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A Multi Criterion Fuzzy based Energy Efficient Routing Protocol for Ad hoc Networks

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ABSTRACT
The routing protocol for an ad hoc network should be efficient in utilizing the available resources to prolong the network lifetime. A Multi Criterion Fuzzy based Energy Efficient Routing Protocol (MCFEER) for Ad hoc Networks selects the path on constraints like bandwidth, battery life, hop count and buffer occupancy. In the route discovery phase, fuzzy system is applied for optimal route selection by destination node leading to successful data transmission. Multiple stable paths are preserved in route cache for usage during the route maintenance phase. The results are competitive when compared with Power aware Energy Efficient Routing (PEER) protocol using standard metrics, which ensures better network quality and efficiency.

KEYWORDS
Fuzzy; routing; ad hoc network; hop count; bandwidth; battery life

1. Introduction

Today in many applications such as conferencing, interactive information sharing, telemedicine, file transfer and warfare situations, setting up an infrastructure is very difficult. Conferencing refers to a communication between multiple devices located in remote places. It helps to share data (audio or video) in real time providing better QoS. Telemedicine is used to exchange medical information from one place to another and extending care to patients in remote places. This helps in integrating ongoing operations of hospitals, health agencies and consumer's homes. This medical information should be transmitted with better QoS between devices.

In such applications, a Mobile Ad hoc Network (MANET) is preferred, which consists of a set of mobile nodes that are associated via wireless links operate as a host as well as router and can be easily deployed in any network with a dynamic topology. The routing protocols designed for such networks should meet the challenges like the mobility of nodes, resource constraints and error-free channel state. These routing protocols assume that each constraint stands independently from one another, but in reality some interactions might exist between the different constraints. Due to uncertainty in topology and bandwidth utilization, fuzzy systems can be merged with conventional protocols to consider multiple constraints like hop count, bandwidth, network lifetime etc. Mamdani fuzzy model is used in the first phase, route discovery of routing protocol during route selection to improve the network quality.

2. Related Work

Many research works for designing a routing protocol using an evolutionary fuzzy system are in the literature (Su, Wang, & Huang, 2008; Zuo, Ng, & Hanzo, 2010). These protocols include single or multiple constraints in selecting the route using the fuzzy model (Marwaha, Srinivasan, Tham, & Vasilakos, 2004; Rea & Pesch, 2004; Wong & Wong, 2002). The secure routing protocol is designed using a fuzzy model (Nie, Wen, Luo, He, & Zhou, 2006; Venkataraman, Pushpalatha, & Rama Rao, 2012). In a fuzzy approach to energy optimized routing for Wireless Sensor Networks (Haider & Yusuf, 2009), the routing decision is based on fuzzy logic for optimizing the energy usage in a sensor network, which acts as a deciding criterion in path selection. The other metrics like link stability or bandwidth is not measured in this approach. The Fuzzy Logic Aided Dynamic Source Routing in Cross-Layer Operation assisted Ad hoc Networks (Zuo et al., 2010) uses fuzzy logic to calculate the route stability based on input variables hop count and route lifetime. Su et al. (2008) proposed a routing protocol applying fuzzy logic on a conventional Ad hoc on Demand Distance Vector (AODV) protocol where the route selection for packet transmission are chosen using remained energies of the nodes on the routes, number of hop counts in a path and sent controlled packages during transmission. The above protocols optimize two metrics using fuzzy system.

The basic AODV (Chelliah, Sankaran, Prasad, & Gopalan, 2012) protocol is modified to include fuzzy logic to take routing decisions based on multiple constraints like buffer occupancy, node energy and hop count for wireless mesh networks. Fuzzy Stochastic Routing (FSR) (Goswami, Rughwani, & Anjikar, 2013) an enhancement of the AODV protocol uses hop count, remaining battery power and signal stability as input parameter and calculates link cost using fuzzy logic. The total cost is calculated when RREQ reaches the destination and route cost when RREP reaches the source.

Ghalavand, Dana, Ghalavand, and Rezahosieni (2010) used a trust value and energy value to generate reliability value. The trust value is measured based on length of association, the ratio between the number of packets forwarded successfully by the neighbors and the total number of packets sent to that neighbor and average time taken to respond a route request (Wong

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& Wong, 2002). An adaptive routing algorithm was proposed by Ebrahimi, Tenhunen, and Dehyadegari (2013) and Sheng, Wang, Huang, and Yen (2006) where the link cost was assigned using fuzzy logic and the results shows that the path has less congestion due to re-routing of network traffic.

Dynamic Route Optimization Algorithm (DROA) is proposed by Liang Huang (Huang, Wang, Yan, & Duan, 2011), which makes use of probabilistic optimization mechanisms and the broadcast nature of wireless network to find the shortest route by reducing the path length and decreasing relay packets resulting in reduced delay. A shrink mechanism (Bilgin & Khan, 2010) is developed to detect whether there is a redundancy in routing path and to select an optimal path through Received Signal Strength (RSS) based on probability. Fuzzy measure and application of Choquet integral (Sirdhar, Madni, & Jamshidi, 2007) as an aggregation operator is used for multicriteria decision-making for path planning and efficient data collection in mobile robots. Distance, battery power, event level and data criticality are the criteria used for decision-making. A mathematical formulation of a multicast communication problem is developed by Gao, Shi, Hou, Sherali, and Zhou (2011) considering scheduling and routing together in the form of a mixed-integer linear program for a cross layer approach. The complexity of the algorithm developed is a polynomial time. A routing protocol (Valarmathi & Malmurugan, 2011) is proposed that considers traffic metrics to provide a solution for a multichannel assignment. This protocol simulation presents, that they provide high throughput and delivery ratio. Another work proposed by Bakhshi (Bakhshi & Khorsandi, 2013) provides a collection of optimal algorithms for channel allocation using mixed integer programming with the acceptance level of QoS. Progressive Energy Efficient Routing (PEER) Protocol (Zhu & Wang, 2011) proposed an accurate analytical model and a simple energy efficient routing protocol that searched for all shortest paths and picked the minimum energy paths based on hop count and energy. PEER is chosen for comparative analysis with Multi Criterion Fuzzy based Energy Efficient Routing Protocol (MCFEER).

The routing protocols in the literature proposed various models to improve the performance of the network and improve efficiency, which are not efficient in all perspectives. The protocols discussed here use the fuzzy system to optimize two constraints or three constraints to improve the network performance and to provide QoS. The proposed MCFEER protocol optimizes four constraints and improves QoS to a greater extent. It uses multiple constraints like bandwidth, battery life, hop count, buffer occupancy to improve quality of service of the network better and can be applied for multimedia applications, which require high Quality of Service (QoS).

3. Problem Formulation

The wireless network can be deployed dynamically in any environment. Routing protocols designed for a wireless network must meet multiple objectives like energy bandwidth, etc. to improve its QoS. MCFEER protocol satisfies multiple constraints, which is a complex multi objective optimization problem. While formulating such a problem, developers will prefer to include every performance index as an objective, rather than a constraint leading to more number of objectives. Such situations may lead to conflicting scenarios between objectives and some objectives will behave in a non-conflicting manner, near the Pareto optimal space.

Definition 1: A general multi objective optimization problem is defined as minimize or maximize $f(x) = (f_1(x), f_2(x), \ldots, f_n(x))$ subject to set of constraints $g_j(x) \le 0$, $j = \{1, 2, \ldots, m\}$ in an objective space X.

That is, X is supposed to be specified by m inequality constraints. Here, all the functions f_n and g_j are assumed to be continuously differentiable.

3.1. Pareto Optimization

A multi-objective optimization task involving multiple conflicting objectives ideally demands ending a multi-dimensional Pareto-optimal front. The Pareto optimal method (Ngatchou, Zarei, & El-Sharkawi, 2005) uses the concept of Pareto-optimal dominance to find a representative set of solutions in the Pareto optimal front.

Definition 2: (Pareto Optimality): A solution $x \in X$ is said to be Pareto optimal with respect to X if and only if there is no $x' \in X$ for which $v = F(x') = (f_1(x'), f_2(x'), \ldots, f_k(x'))$ dominates $u = F(x) = (f_1(x), f_2(x), \ldots, f_k(x))$. The phrase Pareto optimal is taken to mean with respect to the entire decision variable space unless otherwise specified.

Definition 3: Pareto Optimal Solution: A point $x' \in X$ is said to be a Pareto optimal solution or a non-inferior solution to the problem if there is no $x \in X$ such that $f(x) \le f'(x)$.

Definition 4: Weak Pareto Optimal Solution: A point $x' \in X$ is said to be a weak Pareto optimal solution to the problem if there is no $x \in X$ such that $f(x) < f'(x)$.

The concept of Pareto dominance plays an important role when some or all the objectives and constraints are mutually conflicting; there is no single point that generates a best value for all objectives and constraints. Instead the best solutions are often named as Pareto or non-dominated set are a group of solutions such that selecting any one of them in place of another will always sacrifice quality for at least one objective or constraint, while improving at least one other.

3.2. Mathematical Formulation

The proposed wireless network can be modeled as a connected directed network graph $G = (N, L)$ where N is the set of nodes $\{n_1, n_2, \ldots, n_k\}$ and L is the set of links such that $L = \{L_{12}, L_{13}, L_{23}, \ldots, L_{ij}\}$. $L_{ij} \in L$ is an ordered pair (n_i, n_j), link between nodes n_i, n_j. The transmission and reception of packets are performed on L_{ij}. Let $N_i \subset N$ denote set of nodes reached by a node n_i with a constraint that $d(n_i, n_k) \le R$ where $d(n_i, n_k)$ is the distance between n_i and n_k and R is the transmission range of node.

A mathematical model for selecting an efficient path for a given pair of nodes, namely source and destination, accounting for energy consumption of nodes in the path, bandwidth utilization of path, hop count of the path and buffer occupancy of nodes in the path can be formulated as below.

Let q_{ij} be the decision variable associated with link L_{ij} such that

$$q_{ij} = \begin{cases} 0, \text{link not included in path} \\ 1, \text{ link included in path} \end{cases} \quad (1)$$

The objective functions are

$$\max \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(E_{path(k)} \times q_{ij}, B_{path(k)} \times q_{ij} \right) \quad (2)$$

$$\min \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{p} \left(BO_{path(k)} \times q_{ij}, h_{path(k)} \times q_{ij} \right) \tag{3}$$

Subject to

$$B_{path}(k) \geq B_{\min} \tag{4}$$

$$E_{path(k)} \geq E_{rem} \tag{5}$$

$$H_{path(k)} \leq 15 \tag{6}$$

$$\sum_{i=1}^{n} q_{ij} = 1, \forall j \tag{7}$$

$$\sum_{j=1}^{n} q_{ij} = 1, \forall i \tag{8}$$

where $B_{\min}$ is the minimum bandwidth required for data transmission and reception of packets. E_{rem} is the remaining energy of nodes either after transmission or reception. In the simulation environment, an assumption is made such that the length of any path in terms of hop count between source and destination is less than 15. If the length of any path is greater than 15, it is treated as an invalid path.

3.2.1. Energy Consumption

The nodes in the wireless interface can be in any one of four states transmit, receive, idle or sleep mode. In reality energy consumption in each state is different, but for simplicity an assumption is made such that transmit and receive power level are equal and it is 1.3 W (watts) in a simulation environment. The power dissipation is less in idle state and considered as 0.5 W and no power dissipation during sleep mode. For simulation purposes, these power levels are considered, but in a real environment power levels vary due to interference. Due to the shared nature of the wireless medium, energy dissipated during transmission of a packet is given as:

$$E = E_T + c \times E_R \tag{9}$$

where c is count of nodes within transmission and interference range. The initial energy of all nodes in the network is given by E_{ini} and remaining energy (E_{rem}) is calculated using

$$E_{rem} = E_{ini} - E \tag{10}$$

The energy of path k is calculated as the minimum of energy of all nodes (n_i) within the path.

$$E_{path(k)} = \min \sum_{i=n_i}^{n_k} E_{rem} \quad \forall \left(n_i, n_k \right) \in N \tag{11}$$

where E_{res} is remaining energy of a node after transmission or reception.

3.2.2. Bandwidth

The available bandwidth (B_{av}) for any link is vital for successful data transmission. The routing protocol designed should be efficient in choosing a path having a sufficient bandwidth. The bandwidth of the path (B_{path}) is the minimum of B_{av} of all links in the specified path as given by

$$B_{path} = \min \sum_{L_{ij}} B_{av} \ \forall L_{ij} \subset L \wedge L_{ij} \in path \tag{12}$$

$$B_{path} \geq B_{\min} \tag{13}$$

where $B_{\min}$ is the minimum bandwidth required for transmission.

Buffer Occupancy (BO_{path}) of the path is the status of buffers of each node in the path. When the buffers are full, packets may be dropped, which leads to reduction in throughput. The buffer occupancy (BO_{new}) of a node can be computed as:

$$BO_{new} = BO_{old} - D \tag{14}$$

where BO_{old} buffer occupancy of node before receiving a packet of size D bytes.

The hop count (H_{path}) of the path is the total number of hops the packet has to transmit in a path from the source n_s to the destination n_d.

4. MCFEER Routing Protocol

The MCFEER routing protocol involves two phases; route discovery and route maintenance phase. In Phase 1, fuzzy system for route selection is used, which selects routes from source to destination based on multiple constraints like bandwidth (B_{av}), buffer occupancy (BO_{new}), battery life and hop count. In Phase 2, route maintenance is performed if there is a broken link due to dynamic topology and lack of critical resource constraints.

Phase 1: Route discovery

Whenever a source node wants to transmit data to the specified destination, it checks its route cache for valid path. If the path to the destination is available, the source node transmits data; else it discovers new paths to the destination. Whenever a source node wants to transmit a packet to a destination, it checks its route cache for a valid route. If a route is available, it sends the packet, or it broadcasts Route REQuest(RREQ) packet to all its neighbors. The RREQ packet has the following format.

Pkt_id	Source_id	Dest_id	id-array[]	Hop count	Fuzzy parameter B_{av} BO_{new} E_{res}

The neighbor nodes can be either intermediate nodes or destination nodes. The intermediate nodes will update hop count, energy, bandwidth and buffer occupancy in a RREQ packet, and append its id in the id-array[] of RREQ packet. The process continues until the destination is reached. The intermediate nodes will skip RREQ packet if its id is already available in the RREQ packet to avoid loop. The destination node will select a valid path using multiple constraint fuzzy systems based on hop count, bandwidth, network life time and buffer occupancy. On selection, the destination node will send a route reply (RREP) packet to the source. The source node transmits data packet to destination on the same path in which it received the RREP packet. During this process, there may be breakage of links due to lack of a critical resource like energy or packet drop due to buffer overflow or delay due to congestion. So care is taken during the route selection considering the said criteria like energy, bandwidth, buffer occupancy and hop count. These criteria when handled individually can be a crisp value, route selection may be simple. But combining multiple criteria during route selection cannot be handled by crisp values and becomes a complex task with much uncertainty. To handle this uncertainty due to multiple criteria and to provide an efficient method of modeling, fuzzy system will be more appropriate.

Phase 2: Route Maintenance

The dynamic topology of MANET and mobility of nodes leads to frequent link breaks. The routing model of MCFEER chooses the path considering multiple constraints, which improves network efficiency. A rare situation happens when a link break may occur and an alternate path to a specified destination is not readily available and hence the intermediate node will invoke route maintenance process by broadcasting route error (RERR) packet. Neighbor nodes receiving these packets will delete the current path from the route cache and check for any other valid paths in their route cache, if available transmit, the packet through that else invokes the route discovery process.

4.1. Fuzzy System

Fuzzy system is used to model the noise and imprecise environment, which is important for many real time applications. This system imitates human reasoning where a model may not require noise free input, but output generated will be a smooth control function. A range of real values is described by fuzzy sets called domain and a membership function is defined. Each point in the fuzzy set domain will be assigned truth values. The membership function can be one among triangular, beta, Gaussian functions with domain values ranging between 0 and 1.

The fuzzy system basically consists of three modules, namely; fuzzification, fuzzy inference system and defuzzification process. The input variables will be crisp values. These values are mapped to corresponding fuzzy sets and assign a truth value of degree of membership for each fuzzy set. This process of converting the crisp value to the fuzzy value is called the fuzzification process. The fuzzified values are processed by a fuzzy inference system, which consists of fuzzy rules and various methods for inferring the rules. The rule base is nothing, but a collection of IF-THEN rules that relate input with output fuzzy variables. These variables are in fuzzy set and are described by fuzzy implication operators such as AND, OR, etc. The defuzzification finds a single crisp value from the solution fuzzy space (Nguyen, Sugeno, Tong, & Yager, 1995).

4.2. Fuzzy Model for Energy Efficient Routing

The routing protocol for MANET in the literature is efficient based on one constraint hop count or two constraints namely hop count and energy. To optimize a protocol that satisfies multiple constraints will become an NP-Complete problem and it does not have a polynomial solution. The fuzzy system can be used to model any continuous function or system. The fuzzy system is best suited for making an optimal routing decision in a dynamic network like MANET, which involves uncertainty. The quality of the fuzzy system depends on the quality of inference rules. In this MCFEER protocol, fuzzy inference system is included, which routes the packets to the destination based on multiple constraints like hop count, bandwidth utilization, battery life and buffer occupancy.

4.2.1. Fuzzy Input Parameters

The various input parameters for the fuzzy inference system are given below.

(a) Hop Count: The hop count (H_{path}) is the number of hops a packet traverses from source to destination. The hop count is incremented by 1 when a packet is transmitted from one intermediate node to another. When hop count increases, the throughput achieved will be reduced. When the hop count is less, the route is not very congested. So route selection can be made based on hop count. The crisp value for hop count is considered to be in the range 0 to 15. Three fuzzy sets short, med, long are created based on value of hop count. The membership function for hop count is calculated as follows:

$$\mu_h(x)_{short} = \begin{cases} 0 & x > 6 \\ \left(\frac{6-x}{2}\right) & 4 \le x \le 6 \\ 1 & x < 4 \end{cases}$$

$$\mu_h(x)_{med} = \begin{cases} 0 & (x < 4) \text{ or } (x > 8) \\ \left(\frac{x-4}{2}\right) & 4 \le x \le 6 \\ 1 & 6 \le x \le 7 \\ (8-x) & 7 \le x \le 8 \end{cases}$$

$$\mu_h(x)_{long} = \begin{cases} 0 & x < 7 \\ (x-7) & 7 \le x \le 8 \\ 1 & x > 8 \end{cases}$$

(b) Bandwidth: Bandwidth is the capacity of a link measured in terms of bits per second. The route with higher bandwidth may not be the best route, because delay during transmission may occur due to congestion. So the bandwidth utilization should be uniform such that delays during a packet transmission will be reduced. The bandwidth utilization of a node can be measured by knowing network utilization. There are various methods followed in the literature to measure network utilization using MAC layer congestion window, queue length and collision measures. Among these methods the simple one is that intermediate nodes, which are able to listen the channel and track the network utilization to measure available bandwidth per second. 802.11 MAC layer is used to find free and busy times using a CSMA/CDMA through Network Allocation Vector (NAV). MAC layer can detect the status of a channel as busy or free. It detects the channel as busy when NAV sets a new value or receives state changes from idle to any other state and send state changes from idle to another state. It detects the channel as free when NAV is less than the current time or receive state is idle or sends state is idle. The B_{av} ranges from 0 to 100 Mbps and three fuzzy sets low, med and high are calculated using the following equations.

$$\mu_{B_{av}}(x)_{low} = \begin{cases} 0 & x > 40 \\ \left(\frac{40-x}{20}\right) & 20 \leq x \leq 40 \\ 1 & x < 20 \end{cases}$$

$$\mu_{B_{av}}(x)_{med} = \begin{cases} 0 & (x < 20) \text{ or } (x > 80) \\ \left(\frac{x-20}{20}\right) & 20 \leq x \leq 40 \\ 1 & 40 \leq x \leq 60 \\ \left(\frac{80-x}{20}\right) & 60 \leq x \leq 80 \end{cases}$$

$$\mu_{B_{av}}(x)_{high} = \begin{cases} 0 & x < 60 \\ \left(\frac{x-60}{20}\right) & 60 \leq x \leq 80 \\ 1 & x > 80 \end{cases}$$

(c) Battery Life: Battery life is predicted based on the energy spent in transmitting E_t, receiving E_r and overhearing E_o, the packets. If the battery life of the node is less, then the node becomes a dead node, resulting in broken links and decreasing network lifetime. Therefore the energy of the node should be uniformly used. The residual energy of a node is taken as an input parameter for fuzzy inference system to measure battery life and categorized as less, med and high. The membership function of residual energy is given below.

$$\mu_{E_{res}}(x)_{less} = \begin{cases} 0 & x > 400 \\ \left(\frac{400-x}{100}\right) & 300 \leq x \leq 400 \\ 1 & x < 300 \end{cases}$$

$$\mu_{E_{res}}(x)_{med} = \begin{cases} 0 & (x < 300) \; or \; (x > 700) \\ \left(\frac{x-300}{100}\right) & 300 \leq x \leq 400 \\ 1 & 400 \leq x \leq 600 \\ \left(\frac{700-x}{100}\right) & 600 \leq x \leq 700 \end{cases}$$

$$\mu_{E_{res}}(x)_{high} = \begin{cases} 0 & x < 600 \\ \frac{x-600}{100} & 600 \leq x \leq 700 \\ 1 & x > 700 \end{cases}$$

(d) Buffer Occupancy: The length of the buffer is very crucial in ad hoc networks, because nodes act as a router to serve other nodes. So it is supposed to have larger buffers, but not to be over utilized. The membership function for a buffer occupancy is a trapezoid function and classified as low, med, high. The maximum buffer size is assumed to be 150K bytes and membership values corresponding to this assumption are given as follows:

$$\mu_{BO_{new}}(x)_{low} = \begin{cases} 0 & x > 60000 \\ \left(\frac{60000-x}{30000}\right) & 30000 \leq x \leq 60000 \\ 1 & x < 30000 \end{cases}$$

Table 1. Sample fuzzy inference rules.

Input Parameters				Output Parameter
Hop Count	Bandwidth	Battery Life	Buffer Occupancy	Route Selection Grade
Short	Med	Less	High	Low
Med	Low	Less	High	
Short	Low	High	Low	High
Short	Low	High	Med	
Short	High	High	Med	Very high
Short	High	Med	Med	

$$\mu_{BO_{new}}(x)_{med} = \begin{cases} 0 & (x < 30000) \vee (x > 120000) \\ \left(\frac{x-30000}{30000}\right) & 30000 \leq x \leq 60000 \\ 1 & 60000 \leq x \leq 90000 \\ \left(\frac{120000-x}{30000}\right) & 90000 \leq x \leq 120000 \end{cases}$$

$$\mu_{BO_{new}}(x)_{high} = \begin{cases} 0 & x < 90000 \\ \left(\frac{x-90000}{30000}\right) & 90000 \leq x \leq 120000 \\ 1 & x > 120000 \end{cases}$$

4.2.2. *Fuzzy Knowledge Base*

A set of rules is framed with the multiple constraints hop count, bandwidth, battery life and buffer occupancy to calculate fuzzy output route selection grade developed using trial and error approach. A collection of if-then rules is constructed based on experiments and a sample of the few rules is tabulated in Table 1. The rules are re-defined if the results are not converging to an optimal path.

4.2.3. *Fuzzy Output Parameter*

The output parameter Route Selection Grade (RSG) is calculated by destination node for all valid paths to given destination using fuzzy inference rules. The membership function for RSG is given below.

$$\mu_{RSG}(x)_{low} = \begin{cases} 0 & x > 0.3 \\ \left(\frac{0.3-x}{0.1}\right) & 0.2 \leq x \leq 0.3 \\ 1 & x < 0.2 \end{cases}$$

$$\mu_{RSG}(x)_{\mathrm{mod}} = \begin{cases} 0 & (x < 0.2) \vee (x > 0.5) \\ \left(\frac{x-0.2}{0.1}\right) & 0.2 \leq x \leq 0.3 \\ 1 & 0.3 \leq x \leq 0.4 \\ \left(\frac{0.5-x}{0.1}\right) & 0.4 \leq x \leq 0.5 \end{cases}$$

$$\mu_{RSG}(x)_{high} = \begin{cases} 0 & (x < 0.4) \text{ or } (x > 0.8) \\ \left(\frac{x-0.4}{0.1}\right) & 0.4 \leq x \leq 0.5 \\ 1 & 0.5 \leq x \leq 0.7 \\ \left(\frac{0.8-x}{0.3}\right) & 0.7 \leq x \leq 0.8 \end{cases}$$

$$\mu_{RSG}(x)_{veryhigh} = \begin{cases} 0 & x < 0.7 \\ \left(\frac{x-0.7}{0.1}\right) & 0.7 \leq x \leq 0.8 \\ 1 & x > 0.8 \end{cases}$$

The output derived from the input, the output membership function and fuzzy inference rules is also a fuzzy element. To transform fuzzy element to crisp output, defuzzification is performed. The Center of Gravity (COG) method is a defuzzification technique predominantly used in real time applications. The crisp output value (CV) using COG method is calculated using the following equation.

$$CV(RSG) = \frac{\sum_x \mu_{RSG}(x) \times x}{\sum_x \mu_{RSG}(x)} \tag{15}$$

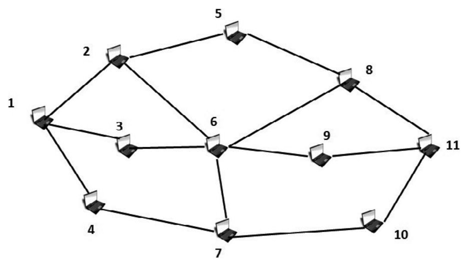

Figure 1. Deployment of laptops in a conference room.

Table 2. Paths between 1 and 11.

Path name	Path
P1	1–3-6–8-11
P2	1–2-5–8-11
P3	1–3-6–7-10–11
P4	1–4-7–10-11
P5	1–3-6–9-11

Table 3. Input parameters for paths.

Path	Hopcount	Band-width(Mbps)	Battery life(-Joules)	Buffer Occu-pancy (bytes)
P1	4	55	800	82500
P2	4	60	300	45000
P3	5	30	250	97500
P4	4	57	300	112500
P5	4	80	600	120000

5. An Illustrative Scenario

The applications will decide the parameters, which will improve its efficiency. Video conferencing allows audio and video transmission to two or more locations simultaneously. In this application Voice over IP (VoIP) is used to transfer audio and video in the application layer. The links in the ad hoc network can be broken due to scarce resources like energy, bandwidth, etc. So fuzzy based energy efficient routing protocol uses fuzzy logic and selects multiple routes with very high and high route selection grade. These routes will be in route cache of nodes. During the route maintenance phase, source node checks its route cache for a valid route to destination and transfers the data without any delay. To illustrate the implementation of routing protocol, a hypothetical network is designed to demonstrate the computation of fuzzy systems. The following example illustrates the routing between a source and destination.

A simple example of 11 laptops is deployed in a conference room shown in Figure 1. The laptops transfer a video file among themselves. The available bandwidth is 100 Mbps, buffer size of each node is 150 kilobytes queue size and initial energy of each node is 1 K Joules. Assume the source node with node_id 1 and destination node with node_ id 11. The sample five paths from source to destination are considered as shown in Table 2.

The fuzzy parameters are updated for each path from source with node_id 1 to the destination with node_id 11 and tabulated in Table 3. The parameters are crisp input, which is translated into a fuzzy value using the membership function as given in Section 5 and represented in Table 4. Using inference rules route selection grade is calculated for each path. In the given scenario, paths P1, P2 and P5 are stored in the route cache. Multiple paths are chosen, because the links may be broken frequently and during route repair process, an alternate route can be used to transfer packet and reduce frequent invocation of route discovery mechanism.

Defuzzification is carried out using the Center of Gravity (COG) technique (Kalpana & Punithavalli, 2013; Nurcahyo, Shamsuddin, Alias, & Sap, 2003) and the CV for RSG is found. The COG method is simple and the most commonly used defuzzication method. The sample input is given for input

Table 4. Fuzzy values of input and output parameters.

Path	Hopcount		Bandwidth(Mbps)		Battery life(Joules)		Buffer Occupancy(bytes)		Route Selection Grade (RSG)
P1	0.4	Short	0.7	Med	0.8	High	0.6	Med	Very High
P2	0.4	Short	0.5	Med	0.3	Med	0.2	Low	High
P3	0.5	Med	0.3	Low	0.5	Less	0.5	Med	Med
P4	0.4	Short	0.5	Med	0.3	Less	0.8	High	Low
P5	0.4	Short	0.9	High	0.6	Med	0.9	High	High

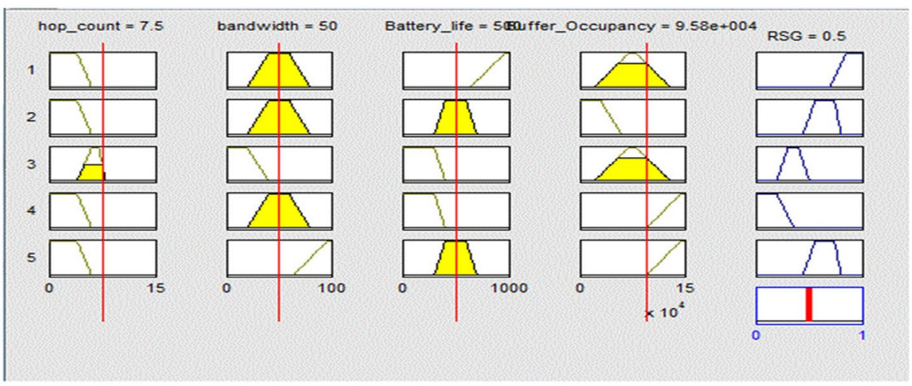

Figure 2. Calculation of crisp output value for RSG based on input metrics.

parameters for which defuzzification are performed to compute crisp value. The pictorial representation of defuzzification is shown in Figure 2.

6. Simulation Results and Analysis

The experiments are conducted using the network simulator (NS2.34) The ns manual (2008) [http://www.isi.edu/nsnam/ns/]. The simulations are conducted by varying pause time in the topographical space of 1000×800 for 400 s. The change in pause time varies the mobility of the node and simulations are carried out. As the simulation starts, each node establishes a connection with the destination and sends packets of 512 bytes with the constant rate of 10 K. The transmission range of each node is assumed to be 250 m. The initial energy of all the nodes is set to be 1000 J. The Drop tail queue is chosen and this queue will discard the packet when queue is full.

The performance of the proposed work is analyzed using the various metrics and is compared with PEER protocol, which uses energy and hop count during the route selection. Throughput is the average amount of packets transferred to the destination over time. Throughput measures the quality of the network. The simulations are carried out with varying speed of the nodes. The proposed method generates the stable route and hence the maximum number of packets generated by source is delivered to the destinations. Thus the throughput is improved in MCFEER as shown in Figure 3.

The performance can be evaluated using network lifetime. It is the time at which the nodes in the network become dead. As the number of dead nodes increases the network lifetime decreases. The network lifetime is evaluated based on the number of dead nodes created over the simulation time. Dead nodes are nodes whose energy reaches a threshold value after which nodes cannot participate in route discovery and route maintenance. The stable paths are chosen by MCFEER since battery life is a constraint used in path selection. The path is chosen such that all nodes in that path have sufficient energy therefore the network lifetime is improved than PEER as shown in Figure 4.

Packet Delivery rate is the ratio of the number of packets delivered to those that are generated by CBR traffic. The packet delivery rate is higher in the proposed work as illustrated in Figure 5. When the mobility is increased, the links in PEER are broken. This lead to increase in packet loss and packet delivery rate is reduced.

Average end to end delay is the time taken for a packet to reach the destination from its source. In MCFEER protocol the constraints are measured at each node. There is a reasonable delay in delivering of packets as shown in Figure 6.

Routing Overhead is the number of routing packets sent for sending the actual data for transmission. In MCFEER, the constraints are measured at each node and hence overhead may increase. But the simulation results in Figure 7 show that the routing overhead is less in MCFEER. In MCFEER protocol initial measurement is there, but routes are optimal and stable. In PEER when mobility of the node increases, the routes are broken and the route discovery is invoked frequently leading to control overhead and energy consumption.

Bandwidth Utilization is the ratio of bandwidth received and total available bandwidth for a traffic flow. This metric is measured for two scenarios by varying node density and data flow. From Figure 8 it is analyzed that as node density increases, bandwidth utilization also increases, which means more number of packet transmissions had occurred. Due to dynamic topology, increase of packets including routing packet had happened. The change of data flow also had shown an increase in bandwidth utilization as shown in Figure 9. Both

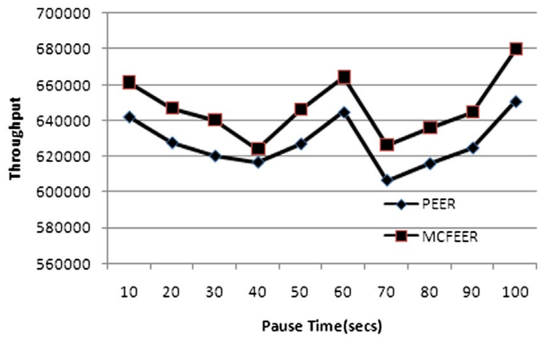

Figure 3. Throughput with Varying Pause Time.

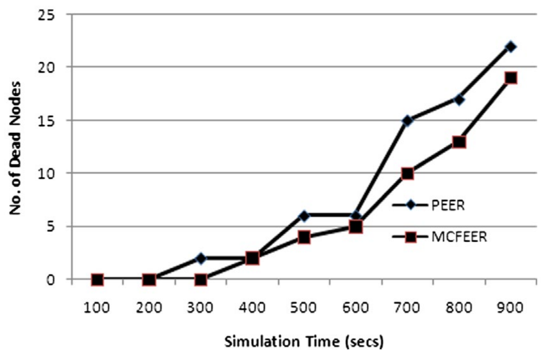

Figure 4. Number of dead nodes varying simulation time.

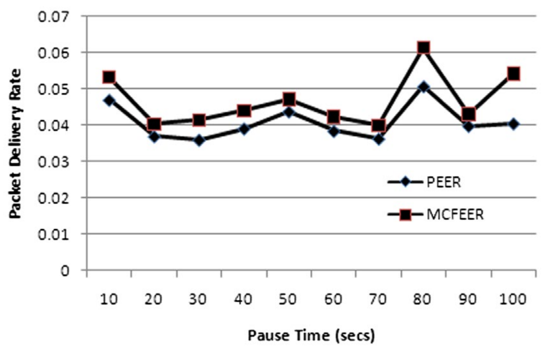

Figure 5. Packet delivery rate varying pause time.

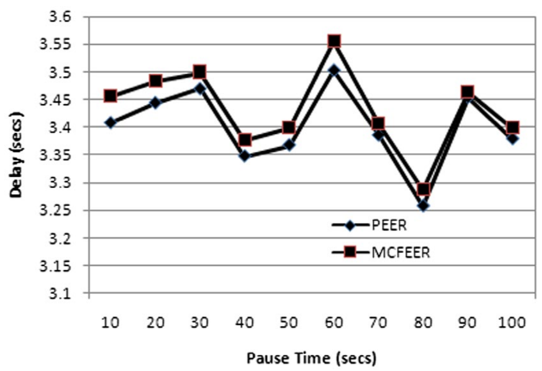

Figure 6. Delay varying pause time.

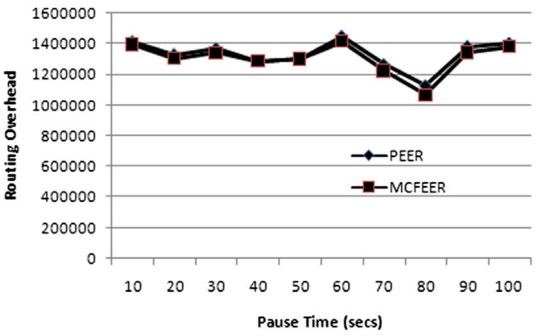

Figure 7. Routing overhead with varying pause time.

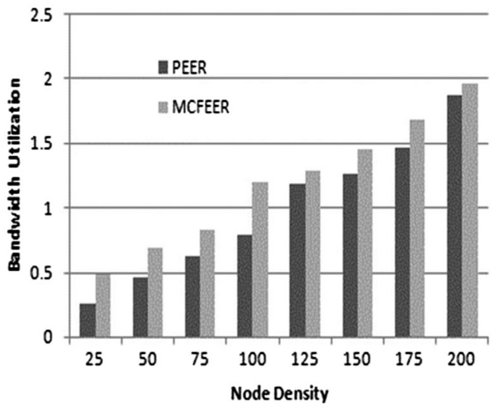

Figure 8. Bandwidth utilization varying node density.

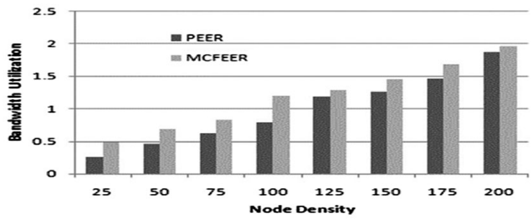

Figure 9. Bandwidth utilization by varying node density.

PEER and MCFEER show a steady increase, but MCFEER is better.

7. Conclusion

Wireless Network is a promising network in the communication world, which can be easily deployed. The routing protocols used in the network will influence the performance of the network. This paper proposed a multi criterion fuzzy based energy efficient routing protocol, which selects a stable path using fuzzy systems in route discovery phase based on the multiple constraints hop count, bandwidth, battery life and buffer occupancy. The route maintenance phase will handle broken links and improves network performance. The proposed protocol concludes that routes are more stable than conventional protocol and thereby increases the network performance, but with considerable delay. This protocol can be further improved to reduce the delay and thereby increasing the performance even better.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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