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Congestion control of Wavelet image compression over wireless networks

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Abstract. The demand of transmission of images and video is increasing quickly recently and researchers are trying to invest good solutions to improve the quality of these over wireless networks. There are still challenges due to the different characteristics and quality of images between wired and wireless channels. An important issue is congestion control to ensure network stability and achieve a reasonably fair distribution of the network resources among the users. The paper will present a model of congestion control by combining Wavelet image compression at the source with applying Fuzzy logic technique to control traffics. The simulation shows a good result, the transmission rate can be adjusted to adapt the changes of wireless channel, the buffer of intermediate devices will not be swung from idle to overflow or vice versa so that the cell loss rate is small.

1. Introduction

For transmission of image over wireless channels, it is important to have a robust system when the channel conditions vary as a function of time. Traditional systems use a DCT transform for image compression and then matched to the bit rate for which the channel code is designed. DCT is one of the most popular technologies for image processing, including JPEG standard, MPEG standards, H.261, ect. There are some problems with this system. Firstly, the system breaks down very fast if the SNR falls below the design level. Secondly, DCT will cause the "blockness artifact" when the compressing ratio over 50:1. Thirdly, the image services are limited by the poor quality and low compression ratio. Lastly, the systems are much suffered by varying of the bit rate over channel.

Wavelet transform has recently been used to replace DCT in many coding systems. The advantages of Wavelet are high compression ratio, avoiding "blockness artifact" and better quality. The multiresolution of Wavelet is very meaningful characteristic for transmission of image over wireless network [1].

Low bit rate, the fading and fast time varying are main drawbacks for transmission of images over wireless channels. Congestion can be occurred at the nodes because the number of incoming packets are unpredictable. Congestion control is an important network element. The purpose of congestion control is to ensure network stability and achieve a reasonable distribution of the network resources among the users.

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TCP is a well-established protocol, which offers reliable transportation of data. The increased demand in using of the Internet lead to the need of designing and applying of effective congestion control algorithms. Many active queue management schemes have been proposed to provide high network utilization with low loss and low delay in TCP/IP networks. Random Early Detection (RED), Explicit Congestion Notification (ECN), TCP Sliding Window, Slow Start are commonly used in wired networks. In these schemes, the discarded policy of arriving packets is based on overflow of the buffer in nodes [2].

In this paper, we use fuzzy logic techniques to develop a new queue management scheme in hop by hop wireless networks. The application of fuzzy control in networks is suitable due to the difficulties in obtaining a precise mathematical model while intutive understanding of congestion control is available. A fuzzy engine is designed to operate on buffer queues and use linguistic rules to control the transmission rate in wireless network.

The paper is organized as follows: Section II discusses the Wavelet image compression. In section III, we briefly review some properties of fuzzy logic controller and present our congestion control scheme. Section IV presents simulation result and discuss the possible of applying fuzzy logic in telecommunication.

2. Wavelet Image compression

2.1. What are wavelets

Today, most of the research and development which related to transform signal has been involving the Fourier transform. The Fourier transform uses infinite-duration sinusoids as the basic function for the transform, the short-time Fourier transform (FFT) use truncated or windowed sinusoids. The input signal is observed only in frequency domain, we don't know when and where they are occurred.

Wavelet transform is linear and square integrable transforms having a mother waveform. There are many types of wavelets, which can be smooth or compactly supported. Once the type of mother wavelet is established, daughter wavelets are formed by shifting and scaling, these form a complete orthonormal set. If we define $\psi(t)$ as the mother waveform, a complete orthogonal set of daughter wavelets $\psi_{a,b}(t)$ can be generated from $\psi(t)$ by dilation (by a factor of a) and shift (by amount b)

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\psi\left(\frac{t-b}{a}\right) \tag{1}$$

Parameter a defines the length of the window time and b is its location. Short, high frequency wavelets can give more time information and less frequency information. Low, long frequency wavelets are used to obtain more frequency information and limited time information.

To analyse data at different resolutions, a scaling function $w(t)$ is used in conjunction with the mother wavelet

$$W(t) = \sum_{k=-1}^{N=2}(-1)^k C_k \psi(2t+k) \tag{2}$$

In equation, C_k are the wavelet coefficients which satisfy the constraints

$$\sum_{k=0}^{N-1} C_k = 2 \text{ and } \sum_{k=0}^{N-1} C_k C_b = 2\delta_{b,0} \tag{3}$$

In this case, δ is the delta function and *b* is the location index. This allows for the defining coefficients to be varied according to the wavelet system to be used [3].

2.2. Comparing between DCT and Wavelet-based Image coding

Wavelet compression offers two main advantages over DCT:

- Improved scalability - This is because the wavelet transform process can be repeated for as many iterations as needed. At the decoder, decoding can stop any time if entire resolution of the original image is not required. This would depend on the resolution of the display device being used.
- Higher efficiency at low bit rates – The fewer wavelet coefficients can be quantized compare with DCT.

However, hardware and software using DCT is much simpler than that using wavelet. This would be an important factor to consider if mobile hand held devices with limited battery capacity being used.

2.3. The tree structure and subband coding

In practical, wavelet transform is referred to as subband coding using tree structure. This takes place in the following way:

a. The image is filtered horizontally by convolving it with the high pass filter, that extracts high spatial frequency and high details.
b. The image is seperately convolved horizontally with a complementary low-pass filter to get low frequencies.
c. The results in two sub-image that contain high and low horizontal frequencies can be convolved with each of the separately vertical filters to obtain four sub-image. This process is illustrated in figure 1
d. This process is repeated for the sub-image block containing low horizontal and low vertical frequencies (LL) to obtain higher band decomposition filter tree.

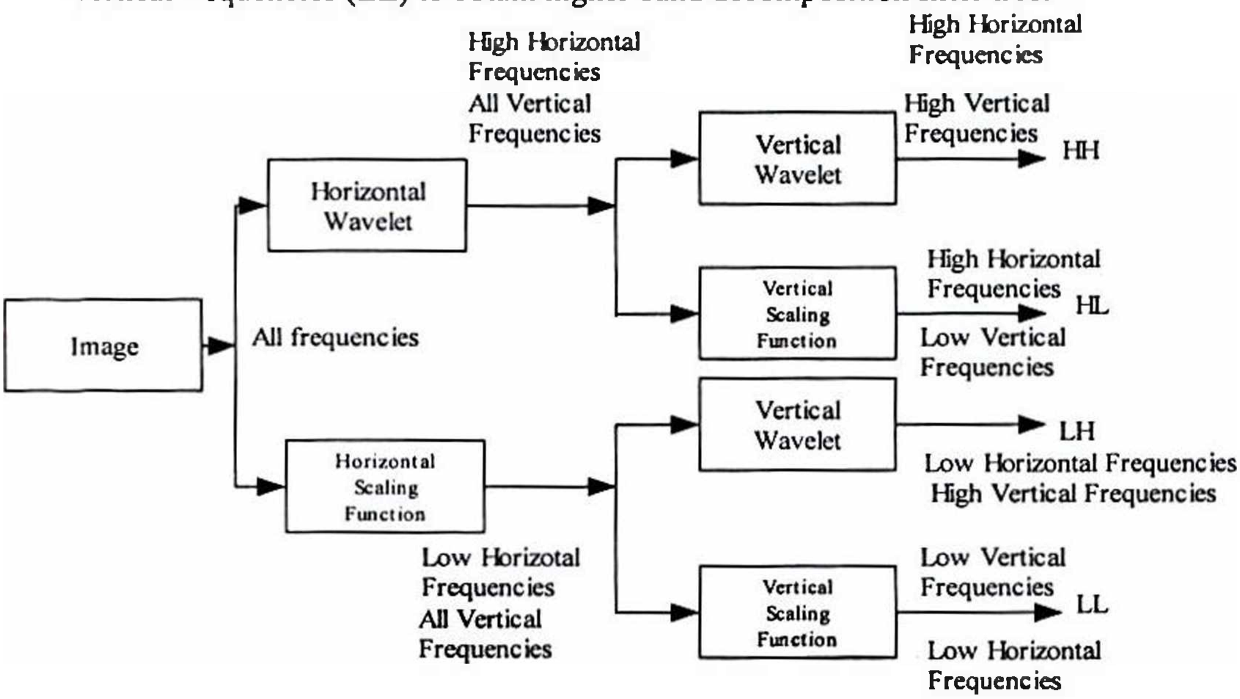


Figure 1. Dividing image into four sub-image [4].

The forward wavelet transform describes the pixel values of the original image and the result is a small number of coefficients. The compression can be obtained by quantizing the non-zero wavelet coefficients and further compression ratio can be got by Huffman coding.

3. Congestion control using Fuzzy Logic

3.1. Fuzzy logic

Fuzzy logic is one of the tools commonly known as Computational Intelligence. Fuzzy logic control may be viewed as a way of designing feedback controllers in situations where rigorous control theoretic approaches can not be used. The control algorithm is encapsulated as a set of linguistic rules. Fuzzy logic controller has been successful for controlling system possibly too complex and highly nonlinear. In recent years, a number of research papers using fuzzy logic to invest congestion control of ATM networks have been published. A survey is given in [5].

3.2. Fuzzy logic implementation

A wireless networks is a large distributed complex system with difficulty of highly non-linear, time varying and chaotic behavior. Dynamic or static modelling of such a system for control is extremely complex. Measurements on the state of the network are incompleted, often poor and time delayed. In order to enable wireless image and multimedia communication, the bottlenecks to communicating image data over wireless must be addressed.

Network congestion control remains a critical issue and high priority, especially in growing size, low speed (bandwidth) of the increasingly integrated networks. Current solutions in existing networks are becoming ineffective and can not easily scale up. The approach to congestion control for traditional TCP/IP and ATM are proceeded separately [6]. Fuzzy logic controllers may be viewed as an alternative, non-conventional way of designing feedback controllers . It is a convenient and effective way to build a control algorithm without relying on formal models of the controlled system and control theoretic tools. The control algorithm is encapsulated as a set of commonsense rules. Fuzzy logic control has been applied successfully to the task of controlling systems for which analytical models are not easily obtainable or the too complex and highly nonlinear model. In this paper, we propose a rate control scheme using fuzzy logic, which is applied in hop by hop wireless networks.

3.3. Fuzzy control algorithm

Our model of fuzzy control system is based on a queue management scheme to provide transmission rate control in hop by hop wireless networks. The system model is shown in Figure 2.

The cell rate of data sources are adjusted by feedback information carried by source management cells. Source management cells are generated by sources, transmitted towards the destination end system hop by hop. The next node will send back these cells to the current node. The feed back cells will examine the state of buffer in next node, and tell the previous how to change Explicit Rate. The data source, upon receiving feedback cells will adjusts it's rate more or less.

In scheme, both current queue length and its growth rate are monitored. The queue length look at the current state of the buffer and the growth rate provides some knowledge's of prediction for the near future of buffer behavior. So the scheme will be more effective than existing schemes they only based on the queue length threshold. The block diagram of fuzzy controller system is illustrated in figure 3.

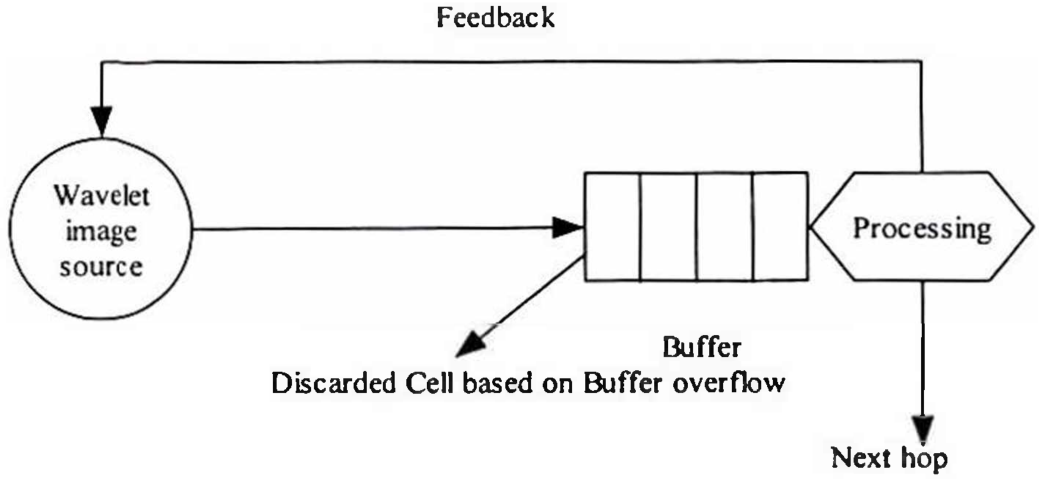


Figure 2. The source channel rate control using fuzzy logic.

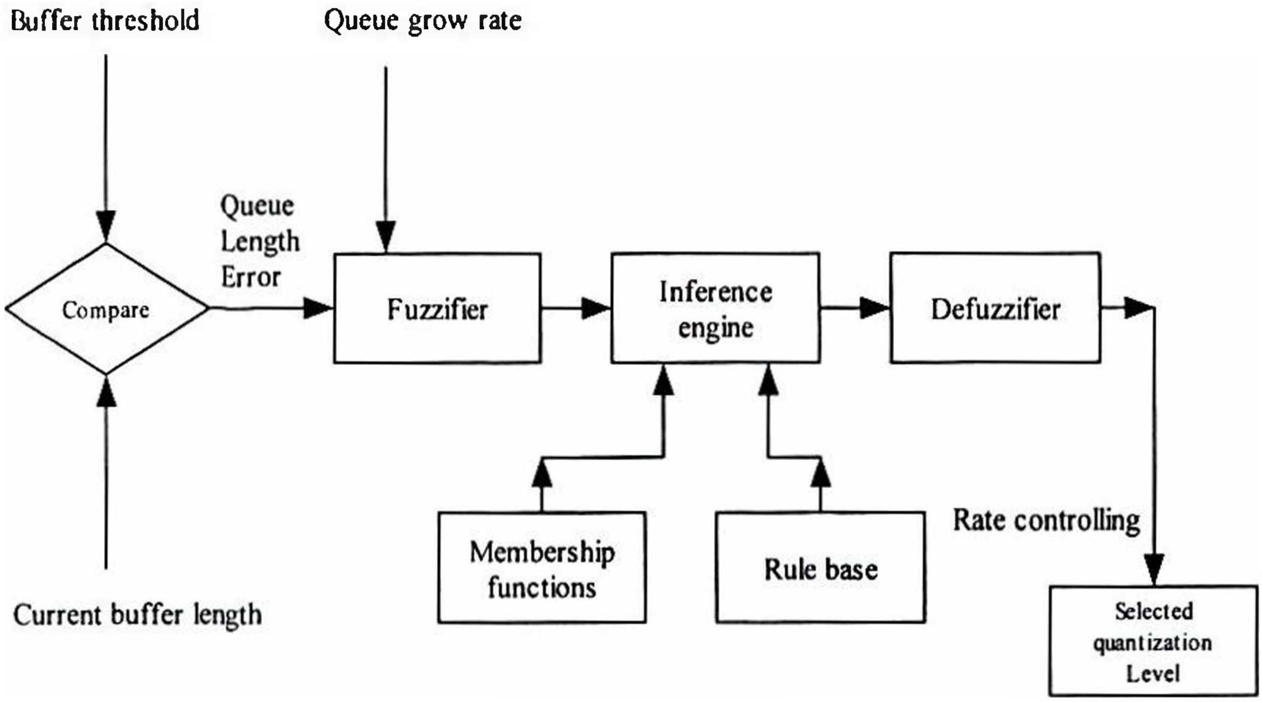


Figure 3. Block diagram of fuzzy control system.

3.4. Rule base design

The design of a rule base [6] includes two parts: First, the linguistic rules are set (table 1) and afterwards, membership functions of the linguistic values are determined (figure 3).

We define INPUT and OUTPUT variables as:

INPUT #1: Number of packets loss %

- Small - when number of packet's losses is less than 0.4% (S)
- Acceptable - when number of packet's losses is 0.4-0.7% (A)
- High - when number of packet losses is greater than 0.7% (H).

INPUT#2: Buffer grow length

- Decrease Fast (-F).

- Decrease Slow (-S).
- Not change (NC).
- Increase slow (+S).
- Increase Fast (+F).

OUTPUT: Transmission rate is in range 0 - 300 Kbps.

Table 1. Fuzzy Rule Matrix.

Packet loss % \ Queue Length Rate	-F	-S	NC	+S	+F
H	300	250	120	75	25
A	300	250	200	100	25
S	300	300	250	125	75

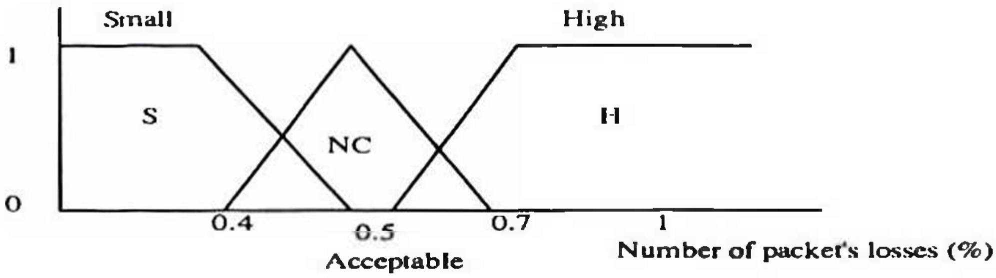
In table 1 shows the fuzzy conditional rules for the model. Rules in table 1 can be interpreted as:
IF queue length is too short and queue is decreasing fast ***THEN*** flow rate is 300 kbps
IF queue length is too short and queue is decreasing slowly ***THEN*** flow rate is 300 kbps
IF queue length is too short and queue is not changing ***THEN*** **flow rate is** 250 kbps
IF queue length is too short and queue is increasing fast ***THEN*** flow rate is 75 kbps
IF queue length is too short and queue is increasing slowly ***THEN*** flow rate is 125kbps

IF queue length is acceptable and queue is decreasing fast ***THEN*** flow rate is 300 kbps
IF queue length is acceptable and queue is decreasing slowly ***THEN*** flow rate is 250 kbps
IF queue length is acceptable and queue is not changing ***THEN*** flow rate is 200 kbps
IF queue length is acceptable and queue is increasing slowly ***THEN*** flow rate is 100 kbps
IF queue length is acceptable and queue is increasing fast ***THEN*** flow rate is 25 kbps

IF queue length is too high and queue is decreasing fast ***THEN*** flow rate is 300 kbps
IF queue length is too high and queue is decreasing slowly ***THEN*** flow rate is 250 kbps
IF queue length is too high and queue is not changing ***THEN*** flow rate is 120 kbps
IF queue length is too high and queue is increasing slowly ***THEN*** flow rate is 75 kbps
IF queue length is too high and queue is increasing fast ***THEN*** flow rate is 25 kbps

3.5. Membership functions

Membership functions are shown in figure 4



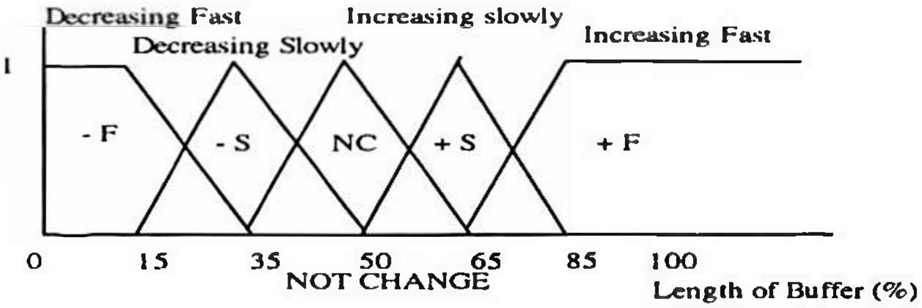


Figure 4. Membership functions for input variables.

3.6 Simulation results

A Matlab program has been developed to simulate the behavior of the fuzzy model. The results are illustrated in figure 5. The x axis represents the cell loss at the buffer and the y axis represents how transmission rate from the source could be. We can see that at one value of cell loss in buffer, one out of five transmission rates could be selected, the rate depends on how growing rate in buffer is.

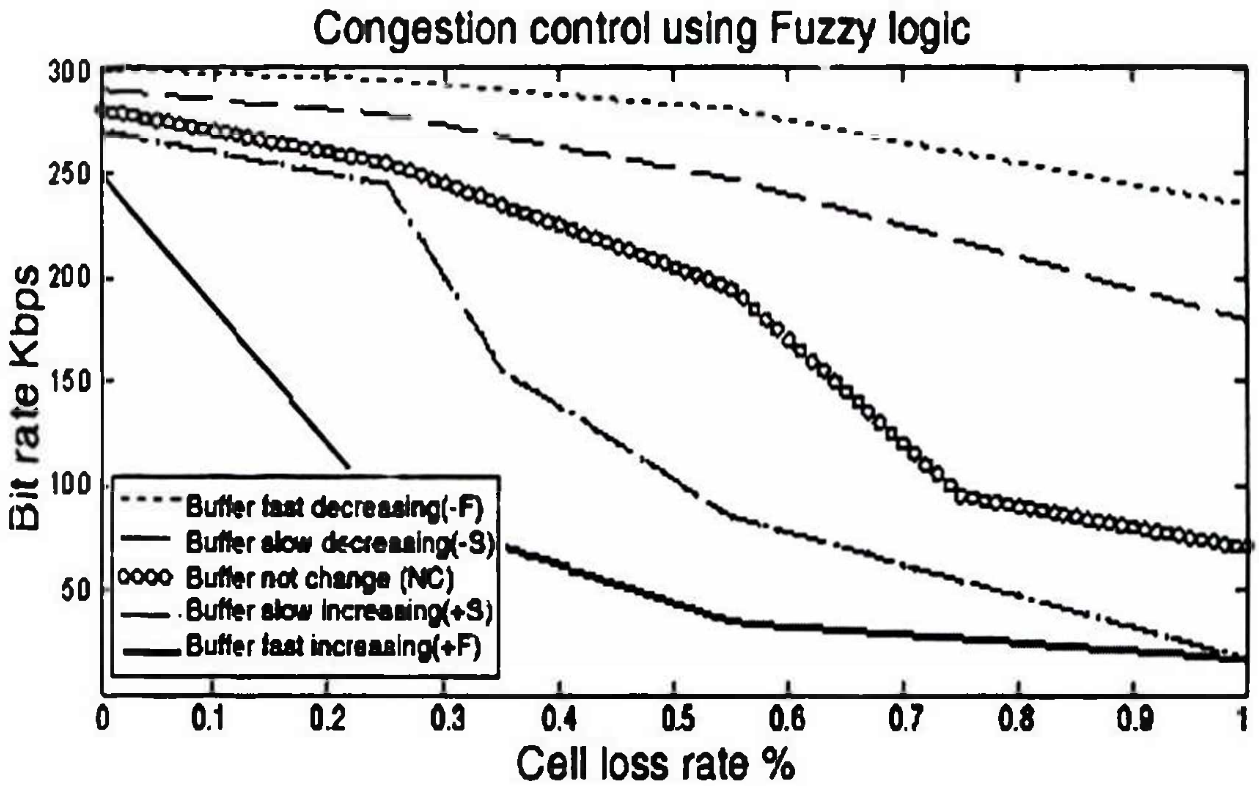


Figure 5. Adjusting the transmission rate of source using Fuzzy logic.

4. Conclusion

Applying Wavelet for image compression can improve the compression ratio, the quality of reproducing image. Using Wavelet image compression, the scalable and progressive image transmission can outperform than other methods. When too many compressed image sources send too much data simultaneously, the network will difficulty to handle. Consequently, network congestion had occurred which causes lost of packets and long delays. In order to control this problem, one method of adjusting transmission rate to avoid buffer overflow at routers using fuzzy logic is presented in the paper. The results show that the transmission rate of the source can be flexible to adapt with the channel capacity. The buffer will not be swung from idle to overflow or vice versa. We can see that fuzzy logic controller can be used not only to control congestion, but also to adjust many other network parameters.

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