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A Fuzzy Based Approach for Priority Allocation in Wireless Sensor Networks

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***Abstract*— Congestion in wireless sensor networks becomes a challenging issue. That is due to the relatively high node density and source-to-sink communication pattern. Congestion not only causes packet loss, but also leads to excessive energy consumption. Therefore, in order to schedule the communication between nodes we target to design a system that, comparing with previous solutions, offers improved performance of CSMA/CA mechanism for IEEE 802.15.4 MAC Layer. The challenge here is to propose a fuzzy logic based algorithm that dynamically adjust the backoff exponent (BE) according to the queue level of each node and the traffic rate in the CSMA/CA method. The fuzzy algorithm attaches a priority level for a specific sensor node. The performance of the scheduler is studied using NS2 and is evaluated in terms of a quantitative metrics such as packet delivery ratio, traffic rate, dropped packets and average end-to-end delay to control congestion in the network.**

***Keywords*—Fuzzy rules, CSMA/CA, priority, queue and traffic rate.**

I. Introduction

Providing Quality of Service (QoS) support in Wireless Sensor priority Networks (WSNs) for improving their timing and reliability performance under severe energy constraints has attracted recent research works. The standardization efforts of the IEEE Task Group 15.4 have contributed to solve this problem by the definition of the IEEE 802.15.4 protocol for Low-Rate, Low-Power Wireless Personal Area Networks (WPANs). In beacon-enabled mode, the IEEE 802.15.4 protocol uses slotted CSMA/CA as a Medium Access Protocol (MAC). Even though the IEEE 802.15.4 protocol provides the GTS allocation mechanism for real-time flows, the allocation must be preceded by an allocation request message. However, with its original specification, the slotted CSMA/CA does not provide any QoS support for such time-sensitive events, including GTS allocation requests, alarms, PAN management commands, etc..., which may result in unfairness and degradation of the network performance, particularly in high load conditions.

The MAC layer has the control for coordinating channel access to maximize throughput at an acceptable end-to-end packet delay and minimal energy consumption. The IEEE 802.15.4 MAC is in fact planned to serve a set of applications with very low power consumption and cost requirement, and with relaxed needs for data rate and QoS.

We propose to schedule data in our work with fuzzy rules to have best optimizations in terms of QoS. We have integrated these rules in the CSMA/CA algorithm where we had added conditions for the priorities for nodes who wish to access to the channel. However, we will modify the value of the backoff exponent BE so it will be increased or decreased according of the length of the queue and the rate of each node. Besides, we know that if the traffic load is greater than the available capacity of the sensor network, congestion occurs and it causes buffer overflow, packet drop, deterioration of network throughput and QoS. This is caused by the whole information which circle between the nodes. Wherever nodes receive more data, traffic rate, the probability of lost information becomes critical and high.

The rest of this paper is organized as follows. In section 2, the related works or those that are partially related to ours are described briefly. Section 3 then presents the design of fuzzy algorithm. In section 4, we use experimental results to evaluate our proposed model and finally section 5 concludes by taking a glance at the proposed algorithm and introducing new open areas for further research activities.

II. RELATED WORK

The improvement of fuzzy logic mechanisms has drawn many research efforts. Particularly for the case of WSN, some recent research works have contributed to enhance fuzzy logic for achieving reduced delay , perform the packet delivery ratio and better estimation of number of dropped packets, as described next.

Authors in [1] proposed a new weighted packet loss metric which is best suited for multimedia sensor networks in order to convey packets of different priority classes. The proposed program tries to minimize the aforementioned criterion by means of fuzzy queue management and a newly introduced adaptive rate control mechanism. To yield lower packet loss and consequently energy loss that is of utmost importance in WSNs.

Mohit and al [2] presented an algorithm to improve the performance of DSR protocol by using fuzzy logic in MANET. The data packets are served in FIFO order for

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packet schedulers in wireless adhoc networks. Authors presented a fuzzy based priority scheduler for MANET to determine the priority of the packet using DSR as a routing protocol.

In [3] authors proposed a fuzzy priority calculation module to calculate priority of packet based on various network parameters like data rate, queue length, expiry time, congestion and packet size. In order to improve the performance and maintain the Quality of Service of MANET, the packet scheduler can be used.

Authors in [4] proposed a hierarchical tree based congestion control using fuzzy logic for heterogeneous traffic in WSN. Where the congestion detection is performed using fuzzy logic technique based on the parameters such as packet service ratio, number of contenders and buffer occupancy.

A mathematical programming approach has been proposed in [5] [6] to develop the membership function of the system performance, in which the arrival rates and service rate of two priority classes are used as fuzzy numbers. Authors applied an algorithm to investigate the queueing model of two priority classes by using triangular fuzzy numbers.

Authors in [7] proposed a traffic management for controlling the congestion, in which routers are associated with intelligent controllers to manage buffers and transfer packets for wired/wireless networks. Authors analyzed various existing traffic control protocols, which estimated auxiliary network parameters such as link latency, bottleneck, bandwidth, packet loss rate and the number of flows for evaluating the performance of the network. The fuzzy logic based controller can measure the router queue size directly by using congestion control algorithm.

III. DESIGN OF FUZZY ALGORITHM

A. Motivation

As shown in Fig. 1, a fuzzy controller is a system based on fuzzy rules whereby instead of binary logic it rests upon fuzzy logic. These systems are comprised of four main components, as follows:

Fuzzifier: As fuzzy systems manipulate fuzzy sets, the crisp inputs should be converted into fuzzy ones in some way. In so doing, the fuzzifier takes in a crisp input and returns a fuzzy set depending on the type of the selected fuzzifier.

Rule Base: All the decisions in a fuzzy system are based on the existing fuzzy rules. These rules are made by combinations of fuzzy antecedents and consequences which are fuzzy sets. The rule base is usually evolved during the time via heuristic approaches or it may be formed by the help of an expert operator who knows the underlying system well.

Inference Engine: After the crisp input converted into a fuzzy set, it is fed into the inference engine for calculation of the output fuzzy set. The inference engine makes use of the rules embedded into the rule base to come into a fuzzy conclusion. Depending on the choice of inference engine different outputs might be produced.

Defuzzifier: Finally, to produce outputs that comply with plants' inputs, the resulting fuzzy set should be converted back into a crisp value via a defuzzifier.

Fuzzy algorithm takes a control action through the use of linguistic variables. An input value to a fuzzy algorithm has a level of uncertainty within a specific range. This structure and flexibility make fuzzy algorithm very adaptive to dynamic conditions, as they can effectively adjust a portion of or all the control knobs. This section provides the details of the proposed fuzzy algorithm, which combines traffic rate and dynamic queue management to achieve energy efficiency and best QoS of the network.

We aim to design a vigorous fuzzy algorithm that can achieve better performance to improve energy consumption and minimize lost of packet, this will be ensured by the control of the queue length of each nodes and with a dynamic scheduling to ensure communication with the channel. In this context, we have proposed as parameters, the queue length of each sensor node and the traffic rate. To monitor their variation, Fig.1 shows the basic idea, of how to make a decision. However, we will be instantaneously monitoring the queue occupancy and the traffic rate for every super frame. All linguistic variables have a random number that will be characterized by a membership function, to handle this function; a triangular form will be associate to it. Other implementations of more widespread forms are: rectangle, hyperbolic and trapezoid. Output membership function will be explicit in the fuzzy singletons.

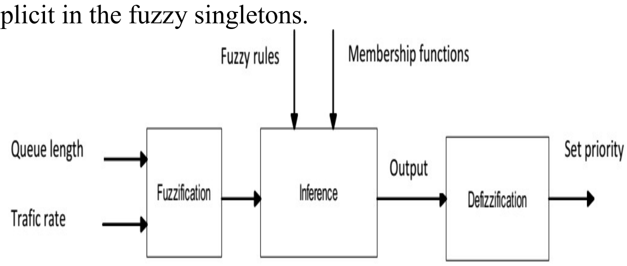

Fig. 1 Proposed Fuzzy controller scheme

B. Fuzzy-logic Rules

Since the fuzzy input variables, queue length and traffic rate, have each three different states, the total number of possible arranged a pair of these states is 9. For each of these, we have to establish an appropriate state of the output fuzzy variable priority. A practical way of defining all essential rules is through a decision table. It consists of 9 rules as shown in Table 1.

TABLE I
FUZZY RULE BASE

T Q	Low	Middle	High
Empty	Low priority	Low priority	Middle priority
Middle	Low priority	Middle priority	High priority
Full	Middle priority	High priority	High priority

Fuzzy controller considers two parameters for fuzzification: Queue length (Q) and the Traffic rate of flow of each application (R). The output of linguistic parameters is the Priority allocation factor for a given application. The membership to each of fuzzy variables is assigned using Min-max method. For each of the considered fuzzy parameter, their ranges of linguistic values are depicted in Fig. 2.

During the normalization phase, each measured value in the system will be modified to provide a value belonging to a simple speech. In order to normalize linguistic variables, we proceed in the following way. If the variation field of the entry variable "y" is [a,b], it can be converted to [-1,1] using the following linear relation:

$$V=\frac{2y-b-a}{b-a} \quad (1)$$

In the fuzzy theory, fuzzy set A of universe X is defined by function $\mu_A(x)$ called the membership function of set A. The universe of discourse is then represented by linguistic variables, which has a relatively small number of terms (usually three, five or seven) to limit the number of rules. Finally, the normalized values derived from each of the inputs are transformed into linguistic terms, using the corresponding linguistic variables.

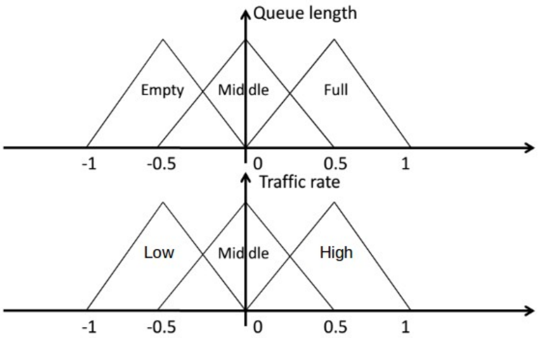

Fig. 2 Membership functions for inputs linguistic parameters

Fig. 3 shows the finite state machine description of the modified CSMA/CA. This diagram will be applied to each node wishing connect to the channel. Firstly we have to get information about its queue length and its rate and according to this informations we will set it's backoff time to connect to the channel. In a second work, the modification within the CSMA/CA code will be done by scheduling the priorities level by giving the first priority with a short backoff time for nodes who attempt a critical situation.

C. Fuzzy Membership Functions

In fuzzy logic, we use membership functions to switch a numerical variable range R to a linguistic one. This conversion is a necessary step in fuzzy systems because the membership functions are employed in the rule base. Besides, one of the most important aspects in such a selection is the full coverage of the input variable range R with N fuzzy functions. In the developed fuzzy controller, each variable has full range coverage through three membership functions. We use triangular membership function for the input as shown in Fig.2. In particular, this figure shows the range coverage of thread utilization rate and queue length.

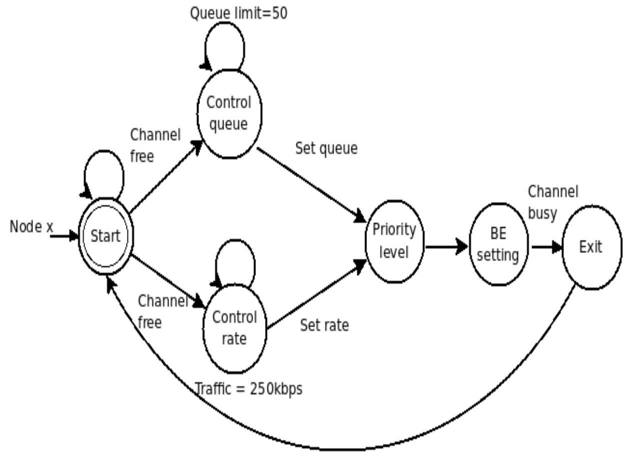

Fig. 3 Finite state machine diagram

Concerning the output variable, the action to give priority can change according to three variation levels as: (Low priority (1), Middle priority (2), and High priority (3)). Fig. 4 illustrates the variation of the output linguistics variables using a singleton function.

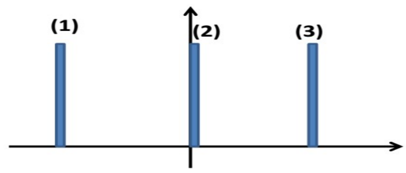

Fig. 4 Finite state machine diagram

IV. SIMULATION RESULTS

The network simulator NS2 provides scalable simulations of wireless sensor networks and helps to analyze and evaluate the performance of the proposed fuzzy program. In this simulation 30 nodes are deployed in a tree cluster topology. The duration of each run is 100 simulated seconds. The radio model used is the two ray model. Traffic source are FTP TCP. Each packet is 512 bytes long, thus resulting 2 kbps data transfer rate for each session. Multiple simulations run with different seed values were conducted for each scenario and collected data was averaged over those simulated results.

D. Performance metric:

The following metrics are used to evaluate the effect of fuzzy rules. We have used packet delivery ratio, end to end delay, traffic rate and dropped packets for evaluating our proposed program.

*Packet Delivery Ratio (PDR): i*t is the ratio of the number of data packets actually delivered to the destination to the number of data packets supposed to be received. This shows the effectiveness of the protocol.

$$PDR = \frac{Packets\ Delivered}{Packets\ sent} \quad (2)$$

Average end-to-end delay: It indicates how long it took for a packet to travel from the source to the application layer of the destination.

$$Avg\ EED = \frac{Total\ EED}{No\ Of\ Packets\ Sent} \quad (3)$$

Traffic rate: is a sequence of packets sent from a particular source to a particular uni-cast, it can be defined as:

$$Rate = \frac{Total\ Pckets\ Sent}{Run\ Time} \quad (4)$$

Dropped Packets: The dropped packets are the data packets that are dropped during the link breaks and collision.

E. Experiment results:

Fig. 5 shows the packet delay variation in the period of simulation (we run the simulation 100 s). The comparison of above simulation shows that the delay of the algorithm with fuzzy rules is much lower than the non-fuzzy rules. From this figure, we observe that the use of high priorities are guaranteed a minimum delay compared to those who don't use our fuzzy approach.

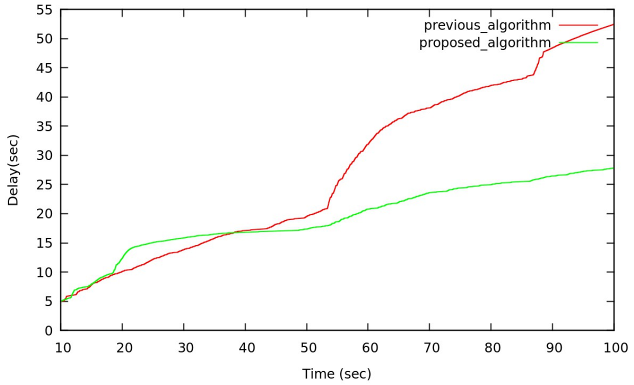

Fig. 5 Average delay as function of time

Fig. 6 demonstrates the average traffic rate during time simulation for both algorithms. According to the figure, it is clear how the new program easily adopts to the varying network conditions. Also, notice how the proposed program outperforms the CSMA/CA program in having more sent packet rate.

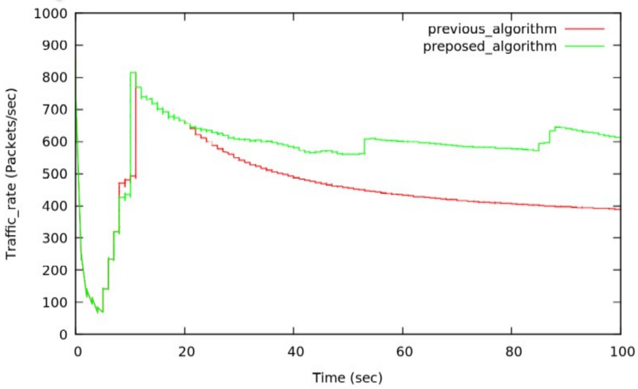

Fig. 6 Traffic rate as function of time

Another word under notation is that although in the proposed program the fuzzy rule increase the allowable transmission rate, this increase is not without bound. This means that there is a compromise in how much the transmission rate is eligible to increase based on reorganization of the priority to access to the channel. That is to say, if an increase in the traffic rate gives rise to a considerable consequent increase in the network weighted packet loss then it stops to become larger and larger and that is what we can see in Fig. 7 where the number of dropped packets has significantly reduced when we have applied the fuzzy rules.

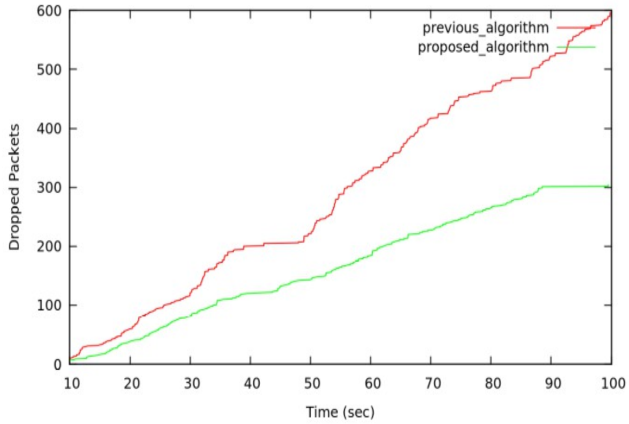

Fig. 7 *Dropped packets as function of time*

Fig. 8 plot the PDR variation versus time simulation. As we can see the use of fuzzy rules with reference to the packet delivery ratio is much improved as compared with the classical program. It is also seen that for small loads, the scheduler does not provide much improvement, but over simulation it has been increased the improvement of the program more. The performance is evaluated with different seed value and the average value is taken for all the performance metrics.

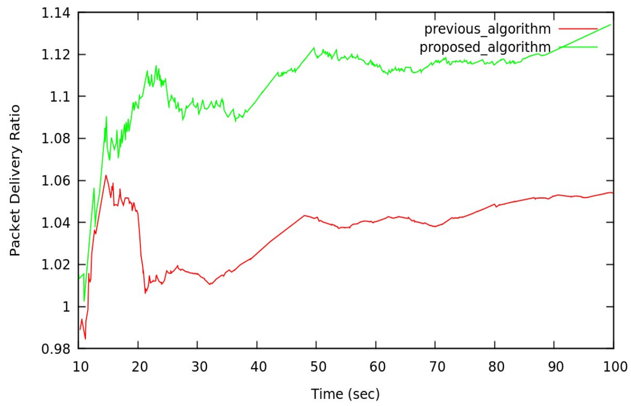

Fig. 8 *Packet delivery ratio as function of time*

V. CONCLUSION

In this paper, a technique based on fuzzy rules for wireless sensor network is presented which analyze the performance of the fuzzy based priority scheduler for QoS parameters in WSN. It combines the input parameters such as queue length and traffic rate to find the priority parameter. The fuzzy program attaches a priority's value to the node who has a high queue length and high rate. The crisp value is calculated based on the inputs such as queue length and traffic rate which are delivered from the network for each sensor node. From the results above it is seen that packet delivery ratio in case of fuzzy rule is better than simply program. Average end to end delay and dropped packets are also improved and shows better results when fuzzy rules is used.

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