Connectivity Analysis of Mobile Ad Hoc Network Using Fuzzy Logic Controller

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Abstract. Nowadays, efficient and fast communication network is a necessity for various real life scenarios, as network connectivity problem is frequent in wireless ad hoc network. Various network parameters provide measures to ensure ideal network performance leading towards better QoS. This research paper focuses on the development of easier approach towards level of node connectivity using fuzzy logic for betterment of the ad hoc network performance, and, also evaluates an ideal transmission range which would ensure perfect node connectivity for a given number of nodes. Hence, ideal transmission range can be easily evaluated for given number of nodes, in such a way, that sure connectivity is achieved, using the easier method of fuzzy logic, as compared to that of the conventional method. Network simulations are performed using QualNet 6.1.

Keywords: Mobile ad hoc network · Network connectivity
AODV routing protocol · MATLAB · Fuzzy logic · QualNet 6.1

1 Introduction

A mobile ad-hoc network (MANET) is defined as a wireless network which consists of number of mobile nodes in an infrastructure-less environment. A wireless ad hoc network has dynamic topology, and node connectivity depends upon the device behavior, mobility pattern, distance between them, etc. Infrastructure-less networks lack any central controller for the nodes, therefore the nodes of such networks possess highly dynamic nature and interconnections of nodes vary continuously. Thus, such wireless ad-hoc networks communicate with the help of routing protocols, which provide routing paths between nodes [1]. In routing process, each node transmits data to other nodes such that the routes are discovered dynamically on a continuous basis, with the help of routing protocols. The main function of any routing protocol is to establish routing path between nodes, which provide efficient transmission of data with minimum delay, expense and bandwidth consumption [2].

QoS (Quality of Service) is defined as the set of parameters, which needs to be fulfilled by mobile ad-hoc networks (MANET) in order to ensure efficient and faster communication between the source and destination nodes. These parameters vary according to the different networking layer. Most commonly used QoS parameters for performance analysis of ad-hoc networks are bandwidth, delay and jitter. Improving

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QoS parameters for mobile ad-hoc networks is very crucial due to the dynamic nature of MANET topology and decentralization [3].

In this research paper, AODV routing protocol is employed by mobile ad-hoc networks for performance analysis in different environments. Ad-hoc On Demand Distance Vector (AODV) routing protocol is a reactive routing protocol which establishes routes on-demand. Thus, the transmission of topology information by nodes occurs only on demand. AODV uses routing tables with one entry per destination. Every node maintains two route entries i.e. (a) broadcast_id which increases each time the source broadcasts a route request packet (b) sequence number to prevent routing loops and to eliminate old, broken routes. Routes are maintained in AODV with the help of RREQ (route request), RREP (route reply) and RERR (route error) control messages [4].

2 Network Connectivity

In mobile ad hoc networks, connectivity differs due to the continuous node movement because of their dynamic property, causing network partition. Connectivity Management is difficult due to dynamic network topology, frequent link occurrence and nodes failure via interference, radio channel effects, and mobility and battery limitation. Hence, Connectivity is a major issue in mobile ad hoc network. The reasons behind failure in the network that divides the network into two or more parts and can obliterate end-to-end connectivity are classified into the following as given below:

2.1 Network Connectivity Issues

Node Failure. This happens when an intermediate node working as router is unavailable because of hardware and software failure, and, secondly, when the node is not in communication range of the network. It is also known as Device Failure.

Critical Point. In a topology such points are nodes and links which fail and cause network division into two or more parts. It is also known as Weak Point.

Link Failure. Link failure happens because of many factors such as link obstacle among communicating nodes, node mobility, fading and high interference. It is also known as Edge Failure.

Power Failure. Power failure happens when the node battery is very low, and hence the node cannot work as router. It is also known as Battery Failure [5].

2.2 Literature Review

Node connectivity was first defined by Cheng and Robertazziin in 1989. They studied the effect of node density and node's broadcast transmission range in a multi hop radio network followed by spatial Poisson method. They prescribed that for transmission range optimization, its value must be low bounded to achieve ideal network connectivity. But, this method is difficult to implement practically [6]. Based on previous work, this research paper studies the Poisson distributed nodes disconnection. It gives comparison between node's critical coverage range and critical transmission range in a square area based on Poisson fixed density [7]. This issue is studied for one dimensional segment which provides critical range of transmission for Poisson distributed nodes in given area of square. But, these researches were difficult to implement in real situation, since, in Poisson process deployed nodes are originally random variable and only its average value can be determined [8].

2.3 Definition

Connectivity is the route directness between nodes in a network topology. For a given network with |N| nodes, where N = {n1, n2, n3….n|N|}, and the degree of node (n_j) is deg (n_i), then connectivity is defined as:

$$\text{Connectivity (NW)} = \sum_{i=1}^{|N|} \frac{\deg(n_i)}{\binom{|N|}{2}}. \tag{1}$$

Where, $\binom{|N|}{2} = |N|^2 - |N|$

A Network has full connectivity when the Connectivity of the Network Connectivity (NW) is 1. The necessary condition for full connectivity is described as:

$$\sum_{i=1}^{|N|} \deg(n_i) = ||N|^2 - |N| \tag{2}$$

Full connectivity implies that the transmission range of a network is more than or equal to the longest distance between any given node pair in the network and the node degree is |N| − 1. The nodes in this network are capable of transferring data. But, the required transmission range is higher. This network topology results into high channel interference, which lowers the network QoS due to very high transmission range.

Each node has a definite maximum transmission power range P_{MAX}. P_a is the transmission power of node a. α is the path loss exponent and τ is the minimum average SNR required for decoding received data. d_{ab} is the distance between node a and node b. For a source node i to communicate with node j in a given straight line as shown in Fig. 1, it should follow [9]

$$P_a(d_{ab}) - \alpha \geq \tau \tag{3}$$

Where, $P_a \leq P_{MAX}$.

3 Fuzzy Logic

MATLAB which refers to Matrix Laboratory is ideal software for high level language programming in diverse environments, basically science and technology, which may include fuzzy logic, DSP system, instrument control, econometrics and lots more.

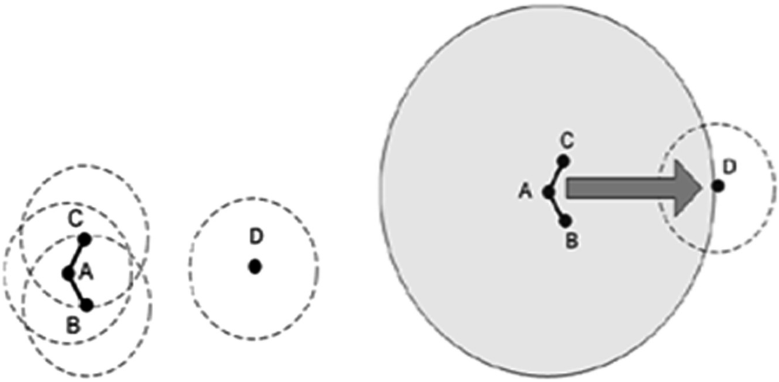

Fig. 1. Effect of transmission range on network connectivity

MATLAB provides easy approach towards intricate problems through simple programming, separate toolboxes and also GUI.

In this research paper, MATLAB software is utilized to embed the concept of fuzzy logic, in order to provide an easier and feasible approach towards perfect network connectivity for a given transmission range and number of nodes in a wireless ad hoc network, thereby, ensuring efficient network performance by improving QoS. In MATLAB's Fuzzy Logic Toolbox, FIS editor is provided for fuzzy inference system development. Mamdani's fuzzy inference system is taken in this research paper. The block description of mamdani's fuzzy inference system is given in Fig. 2 [10].

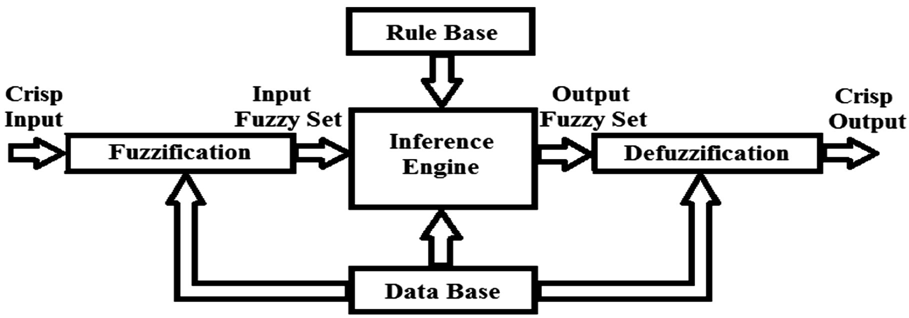

Fig. 2. Block description of fuzzy inference system

The crisp inputs are transformed generating input fuzzy set through fuzzification. After that, the inference engine computes the output fuzzy set with the help of knowledge base which comprises of fuzzy if-then rules in rule base and knowledge about linguistic functions to map called membership functions of the I/O fuzzy set in data base. Finally, the output fuzzy set is transformed generating crisp outputs. Fuzzy Logic is analogous to the human brain functioning, thus enabling feasible computational learning [11].

3.1 Proposed Work

The implemented fuzzy inference system is given in Fig. 3. It consists of two inputs, i.e., number of nodes having membership functions {Low, Medium, High} and transmission range having membership functions {Low, Medium, High} and one output, i.e., network connectivity having membership functions {Poorly-Connected, Surely-Connected}. The Input-Output variables associated with FIS are given in Figs. 4, 5 and 6, retrieved from MATLAB fuzzy logic toolbox.

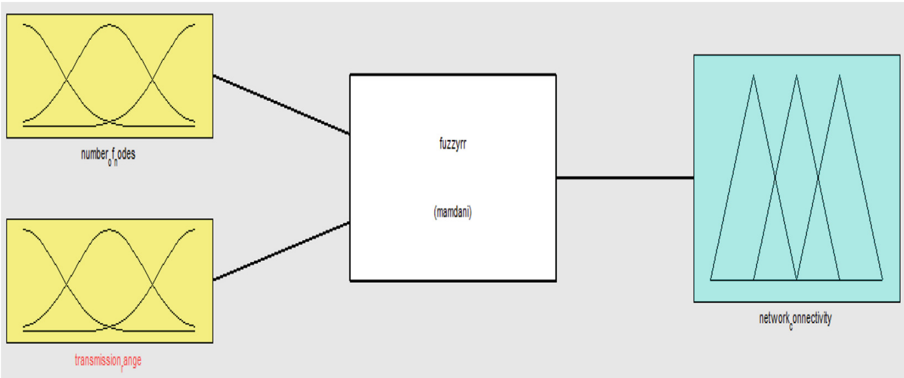

Fig. 3. Fuzzy inference system

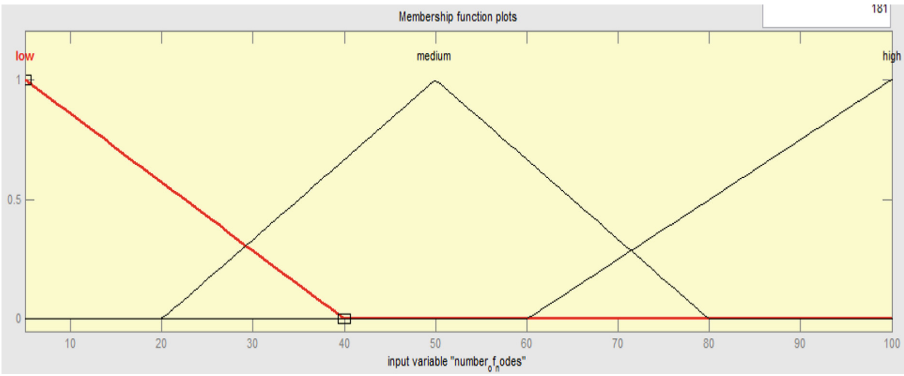

Fig. 4. Number of nodes

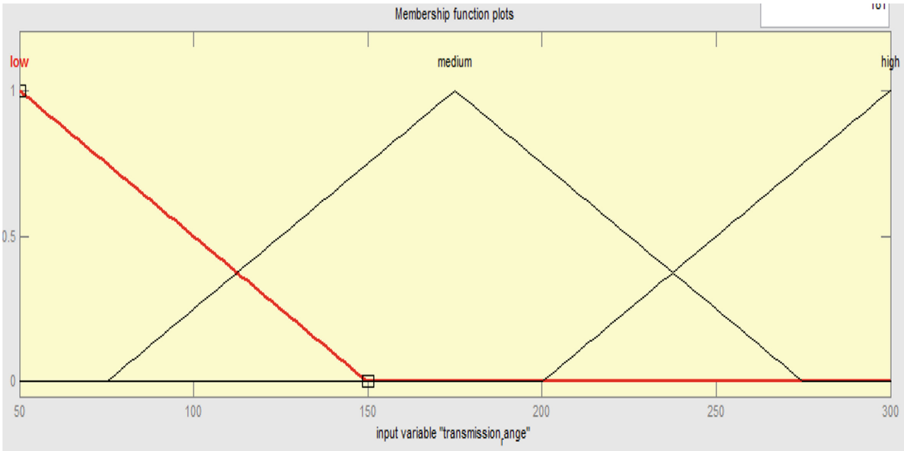

Fig. 5. Transmission range

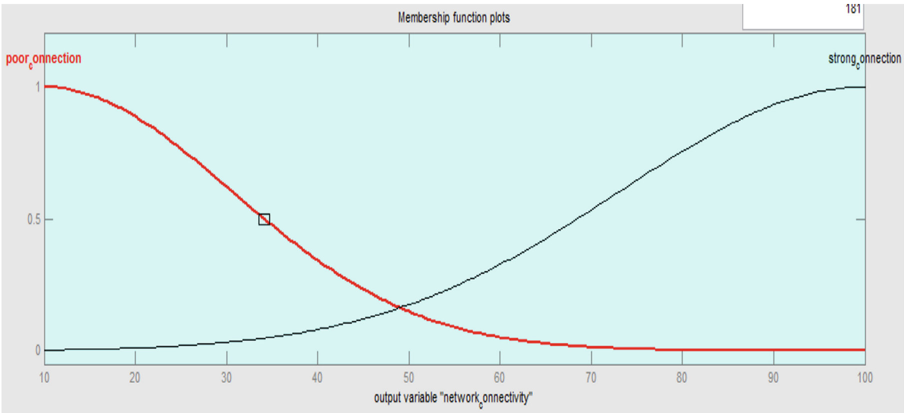

Fig. 6. Network connectivity

The fuzzy rules are described, which are created in the rule editor, for the implemented fuzzy inference system in Table 1, given below [12]:-

Table 1. Fuzzy rule base

Number of nodes / Transmission range	Low	Medium	High
Low	Poor connection	Poor connection	Poor connection
Medium	Strong connection	Strong connection	Strong connection
High	Strong connection	Strong connection	Strong connection

The output consequent to given set of inputs can be obtained using rule viewer, which is graphically depicted using surface viewer. Figure 7 represents the snapshot of FIS rule viewer and Fig. 8 represents the FIS surface viewer, given below:-

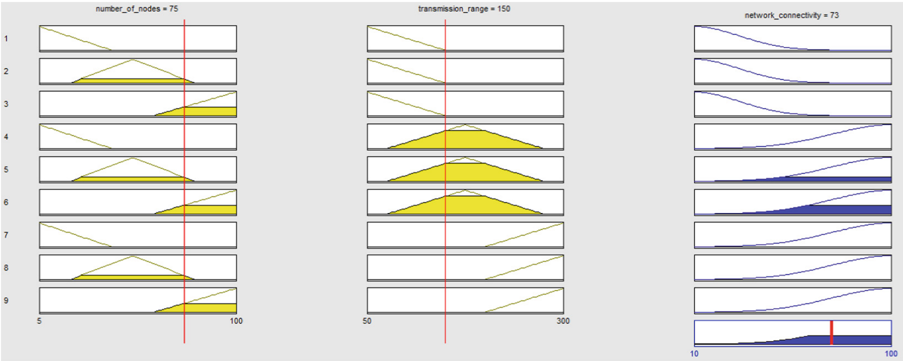

Fig. 7. Snapshot of FIS rule viewer

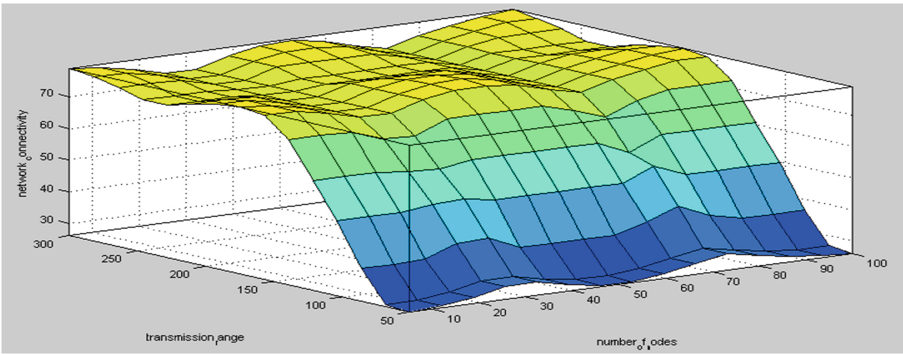

Fig. 8. FIS surface viewer

In Fuzzy Simulation, estimation of network connectivity is being done on the basis of number of nodes and transmission range, which are given in Table 2, as shown below:

Table 2. Fuzzy based simulation parameters

Transmission range, dBm	100	150	250
Number of nodes			
25	49.2	73.8	73.8
50	47.5	77.4	74.8
75	50.6	73	73
100	47.5	77.4	74.8

4 Simulation Environment and Parameters

In earlier research papers, network connectivity analysis has been done using NS 2 network simulator in its older software versions. In this research paper, QualNet 6.1 network simulator is implemented, along with MATLAB fuzzy logic toolbox for network connectivity analysis and its performance improvement. QualNet network simulator is an effective tool to study the performance of existing communication networks through simulation process and design such networks which provide optimum performance by varying various simulation parameters. Thus, it can easily analyze the behavior of any real communication network by virtual simulation on the software. It can also be used to build up real time communication networks with desired configuration and satisfactory performance [14]. The simulation parameters are described below as shown in Table 3:

Table 3. Simulation parameters

Parameters	Value
Simulation area	1000×1000 m^2
Simulation time	300 s
Number of nodes	25, 50, 75, 100
Routing protocol	AODV
CBR	5, 10, 15, 20
Packet size	512 bytes
MAC layer	IEEE 802.11
Traffic type	Constant bit rate (CBR)
Transmission range	100, 150, 250 dBm
Antenna model	Omni directional

Some of the snapshots of the simulation process, for different transmission range, employed for different number of nodes for analysis of improved node connectivity of the network, are shown below, retrieved from QualNet network simulator (Figs. 9 and 10):

Fig. 9. Snapshot of 75 nodes during simulation employing 150 dBm transmit range

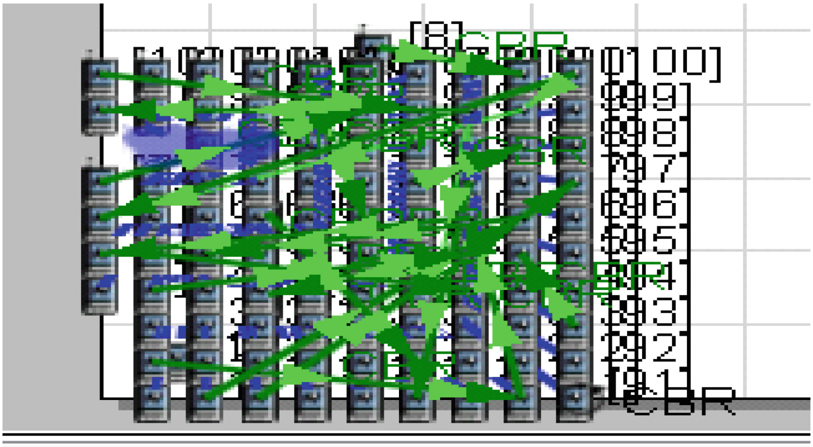

Fig. 10. Snapshot of 100 nodes during simulation employing 100 dBm transmit range

5 Results and Analysis

The performance parameters regarding measure of network connectivity are computed for various numbers of nodes ranging from 25 to 100 nodes using varying transmission range, namely 100, 150, 250 dBm. These performance parameters include generated packet, received packet, forwarded packet, packet delivery ratio, total packets dropped and average end-to-end delay. The respective performance parameters tables for various nodes are shown below (Tables 4, 5, 6 and 7):

Table 4. Performance parameters for 25 nodes

Transmission range Network parameters	100	150	250
Generated packet	126	152	154
Received packet	48	116	111
Forwarded packet	0	53	92
Packet delivery ratio	0.5	0.95	0.97
Total packets dropped	5	16	67
Average end to end delay (ms)	11.104	109.8	57.714

Table 5. Performance parameters for 50 nodes

Transmission range / Network parameters	100	150	250
Generated packet	158	254	289
Received packet	116	176	270
Forwarded packet	60	121	151
Packet delivery ratio	0.5	0.98	0.97
Total packets dropped	10	38	76
Average end to end delay (ms)	20.083	729.832	188.52

Table 6. Performance parameters for 75 nodes

Transmission range / Network parameters	100	150	250
Generated packet	246	334	395
Received packet	173	182	250
Forwarded packet	97	119	161
Packet delivery ratio	0.2	0.8	0.95
Total packets dropped	18	43	105
Average end to end delay (ms)	20.943	659.142	170.606

Table 7. Performance parameters for 100 nodes

Transmission range / Network parameters	100	150	250
Generated packet	263	371	425
Received packet	172	193	278
Forwarded packet	127	134	159
Packet delivery ratio	0.2	0.9	0.96
Total packets dropped	46	58	10.6
Average end to end delay (ms)	45.977	906.055	304.553

From above performance parameters tables, it can be concluded that in case of 150 dBm, there are fewer packets generated and average end to end delay increases while packet delivery ratio drops, as compared to that of 250 dBm, in all the cases of nodes, namely from 25 to 100 nodes. For transmission range 100 dBm, although packets are generated in all cases, they are not being forwarded to the desired destination. Hence, 250 dBm transmission range is best suited for sure connectivity in given networks containing defined number of nodes.

6 Conclusion

With the help of this research paper, performance of mobile ad-hoc networks can be enhanced using network connectivity improvement, through transmission range and number of nodes in a fuzzy based approach, thereby, improving QoS. With the help of the fuzzy approach, it can be concluded that better QoS through sure connectivity is achieved in given networks of defined number of nodes through 250 dBm transmission range.

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