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Optimal Path Routing using Fuzzy Logic in Wireless Sensor Networks

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Abstract — *This paper focuses on designing an optimal path selection for data transmission from source to sink with minimum overhead. A major issue in Wireless Sensor networks is the selection of an optimal path between the sender and receiver. Nodes have limited storage capability thereby making it difficult for the node to maintain all possible paths. Fuzzy logic contributes to improve routing efficiency. The parameters taken into consideration are Number of Hops, Residual Energy and Link Quality. Simulations were done using Matlab and the results show an improvement in the network performance in comparison with the traditional DSDV under the same conditions. The idea of using Fuzzy logic in Wireless sensor networks is a booming technique as it allows many ambiguous parameters to be exploited in an efficient manner. The potential of fuzzy logic goes beyond traditional systems and can be used in research fields involving multidisciplinary approaches.*

Keywords — *Sensor Networks, Routing, Fuzzy, optimal routing, Residual energy*

INTRODUCTION

The drastic developments in Micro Electronic Mechanical Systems (MEMS) and in the Technologies upgrading Wireless Communications have led to the empowerment of low power, cost and compact autonomous sensors to perform various tasks in a wireless sensor networks. The main aim of the WSN nodes is to sense, process the parameter of interest at its close proximity to the place where it got generated, and transmitted in wireless mode to the collection centre at low cost. Figure 1 depicts the architecture of the sensor network where each sensor node has sensing unit to collect the data from physical environment processing unit to process the data and communicating component to communicate sensory data to base station over wireless medium. Though WSNs enable new applications and new possible markets, the requirements set by these applications put several design constraints on them .WSN networks have huge potential applications in the area of environmental monitoring, military surveillance and reconnaissance, structural monitoring, habitat monitoring, health monitoring and home automation. The popularity of Wireless sensor networks has made it a hot topic of research with regard to tons of theoretical and practical changes.

WSN consists of thousands of nodes. The architecture of a Sensor network in shown in Figure 1. Sensor node is the basic unit of a sensor network. A node comprises of a processor, battery and AD Converter.

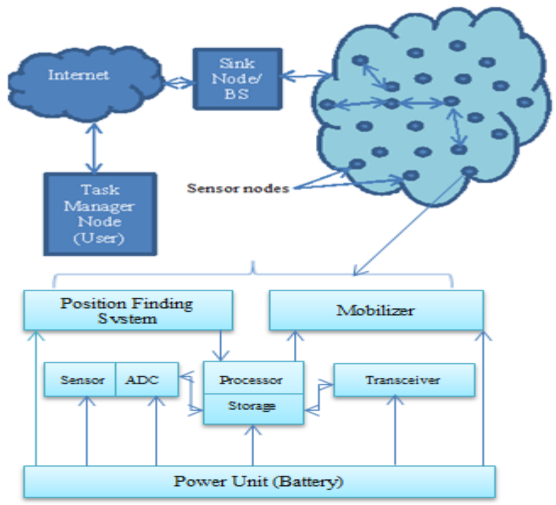


Fig 1: Architecture of Wireless Sensor Network

Wireless Sensor Networks pose stringent design constraints on routing paradigms. The Routing strategies based on Fuzzy logic provides better solutions as fuzzy mimics human thoughts and can thereby be implemented in the un precise real world environment. Node Deployment is facilitated in WSN by reducing the size of the node, thereby also reducing the computational capability and the reduced battery size. Reduction in the battery size eventually makes energy a highly prized yet limited resource. Energy poses a great challenge for network designers in hostile environments. Apart from limited battery resources the sensor nodes also have limited processing and storage capabilities leaving them with restricted computational competence.

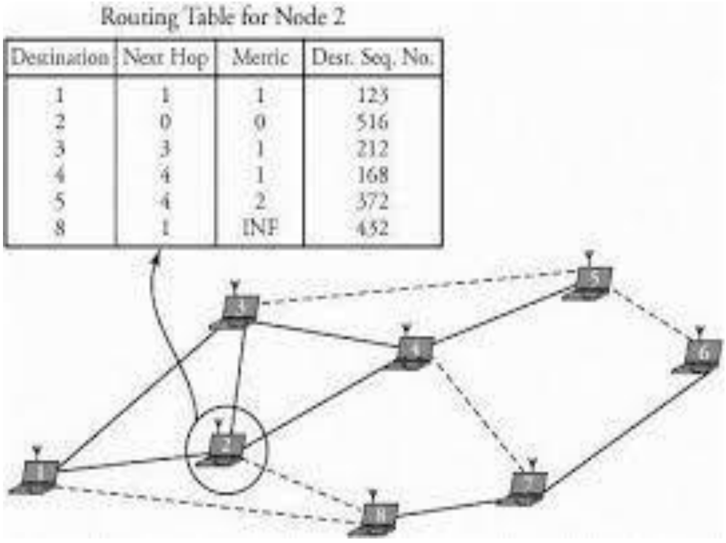
The rest of the paper is arranged into different parts. Part II highlights the related work and their limitation in design of routing algorithm for WSN. Part III highlights the Fuzzy logic. Part IV represents the results obtained from Matlab simulation, Part V is the final part of the paper and it highlights the conclusion.

RELATED WORK

A fuzzy link quality estimator that employs fuzzy logic is proposed [1] that uses the four link quality properties : Stability, Channel Quality, Packet delivery, Asymmetry. However, this work concentrates only on single-hop networks and not on multi-hop networks. Modifications in LEACH protocol [2] is proposed using Fuzzy Logic and the experimental results have proved that LEACH-FL definitely gives a better solution for cluster head selection. Haider et al. proposed [3] a method based on fuzzy logic for optimal cluster head selection.This method accurately employs the concept of fuzzy logic however, it misses certain important metrics such as the communication time and route depth. Fuzzy Ant colony optimization [4] proposed by Veronica M.Mualuko deploys the Energy, cost and the network traffic as input fuzzy parameters which is calculated based on the pheromone deposits. Heuristic A-Star algorithm], an enhancement over the existing A- Star algorithm is proposed which uses fuzzy for the value accuration of A-star. Su Man Nam [6] proposed a method where the sink decides the condition of the network depending on the fuzzy logic input parameters. More the number of effective reports higher are the chances of reliability. However, since more number of reports determine the reliability of the network, there is an increase in the overload. A free space energy consumption model [8] is proposed that employs single hop forwarding scheme and the simulation results prove that this method extend the lifetime of the network. In the work proposed by Mohammed Abdul Azim the nodes calculate the routing metrics using localization algorithms and then use FIS to calculate the optimal path . This protocol is used in both proactive and reactive cases. Teng Gao et.al achieved efficiency and extensibility by using distributed clustering algorithm that used fuzzy weighted attributes for cluster head selection.

DSDV – Destination Sequence Distance Vector

DSDV is a table driven protocol that follows the classical Bellman Ford Algorithm. The Routing table of DSDV comprises of all the available destinations, the number of hops to reach the destination and the sequence number assigned by the destination node. The sequence number greatly helps to distinguish the stale routes from the fresh ones and thereby avoids the formation of loops. Figure 2 shows the periodic transmissions of routing table with the immediate neighbours help in the updation of the table. When the node receives a route update with a higher sequence number, the table entry is replaced with this fresh route. If there are many routes available with the same sequence number, the better metric is used.



Routing Table for Node 2

Destination	Next Hop	Metric	Dest. Seq. No.
1	1	1	123
2	0	0	516
3	3	1	212
4	4	1	168
5	4	2	372
8	1	INF	432

Fig 2: DSDV Routing table

There are two different types of Routing updates in DSDV : Full Dump and Incremental Dump. Packets are transmitted infrequently during any occasional movement in the network in full dump update. In Incremental dump the packets contain information that was changed since last dump.

FUZZY LOGIC

Fuzzy logic imitates the logic of human thought, [10] which is much less rigid than the calculations computers generally perform. Fuzzy Logic offers several unique features that make it a particularly good alternative for many control problems. It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely. The output control is a smooth control function despite a wide range of input variations. Since the FL controller processes user defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance. Fuzzy Logic deals with the analysis of information by using fuzzy sets, each of which may represent a linguistic term like “Warm”, “High” *etc*. Fuzzy sets are described by the range of real values over which the set is mapped, called domain, and the membership function. A membership function Assigns a truth value between 0 and 1 to each point in the fuzzy set’s domain. Depending upon the shape of the membership function, various types of fuzzy sets can be used such as triangular, beta, PI, Gaussian, sigmoid *etc*.

A Fuzzy system basically consists of three parts:

- ✓ Fuzzifier
- ✓ Inference engine

✓ Defuzzifier.
✓

The fuzzifier maps each crisp input value to the corresponding fuzzy sets and thus assigns it a truth value or degree of membership for each fuzzy set.
The fuzzifier (Fig 3) maps each crisp input value to the corresponding fuzzy sets and thus assigns it a truth value or degree of membership for each fuzzy set. The fuzzified values are processed by the inference engine, which consists of a rule base and various methods for inferring the rules. The rule base is simply a series of IF-THEN rules that relate the input fuzzy variables with the output fuzzy variables using linguistic variables, each of which is described by a fuzzy set. The defuzzifier performs defuzzification on the fuzzy solution space. That is, it finds a single crisp output value from the solution fuzzy space.

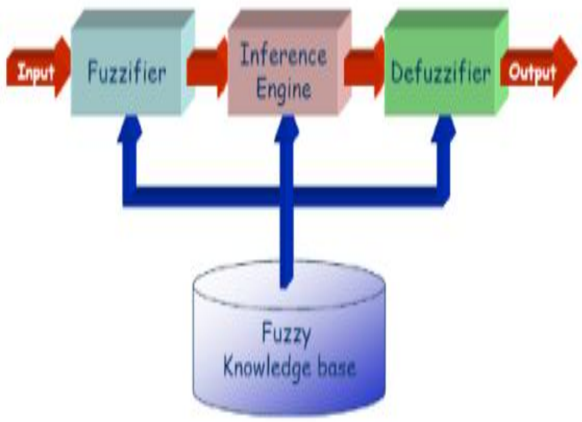


Fig 3: Fuzzy Logic System

Unlike traditional reasoning, comprising of either true or false, fuzzy logic accepts approximate truth values based on linguistic variables and inference rules. A linguistic variable is a variable whose values are words or sentences in natural or artificial language [12]

When hedges like 'many', 'more', 'few' and connectors like 'AND', 'OR', 'NOT' are used along with linguistic variables,[12] rules are formed for governing the approximate reason. An element can either be a

member or a non member in a set, in the context of crisp system. Whereas in fuzzy logic, an element may have partial membership in a set.

Parameters :
The input parameters to be considered are:

- Number of hops: this is the length of the path. In general, a lower number of hops will represent a better route, but this is not true at all, since it is possible that some nodes in the route have low battery or bad Received Signal Strength Indicator (RSSI), so it is very important to consider more variables to decide the route.
- Residual Energy: this parameter must be considered in order to avoid nodes with low battery taking part in data paths since they can cause failures in communication. Route construction considering nodes with high energy levels will help to save the energy of low-battery nodes and will cooperate to balance network lifetime. Moreover, the consideration of the battery level will ensure data transmission, preventing nodes in the route from running out of battery.

Remaining energy = I.E. – ((No. of packets transmitted * T.E) + (No. of packets received * E.C))

I.E. – Initial Energy of the node
T.E - Transmission Energy to transmit the packet
E.C– Energy Consumed by receiving a packet

- Link Quality: the Link Quality is determined by various parameters, the most prominent being Received Signal Strength.

- Received Signal Strength (RSS) is the measure of voltage by Received Signal Strength Indicator (RSSI) circuit of the node. Since there is no additional hardware required to calculate the mentioned parameter, RSS measurement is not a difficult and time consuming task for each node. After measuring the RSS, the theoretical models are usually applied to convert the RSS into a distance estimate.

$$\text{RSSI [dBm]} = -(10 * n * \log(d) + A),$$

$$d = 10^{\left(\frac{-\text{RSSI [dBm]} - A}{10 * n}\right)},$$

where, RSSI is the received signal strength, d is the distance between the nodes, n is the damping coefficient of the signal and A is the absolute value of the signal strength with 1 m distance between the transmitter and the receiver.

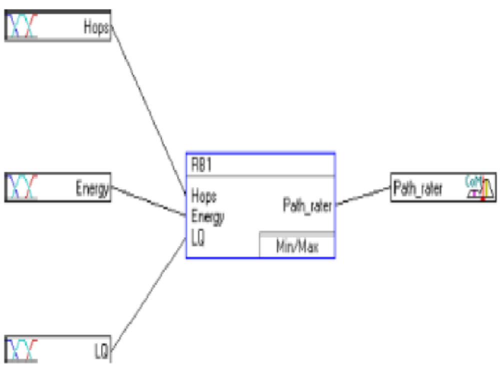


Fig 4: Structure of Fuzzy Logic System

Figure 5 shows the Input linguistic variables of the fuzzy controller are Energy (E) , Number of Hops (H) and the Link Quality (L) , the output variable is chance of Receiving (C), which determines the selection of the optimal path.

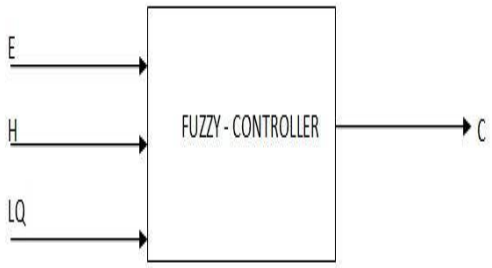


Fig 5 : Architecture of Fuzzy Controller

Energy can be defined in terms of “low”, “medium” and “High”. Therefore E can be represented as

T(E)= { Low (L), Medium (M), High (H)}

Membership Functions for T(E) is represented in Figure 6

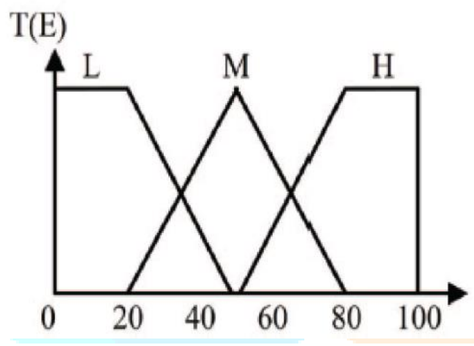


Fig 6 : Membership function for the E linguistic variable

The number of hops can be defined in terms of “few”, “several” and “many”. Therefore H can be represented as

T(H)= { Few (F), Several (S), Many (M)}

Membership Functions for T(H) is represented in Figure 7

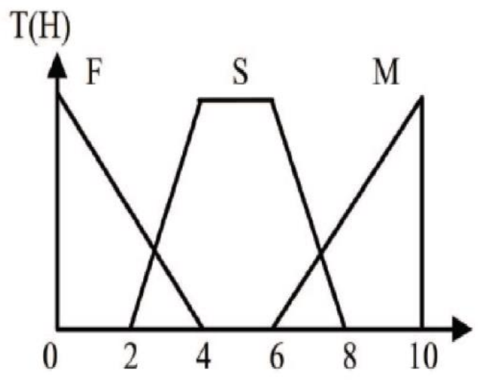


Fig 7: Membership function for the H linguistic variable

The Received Signal Strength (RSS) can be defined in terms of “weak”, “medium” and “strong”. Therefore H can be represented as

T(R)= {Weak (W), Medium (M), Strong (S)}

Membership Functions for T(R) is represented in Figure 8

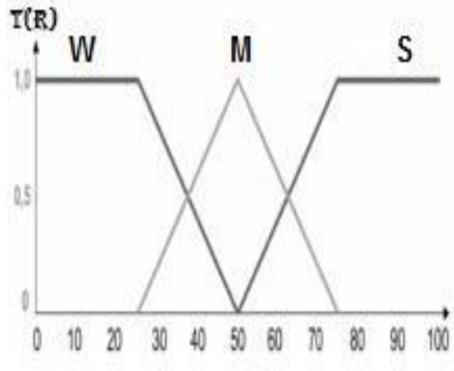


Fig 8:Membership function for the R linguistic variable

The chance of receiving C can be defined in terms of “near”, “average” and “Far”. Therefore H can be represented as

T(C)= { Poor(P), Average (A),Good (G)}

Membership Functions for T(C) is represented in Figure 9

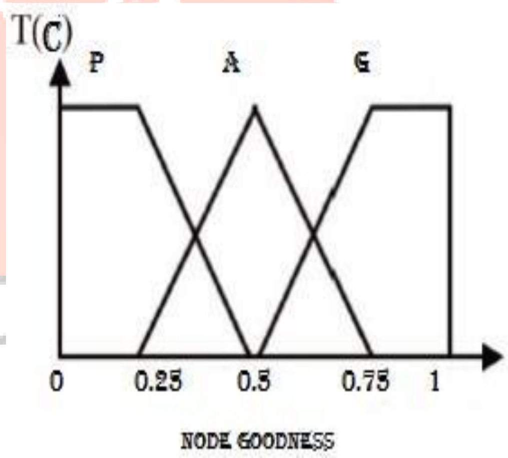


Fig 9: Membership function for the C linguistic variable

The proposed Fuzzy System works on the following rule bases:

RESIDUAL ENERGY (E)	NO. OF HOPS (H)	LINK QUALITY(R)	OUTPUT (C)
L	F	W	P
L	F	M	P
L	F	S	P
L	S	W	P
L	S	M	P
L	S	S	P
L	M	W	P
L	M	M	P
L	M	S	P
M	F	W	P
M	F	M	A
M	F	S	G
M	S	W	P
M	S	M	P
M	S	S	A
M	M	W	P
M	M	M	A
M	M	S	G
H	F	W	A
H	F	M	A
H	F	S	G
H	S	W	P
H	S	M	A
H	S	S	A
H	M	W	P
H	M	M	P
H	M	S	A

Table 1 : Fuzzy Rules

Operation of the Fuzzy Controller:

Fuzzifier Operation:
The corresponding fuzzy value for each input is :

Energy (E) E_L , E_M , E_H

No. Of Hops (H) H_L , H_M , H_H

Link Quality (R) R_W, R_M, R_S

Inference Engine Operation :

$W_1 = \min [E_L , H_F, R_W]$,
$W_2 = \min [E_L , H_F, R_M]$,
....
$W_{27} = \min [E_H , H_M, R_S]$

Defuzzifier Operation:

$$C = \frac{\sum_{i=1}^{27} w_1 \cdot C_1}{\sum_{i=1}^{27} w_1} .$$

SIMULATIONS & RESULTS

Simulations were carried out using OPNET 14 along with MATLAB to incorporate the proposed algorithm. Each sensor node has a transmission range of 100mand spread over 3 square km area. Each sensor node moves randomly using the random waypoint model within the network. Pause time was selected randomly to be within 120–180 s
Figure 10 shows that the Average Packet Delivery Ratio is higher using Fuzzy Routing in comparison to DSDV. The Average end to end delay for fuzzy logic is lower than DSDV. When Fuzzy routing is used , it is observed that the Residual Energy in the nodes is comparatively more than the traditional methods, thereby increasing the network lifetime. Figure shows that the Average number of hops is lesser in Fuzzy routing, which eventually leads to shorter paths between source to destination and thereby reduction in power consumption.

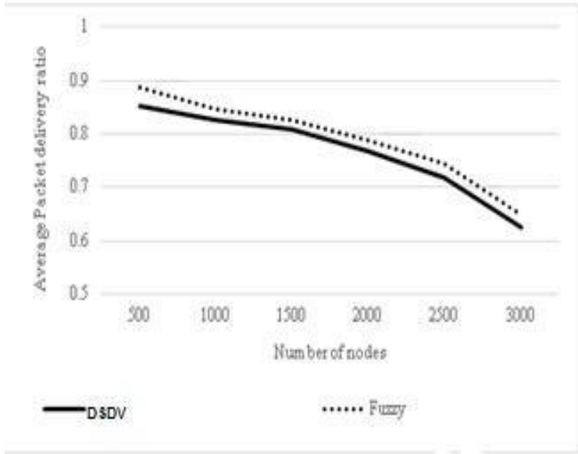


Fig 10 : Average Packet Delivery Ratio

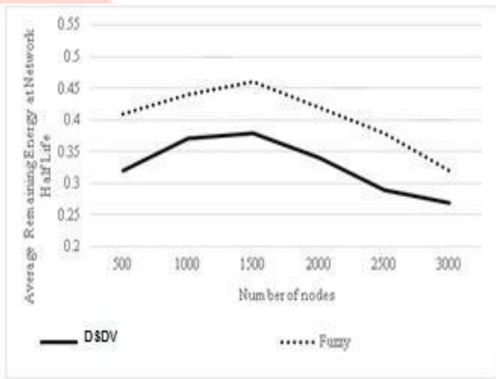


Fig 11 : Average Remaining Energy of Networks

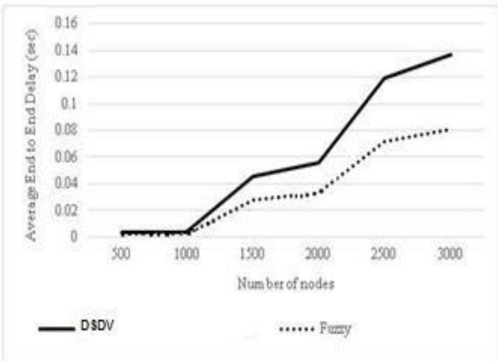


Fig 12: Average End to End Delay

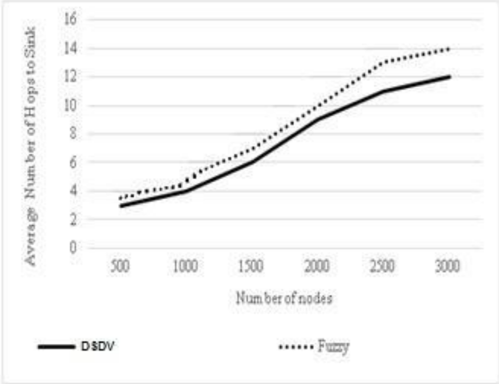


Fig 13 : Average number of hops

CONCLUSION

The routing model was based on fuzzy logic. This logic is applied to choose the best node by choosing the Residual Energy, Link Quality and the number of hops between the source and destination as input fuzzy parameters. The results show that the proposed scheme offers an enhanced network lifetime with an increase in the PDR and throughput when compared with the traditional DSDV protocol. Further, the same fuzzy logic algorithm can also be tested with increasing fuzzy parameters for an optimized route. The same algorithm can also be enhanced for multipath routing.

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