

# Multipath Routing Sensor Network for Finding Crack in Metallic Structure Using Fuzzy Logic

Dulal Acharjee, and Punyaban Patel

**Abstract**—For collecting data from all sensor nodes, some changes in Dynamic Source Routing (DSR) protocol is proposed. At each hop level, route-ranking technique is used for distributing packets to different selected routes dynamically. For calculating rank of a route, different parameters like: delay, residual energy and probability of packet loss are used. A hybrid topology of DMPR (Disjoint Multi Path Routing) and MMPR (Meshed Multi Path Routing) is formed, where braided topology is used in different faulty zones of network. For reducing energy consumption, variant transmission ranges is used instead of fixed transmission range. For reducing number of packet drop, a fuzzy logic inference scheme is used to insert different types of delays dynamically. A rule based system infers membership function strength which is used to calculate the final delay amount to be inserted into each of the node at different clusters.

In braided path, a proposed 'Dual Line ACK Link' scheme is proposed for sending ACK signal from a damaged node or link to a parent node to ensure that any error in link or any node-failure message may not be lost anyway. This paper tries to design the theoretical aspects of a model which may be applied for collecting data from any large hanging iron structure with the help of wireless sensor network. But analyzing these data is the subject of material science and civil structural construction technology, that part is out of scope of this paper.

**Keywords**—Metallic corrosion, Multi Path Routing, Disjoint MPR, Meshed MPR, braided path, dual line ACK link, route ranking and Fuzzy Logic.

## I. INTRODUCTION

THIS work aims to a particular type of application for gathering information about the weakness or strength of joint in each iron structure of any bridge, roof of the indoor stadium, railway bridge or any type of civil construction which may cause risky factor to large number of people lives. Due to over load, earthquake or any other natural calamities, lot of old bridges and civil constructions may cause tremendous accident in any time. The iron structure may be static or mobile like children park moving chairs, rotating circles, rope-way toys, in any case wireless sensor network

with DSR protocol may be used. The characteristic of DSR protocol is that at any hop, the sensor node takes decision to whom the next packet to be sent. Decision is taken packet by packet basis. Attaching wireless sensors to each cross-joint or at suspected regions; it is possible to make an ad-hoc network with a server computer as a controller of all of the wireless nodes. In [10],[11], a technique is used to monitor the change of magnetic properties of material, variations in the hysteresis curve and Barkhausen emission which may be the basis of preparing the sensor nodes.

In [13], Different types of sensors are used to detect – corrosion (wide area and hidden area monitoring), fatigue monitoring, dynamic stress and ingress detection (moisture ingress in closed cavities inside joints). Monitoring hidden locations using projected field sensors for subsurface defect and monitoring at faying surface for crack growth of outside and inside of the metallic joints, are the main role of metallurgical science and architectural construction. In [14], open ended coaxial line sensors are used to detect special resolution for detection of small SD crack.

Here, in this work for particular type of application, each of the sensor nodes is considered a source of data collection and it works as a router of data transportation also. Each node gathers data and transmits to the node of next hop. Finally, hop by hop basis, it reaches to the Sink Node (destination). Generally, the nodes, nearer to the sink node get more loads than the nodes which are in more distance from sink node [1,2] and this concept is more explained in section IV.

The lifetime of sensor network is battery-power dependent. Generally, the small battery source has very short lifetime and is non replaceable in some applications. It is required to develop a standard data link protocol and network topology to communicate among the nodes which can give a more lifetime of the network. For this tradeoff, we need to control different parameters like residual power, route-cost, packet loss rate, delay of service etc. of all nodes for all routes. In multi path sensor network, a large packet is fragmented and transmitted through multiple paths. Based on delay-T, residual energy-E and probability of packet loss-P, all possible paths are ranked. According to the ranking, load amount to each path is decided. Here, in this paper, some Multi Path Routing (MPR) protocols are explained in concept of power utilization and probability of packet loss. To improve the performance of different MPRs (Multi Path Routing), two techniques are proposed to implement, (i) dual line anti link for ACK and (ii) inserting a delay amount 'di'. Option-(i) is used to exploit the braided

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nature of the topology and option-(ii) is to find out an optimal delay amount from a rule set of Fuzzylogic Inference System (FIS). To overcome any faults in a node or link, a subset of total path or newly established path with dummy nodes will be dynamically interconnected as braided alternate path. It makes a hybrid of DMPR and MMPR. In this way, a better throughput is achieved to maintain minimum reliability requirement [2] for this type of particular application.

MAC (medium access control) layer of sensor networks operating system(OS) should support highly correlated and very precise periodic traffic. A variant of MAC protocol known as 'carrier sense multiple access (CSMA)' has two main roles i.e. listening mechanism and back off scheme. It has constant listening characteristic and a random delay provider required to continuous data link [3]. Instead of random delay provider, a FIS scheme of delay is proposed. It is assumed that all tiny sensor units will have protocol like MAC and LLC (logical link control) sub layers within the event driven control based operating systems like TinyOS.

## II. DIFFERENT TYPES OF MULTIPATH ROUTES

According to link state of source(S) to destination (D), intermediate nodes of it or other hops may be linked in different ways. Different types of multi path routing protocols are:

### A. DMPR (Disjoint Multi Path Route)

Intermediate nodes are disjoint with the nodes of other primary routes and have only one link with the downstream nodes as Fig. 1. Generally, for synchronous data transceive parallel paths are required.

### B. MMPR (Meshed Multi Path Route)

Intermediate nodes are interconnected and may have many links to forward packets as Fig. 2 and have better throughput than DMPR [2].

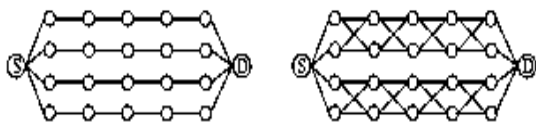


Fig. 1 DMPR, 6 hops

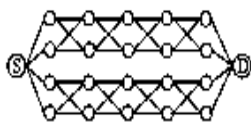


Fig. 2 MMPR, 6 hops

### C. Braided Multipath

These are partially disjoint links, not fully node-disjoint; locally braided path is used when a node of main path is faulty or malicious. It has some advantages in energy consumption constraint when density of nodes is very high and distances of nodes are very short. Detail works on braided multi path routing are available in [4].

Another two modes of data forwarding are:

- 1) Packet Replication (PR): In this scheme, multiple copies of data packets are sent through different routes from a source to a destination [2].
- 2) Selected Forwarding (SF): In packet by packet basis, only

the best or selected route(s) is/are selected for data transmission. If all routes are equally of same ranked, randomly any one route is selected for next downstream [2].

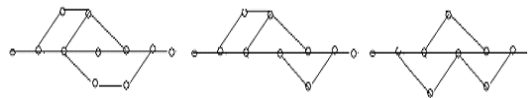


Fig. 3 (a) Idealized Braid (b) Localized Braid (c) Perfect Braid

## III. POWER CONSUMPTION MODEL

In Selected Forward (SF) protocol, data packets are transmitted to selected one or more node(s) of next hop. Other reachable nodes remain in sleep mode and only selected nodes receive and buffer the packets. The time for which packets will wait in queue or buffer is known as queuing delay. For holding data for more time in queue requires more power energy. For transmitting or receiving data from a port, energy required is 'port activation energy + energy required to transmit data to a distance of radius-r'. For one bit transmission, port activation energy is  $E_{elec} = 50$  nJ/bit. Energy required to send data to a distance of 1m is:

$E_{amp} = 100$  pJ/bit/m<sup>2</sup>. And energy required to transmit 'n' bits of data at a distance of 'r' is as [1].

$$E_{Tx}(n, r) = nE_{elec} + nr^2 E_{amp} \quad (1)$$

Here, transmission range-r is changeable and programmable; as required for the system. Variable transmission range with shortest path is done in previous work [12] and they concluded that energy can be saved in that way.

## IV. LOAD COMPLEXITY

In this type of communication, nodes which are far away from the sink node have less load and nodes nearer to the sink node have more load to process. Here, n<sup>th</sup> node receives load of all (n-1) nodes meaning that it has a load of its own plus load of preceding (n-1) nodes. A large metallic iron frame is a cluster based structure divided into many monolithic frames. All of its joint's strength makes it stronger as a monolithic structure. So, it is required to study or collect data of each of the joint at every moment. To develop a real time security based alarm system, synchronous data transmission protocol is required. For this purposes DMPR type of parallel multipath routes are required for communication. But, for asynchronous data collection, MMPR topology with braided local route may be used.

Load complexity for each of the nodes shown in Fig. 4 is  $O(n)$ . It is required to know because; the amount of delay to be inserted is a function of load complexity. Nodes having more loads should have more delay to insert for letting to finish previous jobs first. If any node is detected as faulty, then through braided route with the help of nodes of other primary route data to be transported, for that more delay to be inserted and more packets to be buffered also to make the

node proper functional.

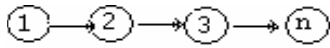


Fig. 4 Load complexity of nodes

#### V. POWER REQUIRED FOR MAINTAINING BACKUP ROUTE

As shown in Fig. 5, let source node S want to send data to N1. But there are some probabilities of packet losses along the main route SN1. So, to sustain reliability of the service, in MPR protocols, may be either MMPR or DMPR (Figs. 1, 2), one or more backup route(s) is/are created to send duplicate copies of data to overcome the situation of any failure of node or link. In any case, if N1 fails to receive the packet properly within the scheduled time, the same packet may be received from node B1. In spite of extra cost for maintaining the backup route SB1N1, reliability of the network is assured. If packet loss probability is high, more than one backup route is preferred. Let us assume that the probability of packet loss from S to N1 is  $P_i$  and in a session there are 'n' packets. Therefore, transmitting and receiving energy required for path SN1 and SB1 is ' $2n(E_{Tx} + E_{Rx})$ '. Let us assume it is  $2nE$ .

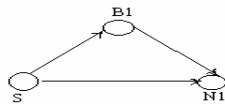


Fig. 5 One backup route

If  $P_i$  is the number of lost packets then approximate energy required for maintaining the alternate path SB1N1 is ' $P_i E_{Tx}$ ' considering no packet loss at node B1. In this assumed case, total energy to maintain a backup path with a primary path is:

$$E_{back} = 2nE + P_i E_{Tx} \quad (2)$$

In this case, backup path is used as braided path; for maintaining a backup path, required extra energy and achieved reliability can be summarized as two theories:

**Theory-1:** Energy required maintaining a backup path is more than double than that of a single path.

**Theory-2:** Communication reliability is assured 100% when alternate route has zero probability of error (i.e. if  $P_i = 0$  along route SB1N1).

#### VI. OPTIMIZATION USING SELECTED AND BEST RANKED ROUTE

At each hop, there are many reachable nodes within the transmission range. Two points are considered for selection of next hop node; (a) it is required to form node disjoint route (for parallel route formation) and (b) selecting a node for next hop which has lowest route ranking. All parameters are used as normalized form. At each hop level, before sending the packet to the next hop, all possible routes are calculated dynamically and a list of routes is prepared in ascending order of route-rank  $R_i$ . Lowest ranking coefficient means the best route.

In [12], Ranking coefficient of a route is calculated adding absolute value of gradient of a node modifies the previous equation as:-

$$R_i = \alpha(1 - \hat{E}_i) + \beta \hat{T}_i + \gamma \hat{P}_i + abs(m) \quad (3)$$

Where,  $\alpha + \beta + \gamma = 1$ ,  $m = \frac{dy}{dx}$  and  $\alpha, \beta, \gamma$  are tuning

parameters. Normalized residual energy ( $\hat{E}$ ), normalized packet loss probability ( $\hat{P}$ ) and normalized queuing delay ( $\hat{T}$ ) are calculated as mentioned in [1].

The number of routes preferred for replicating transmission will be found from the equation given below:

$$\sum_{i=1}^K \sum_{l=0}^{N_i} \binom{N_i}{l} p_i^l (1 - p_i)^{N_i - l} \geq n \quad (4)$$

Where  $P_i$  = packet loss probability in route i.

$n$  = original nos. of packet routed.

$N_i$  = total no. of packets routed in a route.

Total number of paths,  $K$ , to be chosen such that the expected number of received packets at destination nodes are more than or equal to 'n'. It means, packets reach at destination from different sources through different paths with different packet-serial-number at different time stamp. After concatenation, all consecutive packets should form a original packet.

#### VII. NETWORK ENCODING

Problem arises when any node of a primary path fails due to any type of fails like isolated failure or patterned failure [4]. When a parent node detects any type of failure of a child node (intermediate node) it should send acknowledgement to notify the source node for immediate response for updating their route table. It may change the ranking status of all selected routes because when one route is cancelled for a session, another route to be selected from other possible alive routes. This will change the previous ranking of routes. It is known as dynamic updating of routes at each hop for each reachable node [5]. The probability of failure of a node for a chance of minimum once is known from Poisson's distribution [7], [8]. From this, it can be found that for a fixed number of nodes, fixed number of alternate paths and for a fixed number of rounds in a session, number of possible failures can be calculated.

**Example:** If there are 10 nos. of nodes in a route of a wireless network and if minimum one node fails in a session where in a session there are 2000 rounds (say). What is the probability of failure of node in a session?

**Ans:** Here,  $P = 1/2000$  and  $n=10$  therefore,  $m = nP = 10/2000 = 0.005$

$P(\text{at least } 1) = P(1 \text{ or } 2 \text{ or } 3 \text{ or } \dots 10) =$

$P(1) + P(2) + P(3) + \dots + P(10) = 1 - P(0)$

$$= 1 - \frac{e^{-m} m^0}{0!} = 0.004987$$

This is nearer to mean probability  $m$ .

$$\text{where } P(r) = \frac{e^{-m} m^r}{r!} \quad (5)$$

Let us assume that in a session 2000 packets will be transmitted and say total failure of nodes for this session is 'F'. Due to failure of node or link transmission-delay increases, probability of packet loss increases and unnecessary more energy is lost. 'Delay increases' means, for 'F' times the parent node needs to wait to get response from the child node whether the packet is received properly or not considering the failed node is not physically damaged. A malicious node will create unnecessary delay, wait till 'route request time out(rtrto)' period. Generally ACK packet size is smaller than that of data packet. So, chances of losing ACK packets are less than data packet also. In traditional method, acknowledgement is sent through one single line, if it is failed to reach to parent node anyway, it will create more and more delay for the whole system. Immediate it is required to send request signal to parent node for updating all related route table containing faulty node id. For that, chances of failure of ACK signal should be negligible. In [5], a piggyback ACK sending, buffering the route error and new route discovery was approached. Here, it is proposed dual line for routing acknowledgement signal to decrease chances of failure. Dual line will ensure ACK signal to reach at parent node in due time. In MPR, if one route is damaged, data may propagate through other paths also.

In [6] it is stated that  $h'$ , the dimension of edge of a graph  $G$ , can control the cost of communication by proper network coding. To sustain at least previous probability we need some network topology coding in any way. How, where and in how many edges re-coding would be required, it depends on four cluster based FIS scheme that we have proposed to identify the faulty node's location and taking decision about the amount of delay to be inserted. We have considered four situations of failure-occurrence-zones as 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> zones. If the node failure is under any one of the mentioned four zones, we handle each case differently. If a fault is detected within 1<sup>st</sup> zone, our decision would be: try to connect with any dummy node located within the transmission range compromising parallelism characteristic of routes anyway, if dummy nodes are not found let be connected with neighbor main routes and it is considered the worst case routing. Fault detecting in 3<sup>rd</sup> zone may be considered to connect with the dummy node must, because the load complexity of nodes of main routes are very high and should not be given more load to it. In this way for four zones we prepare a priority list of selecting sensor nodes or dummy nodes.



Fig. 6 Braided path to continue link.

In Fig. 6, it is shown that six nodes (shown as '\*') and twelve links (shown as '---') attached with those nodes are faulty. Throughput decreased due to these faults are found from [2]. Adding more twelve braided links and inserting proper delay proposed in next section, it is possible to sustain the network and to get a acceptable throughput for this particular application reducing delay using fuzzy based system. There may be varieties of link topologies within the existing nodes and links. This non real time system demands a optimized cost also expected throughput which may be achieved from inserting delay parameters calculating from fuzzy inference system. It is required to look after the both packet queuing time (qt) and process time (pt) [5] properly. From the fuzzy rules set proper delay amount may be found and it improves the packet loss probability. It may increase process complexity but probability of reaching the packets can be ensured.

#### VIII. BASICS OF FUZZY LOGIC

**Fuzzification:** Some times, if an unknown input is implied, in that situation to learn output value, Fuzzification and Defuzzification are required to apply. Output is generally in fuzzy form and after Defuzzification a crisp value comes as a result. Let there are two rules in a rule based system as:

R1: IF  $x_1$  = low AND  $x_2$ =medium, THEN  $y$  = high.

R2: IF  $x_1$  = low AND  $x_2$ =high, THEN  $y$ =very high.

For rule R1, the membership function of output can be found as:

$$\mu_R(x_1, x_2, y) = \text{MIN}(\mu_L(x_1), \mu_M(x_2), \mu_H(y)) \quad (6)$$

Where, for AND operation MINIMUM and for OR operation MAXIMUM functions are used.

Fuzzification is to transform fuzzy or crisp input(s) into a vector of membership degree or level of participation in that particular activity as shown in Fig. 8 to Fig. 13.

**Defuzzification:** The process for obtaining a crisp value from the output of fuzzy result set is known as Defuzzification. Well known Defuzzification formulas are: **centroid of area, bisector of area, mean of max, smallest of max and largest of max** [17]. Here, in this work, centroid of area or centre of gravity is used for Defuzzification. The equation for extracting crisp output is represented in [18] as:

$$y = \frac{\sum_{i=1}^n y_i H_i}{\sum_{i=1}^n H_i}$$

## IX. FUZZY INFERENCE SYSTEM MODEL

**Problems definition:** “Sensor nodes and Dummy nodes are deployed at different points of the iron structure. Few numbers of dummy nodes are deployed within four clusters in a way that: very less numbers in cluster-1, less number in cluster-2, then more and more numbers in cluster-3 and cluster-4 respectively. When any node or link fails, it causes more delay than normal propagation. It is required to control different delay parameters for meeting required throughput of the network”. Four zones of occurrences of failure are considered. If a failure is occurred within any one of 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> clusters of total route, there are two options for sustaining link i.e. (i) selecting another nearer sensor node of any primary route or (ii) selecting a dummy node(some extra nodes deployed only for routing data) to form an alternate path.

Four types of input parameters used are shown in Table I.

TABLE I  
LIST OF INPUTS USED FOR FUZZY RULES

Nodes	Routes	Delays	Clusters
Sensor(SN)	Primary	nprto	C1
Dummy(DN)	Braided	rrto	C2
		rrsl	C3
		nprr	C4
		mrrp	

In [5], six types of delays with fixed values were used for dynamic source routing (DSR) to control mobility of nodes. It is also proposed that delay is a linear function of hop numbers. Here, in this present work, delay is used as a function of four inputs but not as a function of only hop number. These delays, according to their duration length in ascending order, are: nonpropagating route request time out(nprto), route request time out(rrto), route request slot length(rrsl), non propagating route request(nprr), maximum route request period(mrrp). They used another negligible parameter ‘route reply holdoff per-hop delay’ but in this paper last one is not considered for designing fuzzy rules. It is not convenient to take more parameters which will create more and more rules. For different processors, these delay parameters should vary.

Fuzzy logic based systems are found in previous works [15], [16] and [17]. But exact similar types of applications or works are not found anywhere. Some knowledge are acquired from references but developed model is unique so far in our knowledge.

Here, it is assumed, these delays are a linear function of the processor speed of the sensor node and can be expressed as  $t/x$ , where ‘t’ is the delay amount in second and ‘x’ is the speed of processor in GHz.

Fig. 7 represents fuzzy controller used in this work, here, four types of inputs are used as: (a) node types-N (two types of nodes are there, SN=Sensor Node and DN=Dummy Node), (b) Route type-R (two types, M=Medium, for Primary route and H=High, for Braided route), Delay type-D (5 types,

mentioned above), Cluster type-C (4 types: VL=Very Low ‘known as Cluster-1’, L=Low for ‘Cluster-2’, M=Medium for ‘Cluster-3’ and H=High to represent ‘Cluster-4’). Only one output is ‘di’ is the variation of delay under different situations of inputs. Here, ‘di’ is not the real life delay, it is an delay index known as membership function,  $\mu(y)$ , when y is considered as output.

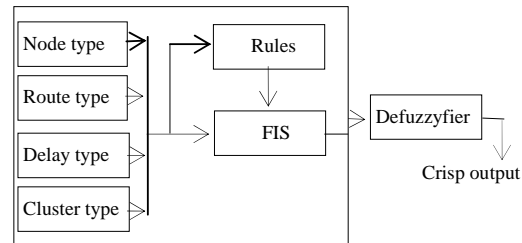


Fig. 7 Fuzzy Inference System (FIS)

These four sets of inputs make total  $2*2*5*4=80$  types of linguistic rules shown in Table II.

TABLE II  
FUZZY RULES SET

Rul es	Anteced ent1= N	Anteced ent2= R	Anteced ent3= C	Anteced en t4= D	Consequent= di
1	DN	P	VL	VL	Z
2	DN	P	VL	L	Z
3	DN	P	VL	M	Z
4	DN	P	VL	H	Z
5	DN	P	VL	VH	Z
6	DN	P	L	VL	Z
7	DN	P	L	L	Z
8	DN	P	L	M	Z
9	DN	P	L	H	Z
10	DN	P	L	VH	Z
11	DN	P	M	VL	VL
12	DN	P	M	L	VL
13	DN	P	M	M	VL
14	DN	P	M	H	VL
15	DN	P	M	VH	VL
16	DN	P	H	VL	L
17	DN	P	H	L	L
18	DN	P	H	M	L
19	DN	P	H	H	L
20	DN	P	H	VH	L
21	DN	B	VL	VL	VL
22	DN	B	VL	L	VL
23	DN	B	VL	M	VL
24	DN	B	VL	H	VL
25	DN	B	VL	VH	VL
26	DN	B	L	VL	VL
27	DN	B	L	L	VL
28	DN	B	L	M	VL
29	DN	B	L	H	VL
30	DN	B	L	VH	VL
31	DN	B	M	VL	L
32	DN	B	M	L	L
33	DN	B	M	M	L
34	DN	B	M	H	L
35	DN	B	M	VH	L
36	DN	B	H	VL	L
37	DN	B	H	L	L
38	DN	B	H	M	L
39	DN	B	H	H	L
40	DN	B	H	VH	L

41	SN	P	VL	VL	VL
42	SN	P	VL	L	VL
43	SN	P	VL	M	VL
44	SN	P	VL	H	VL
45	SN	P	VL	VH	VL
46	SN	P	L	VL	L
47	SN	P	L	L	L
48	SN	P	L	M	L
49	SN	P	L	H	L
50	SN	P	L	VH	L
51	SN	P	M	VL	M
52	SN	P	M	L	M
53	SN	P	M	M	M
54	SN	P	M	H	M
55	SN	P	M	VH	M
56	SN	P	H	VL	M
57	SN	P	H	L	M
58	SN	P	H	M	M
59	SN	P	H	H	M
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65	SN	B	VL	VH	L
66	SN	B	L	VL	L
67	SN	B	L	L	L
68	SN	B	L	M	L
69	SN	B	L	H	L
70	SN	B	L	VH	L
71	SN	B	M	VL	M
72	SN	B	M	L	M
73	SN	B	M	M	M
74	SN	B	M	H	M
75	SN	B	M	VH	M
76	SN	B	H	VL	H
77	SN	B	H	L	H
78	SN	B	H	M	H
79	SN	B	H	H	H
80	SN	B	H	VH	H

'AND' operator is used between conditions as: IF *Antecedent-1* AND *Antecedent-2* AND *Antecedent-3* AND *Antecedent-4* is TRUE then *Consequent*. The rules in Table II are interpreted as:

**Rule-1:** IF Node type is DN(dummy node) AND route type is P(primary route) AND cluster is VL(very low, i.e 1<sup>st</sup> cluster) AND delay type is VL(very low, for nprto) THEN output(di) is Z(zero).

Four types of inputs and one output FIS model developed is shown below for reference.

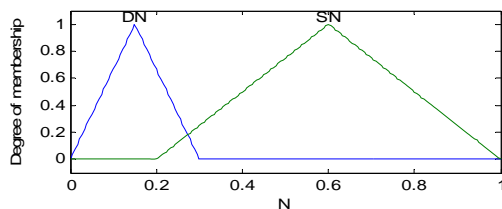


Fig. 8 Input-1, Two types of Nodes, DN and SN

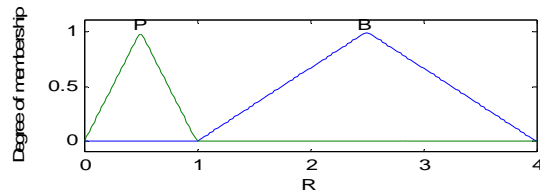


Fig. 9 Input-2, Two types of Routes, B and P

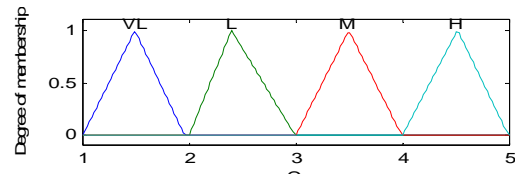


Fig. 10 Input-3, Four types of Clusters

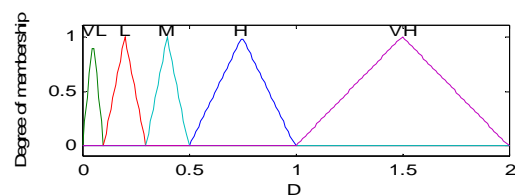


Fig. 11 Input-4, Five levels of delays

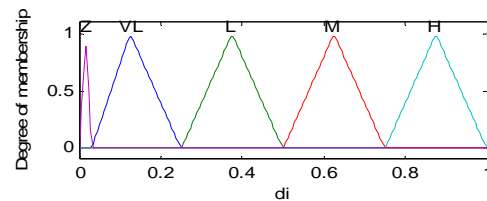


Fig. 12 Output levels of grading

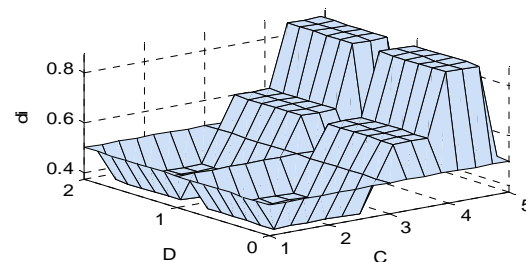


Fig. 13 Cluster vs. delay mapping

#### X. SERVER SIDE DATABASE MAINTAIN

Sink node (or server) receives all data generated from sensor nodes after each of 2 seconds and stored in a database like: {*node-id*, *time*, *data*}. Time of generating data packet is very important because for a small change in property of any one joint of iron structure may collapse the total structure, it is required to collect data at a sharp interval. If any SN has multiple sensing units, then different events can be recorded using data structure like: {*event-id*, *node-id*, *time*, *data*} and for different event different types of database to be maintained.



It is a large database and if the experimental test case is run for one hour, its size becomes 900000 records for 500 sensor nodes. Data received from same node at different time is analyzed to detect the nature of changes happened within the iron structure within that interval of time. This analysis part is the subject of material science and civil architecture and beyond the scope of this paper.

## XI. RESULTS

For each of the four inputs, one defuzzified crisp value is obtained from the FIS tool. The aggregated crisp value is the output value for a particular input set. The defuzzified output is an index and the proportional part related to all delays are calculated and added with original delays in this way:

*Step-1:* Sum of of all delays:  $w = \sum(\max(D_i))$  for  $i=1.. n$ , where,  $D_i$ = predefined five types of delay values.

*Step-2:* Difference of delay:  $dd = \max(D_i) - \min(D_i)$ .

*Step-3:* Delay amount inserted at any node at any cluster is:

$$d_i = \left( \frac{DF_c}{w} \right) * dd$$

Where,  $DF_c$ = defuzzified crisp value.

*Step-4:* Average delay:

$$ad = \frac{\max(D_i) + \min(D_i)}{2}$$

*Step-5:* Final delay is:

$$d = ad + d_i \quad (7)$$

A hypothetical communication of 1000 packets are transmitted from node one to the Sink node in hop by hop basis assuming that there are six nodes or hops within assumed four clusters, in communications both SN and DN took part. Randomly some nodes are assumed damaged and time taken by traditional system and Fuzzy Systems are calculated and compared.

The five types of process delays used here are related to route search, wait for route request, and route slot length. To calculate variations of these delays, other parameters were considered fixed. Finally, the Fuzzy model used here gives less time to transmit 1000 packets in braided route under different failure environment of 10 sessions average value is shown in Fig. 14. Throughput of network is inversely proportional to delay; if other parameters are constant, less delay means better throughput.

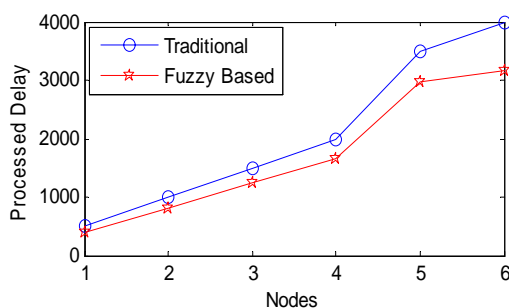


Fig. 14 Traditional vs. Fuzzy Based System

## XII. CONCLUSION

An application oriented multipath routing protocol related with braided path is discussed here. Braided path formation under different zone and load complexity of each node is presented in detail. Different parameters required calculating rank of different paths is discussed and finally two theories are summarized for energy requirement of maintaining backup route. Fuzzy logic based proposed system shows less time required to communicate than time taken by traditional method. It is scalable and applicable for any numbers of faulty nodes and links to be fit in any wireless communication network for detecting defects of joints of any iron constructions.

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## REFERENCES

- [1] C. Huang, M. Chatterjee, W. Cui and R. Guha, "Multipath source routing in sensor networks based on route ranking", IWDC, 2005.
- [2] S. De, C. Qiao and H. Wu, "Meshed multipath routing with selective forwarding...", WCNC, 2003.
- [3] A. Woo, and D. Culler, "A Transmission control Scheme for Media Access in Sensor Networks" Proc. ACM Mobile com '01, Rome, Italy, pp 221-35, July 2001.
- [4] D. Ganesan, R. Govindan, S. Shenker, D. Estrin, "Highly-Resilient, Energy-Efficient Multipath Routing in Wireless Sensor Networks", Mobile Computing and Communications Review, volume 1, Number 2.
- [5] D. B Johnson, D.A. Maltz, "Dynamic Source Routing in Ad Hoc Networks", book "Mobile computing" by Kluwer Academic Publishers, 1996.
- [6] A. L. Toledo and X. Wang, "Efficient multipath in sensor networks using diffusion and network coding", in 40th Annual Conference on Information Sciences and Systems, Princeton University, NJ, USA, March 22-24, 2006.
- [7] H K Dass, "Engineering Mathematics", S. Chand & Co Ltd. ,2001 edition, pgs 780-90.
- [8] K L Chung, "Elementary probability theory", Narosa Publishing house, New Delhi, 1995 edition, pgs. 192-200.
- [9] Qilian Liang and Qingchun Ren, "Energy and Mobility Aware Geographical Multipath Routing for Wireless Sensor Networks", IEEE Communications Society / WCNC 2005.
- [10] J W Wilson, G Y Tian and S Barrans, "Residual Magnetic Field Sensing For Stress Measurement", University of Huddersfield, UK., ECNDT, 2006.
- [11] V Singh, M L Wang and G M Lloyd, "Measuring and modeling of corrosion in structural steels using magnetoelastic sensors", University of Illinois, Chicago, USA, 2005.
- [12] D.Acharjee, N.Sharma, "Slope based shortest path routing for wireless sensor network", ADCOM-2007, IIT- Guwahati, India.
- [13] www.virtualacquisitionshowcase.com/docs /2008/JENTEK3-Brief.pdf :access on 24/10/08
- [14] Saka M, Yang Ju, Daying Luo, Abc H, "Infrared and Millimeter waves,2000" conference digest, 25<sup>th</sup> International conference on vol, Issues, pgs 423-424.
- [15] Feng Xia, W. Zhao, et. el., "Fuzzy Logic Control Based QoS Management in Wireless Sensor/Actuator Network", Sensors 2007, 7, pgs. 3179-3191.

- [16] X. Cut, T. Hardian and et. el., "A Swarm-based fuzzy logic control mobile sensor network for hazardous contaminants localization", IEEE 2004.
- [17] J.-S.R. Jang, C.-T.Sun and E.Mizutani, "Neuro-Fuzzy and Soft Computing" by PHI, Eastern economy edition, pgs. 74-79.
- [18] Vojislav Kecman, "Learning and Soft Computing", by Pearson Education, 1<sup>st</sup> Indian reprint, 2004, pgs. 391-394.

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