A Fuzzy Logic-Based Energy Efficient Scheme for Real-Time Packet Transmission in WSN

Seyed Mahdi Jamei, Karim Faez

Abstract **— Timeliness and energy efficiency are two important parameters of Quality of Service (QoS) in Wireless Sensor Network (WSN). So, making optimal choices for real-time and energy efficient packet transmission in real-time environment is vital. In this paper, a Fuzzy Logic System (FLS) is used as a decision mechanism for next hop node selection. Both transmission rate and energy are chosen parameters for choosing the next-hop node in real-time packet transmission. Simulation results show that the proposed scheme provides improvement on real-time transmission and energy efficiency performance, when operating in varying real-time environment.**

Keywords- **Sensor Network, Next hop selection, Fuzzy Logic, Delay, Energy Efficiency**

I. Introduction

Supporting service differentiated real-time communication is important for WSN to achieve the collaborative sensing task with specific timing constraints. The timing constraints can arise for various reasons. The collected event information needs to be sent to the sink within a certain period of time, so that proper event response can be performed in a timely manner. According to the event urgency and importance, the data packets associated with different events can be assigned different end-to-end deadline requirements. Only the packets that are delivered to the sink before the deadline are deemed useful. Since the network lifetime is an important issue in WSN, we have to maintain the balance between end-to-end performance and energy consumption. In this paper, we propose an energy efficient fuzzy logic-based scheme for real-time packet transmission in WSN. Both transmission rate and energy are chosen parameters for the FLS to choose next hop node for real-time packet transmission.

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This paper is organized as follow: we first present survey of related works in section 2 and point out their limitations accordingly, section 3 introduces the fuzzy logic. Section 4 presents our real-time scheme for packet transmission. Simulation results are explained in section 5 and the paper is concluded at section 6.

II. Related Works

Most routing protocols in WSNs only care about energy efficiency and few of them adequately address real-time requirements [2]. SAR [3] introduces the notion of QoS into routing decision but it suffers from overhead of maintaining the tables and states for each sensor node, especially when the number of nodes is huge. SPEED [1] is a successful real-time WSN routing protocol, but it also has not carefully considered the energy consumption, because it intends to select a node with high transmission velocity without considering the remaining energy of nodes. MM-SPEED [4] does some improvements to SPEED and differentiates the different real-time level. In [5], a new real-time communication architecture (RAP) is proposed for large scale sensor networks. It is suitable for communication scheduling in sensor networks in which a large number of wireless devices are seamlessly integrated into a physical space to perform real-time monitoring and control. Octav Chipara and Zhimin He, propose a Real-time Power-Aware Routing (RPAR) protocol, which achieves application-specified communication delays at low energy cost by dynamically adapting transmission power and routing decisions [6]. In [7], an adaptive routing protocol (ARP) proposed that dynamically adjusts the transmission rate of data packets during the end-to-end transmission. In this paper, we propose an intelligent, real-time, and energy efficient scheme for packet transmission in WSN based on fuzzy logic.

III. Overview of Fuzzy Logic

Fig. 1 shows the structure of a fuzzy logic system [8]. A fuzzy logic system basically consists of three parts: fuzzifier, inference engine and defuzzifier. When a crisp input is applied to a FLS, the inference engine computes the output set corresponding to each rule. Rules form the heart of a FLS and maybe provided by experts or extracted from numerical data. The IF-PART of a rule is its antecedent and THEN-PART of a rule is its consequent.

Crisp inputs are made fuzzy by the fuzzification process. A common fuzzification process is singleton fuzzification [2]. Fuzziness for a particular fuzzy set is essentially characterised by the membership functions (MFs). The rules relates the input fuzzy variables with the output fuzzy variables using linguistic variables each of which is described by a fuzzy set and fuzzy implication operators AND, OR etc [9]. Defuzzification is the last process in a FLS and finds a crisp output value from the fuzzy solution space. Common defuzzification methods are maximum, mean-of-maxima, centroid, centre-of-sums and centre-of-sets [8].

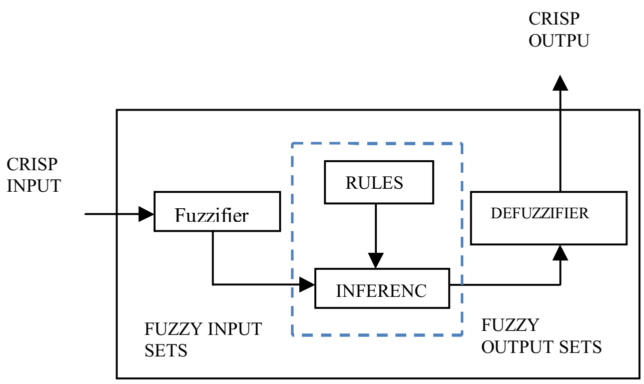


Fig. 1. Fuzzy logic system structure

IV. Proposed Scheme

In this scheme, we assume that each node knows its distance to the sink. The basic idea is that for next hop node selection in packet transmission, the remaining energy of the candidate node and the real-time status of the packet is considered simultaneously. So, we assume that each packet has two special fields: RT field and TTL field. RT (real-time) field is used to indicate if the packets have real-time transmission requirement. TTL (time to live) field is used to indicate how much time it remains for the data to arrive at the sink. Each sensor node has a buffer and all packets in its buffer are sorted based on TTL. The smaller the TTL is, the sooner the data packet would get service.

At first, we should build up the candidate set of the next hop nodes. The candidate set is composed of all neighbor nodes that are closer to the sink than the current node. Each entry of the candidate set stores the following information of one candidate:

- ID
- Location
- T_{RTT}
- TR (CN,Can)
- E_{rem}

T_{RTT} is the time duration between sending a test packet to the sink node and receiving its ack. TR (CN,Can) is defined as follow:

$$TR(CN,Can) = (d(CN, Sink) - d(Can, Sink)) / T_{RTT}(CN, Can)$$

d(CN, Sink) is the distance from the current node to the sink node.

E_{rem} is the remaining energy of the candidate node. All those information should be updated from time to time.

If data packet is real-time application data, this mechanism first chooses nodes from the candidate set of next-hop nodes as primary candidate set according to Rule 1.

Rule 1: $TR(CN, Can) \geq TR(S, Sink)$

TR (S , Sink) is a constant, which indicates the transmission rate requirement of the Source node. After creating the primary candidate set, the fuzzy logic system is used to determine the possibility of selecting each primary candidate node as next hop node. we setup fuzzy rules for next hop node selection based on the following tree antecedents:

1) Antecedent 1: TTL / TTL_{max} ratio of current packet.
2) Antecedent 2: TR(S,Can) / TR_{max}(S,Can).
3) Antecedent 3: E_{rem} / E_{max} of candidate node.

The linguistic variables used to represent all Antecedents are divided into three levels: low (L), moderate (M), and high (H). The consequent is the possibility of this candidate node will be selected for data forwarding. It was divided into 5 levels: very strong (VS), strong (S), medium (M), weak (W) and very weak (VW).

The fuzzy inference rule set is proposed as follows:

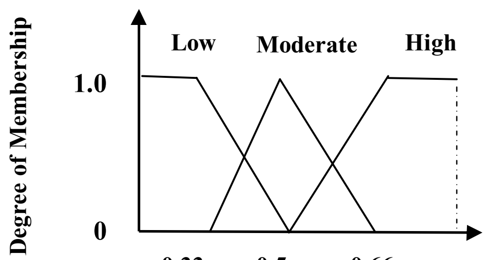
• IF (TTL/TTL_{max}) is H and TR(S,Can) / $TR_{max}(S,Can_i)$ is H Then consequence is VS.
• IF (TTL/TTL_{max}) is H and TR(S,Can) / $TR_{max}(S, Can_i)$ is M Then consequence is M.
• IF (TTL/TTL_{max}) is H and TR(S,Can) / $TR_{max}(S, Can_i)$ is L Then consequence is VW.
• IF (TTL/TTL_{max}) is L and E_{rem} is H Then consequence is VS.
• IF (TTL/TTL_{max}) is L and E_{rem} is M Then consequence is M.
• IF (TTL/TTL_{max}) is L and E_{rem} is L Then consequence is VW.
• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is H and (E_{rem}/E_{max}) is H Then consequence is VS.
• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is L and (E_{rem}/E_{max}) is H Then consequence is M.

• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is H and (E_{rem}/E_{max}) is L Then consequence is M.
• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is L and (E_{rem}/E_{max}) is L Then consequence is VW.
• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is M and (E_{rem}/E_{max}) is H Then consequence is H.
• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is M and (E_{rem}/E_{max}) is M Then consequence is M.
• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is M and (E_{rem}/E_{max}) is L Then consequence is W.
• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is H and (E_{rem}/E_{max}) is M Then consequence is S.
• IF (TTL/TTL_{max}) is M and TR(S,Can) / $TR_{max}(S, Can_i)$ is L and (E_{rem}/E_{max}) is M Then consequence is W.

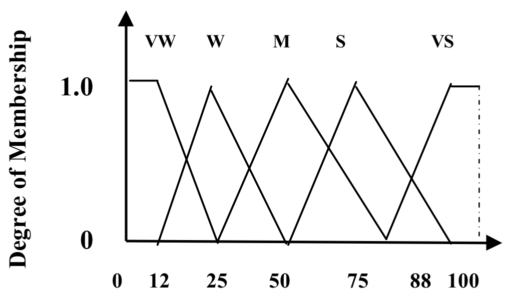
In this rules, TR_{max}(S, Cani) is the maximum TR between Source node and each candidate node. As the rules indicate, if the TTL of packet is moderate, we should consider to TR(S,Can) and E_{rem} metrics simultaneously, But if the TTL of packet is low, we should have great consideration to TR(S,Can) and if it is high, the E_{rem} should be considered greatly.

We used trapezoidal membership functions (MFs) to represent low, high, very strong, very weak; and triangle MFs to represent moderate, medium, weak, and strong. These are shown in fig. 2. After getting the fuzzy output from the rule base and deffuzification using the Centroid Method, the crisp output is calculated. The output of the defuzzification procedure is the probability of selecting the candidate node as next hop node.

If data packets are not real-time application data, one node which has the largest E_{rem} is chosen from the candidate set as the next hop.



(a) MFs for antecedents



(b) MFs for consequent

Fig. 2. MFs used to represent the linguistic variables.

V. SIMULATION RESULTS

In this section, we evaluate the performance of our proposed scheme in J-SIM simulator. J-SIM is a well-known Java-based simulation environment for numerical analysis [10]. We compare our scheme with SPEED and MMSPEED in terms of packet delivery ratio within deadline, energy consumption, and network lifetime.

The simulation parameters are described as follows. Our simulation modeled a network of N nodes placed randomly within a 200m * 200m area uniformly. The value of N varies in different experiments. Radio propagation range for each node was 50 meters and transmission rate was 256 kbit/sec. Initial energy of each node has been assumed equal to 1 Jule and the required energy for transmitting and receiving packets is equal to 0.003 Jules. Furthermore, the packet size is equal to 53 byte. For these simulations, a sensor node is supposed to transmit information every 3second.

In the first experiment, by assuming different number of nodes, we compared the Packet delivery ratio within deadline in the proposed protocol to SPEED and MMSPEED routing protocols. Packet delivery ratio within deadline is defined as how many packets are delivered to a sink within deadline. Results of this experiment are shown In Fig. 3.

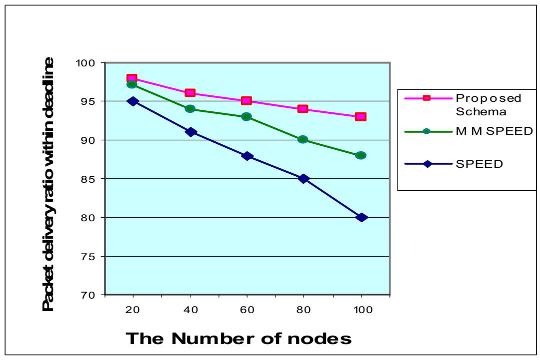


Fig. 3. Packet delivery ratio within deadline

As you can see, our scheme shows better performance than SPEED and MMSPEED. As the number of nodes increases, the bigger difference is measured. This is because SPEED does not differentiate different real-time applications and takes the best route for all packets. This way cannot guarantee that all real-time data are transmitted timely. For MMSPEED, the performance is improved and it has better performance than SPEED. For Our scheme, when the number of nodes increases, it has better performance than SPEED and MMSPEED, because it differentiates the different real-time packets and takes different transmission methods for them.

In second experiment, the sum of residual energy of nodes in proposed scheme has been compared to SPEED and MMSPEED protocols at different time. The number of nodes assumed equal to 100. As shown in Fig. 4, energy saving in our scheme is better. we can find that the energy consumption in proposed scheme is least and SPEED costs most energy.

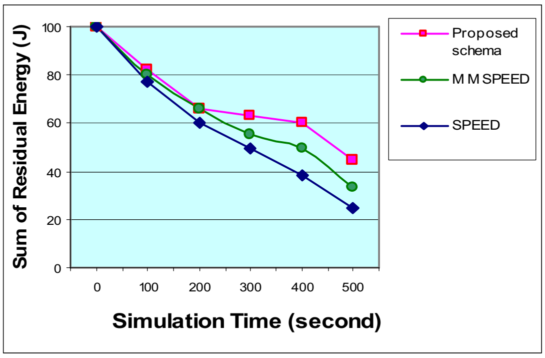


Fig. 4. Sum of residual energy

In the last experiment, by assuming different number of nodes, we compared the network lifetime in the proposed scheme to SPEED and MMSPEED routing protocols. Results of this experiment are shown In Fig. 5.

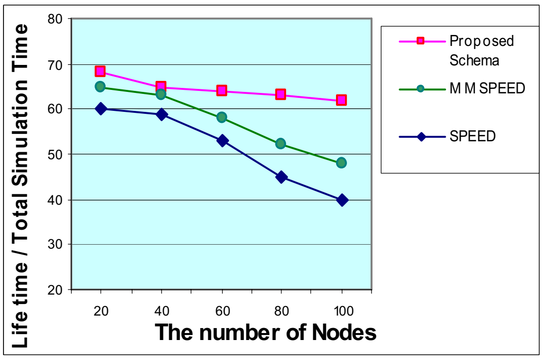


Fig. 5. Lifetime Vs Node Density

In the proposed scheme, by increasing the number of nodes, the network lifetime will be increased. This is mainly because battery drain is well-balanced in our scheme and the traffic on each path is proportional to the residual energy of their nodes. So, more protection is done for weaker nodes. Since SPEED simply uses the best links to transmit data, nodes along these links will die out quickly. Also MMSPEED doesn't change route based on nodes' remaining energy, which causes the unbalance of energy consumption among all sensor nodes.

VI. CONCLUSIONS

The real world requires real-time routing protocol in wireless sensor networks to achieve real-time communication besides the energy efficiency. In this paper, we proposed a fuzzy logic-based Energy Efficient scheme for real-time packet transmission in WSN. Both transmission rate and energy are chosen parameters for the FLS, to choose the next-hop node for real-time packet transmission. The simulation results indicated that the proposed scheme can get low energy consumption and high packet delivery ratio within deadline compared with some other routing protocols.

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