtml.

H. B. Kazemian (SM'1988) received B.Sc. Engineering from Oxford Brookes University UK, M.Sc. Control Systems Engineering from University of East London UK and Ph.D. in Learning Fuzzy Controllers from Queen Mary University of London UK, in 1985, 1987 and 1998 respectively. He is currently a Professor at London Metropolitan University UK. He worked for Ravensbourne College University UK as a senior lecturer for 8 years. Previous lecturing experience: University of East London UK, University College Northampton UK, Newham College UK. Research interests include fuzzy and neuro-fuzzy control of networks, Bluetooth, ATM, digital video, bioinformatics and robotics. Dr. Kazemian is a senior member of the Institute of Electrical and Electronics Engineers (SMIEEE), member of the Institution of Engineering and Technology (former IEE) UK and Chartered Engineer (C.Eng.) UK.

S. Chantaraskul received B.Eng. Electronics from King Mongkut's Institute of Technology, Bangkok, Thailand in 1999. Received M.Sc. Mobile and Satellite Communications from University of Surrey UK and PhD in Intelligent Agent Approach for Managing Congestion in W-CDMA Networks from Queen Mary London University UK, in 2001 and 2005 respectively. She is currently a Postdoctoral Research Fellow at London Metropolitan University UK. Research interests include intelligent video transmission over Bluetooth to improve quality of picture. Intelligent agent in W-CDMA radio resource management.