Design a New Fuzzy Congestion Controller in Wireless Sensor Networks

M. Samimi, A. Rezaee, and M. H. Yaghmaee

***Abstract*—Wireless Sensor Networks (WSNs) become active suddenly, when an event occurs in order to respond to the event. Depending on the network and the application, there exist different levels of congestion that need to be controlled. This article presents the design of a new fuzzy congestion controller (FCC) in WSNs. This FCC detects and avoids congestion by developing the ad hoc fuzzy rules base as well as membership functions. In this concept, two parameters have been used as the sign of congestion: a) Channel load b) The size of queue within intermediate nodes. These parameters constitute the input to FCC. The output of this FCC (sending rate) derives from the conjunction with Fuzzy Rules Base and Fuzzy Inference Engine. The congestion is controlled by the sending rate. The simulation results reveal that usage of fuzzy congestion controller has reduced packet-loss about 16%, comparing with non-fuzzy methods. It has also increased throughput and saving energy.**

***Index Terms*—Congestion; fuzzy rules, fuzzy sets, membership function, sending rate.**

I. Introduction

Wireless sensor networks have different forms regarding its geographical area. Usually, a wireless sensor network consists of one or several nodes named sink and many sensor nodes which are placed in the same area. By sensing the information and performing the calculations and wireless connections of the sensor nodes, they can sense the physical phenomena. One or more nodes can also be considered as source which will be packets generators.

These networks have a few loads in normal situation, but when they receive an occurrence, they become active in order to detect the occurrence and control it. In this case, the network load increases and congestion happens in intermediate nodes. Generally, congestion in wireless are two kinds:

A. Congestion in Node-Level

It occurs when its buffer spills. This kind of congestion is common in all networks.

B. Congestion in Link-Level

It occurs, when different nodes use the same wireless channel (in common).

Occurrence of this congestion in wireless sensor networks will cause waste of energy and packet losing. By controlling the congestion effectively, the network lifetime increases.

Generally, we have two methods for congestion control:

- Increase of network resources
- Traffic control

In wireless sensor networks, increase of resources, include increase of energy source, and increase of the number of radio intermediates which it is difficult.

In the next method, we can control the traffic. It can be done by controlling the traffic rate in the source nodes or middle nodes in this research we tried to control traffic and congestion effectively by the use of fuzzy controller.

The rest of this paper is organized as follows: In the second part of the paper, the related works are presented. In the third part the proposed method will be discussed. In the forth part, the simulation results and their figures are shown, and the fifth part includes conclusions, results and the future work.

II. Related Works

Congestion control in wireless networks and wireless sensors has been studied in different researches. Each one tried to control the congestion, and also introduce the congestion signs and define the avoidance methods. But none of the presented protocols has used the fuzzy methods for congestion control in wireless sensor networks.

A. Congestion Detection and Avoidance (CODA)

In this protocol, the channel load has been used as congestion indicator parameter and the traffic is controlled by the use of this parameter.

Wireless channel is sampled in certain times and the congestion is detected by calculation of channel load. Then a suppression message is sent to the source and the source controls the congestion by adjusting the sending rate. The intermediate node through which the suppression message passes, adjust and control its rate. The rate adjustment is in the form of classic formulas [1].

B. Event to sink Reliable Transport

A protocol is presented for congestion control in wireless sensor networks which is event-to-sink and has considered reliability and saving energy [2].

C. Rate Controlled Reliable Transport (RCRT)

This protocol is also presented on wireless sensor networks and works effectively for the applied program that needs high service rate. In this protocol, rate adjustment is done in the Sink node which has a high flexibility and efficiency [3].

D. Priority-based Congestion Control Protocol (PCCP)

Congestion control on wireless sensor networks is discussed which its main idea is based on node priority index and congestion rate and it supports the service quality for different programs [4].

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All of the presented protocols on the wireless sensor networks have used AIMD idea of Additive Increase – Multiplicand decrease, for congestion control.

None of them has studied congestion control on wireless sensor networks in the form of fuzzy [5]-[1 4]

III. FCC SCHEME

In the proposed method, a fuzzy congestion controller (FCC) consists of two inputs and one output which two signs (wireless channel load, the length of each node queue) are used. A sampling process is done in time intervals from channel. We added two fields in packet format, one for channel load and another for queue length.

A. Detection (at Intermediate Nodes)

Each node sense channel load. When an intermediate node receives a packet, it gets channel load and queue length fields of packet header and compares them with sensed channel load and its queue length. then it replaces sensed channel load and its queue length in header fields of packet if and only if the value of sensed channel load and its queue length are more than value of header fields of packet.

B. Notification (at Sinks)

When the packet arrives to the sink, the sink node gets channel load and queue length of packet that these values are the maximum values for sensed channel load and queue length through the path of network. Sink node makes a notification message and sets maximum value of channel load and queue length in header of message then it sends notification message to source node.

To prevent the similar notification messages and to optimize energy consumption, the channel load is divided into: Small, Medium and Big and queue length divided into Small and Big. The sink node sends the notification message to the source, when the rate of the sensed load or queue length is different from the rate of the sensed load or queue length in the last sampling.

C. Rate Adjustment (at Source)

The source node adjusts its sending rate, based on these two parameters in order to prevent congestion. In source node we used a fuzzy congestion controller which calculates sending rate based on maximum value of sensed channel load and queue length of intermediate nodes.

D. Network Topology

The intermediate nodes are usually distributed between Source node and Sink node. In this research, the topology is considered like Fig. 1 in which the source is the packet generator and the collected information is sent to the sink node.

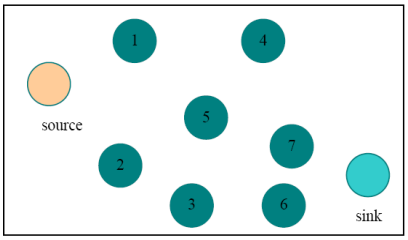


Fig. 1. Network topology

E. Fuzzy Controller

The general structure of a fuzzy controller consists of: fuzzifier, inference engine, defuzzifier and fuzzy rule base.

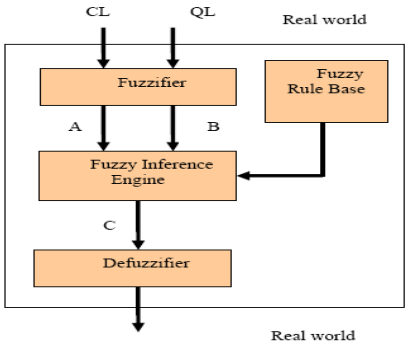


Fig. 2. General structure of fuzzy controller

A, B, C are fuzzy sets for channel load, queue length, and sending rate respectively.

TABLE II :LINGUISTIC VARIABLES

Sending Rate (R)		Queue Length(QL)	
		Small	Big
Channel Load(CL)	Small	H	MM
	Medium	M	M
	Big	LM	L

F. Fuzzy Rules Base

One of the important sections in a fuzzy controller is fuzzy rule base which consists of the rules are in the form of **If-Then.**

Since the sending rate(R) is adjusted based on the channel load(CL) and the length of every node queue(QL), the rule base consists of 6 separate rules in this research. Fuzzy rule base and linguistic variables are shown in Table I and Table II respectively.

TABLE I :FUZZY RULE BASE

1	If **CI** is Small(S) and **QL** is Small(S) then **R** is High(H)
2	If **CI** is Small(S) and **QL** is Big(B) then **R** is More than Medium(MM)
3	If **CI** is Medium(M) and **QL** is Small(S) then R is Medium(M)
4	If **CI** is Medium(M) and **QL** is Big(B) then **R** is Medium(M)
5	If **CI** is Big(B) and **QL** is Small(S) then **R** is Less than Medium(LM)
6	If **CI** is Big(B) and **QL** is Big(B) then **R** is Low(L)

G. Fuzzy Sets

Considering the linguistic variables which has been used in the fuzzy rules base, for channel load, queue length and sending rate (CL,QL,R) are shown, The fuzzy sets are in Fig. 3, Fig. 4 and Fig. 5.

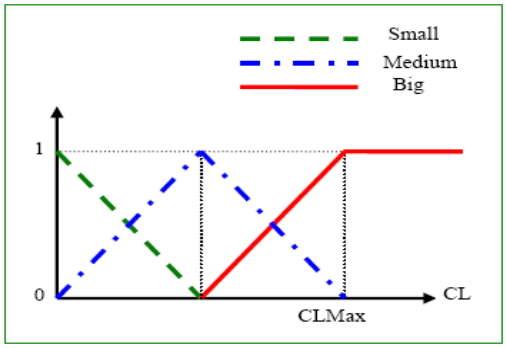


Fig. 3. Fuzzy sets for the channel load (CL)

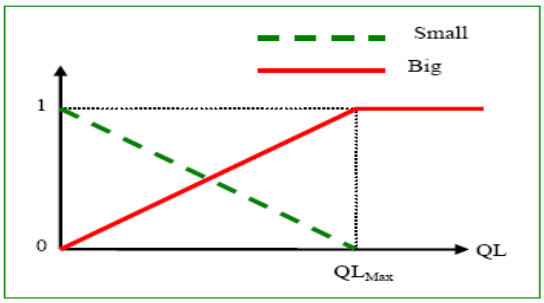


Fig. 4. Fuzzy sets for the queue length(QL)

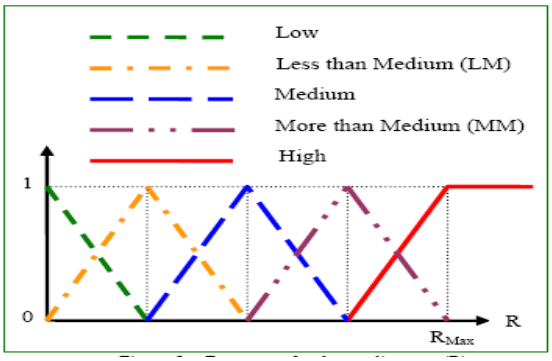


Fig. 5. Fuzzy sets for the sending rate (R)

H. Rate Adjustment (at Source)

Considering the six fuzzy rules that mentioned, each rule is made separately from combination of the channel load and queue length, by the use of Mamdani product in the form of equations 1 to 6.

$$\mu_{Small}(cl) * \mu_{Small}(ql) \rightarrow \mu_{High}(r) \quad (1)$$

$$\mu_{Small}(cl) * \mu_{Big}(ql) \rightarrow \mu_{MM}(r) \quad (2)$$

$$\mu_{Medium}(cl) * \mu_{Small}(ql) \rightarrow \mu_{Medium}(r) \quad (3)$$

$$\mu_{Medium}(cl) * \mu_{Big}(ql) \rightarrow \mu_{Medium}(r) \quad (4)$$

$$\mu_{Big}(cl) * \mu_{Small}(ql) \rightarrow \mu_{LM}(r) \quad (5)$$

$$\mu_{Big}(cl) * \mu_{Big}(ql) \rightarrow \mu_{Low}(r) \quad (6)$$

The average of the centers (W1 to W5) is defined by the use of Fig. 3:

$W1=1,\ W2=R_{max}/4,\ W3=R_{max}/2,\ W4=R_{max}/2,\ W5=3R_{max}/4,\ W6=R_{max}$

Since, the sending rate for rule 3 and rule 4 is equal, we set W3=w4.

Table III shows the specifications of the fuzzy congestion controller.

TABLE III: FCC SPECIFICATION

1	Inference Engin	Separated rules with union combination
2	t-norm	Algebra product
3	s-norm	Maximum
4	Fuzzifier	Triangular
5	Defuzzifier	Center average

According to the above specifications and considering the equations of 1 to 10, the sending rate in every step is obtained from the equation 12.

$$R^{*} = \sum_{l=1}^{6} R^{l} w_{l} \; / \; \sum_{l=1}^{6} w_{l} \quad (12)$$

Which R^{l} is the sending rate for each rule.

IV. SIMULATION RESULTS

The simulator used in this research is Opnet 14 software. Based on that, the simulation has been done in two different scenarios:

1) *Without fuzzy congestion controller*
2) *By the fuzzy congestion controller*

The results are shown in the Fig. 6 to 13.

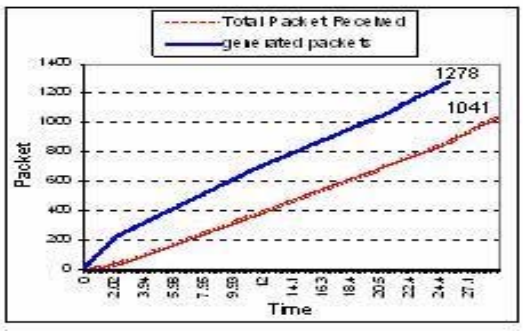


Fig. 6. Packet-loss =%18.5 by FCC

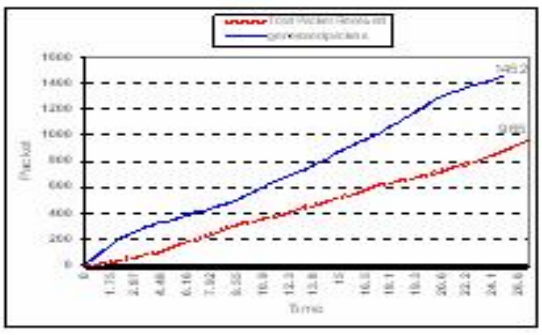


Fig. 7. Packet-loss =%34.5 without FCC

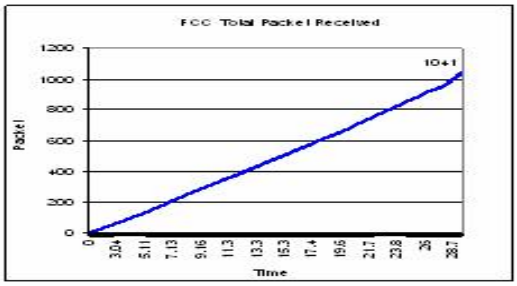


Fig. 8. Throughput =1041/30 ≈ 34 (packet/second)

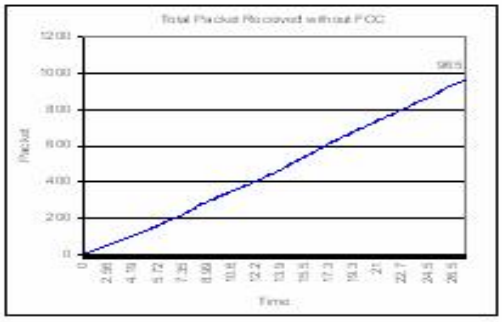


Fig. 9. Throughput =9651/30 ≈ 32 (packet/second)

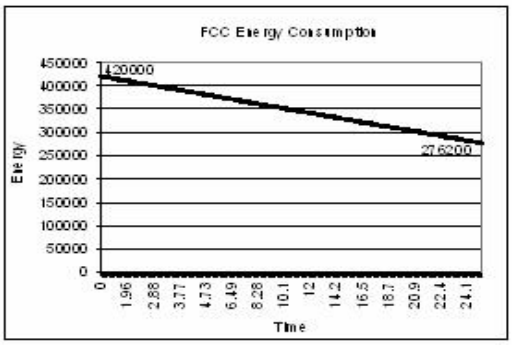


Fig. 10. Energy consumption=143800

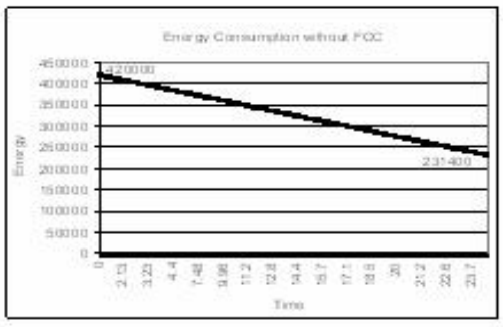


Fig. 11. Energy consumption=188600

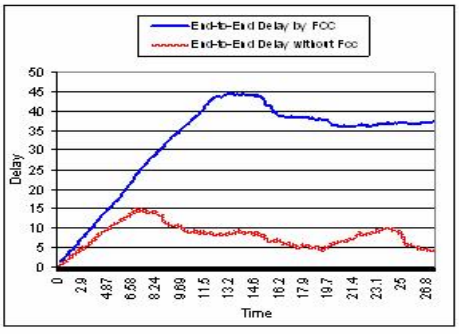


Fig. 12. End-to-end delay (second)

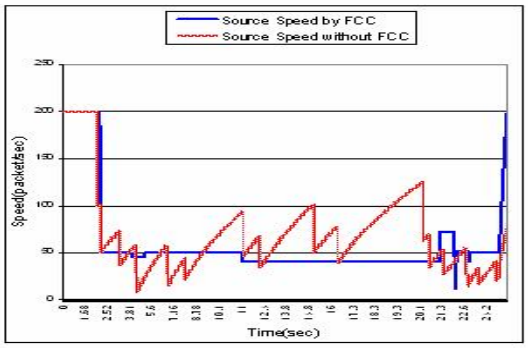


Fig. 13. Source speed

V. Conclusion

In this research, we observed that a fuzzy controller can reduce losing the packet about 16%.

It can also optimize energy consumption, and increase the efficiency of the network. As a result, the fuzzy controller can control congestion in wireless sensor networks.

As a future work, we can do research on rate adjustment in middle nodes and sink nodes, and also test other fuzzy inference engines.

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