An Agent-assisted Fuzzy cost based Multicast QoS routing in MANETs

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Abstract:- Multicast routing and provision of QoS (Quality of Service) are challenging problems due to the dynamic topology and limited resources in Mobile Ad hoc Networks (MANETs). This paper proposes an agent based QoS routing algorithm that employs fuzzy logic to select an optimal path by considering multiple independent QoS metrics such as buffer occupancy rate, remaining battery capacity of a mobile node number of hops. In this method all the available resources of the path is converted into a single metric fuzzy cost. This is based on multi-criterion objective fuzzy measure. The path with the minimum fuzzy cost is used for the transmission. Here, the intelligent software agents move around the network and collect information of all mobile nodes. These agents can reduce the network delay and participate in network routing and route maintenance. The performance of the proposed Agent assisted Fuzzy cost based Multiobjective QoS Routing protocol (Agent_FCMQR) is compared with E-AOFR (Evolutionary Ad hoc On demand Fuzzy Routing) and MQRFT (Multi metric QoS routing based on Fuzzy Theory) and the simulation results show that the proposed protocol is superior over existing intelligence based routing protocols.

Key words: MANETs, multicast routing, Quality of Service, mobile agents, multi-objective, fuzzy cost

1 Introduction

Mobile Ad-hoc Network comprises group of mobile nodes that communicate with each other over multi-hop wireless links with no fixed infrastructure support. In MANETs the nodes are free to move randomly and a node may join or leave the multicast tree at any time [1]. The provision of QoS guarantee is of utmost importance for the development of the multicast services since it can improve performance and allow critical information to flow even under difficult conditions [2]. Most of the conventional routing protocols for MANETs consider one or two QoS metrics for route selection [3]. But this is not sufficient since the topology of the MANET is determined by many factors such as link stability, node mobility and battery power of the mobile devices. All of these factors are correlated. Thus, consideration of only one or two factors is not sufficient for choosing an optimal path [4].

However, selecting a route which satisfies all multiple constraints is an NP complete problem [5]. There is no accurate mathematical model to describe it. Fuzzy logic can be used to model any continuous function or system. Fuzzy logic is a theory that not only supports several inputs, but also exploits the pervasive imprecision information [6]. This inherent property of fuzzy logic leads to solve multi metric problems in ad hoc networks.

Shivanajay Manvaha et.al. proposed Evolutionary Ad-hoc On-demand Fuzzy Routing

(E-AOFR) models the uncertainty in MANET by fuzzy set theory [13]. Fuzzy logic function is embedded into every mobile node, which takes three parameters at a node (remaining battery capacity, buffer length, link stability) as input and producing a single cost metric. Each node which receives route request packet calculates its fuzzy cost and then adds its cost to the previous cost of RREQ packets. The destination node waits a certain amount of time to collect the cost information of all possible routes, and then chooses the least cost one as the routing path between the source and destination and then sends back its RREP. In E-AOFR, every node needs to compute its fuzzy cost as long as it receives RREQ packets between any two pair nodes. The frequency of this computation is very high, placing a heavy burden on the node. As there is no constraint on end-to-end QoS requirement in terms of bandwidth or delay, the search space is not reduced efficiently for real time applications.

Cohen et al. presents a new fuzzy-based method for path selection. The goal of this algorithm is to identify an optimal path with reducing the overall route setup time [14]. *Susan Rea and Dirk Pesch* proposed a fuzzy logic based caching decision as a route selection method [7]. In which multiple QoS metrics like link strength, energy available at a node, and number of hops in a path will be combined into a single decision for selecting a route and thereby optimizing a routing protocol.

Wen Song proposed Multi-metric QoS Routing Based on Fuzzy Theory (MQRFT) to solve traffic management problem and achieve a good trade-off between QoS provision and network performance based on DSR [15]. In this paper multiple metrics are combined into an integrate route cache decision thereby optimizing route selection and make it more effective for traffic engineering.

In recent developments, agent technology is making its way as a new paradigm in the areas of artificial intelligence and computing which facilitates sophisticated software development with features like flexibility, scalability, adaptability and efficiency [7]. Agents are the autonomous programs that can migrate from node to node in a heterogeneous environment and complete a task specified by its owner without disturbing the activities of the host [8]. Hence, the proposed system tries to capture the performance benefits of mobile agents and fuzzy logic based caching decision by integrating them to design a new hybrid routing protocol.

This paper proposes a simple and effective protocol called Agent assisted Fuzzy-Cost based Multi-objective QoS multicast Routing protocol (Agent_FCMQR) for MANETs. It builds a low cost multicast tree with bandwidth and delay constraints. The proposed Agent_FCMQR has various objectives. (i) maximize packet delivery fraction (ii) minimize end-to-end delay (iii) maximize the route life time (iv) minimize the transmission cost of multicast tree. Several QoS metrics considered are buffer occupancy rate (Q_i), remaining battery power (BP_i) of a mobile node and number of intermediate nodes (N). These metrics are translated into a single metric fuzzy-cost (C). This is based on multi-criterion objective fuzzy measure. The proposed system chooses the most cost effective path which satisfies the bandwidth and delay constraints. Considering the dynamic characteristics of routing in ad hoc networks, an agent model is applied to apperceive the changes in network topology and network communication flow.

2 Network model

A network is usually represented as a weighted digraph G = (V, E), where V denotes the set of nodes and E denotes the set of communication links connecting the nodes. |V | and |E| denotes the number of nodes and links in the network, respectively. Here, the multicast routing problem is designed with bandwidth and delay constraints from one source to multiple destinations. Let $s \in V$ be source node of a multicast tree, and $M \in \{V- \{s\}\}$ be a set of destination nodes of the multicast tree. R^+ the set of all positive real numbers. For any link ($e \in E$), we can define some QoS metrics:

delay function: Delay(e): $E \rightarrow R^+$
bandwidth function : Bandwidth(e): $E \rightarrow R^+$
cost function: Cost(e): $E \rightarrow R^+$

T(s, M) is used to denote the multicast tree, which is subjected to the following functions:

$$Cost(T(s,M)) = \sum_{e \in T(s,M)} cost(e) \qquad (1)$$

$$Delay(p(s,t)) = \sum_{e \in p(s,t)} delay(e) \qquad (2)$$

$$\text{Bandwidth}(p(s,t)) = \min\left(\text{Bandwidth}(e)\right), e \in p(s,t) \qquad (3)$$

where p(s, t) denotes the routing path of the multicast tree T(s, M) from the node source ‘s’ to destination node t Є M. Multicast tree T(s, M) should satisfy the following bandwidth and delay criteria for an application to begin and proceed.

(i) Delay constraint: Delay(p(s,T)) $\leq D$

(ii)Bandwidth constraint: Bandwidth(p(s,T)) $\geq B$

where, the delay (p(s,T)) is the maximum end to end delay from the soure ‘s’ to the more delayed destination in the multicast tree T should be inferior or equal to the delay threshold ‘D’. Also Bandwidth (p(s, T)) is the minimum bandwidth in every link in the whole multicast tree which must be greater or equal to the minimum bandwidth B.

The quality of service multicast routing problem with multi constraints represents a minimization problem where their function is to find a multicast tree *T(s, M)* which minimize the cost T(s, M). Suppose *S*(*R*) is the set, *S*(*R*) satisfies the conditions above, then, the multicast tree *T* which we find is:

$$Cost\ T(s,M) = \min\ (Cos\ (T(s,M)_s),\ T(s,M)_s \in S(R) \quad (4)$$

3 Fuzzy-Cost based QoS routing model for MANETs

3.1 Description of multiple QoS routing metrics

The various objectives that are considered in Agent-FCMQR are (i) minimize the end-to-end delay; (ii) maximize packet delivery; and (iii) minimize the transmission cost. Each objective is linked to multiple metrics. Several QoS metrics have been chosen to meet these objectives and they are converted into a single cost metric *(C).* QoS metrics considered here for selecting the routes are available buffer occupancy rate (Q_i), remaining battery power (BP) and number of hops (N). The relationship between the cost C and the other QoS metrics is given by Eqn. (5)

$$C = f\ (Q_i, BP, N) \qquad (5)$$

Effect of buffer occupancy rate on cost: The buffer occupancy rate as a parameter helps in selecting routes that are not congested, thus decreasing congestion loss and end-to-end delay. The packet buffer occupancy rate (Q_i) of the whole path is calculated as

$$buffer\ occupancy\ rate(Q_i) = \frac{\sum q_i}{\sum b_i} \qquad (6)$$

where $\sum q_i$ is the sum of length of packet queue for all nodes on the path. $\sum b_i$ is the sum of packet buffer capacity for all nodes on the path. The buffer occupancy rate is usually used to represent the network congestion degree. The following rules are proposed to explain the relationship between buffer length and cost.

R1: If buffer length is low, then cost is low.
R2: If buffer length is medium, then cost is medium.
R3: If buffer length is high, then cost is high.

\Higher cost for increased buffer length: An increase in buffer length means more waiting time for data packets to be processed and routed. If the buffer is full, it leads to an increased probability of congestion and network begins to discard packets. This adversely affects the primary objectives, which are to achieve reduced delay, and increased packet delivery.

Effect of remaining battery power of a route on cost: The remaining battery power of a path is described as the minimum amount of battery power available on any node along the path. The available battery power and the required transmit power level of a node are taken into account to find the remaining battery power of a node.

$$BP\ (p(s,d) = \min\{BP(n),\ n \in p(s,d)\} \qquad (7)$$

where p(s, d) is the path from source node ‘s’ to destination node ‘d’. The route with more battery power requires less cost. Consequently, the following rules are proposed.

R4: If battery power is low then cost is high
R5: If battery power is medium, then cost must be medium.
R6: If battery power is high then cost is low.

The cost of using a route increases as the remaining battery power decreases. The nodes with lower battery power for routing packets would result in frequent route failures due to the expiration of batteries of intermediate nodes in the route. This would have a negative impact on both end to end delay and packet delivery ratio.

Effect of path length on cost: The number of intermediate hops plays an important role in route selection. It allows the routing protocols to find the routes having the shortest distance. To some degree, the shortest distance in network means the least end-to-end delay between the source and the destination. Based on previous studies, the following rules are proposed.

R7: If hop count is low, then cost is low.
R8: If hop count is medium, then cost is medium.
R9: If hop count is high, then cost must be high.

Higher cost for increased number of intermediate hops: If data is transmitted through the route with the higher number of intermediate hops, the possibility of route failure is high due to node mobility and reduces the life span of routing path. In addition, larger number of intermediate hops resulting in a higher end-to-end delay.

3.2 Implementation of Fuzzy Inference Engine

Figure 1. describes the three major processes of Fuzzy Logic System (FLS). They are fuzzification, knowledge base rule structure and defuzzification [19]. The inputs into our FLS are: i) the number of intermediate hops ii) remaining battery capacity iii) buffer occupancy rate.

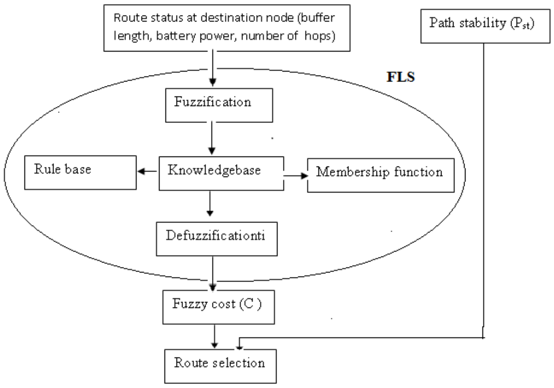

Figure 1. Selection of Multi objective optimal route

a)Fuzzification of Inputs and Outputs: The three input variables to be fuzzified are the number of intermediate nodes, battery capacity and queue length. On the existing knowledge of MANET, the terms “Low”, Medium”, “High” are used to describe the buffer length, battery power and number of hops. For the output variable cost the terms “Very Low”, Low”, “Medium”, “High” and “Very High” are used. (Fig.2 & Fig.3) Triangular membership functions are used for representing the variables.

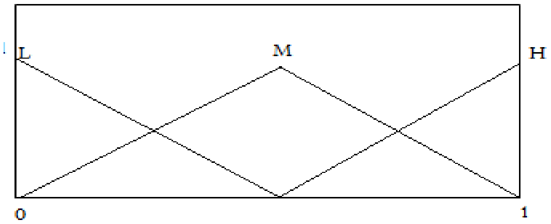

Figure 2. Fuzzy memberships function for buffer length, remaining battery capacity and hop count

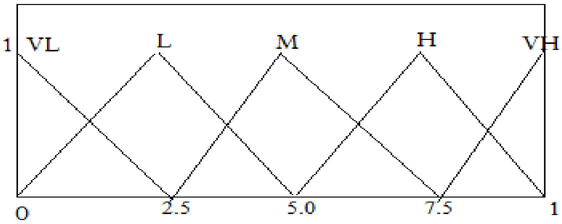

Figure 3. Fuzzy membership function for cost

b) *Knowledge Base Rule Structure:* The fuzzy rules have IF-THEN structure. The inputs are then combined using the AND operator. The following is an example of rule which describes the input-output mapping.

If (Buffer length is "low") AND (Battery power is "high") AND (Number of hops is" Low") Then Cost is "Very Low"

The interpretation is that the route with lower buffer length, high battery power and minimum number of intermediate hops are favorable inputs and hence it yields very low cost. Since each input variable has 3 linguistic states, the total number of possible fuzzy inference rules is 3*3*3 = 27. To find the cost, the above fuzzy rules R1 to R9 are combined and the results are presented in Table 1, 2 and 3.

Table 1: Fuzzy rule base for lower number of hops (N)

BP Q	Low	Medium	High
Low	Low	Medium	High
Medium	Very low	Low	Medium
High	Very low	Very low	Low

Table 2: Fuzzy rule base for medium number of hops (N)

BP Q	Low	Medium	High
Low	Medium	High	High
Medium	Low	Medium	High
High	Low	Low	Medium

Table 3: Fuzzy rule base for high number of hops (N)

BP Q	Low	Medium	High
Low	High	High	Very high
Medium	Medium	High	High
High	Medium	Medium	High

The fuzzy set parameters and rules are initially set by expert knowledge and then further calibrated through simulations.

c) *Defuzzification:* Defuzzification refers to the way a crisp value is extracted from a fuzzy set as a representation value. There are many kinds of defuzzifiers. Here we take the centroid of area strategy for defuzzification [20].

$$C = \frac{\sum_{AllRules} x_i \cdot \mu(x_i)}{\sum_{AllRules} \mu(x_i)} \tag{8}$$

where C is the fuzzy cost, x_i is the element and $\mu(x_i)$ is its membership function. This is the most widely adopted defuzzification strategy, which is reminiscent of the calculation of the expected value of probability distributions.

4 Mobile agent model for QoS routing

Agents are the autonomous programs situated within an environment, which sense the environment and acts upon it to achieve the goals [12]. The agents can be static or mobile [13]. Every node in a network maintains an agency for QoS routing.

agent_id
source_id
destination_id
agent.type
agent.history
agent.hopcount
agent.request_info
agent.resource_info
agent_TTL

Figure 4. Data structure of the agent

An agency consists of a mobile forward agent, mobile reverse agent, static fuzzy agents for setting up a feasible path, and a QoS status profile. The data configuration of the agent's structure comprises the following fields: (fig.4)

- agent.ID: the agent's ID.
- source_id : source node address
- destination_id : destination node address
- agent.type: the type of agent in the route discovery and maintenance process. It

distinguishes between forward agent, backward agent and fuzzy agent.

- agent.history: the nodes-visited-stack, contains the IDs of nodes by which the agent passes.
- agent.hopcount: calculates the number of hops by which the agent traversed from the source.
- agent.request_info: includes QoS constrained information.
- agent. resource _info: Each type of agent uses this field to cache nodes resource information such as available bandwidth and link delay etc. This filed is updated by invoking the QoS status profile of a node.
- agent_TTL – how long the particular agent is valid.

The QoS status profile (figure. 5) consists of information such as buffer length and remaining battery power of a mobile node. The monitoring agent collects these information and updates the QoS status profile at regular intervals. All the parameters are computed within a given continuous time window. In the QoS based routing algorithm, the forward agent and the reverse agents are mobile agents. They are adopted to establish the routing strategy of mobile nodes

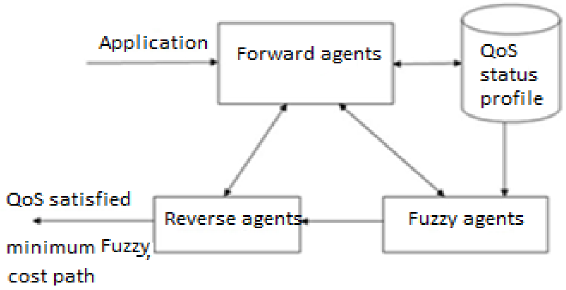

Figure 5. Agency for QoS routing

4.1 Forward agent

The source node creates a forward agent and writes into its own address and then continuously sends the forward agent to each adjacent node in flooding mode. When a neighbor node receives a forward agent, it checks whether there exist some visited nodes in its travel records. If exists, it shows that circulation appears in agent travel and delete it from the stacks. If the visited node is not the destination node, the value of the hop counter is incremented by 1 and updates the travel record in the forward agent.

Current node	Local time	Travel record
S	t_S	S
A	t_A	S,A
B	t_B	S,A,B
D	t_D	S,A,B,D

Figure 6. The change of data structure in the routing process of the forward agent

The QoS resources information such as available remaining battery capacity, queue length of the nodes are updated in the forwards agent's data structure. By the flooding communication, the intermediate nodes can copy and broadcast the forward agent. The forward agent finds the QoS route that satisfies specified QoS by using following steps.

- *Link pruning*. The forward agent prunes all the links in the collected connectivity information that do not satisfy the minimum guaranteed bandwidth.
- *Check path for delay satisfaction*. Once the paths are found with the threshold bandwidth, the forward mobile agent checks the paths for eligibility of delay requirement satisfaction. If more than one path is available with delay requirements, the path with minimum fuzzy cost is selected among the eligible paths. In the case of path unavailability, the mobile agent informs the source to reject the application and disposes itself.

4.2 Reverse agent

The task of the reverse agent is to return to the source node 'S' along the path of the forward agent, and to implement the corresponding routing algorithm. When a forward agent arrives at the destination node ‘D’ the destination node calculates the fuzzy cost using the FLS for the multiple paths received. The path with minimum fuzzy cost is selected for transmission and the destination node initialize the forward agent into a reverse agent through changing some signs, and the reverse agent inherits the travel records of the forward agent. Considering the reverse agent needs to follow the travel record of forward agent to return to the source node, the reverse agent will no longer transmit message in flooding mode. When the reverse agent returns to the source node according to the travel record route, it adjusts the node routing tables it passed according to the network situation.

5 Fuzzy cost and agent based QoS routing model

The routing of the forward agent uses the way of broadcasting; thus multiple forward agents will arrive at the destination node. Hence there will be more paths between the source node and the destination node. Every node in MANET acts as both a terminal and a router. Each node can become a destination for data traffic, thus, Fuzzy Logic System (FLS) is embedded in every mobile node. When multiple paths are found at the destination, the FLS available in the destination node calculates the cost based on the gathered information of network resources. It sends back the route reply to the source node, through the route which has the minimum fuzzy cost using reverse agents.

The Fuzzy-agent algorithm can be performed by the following steps.

1) Source node floods the forward agents to all neighbors.
2) If the agent is new, but the link of the node does not satisfy bandwidth(e) $\geq B$, drop the request.
3) If the agent is new, and the link of the node pair can satisfy bandwidth(e) $\geq B$ and the node is not destination, it pdates the resource info field of the agent, increments the agent’s hop count and push the node id on the agent’s history stack.
4) Repeat step3 until it reaches the destination.
5) Delete the routes from the collection which does not satisfy Delay(p(s,d)) $\leq D$
6) If the collection is not empty, calculate fuzzy cost using fuzzy agents for all QoS satisfied routes.
7) Select the route with minimum fuzzy cost and initialize the reverse agents.
8) Reverse agents reaches the source according to the travel record inherited from forward agents.

6 Simulation Results

The proposed scheme has been simulated in various network scenarios using NS-2 simulator. A mobile ad hoc network consisting of ‘n’ nodes is generated by using a random placement of the nodes and allowed for the free movement within the area of ‘1000 x 1000’m^2. All nodes are considered to be non-malicious. (Table 5.)

Table 4. Simulation Parameters

Parameters	*Value*
MAC Layer	IEEE 802.11
Simulation area(m^2)	1000m*1000m
Simulation Time	180 secs
Number of nodes	60
Bandwidth	2 Mbps
Node mobility speed	0-60m/s
Mobility pattern	Random way point
Traffic flow	CBR
Packet size	512 bytes
Transmission range	250m

The performance of proposed Agent_FCMQR has been evaluated through extensive simulations and compared with that of E-AOFR, MQRFT and MAODV. E-AOFR is an evolutionary multi objective routing protocol based on GA optimization. MQRFT is a multi metric routing protocol based on fuzzy theory caching decision for route selection and provides QoS in wireless networks. To measure the performance of Agent_FCMQR the following QoS parameters are used.

- *Packet delivery ratio*: defined as the ratio of the average number of data packets received by the destination node to the number of data packets transmitted by the multicast source.

$$packet\ delivery\ ratio = \frac{\sum_{i=1}^{n} number\ of\ data\ packets\ delivered}{\sum_{i=1}^{n} number\ of\ data\ packets\ sent} \quad (9)$$

where '*n*' is number of nodes in the network.

- *End-to-end delay*: It is defined as the average of the time taken by all the multicast packets to reach its destination. First, for each source-destination pair, average delay for packet delivery is computed. Then the whole average delay is computed from each paired average delay.

- Call success ratio: defined as the ratio of number of calls generated by the source to the number of calls accepted by the destination node**.**

$$success\ ratio = \frac{\sum number\ of\ valid\ calls\ accepted}{\sum number\ of\ calls\ generated} \quad (10)$$

Each time a route is used to forward a data packet, it is considered as a valid route. If that route is unknown or expired, it is considered as an invalid route.

- *Agent overheads*: defined as the ratio of sum of bandwidth used by all mobile agents successful in feasible path discovery to number of feasible paths discovered.

- *Agent response time*: defined as the ratio of sum of time taken by mobile agent of each successful discovered feasible route of QoS requested connections to number of QoS connection requests that are successful in discovering a feasible route.

Packet delivery ratio

Figure 7. depicts packet delivery ratio against various multicast group size. High packet delivery is achieved in Agent-FCMQR because it selects the route with least congestion and less number of intermediate nodes. Whereas in case of MAODV, E-AOFR and MQRFT there is no such feature and so the source nodes keep on sending packets unaware of the congestion. This leads to a large amount of data packets being dropped which reduces the packet delivery ratio. In MAODV the hop count is considered as the only QoS metric and the availability of other resources is not taken into account. Whereas in Agent-FCMQR the end to end QoS requirement is defined and the routes those fulfill the constraints are only chosen for data transfer. An average of 15% to 20% of packet delivery ratio is increased in Agent-FCMQR compared to other protocols. Also from the graph, we observe that the packet delivery ratio decreases with increasing number of nodes due to arrival of more requests.

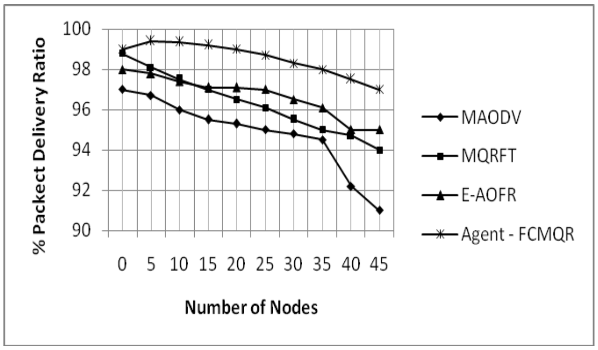

Figure 7. Packet delivery ratio against group size

End-to-End Delay

The average end-to-end delay includes buffering delay and queuing delay at each node's interface queue, retransmission delays and propagation and transfer times. The average end-to-end delay for Agent_FCMQR (Figure. 8) is significantly 30% to 40% is reduced for fuzzy-cost based system

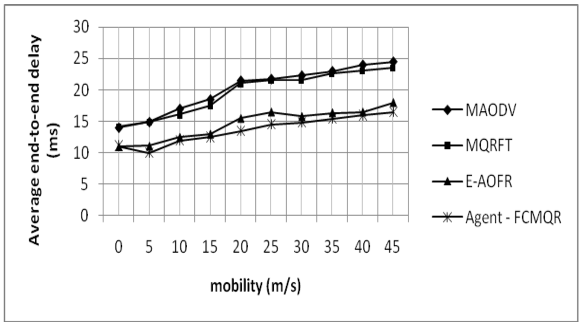

Figure 8. End-to-end delay against mobility speed

compared to MAODV and MQRFT even at higher node mobility for constant group size. The decrease of delay is mainly introduced by route updating predicted in Agent-FCMQR. Both MQRFT and E-AOFR suffers frequent link breaks and needs route reconstruction frequently which results in increasing average end-to-end delay. The advantage of Agent-FCMQR is resulted from choosing the right routing path by the virtue of the suitable route lifetime estimation.

Agents overhead

The routing overhead for agent-based routing is independent of the traffic. Even if there is no communication the agents would still be traversing the network and update the routing tables. However in case of MAODV and FQMRT, the overhead is dependent on the traffic and if there is no communication then there will be no control messages generated in the network. From the comparison results (Fig. 9) it is seen that the normalized overhead is high for agent based routing scheme because of the continuous movement of agents in the network. In case of MAODV the normalized overhead is the least. The continuous gradual drop in normalized routing overhead for all the protocols is attributed to the increased packet delivery fraction at higher pause times.

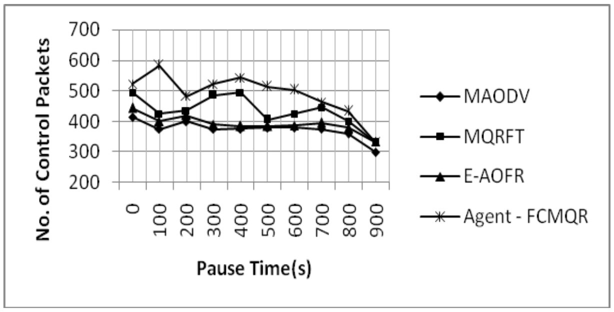

Figure 9. Agents overhead against simulation time

Call success ratio

We observe that agent-based routing has an average higher call acceptance rate of 96% in all the cases as compared with all other protocols (Figure. 10). The improvement is due to capability of mobile agents to compute multiple paths and select a feasible path among them. Intuitively, the call success ratio declines with increase in QoS request arrival rate.

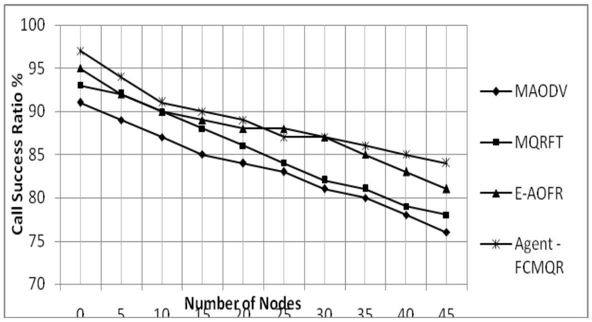

Figure 10. Call success ratio under various group size

Agent response time

Agent response time includes execution, waiting and migration time. Agent response time increased with increase in QoS arrival rate. It is observed from the Figure. 11 the response of Agent-FCMQR is slightly higher than the non-agent based

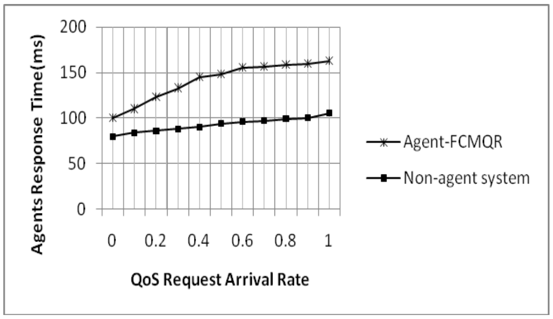

Figure. 11. Agents response time against QoS request arrival rate

systems. Because the data has to wait in the buffer till agents visit that node and provide it with routes.

7 Conclusion

In this paper the QoS aware routing problem is formulated as maximizing the link stability and lifetime of the routing path while minimizing the cost. Fuzzy rule base is developed to combine the various metrics such as buffer length, remaining battery capacity of a mobile node and number of nodes to generate a single cost value, which is used for route selection. Here, the intelligent software agents are used to find the multicast routes and to create the backbone for reliable multicasting. These agents participate in network routing and route maintenance. This makes Agent-FCMQR hybrid routing protocol suitable for real-time data and multimedia communication. Higher call success ratio and reduced end-to-end delay are achieved at the cost of extra processing of the agent messages and the slightly higher overhead occupying some network capacity. However this does not adversely affect the packet delivery fraction. The proposed protocol can be further investigated based on other QoS parameters such as bandwidth, delay jitter and node mobility etc. in order to design better adaptive mechanism for mobile ad-hoc networks.

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