FTAM: A Fuzzy Traffic Adaptation Model for Wireless Mesh Networks

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***Abstract*—Wireless mesh networks (WMNs) are considered as the next step towards providing a high-bandwidth network over a specific coverage area. Because of their advantages over other wireless networks, WMNs are undergoing rapid progress and inspiring numerous multimedia applications such as video and audio real-time applications. These applications usually require time-bounded service and bandwidth guarantee. Therefore, there is a vital need to provide Quality of Service (QoS) support in order to assure better quality delivery. However, providing QoS support for real-time traffic in WMNs presents a number of significant technical challenges. In this paper, we focus on one of the most critical technical issues in QoS support, by proposing a novel QoS traffic adaptation model based on fuzzy logic theory, named FTAM, which is capable of supporting real-time traffic such as video and voice services. By monitoring the rate of change in queue length in addition to the current length of the queue, FTAM is able to provide a good measurement of the future queue state, and then to achieve the convenient traffic adaptation according to the network state.**

***Index Terms*—Wireless Mesh Networks; QoS; Traffic Adptation; Fuzzy Logic;**

I. Introduction

The last few years have witnessed a wealth of research ideas on Wireless Mesh Networks (WMNs) that are moving rapidly toward implemented standards. Although WMN research is a relatively new field it is gaining more popularity for various new applications. For instance, multimedia application that opens up for converged services and new purposes is quickly becoming a key focus area for wireless mesh communications [1]. With the increase in both the bandwidth of wireless channels and the computing power of mobile devices, it is expected that video and audio services will be offered over WMN in the future. However, enabling multimedia communications over such networks is remaining a challenging task for both academic and industrial communities. Video and audio real-time services typically require stringent bandwidth and delay guarantees. This makes the deployment of Quality of Service (QoS) mechanisms a vital need for the satisfaction of user's requirements. Real-time applications generate traffic at varying rates and usually require the network to be able to support such a changing rate. Therefore, providing QoS guarantees is crucial for supporting disparate services envisioned for future wireless mesh networks [2].

Despite the efforts made to alleviate this issue, there still exist a number of barriers to the widespread deployment of real-time applications. The most prominent one is how to ensure the traffic adaptation in the case of heavy congestion case. It is important to note that the existing solutions developed for wired networks can not be deployed directly within WMNs. Difficulties with these models lie in the fact that they are not adapted to different node states and resource variation, as in mesh environments the available bandwidth for each node varies with time since the medium is shared [3].

In this paper, we introduce a novel QoS model for traffic adaptation based on fuzzy logic that is capable of supporting real-time traffic such as video and voice services. A major factor behind using fuzzy logic theory to ensure the traffic adaptation, is its adequation to the uncertainty, the heterogeneity and the information incompleteness of WMN environment characterized by dynamic traffic changes. Our proposed model, build on both MAC and network layers, will bring about the benefits of the advances in the areas of artificial intelligence and wireless networking. The evaluation of the model performances will be studied under different traffic and network conditions. The balance between network performances and reliability when transmitting multimedia traffic is an important issue to consider too.

The remaining of the paper is organized as follows. A brief description of Fuzzy Logic theory is provided in Section II. Section III gives a state of the art regarding QoS fuzzy models in WMN. Section IV presents our proposed model. In Section V, we discuss the performance evaluation of FTAM, while Section VI concludes the paper.

II. Fuzzy Logic

In this section, we give a brief overview of the Fuzzy Logic theory to help the unfamiliar reader to understand the rest of the paper. Exhaustive description can be founded in the literature [4] [5].

A. Fuzzy Sets

Fuzzy sets represent a modernization of traditional crisp sets where the membership of an object x in a set A is evaluated by 1 (true) or 0 (false). True signifies that x is member of A and false signifies that x is non-member of A. Fuzzy sets allow the partial membership of x in A. The degree of membership has a real value in [0, 1], where 0 and 1 correspond respectively to the full non-membership and the full membership of x in A. If A is a fuzzy set in a universe U, the membership of x in A is evaluated by the membership function μ_A as following:

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$$\mu_A : U \rightarrow [0, 1]. \quad (1)$$

Each $u \in U$ has a degree of membership in A equal to $\mu_A(u)$. An object x is defined as a linguistic variable such as distance or speed, and a fuzzy set A is defined as a linguistic term such as far or high.

B. Fuzzy Logic Controllers

A *Fuzzy Logic Controller* (FLC) is a tool used to compute the value of an output based on several inputs having between them a complex relation which cannot be solved via traditional mathematical tools such as weighted sum. The structure of a FLC is shown in Figure 1. To compute the value of the output of a FLC, the following steps must be applied.

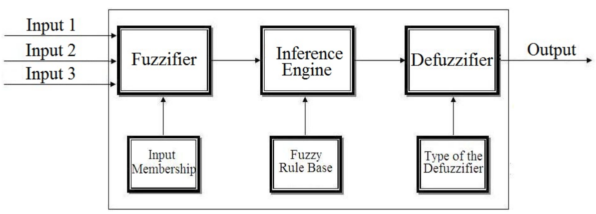

Fig. 1: Fuzzy Logic Controller

First, we compute or measure from the external environment the value of each input. Second, these values are converted by the *fuzzifier* into fuzzy variables ready to be used by the *inference engine*. This step is called *fuzzification* and it is executed based on the *membership functions* of each input. An example of *membership functions* is shown in 1. Third, the *inference engine* applies each rule of the *fuzzy rule base* to the input fuzzy variables to compute an output fuzzy variable. An example of *fuzzy rule base* is shown in Table I. The rules of the *fuzzy rule base* have the following form: IF (*input 1* is X_1 and *input 2* is X_2 and *input 3* is X_3) THEN (*output* is Y). Fourth, the output fuzzy variables of all the rules are connected to compute the final output fuzzy variable. Finally, the final output fuzzy variable is converted by the *defuzzifier* into a crisp output ready to be used in the external environment.

III. Fuzzy Logic In Wireless Multihop Networks

Fuzzy logic has been successfully applied to resolve problems that are either difficult to tackle mathematically or where the use of fuzzy theory provides improved performances [6]. In what follows, we present some relevant QoS models proposed in the literature.

In [7], we proposed an integrated stateless cross-layer QoS protocol FuzzyQoS based on fuzzy logic for wireless mobile ad hoc networks. The choice of using fuzzy logic is justified by the fact that fuzzy logic is well adapted to systems characterized by imprecise states, as in the case of ad hoc networks. The fuzzy approach aims to improve the control of traffic regulation rate and congestion control of multimedia applications. FuzzyQoS uses fuzzy thresholds to adapt the traffic transmission rate to dynamic conditions. The performance evaluation has shown that FuzzyQoS can achieve low and stable end-to-end delay, and high throughput under different network conditions.

In [8] a fuzzy logic based cooperative MAC protocol (FLCMAC) is proposed to cooperate amongst network flows and dynamically adjust access probability of each low priority flow affecting the high priority flows to satisfy their QoS requirement. The simulation results have indicated that compared to the enhanced distributed channel access (EDCA) scheme of 802. 11e, the FLCMAC gives better performances in terms of throughput and delay under moderate and heavy background traffic both in single-hop and multi-hop scenarios. This work addresses the problem of spatial reference estimation in mobile scenarios.

In [9], the authors proposed a new model to investigate the use of fuzzy logic theory for assisting the TCP error detection mechanism in an ad hoc network. An elementary fuzzy logic engine was presented as an intelligent technique for discriminating packet loss due to congestion from packet loss by wireless induced errors. The results have shown that the fuzzy engine may distinguish congestion from channel error conditions, and consequently assist the TCP error detection [9]. Reznik *et al.* in [10] have investigated the issues for improving the reliability and accuracy of the decisions in wireless ad hoc networks. They proposed an approach that offers a way of integrating wireless units measurement results with association information available or priori derived at aggregating nodes. This approach is used for describing both wireless units results and association information with consideration given to both Neuro-Fuzzy and probabilistic models and methods. The information sources available in the system are classified according to the model (fuzzy or probabilistic), which seems more feasible to be applied [10].

IV. Fuzzy Traffic Adaptation Model

An efficient network congestion control has to prevent the packets losses, which are caused by unexpected traffic bursts. Thus, it has to estimate the dynamic behavior of the traffic in the nodes buffers and to send sources the congestion notifications early enough. Therefore, due to the dynamic nature of buffer occupancy and congestion at a node, we expect that applying a fuzzy logic control seems to be a very interesting issue.

In this section, we propose a *fuzzy logic controller* FLC-FTAM (Figure 2), which is designed to offer a better adaptability under varying network conditions by better tuning of rules without intervention of operators.

The proposed model is conceived as a nonlinear controller in which the input-output relationship can be expressed by using a small number of linguistic rules or relational expressions. The goal of our proposal is to make rate control decisions based on the instantaneous queue length and the variation rate of the queue length at each wireless node. By monitoring the rate of changes in queue length (variation rate) in addition to the queue length, the model is able to provide a measure of queue state, and by using explicit rate congestion notifications

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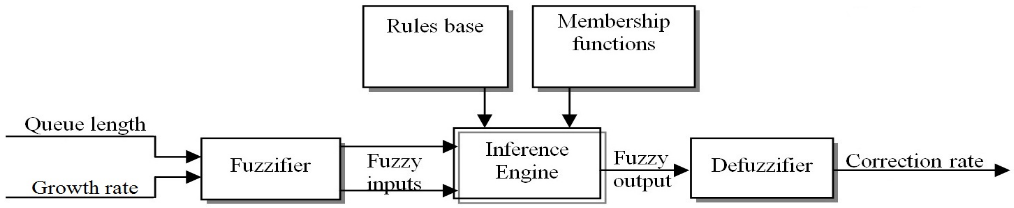


Fig. 2: FTAM model

we can make source nodes more responsive to sudden changes in the network traffic volume.

Let's consider that the current queue length of a node is around the half of the queue size and the rate changing of the queue length is during an increasing phase, then the queue will be filled in the near future. Hence, a congestion may occur and future arrival packets may be dropped. To prevent congestion, the incoming flow rate should be immediately decreased. In the other case, when the current queue length of a node is close to zero and the rate changing of the queue length is during a decreasing phase, then the flow rate should be increased to fully optimize the utilization of radio resources and to fully maximize the overall throughput of the wireless network.

To illustrate well this concept, we use the following rule (all rules used by our model to achieve the traffic adaptation process are shown in Table I):

"If the rate changing in the buffer is rising fast and the buffer is filled, then the flow rate should be very-little".

In this expression, *"buffer"*, *"rate changing"* and *"flow rate"* are called linguistic variables which accept values among the words of a natural or synthetic language such as *"filled"*, *"rising fast"* or *"very-little"*. Usually, the values related to the linguistic variables are modeled by means of fuzzy sets. In most cases, this way of representation offers both a good description of systems and a natural behaviour of any inherent non linearity in the control process. The design of FTAM involves the selection of suitable mathematical representation of fuzzification and defuzzification operators, fuzzy implication functions, and forms of membership functions among a set of candidates. Particular choice of these functions and operators may affect the behavior of the traffic adaptation controller.

Figure 2 illustrates the structure of the proposed *fuzzy logic controller* FLC-FTAM. FLC-FTAM uses two input parameters to compute an explicit traffic rate: queue length (QL) and its growth rate (GR). The value of GR is computed as the difference between the current queue length and the queue length from the previous control interval (i. e. queue growth rate). Based on the values of GR and QL parameters, and the information stored in the traffic rules base, FTAM can calculate the required change in the session rate and store this information in a field named *Explicit Rate "ER"* in a newly created congestion notification packet (*CNP*). Within the present control interval, the congested node sends a *CNP* packet that will travel to the upstream nodes along the route.

In order to obtain the *flow correction rate*, we define the fuzzy Rule Base shown in Table I. This table is a proposal for the FLC-FTMA determined via the analysis in the previous section but also by observations during simulations. Note that the rule base is malleable enough so that other researchers can argue and propose different rules for different reasons.

TABLE I: FTAM Fuzzy Rule Base

	IF		THEN
n	Growth Rate	Queue Length	Flow Rate
1	*Negative*	*Very Small*	*Increase sharply*
2	*Negative*	*Small*	*Increase sharply*
3	*Negative*	*Medium*	*Increase moderately*
4	*Negative*	*Big*	*Do not change*
5	*Negative*	*Very Big*	*Do not change*
6	*Acceptable*	*Very Small*	*Increase sharply*
7	*Acceptable*	*Small*	*Increase moderately*
8	*Acceptable*	*Medium*	*Do not change*
9	*Acceptable*	*Big*	*Decrease moderately*
10	*Acceptable*	*Very Big*	*Decrease sharply*
11	*Positive*	*Very Small*	*Do not change*
12	*Positive*	*Small*	*Do not change*
13	*Positive*	*Medium*	*Decrease moderately*
14	*Positive*	*Big*	*Decrease sharply*
15	*Positive*	*Very Big*	*Decrease sharply*

Note that in the implementation phase of FTAM model, the choice of traffic rules is performed depending on the manner how the system should behave to ensure the traffic adaptation process. After classification of the appropriate rules, the membership functions associated to each parameter's rule are identified. For that aim, a variety of membership functions may be applied to ensure the adaptation process such as triangular, Gaussian, and trapezoidal functions. In FTAM, we have chosen triangular and trapezoidal functions because of their simplicity in computation. After that, the rule base is fine tuned by observing the progress of simulation in order to achieve a suitable balance between a tolerable average end-to-end delay and increase the throughput.

V. Performance Evaluation

A. FTAM Analysis

Before simulating our proposal by computer-based simulation, we should first validate the effectiveness of using the fuzzy logic within the proposed traffic adaptation model. Since our model is based on IF-THEN rules rather than on mathematical equations, we need to show how the traffic adaptation changes as function of fuzzy inputs.

Figure 3 shows the relation function between the output (*flow correction rate*) of the model and its two inputs (*queue length* and *growth rate*). We observe that when the *queue* is

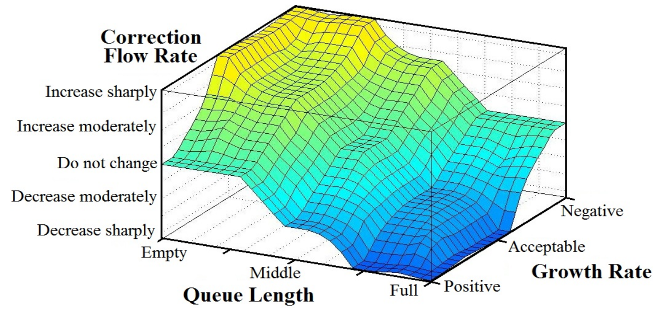


Fig. 3: Correction Flow Rate as a function of Queue Length and Growth Rate

full or empty, the *flow correction rate* is less dependent on the *growth rate*. For instance, if the *queue* is full, then the *flow rate* should be decreased except if the *growth rate* is negative. However, when the *queue* is empty, the *flow rate* should be increased except if the *growth rate* is positive. In the other case, we observe that when the *queue length* is middle, the *flow rate* is more dependent on the *growth rate*. If the *growth rate* is positive, acceptable or negative, then the *flow rate* should be decreased, not changed or increased, respectively.

The previous results typically express the relation between the *queue length* and the *growth rate*. As explained above, the target *queue length* in our model is equal to the *Medium* value of *queue length* (here equal the half of the buffer size). For instance, when the *queue* is empty, the *flow rate* should be increased until the half of the buffer size will be filled. The degree of the rate increasing is function of the distance between the current *queue length* and the half of the buffer size. However, when the *queue length* is equal to the half of the buffer size and the *growth rate* is positive, the *flow rate* should be decreased moderately to save the *queue length* in this range.

This example shows again the flexibility provided by the fuzzy logic to control carefully the traffic adaptation. Such results cannot be obtained using a traditional weighted sum models.

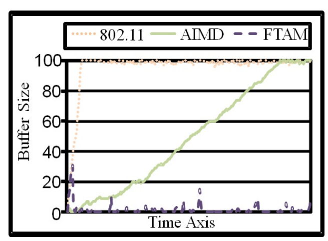
B. Simulation Results

In what follows, we present some preliminary simulation results of the proposed model using GlomoSim simulator. Throughout the simulation, each wireless node has a transmission range of 250 meters and shares an 11 Mbps radio channel with its neighboring nodes. The source and destination nodes associated with flows are distributed among the nodes in the wireless mesh network. The simulated environment has a square shape of 1000m x 1000m where all wireless nodes share a single radio channel of 11 Mbps. The performances of FTAM are compared with IEEE 802.11 and SWAN-AIMD [11]. During the simulation, real time voice and video flows are active and monitored. Voice and video traffic are modeled as 80 Kbps and 200 Kbps constant rate, respectively.

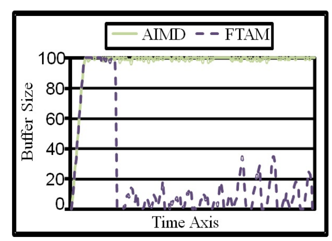
Figure 4a shows the buffer size variations at a source node at the beginning of the simulation. This figure shows clearly that the buffer size in FTAM is always limited. At the beginning of the simulation, the buffer size may go up to 30%, this is due essentially to the fact that there is no much traffic in intermediates nodes; hence it is possible to send additional packets over these nodes. Figure 4a illustrates also that buffers in AIMD remains almost full for a longer period of time waiting for successive messages losses. It is clear that FTAM improves exponentially the performance of 802.11 in terms of QoS. Therefore, it would be more significant to compare FTAM to an enhanced and well known approach as SWAN-AIMD.

Figure 4b is a capture of the buffer size variation at an intermediate node. We can observe clearly that FTAM attempts to reach the maximum tolerable throughput; which means that the buffers in intermediate nodes will be filled as rapidly as in SWAN-AIMD. Nevertheless, a best value of throughput is reached more quickly. Thus, the buffer size in intermediate nodes will take a small value which can help to reduce the congestion and to decrease the time delivery of traffic packets. Regarding the buffers in AIMD, they are filled gradually upon the detection of packets lost problem.

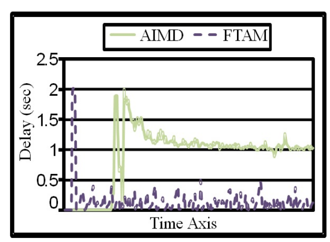
Figure 4c illustrates the impact of the buffers variations at intermediate nodes on the end-to-end delay. We observe that AIMD increments gradually the throughput upon the detection of congestion problem, and packets will wait longer in buffers in intermediate nodes. However, our model, FTAM, maintains the size of buffers as low as possible; thus the traffic packets do not lose much time, waiting in the intermediate nodes.



(a) Buffer size at a source node



(b) Buffer size at a intermediate node



(c) Delay

Fig. 4: Buffer size and delay variations

VI. Conclusion

This paper explored the usage of artificial intelligent (Fuzzy Logic) technique in order to control the rate adaptation of multimedia real time traffic in WMNs. The proposed model, FTAM, uses the queue length variation rate in addition to the current queue length in order to predict and control the network congestion. One of the benefits of FTAM is that the regulation rate is predicted as soon as the congestion is expressed in the nodes. Moreover, FTAM ensures that best-effort traffic coexists well with real-time traffic in the multimedia applications.

Future works include extensive simulations using GloMoSim underboth the single-hop and multi-hop environment and compare the performances of FTAM with the standard IEEE 802.11. and SWAN-AIMD

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