Intelligent Energy Efficient and MAC aware Multipath QoS Routing Protocol for Wireless Multimedia Sensor Networks

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Abstract. Sensor devices are limited energy, limited processing power and low memory devices. Providing quality of service (QoS) with highly constrained devices is always a challenging issue. To conserve energy and to provide application specific QoS requirement is a major concern of wireless multimedia sensor networks (WMSNs). The best solution for such network is using multi-criteria decision making. An artificial intelligence (AI) suits best for decision based on multiple criteria. In this paper fuzzy logic is used to select an optimal path for routing from multiple paths. Expected transmission count (ETX), residual energy (RE) and hop count (HP) is used in decision making by fuzzy logic. The proposed approach improves the throughput and avoids lossy links using the ETX which is the requirement of multimedia traffic and RE and HC also help in selecting high energy and minimum hop count path. Duty cycle (DC) is adjusted dynamically which minimizes the energy consumption of a node as compared to the static duty cycle approaches.

Keywords: Fuzzy logic, wireless multimedia sensor networks, QoS, routing

1 Introduction

Diversity of wireless sensor networks (WSNs)[1] opens many new research areas. This lead researchers to explore complex nature of WSNs and their solutions. WSNs are involved in every other application of a life, i.e. in health care, in surveillance, for traffic control, in the agriculture and the environment, underwater, at home for the automation and many more. Due to diversity of WSNs, mostly applications are using heterogeneous data, i.e. audio, video and scalar data. Also sensor devices are energy constrained and low power limited capability devices. Keeping in view the heterogeneous nature of data and sensor node constraints there is a need to devise an intelligent protocol for forwarding packets to the sink with minimum energy consumption, high data rates and on-time delivery.

Taking decisions based on one metric is not feasible for WMSNs [2]. For attaining QoS and on-time delivery of multimedia traffic requires more than one parameters to decide which path to follow for forwarding the packets. And for multiple criteria decision making, AI is the best choice. In this paper we have used artificial intelligence and proposed an intelligent energy efficient and MAC aware multipath QoS routing protocol (IE2MR) for data delivery in WMSNs. The main points of protocol are as follows:

- Three crisp inputs (ETX,RE and HC) and one output (PS) is defined as a first step.
- Crisp inputs are mapped to fuzzy sets.
- Membership functions (MFs) are defined for three input variables.
- Rules are made based on the defined input variables and their MFs.
- Rules are evaluated and defuzzified using centroid and probability of PS is done.
- Based on PS probability forwarding candidate is selected. Node with the high energy and high throughput link is selected for forwarding packet.
- DC is adjusted according to the selected path probability to conserve nodes energy. Nodes which are not involved in routing are given more sleep time to increase network's life time.

The rest of the paper is organized as follows. Related work is discussed in section 2. In section 3 proposed approach is explained. Results are elaborated in section 4 and section 5 concludes the paper.

2 Literature review

Many fuzzy logic based routing and cluster head (CH) selection algorithms for WSNs are proposed in literature. Some of them with their core features are explained below.
G. Rana et. al.[3] proposed an improve version of LEACH [4] protocol using fuzzy logic. In the proposed technique metrics used for fuzzy logic decision making are battery level, distance and node density. Based on these three variables decision is made and cluster head (CH) is selected. Authors claimed that in the proposed protocol node survived for the longer time as compared to the LEACH. CHEF another cluster head selection algorithm is proposed by J.M. kim et. al.[5]. The aim of the proposed approach is to increase the life time of a network by minimizing energy consumption. Fuzzy logic is used for the CH selection and parameters used for a decision are energy and local distance.
A fuzzy approach to energy optimized routing for WSNs is proposed in [6] to increase life time of a network. Metrics used for the decision making are transmission energy, remaining energy,energy consumption rate , queue size, distance from gateway and weight. In [7] author proposed a QM-EDCA which is the enhancement of 802.11*e* EDCA. Collision rate and remaining energy level is used as variables in the fuzzy logic decision making. Arbitration inter frame space number for different traffic classes is set according to the fuzzy logic decision. Results shows that the proposed approach is energy efficient and with less collisions. Improving Decision-Making for Fuzzy Logic-based Routing in Wireless Sensor Networks is proposed by E. Ahvar et. al. [8]. In this paper number of

hops and the energy level is considered as a fuzzy logic parameters for decision making.
H. Jiang et. al. [9] proposed a fuzzy-logic based energy optimized routing for wireless sensor networks. The aim of a proposed approach is to increase network lifetime by balancing nodes energy and by finding the degree of closeness of a node to the sink.

3 IE2MR Model and Design

In this paper fuzzy logic [10] is used to intelligently decide a path for a routing with the high energy node, minimum hop count and a successful packet transmission count. From multiple paths with different probabilities, a path with the highest path selection (PS) probability is used for forwarding a packet. Based on the fuzzy decision maker DC is adjusted. The complete proposed model is elaborated in subsequent sections.

3.1 Fuzzy Inference Engine (FIE)

Fuzzy logic uses two different FIE, sugeno and mamdani. In this paper mamdani type FIE is used. FIE works with different modules to give one aggregated output shown in Fig. 1. It has the capability to combine different metrics for decision making. Different parts of FIE are fuzzification to fuzzify the inputs, inference engine for rule evaluation and defuzzfication for aggregation. Block diagram of a proposed methodology is shown in Fig. 2 and detailed explanation of proposed approach is given in following sections.

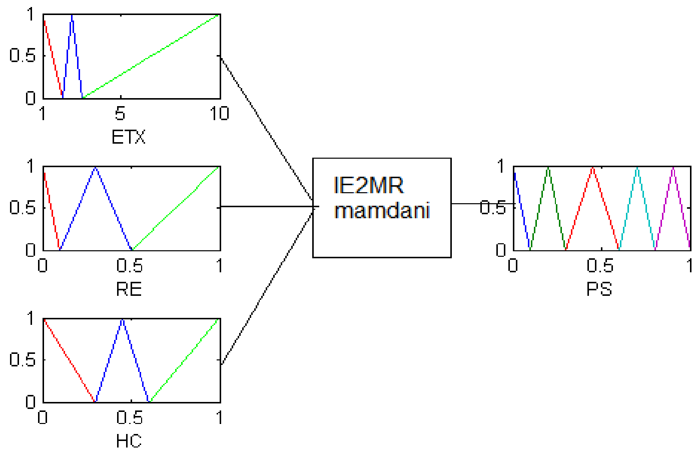


Fig. 1: Mamdani fuzzy system with MFs

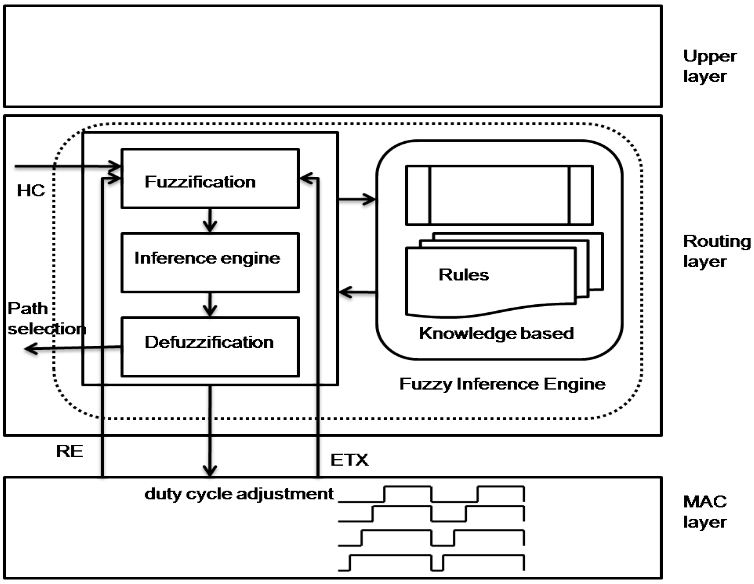


Fig. 2: Block Diagram of a proposed approach : IE2MR

Fuzzification In fuzzification crisp inputs which are human understandable numbers are converted into fuzzy sets which are range of values. Based on these fuzzy sets MFs are designed. Every MF has its unique range, which help in decision making. Different performance metrics used in this paper for decision making are:

- HC : No of hops are calculated from a source to the sink using advertisement packets. No of hops is a numeric value and crisp input. Let n be the total number of nodes and h be the number of hops from source to sink then fuzzified input for HC is calculated using (1).

$$HC = \left(\frac{h}{n}\right) \times \pi \tag{1}$$

  Whereas value of π is 3.14 and it is used to elevate the HC fuzzified input. HC is fuzzified into range of values from 0 to 1 based on the calculated value using (1). The categorization for MF is as follows: if HC is 10 or less than 10 in 100 nodes then MF will be minimum and value of HC using (1) will be less than 0.1.It means that HC 10% of total number of nodes means MF as minimum, HC between $10 - 20\%$ means MF as moderate and HC above 20% means MF as maximum as shown in Fig. 3c.
- RE : RE is calculated at the media access control (MAC) layer and given to the routing layer for decision making. Different MFs for RE is shown in Fig. 3a. Fuzzified values for RE are calculated using (2).

$$RE = \frac{RE}{100} \tag{2}$$

The range of values for RE is between 0 to 1.

- ETX :ETX is calculated at the MAC layer using probe packets. ETX is expected number of counts for successfully delivering a packet from source to sink. ETX was first proposed by De Couto et al. [11], for improving throughput of a wireless link.To find ETX probability of a successful transmission of a packets and its acknowledgments are calculated. Let number of probes received by any given node is r_p and r_t is the number of probes that should have been received, then probability P of a successful packet transmission is given by (3).

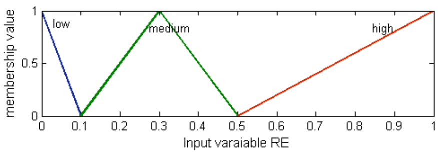
$$P = \frac{r_p}{r_t} \tag{3}$$

Equation (4) calculates ETX between two nodes A and B.

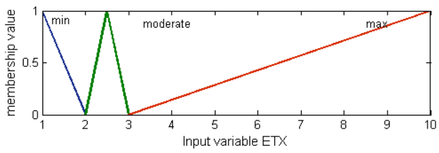
$$ETX = \frac{1}{P_A \times P_B} \tag{4}$$

The ETX value 1 denotes loss-less path and 100% throughput. The range of values for ETX is between 1 to infinity, for our convenience we have limit maximum value till 10. MFs and fuzzy set for ETX is shown in Fig. 3b.

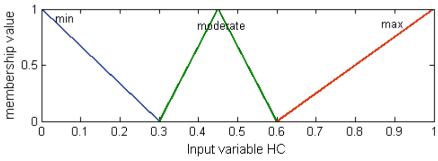
- PS : PS is output variable and based on the three input variables path is selected. MFs for probability of a PS is very low, low, medium, high and very high given in Fig. 3d. Path with the very high probability is given preference over other MFs. Path with the low and very low probability is not selected for forwarding packets.



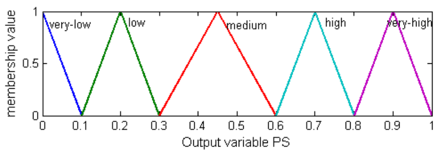
(a) MFs for RE



(b) MFs for ETX



(c) MFs for HC



(d) MFs for PS

Fig. 3: Variables and their MFs

Inference engine In inference module rules are made and evaluated using Boolean logic. For three variables each with three MFs total possible rules are: $3^3 = 27$, shown in Table(1). Rules are evaluated using AND, OR or inverse logic. In our proposed method we have used AND logic shown in (5).

$$AND : \cup_{RE \cap ETX \cap HC}(x) = min(\mu_{RE}(x), \mu_{ETX}(x), \mu_{HC}(x)) \tag{5}$$

Table 1: Possible rules for three variables and output decision

Rules	IF HC	IF ETX	IF RE	THEN
1	minimum	minimum	low	very low
2	minimum	minimum	medium	high
3	minimum	minimum	high	very high
4	minimum	moderate	low	very low
5	minimum	moderate	medium	medium
6	minimum	moderate	high	medium
7	minimum	maximum	low	very low
8	minimum	maximum	medium	very low
9	minimum	maximum	high	very low
10	moderate	minimum	low	very low
11	moderate	minimum	medium	medium
12	moderate	minimum	high	high
13	moderate	moderate	low	very low
14	moderate	moderate	medium	medium
15	moderate	moderate	high	medium
16	moderate	maximum	low	very low
17	moderate	maximum	medium	low
18	moderate	maximum	high	low
19	maximum	minimum	low	very low
20	maximum	minimum	medium	medium
21	maximum	minimum	high	medium
22	maximum	moderate	low	very low
23	maximum	moderate	medium	low
24	maximum	moderate	high	medium
25	maximum	maximum	low	very low
26	maximum	maximum	medium	very low
27	maximum	maximum	high	low

Defuzzification After rules evaluation defuzzification is done by means of a centroid method. Based on evaluated rules and aggregation of inputs, output is calculated for PS. Defuzzification of output and rules evaluation is shown in Fig.

4. It shows that probability of PS is very high when we have high RE, minimum HC and minimum ETX.

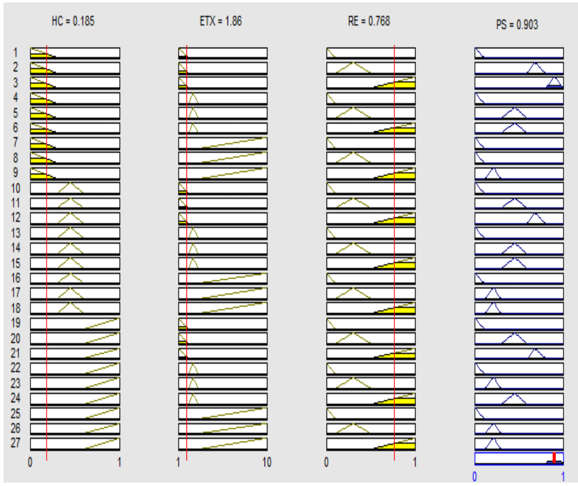


Fig. 4: Rules evaluation with min. HC, min. ETX and high RE with resulting output PS as very high

3.2 DC adjustment

DC is adjusted according to a PS decision. As shown in the Fig. 5 initially duty cycle of a node is half sleep (OFF) and half wake (ON) mode. After FIE decision, duty cycle is adjusted according to probability of PS. With probability of PS as medium the sensor node ON its receiver for 25 % more time and sleep 25 % less time as compared to initial DC. And the decision of PS as very high lead to 75 % more wake time for a sensor node and 75 % reduction in the sleep time. In this way DC is adjusted dynamically, high energy and high throughput paths is given more wake time as compared to low energy and lossy paths.

4 Results

Surface graph for three input variables and one output variable is shown in Fig. 6a,6b and 6c. The combination of two inputs are on x-axis and y-axis and the output is at z-axis. In Fig. 6a, HC and ETX is plotted against the PS with RE value 0.6. With higher HC and ETX value the probability of PS is very low and with lower HC and ETX probability of PS is high. With the lower value of RE in Fig. 6b and Fig. 6c probability of PS is very low.

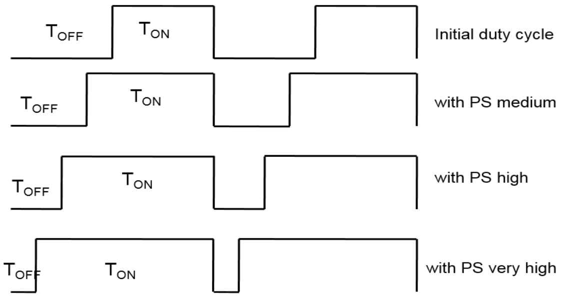
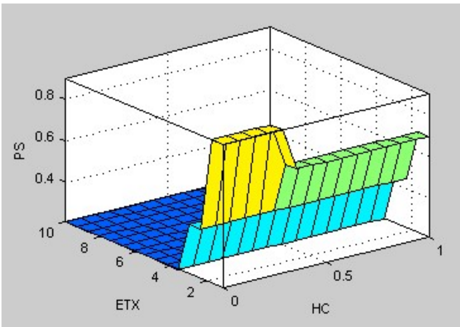
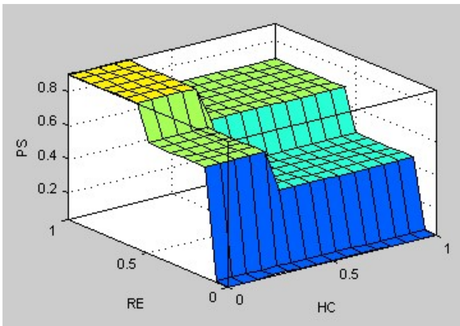


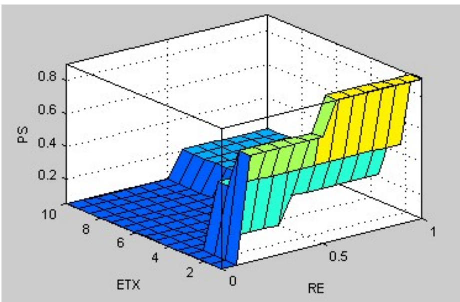
Fig. 5: Duty cycle adjustment



(a) HC and ETX against PS



(b) HC and RE against PS



(c) RE and ETX against PS

Fig. 6: Surface graph of RE, ETX and HC against PS

5 Conclusion

In this paper fuzzy logic based path selection algorithm is proposed for attaining high throughput and conserving energy. The proposed approach selects best feasible path from multiple paths for forwarding data. The intelligent decision making is through FIE, based on three different performance metrics. HC, ETX and RE metrics are used to decide energy efficient, loss-less and minimum hop count path for routing. DC is adjusted dynamically based on probability of path selection to minimize energy consumption.

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