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Fuzzy-controlled Power-aware Multicast Routing (FPMR) For Mobile Ad Hoc Networks

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Abstract

Ad hoc networks are highly dynamic networks where the nodes are battery-powered. Routing in such networks is an issue of upcoming concern due to the possibility of frequent link breakage as a result of node mobility and/or high rate of energy depletion of nodes. Also to fulfill certain quality parameters, presence of multiple node disjoint paths become essential. Such paths aid in the optimal traffic distribution and reliability in case of path breakages. In this paper we propose a fuzzy controlled power aware multicast routing (FPMR) protocol that takes into account estimated network evolution in terms of residual energy of nodes w.r.t. approximated energy required to complete the multicast operation, link stability, geographical positions of multicast receivers etc. Extensive simulation experiments have been conducted to compare the performance of FPMR with other state-of-the –art multicast protocols. The results w.r.t. a wide range of parameters show that FPMR attains significantly high packet delivery ratio at much lesser cost than its competitors, thereby improving the lifetime of nodes.

Keywords: Ad hoc networks, eligible intermediate node, fuzzy, multicast, power-aware,

1. Introduction

Ad hoc networks are collections of mobile nodes communicating using wireless media without any fixed infrastructure. Conventional multicast routing protocols are inadequate in a harsh mobile environment, as mobility can cause rapid and frequent changes in network topology [1-10]. Frequent state changes require constant updates, reducing the already limited bandwidth available for data and possibly never converging to accurately portray the current topology. Mobility represents the most challenging issue to be addressed by multicast routing protocols.

Broadly, the class of multicast protocols in ad hoc networks can be categorized into tree-based and mesh-based approaches. ODMRP (on-demand multicast routing protocol [1]) is the most popular

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representative of mesh-based ones, whereas MAODV (multicast on-demand distance vector [2]), ADMR (Adaptive Demand-driven Multicast Routing [5]) and ITAMAR (independent tree ad hoc multicast routing [3]) are significant among tree-based protocols. PAST-DM (progressively adapted sub-tree in dynamic mesh [4]) is a special multicast routing protocol which inherits the flavor of both tree-based and mesh-based protocols. ODMRP requires control packets originating at each source of a multicast group to be flooded throughout the network. The control packet flood helps in repairing the link breaks that occur between floods. Limitations of ODMRP consist of network-wide control packet floods and sender initiated construction of mesh. This method of mesh construction results in a much larger mesh as well as numerous and unnecessary transmission of packets. DCMP [7] and NSMP [9] are extensions of ODMRP aiming to restrict the flood of control packets to a subset of the entire network. However, both of them fail to eliminate entirely ODMRP's drawback of multiple control packets per group. From the point of view of bandwidth efficiency, tree-based protocols are better than mesh based protocols. However a multicast tree is more subject to disruption due to link failure and node mobility than meshed structures. It has already been established that although performance of MAODV is very good for small groups, low mobility and traffic. Its performance degrades sharply once the values of group size, mobility and traffic load crosses a threshold, with the reason being a sharp increase in the number of control packets transmitted to maintain the structure. ITAMAR and PAST-DM also suffer from these problems. The protocol ADMR [5] creates source-based forwarding trees connecting each source with receivers of the multicast group. The multicast forwarding state for a given multicast group and a source is conceptually presented as a loosely structured multicast forwarding tree routed at the source. The forwarding mechanism is based on the shortest delay path through the tree to the receiver members of the multicast group.

MP-MAODV[10] is the multipath extension of MAODV that creates from the multicast source to each multicast destinations to provide at least one backup route. When the primary route fails to deliver packets for some reason, the backup is used. This provides better fault tolerance in the sense of faster and efficient recovery from route failures. Multiple paths can also provide load balancing along with route failure protection, by distributing the traffic among a set of node-disjoint paths promoting energy awareness.

PAMRRP (Power-aware Multicast Reactive Routing Protocol [6]) employs the techniques of cautious distribution of forwarding load, reduction in control overheads and proactive tree maintenance with a view to maximize the lifetime of a network with dynamic topology. It considers the battery capacity of the nodes as a crucial resource of the system and extends the lifetime of each mobile node and network by avoiding the inclusion of low power nodes in the multicast tree. If available battery power of a node goes below a threshold value B, that node is used to forward more crucial data only and rejected for rest of the data. On the other hand, if available battery power of a node measures less than or equal to a threshold value A (A is the minimum battery power of the network required to transmit some information, $A<B$), then any kind of forwarding through that node is avoided. Moreover, in PAMRRP, a route is reconfigured quickly in case of a node goes off because of complete drainage of resources.

In this paper we propose FPMR, a fuzzy controlled power-aware multicast routing (FPMR) protocol, where two fuzzy controllers EINS (Eligible Intermediate Node Selector) and RPE (Route Performance Evaluator) are embedded in each node to incorporate intelligence in them. EINS evaluates eligibility of a node as a router in a multicast path depending on its residual energy w.r.t. the minimum required energy to transfer all multicast packets through the node, stability of its link with its predecessor (s) in the multicast communication path(s) and number of established routes to one or more multicast members. RPE evaluates the performance of a multicast route depending upon its hop count, number of eligible intermediate nodes in it and number of multicast members present in it as an intermediate node.

2. Overview of FPMR

In FPMR, each node is equipped with two fuzzy controllers EINS (eligible intermediate node selector) and RPE (route performance evaluator). A node is included in the multicast tree as router, irrespective of whether it is a multicast destination or not, if it is sufficiently eligible in terms of its remaining energy to complete the multicast operation, stability of its link with its predecessor in the multicast tree and fault tolerance in terms of the number of the recent alternative routes it has stored to a multicast destination. EINS of a node n_i tests eligibility of n_i as a router in the multicast tree. RPE determines performance of a route w.r.t. its hop count, the number of eligible routers in, number as well as positions of the multicast receivers present in that route of the tree and intersection of intermediate nodes in the route with intermediate nodes of other routes established already to same or different multicast destinations. FPMR intends to store as many node disjoint paths as possible to the multicast destinations.

Each node n_i in the multicast tree periodically evaluates its own energy efficiency and the stability of its link with its predecessor in the associated route. If it is equal to it's lower limit (0.4 in case of energy efficiency and 0.25 in case of link stability – detailed discussion about all these appear in section 3), then the node sends an *alarm* message to its predecessor n_j indicating that the link is going to break soon. If n_i is a multicast member and n_j doesn't have any stored alternative path to n_i then n_j sends a route-error message to source of the multicast operation and instructs it to initiate a route discovery session to n_i. The route-error message also contains the last known location of n_i. Receiving this message, the multicast source floods route-request message in a limited geographical region of the network around the last known location of n_i. Details of this route discovery technique appear in reference 11. On the other hand, if n_i is not a multicast member then n_j tries to discover an alternative route to any successor of n_i in the communication route that is not the successor of any multicast receiver, provided n_j doesn't already have one such alternative stored in it. The latency in finding new route in case of link or node failure is thus reduced by reconstructing the routes using proactive approach, before complete failure of the node/link. The technique increases node lifetime, prevents network partitioning as much as possible and also significantly reduces the end-to-end delay involved in the multicast operation.

3. Input Parameters of Eligible Intermediate Node selector (EINS)

The input parameters of EINS are energy efficiency, link stability and reliability. Detailed descriptions of these parameters are mentioned below:

1. Energy Efficiency – Energy efficiency $ef_i(t)$ of a node n_i at time t is formulated in (1). It indicates how well battery charge equipped the node n_i is at time t to complete the multicast operation w.r.t. the highest receive threshold power among it's the then set of downlink neighbors and distance of the farthest downlink neighbor from n_i at that time. Please note that, according to the study of discharge curve of batteries heavily used in ad hoc network at least 40% of total battery charge is required to remain in operable condition and we want every router to remain in operable condition even after completion of the multicast operation, which is very much desirable from the perspective of network connectivity.

$$ef_i(t) = \begin{cases} (1 - (E'_i(t) + m \times r_i(t)) / E_i) & \text{when } (E_i - E'_i(t) - m\, r_i(t)) > 0.4\, E_i \\ 0 \text{ otherwise} \end{cases} \tag{1}$$

Where m is the number of multicast packets to be transferred, E_i is the maximum battery charge of n_i, $E'_i(t)$ is the amount of charge consumed by n_i within current time t. $r_i(t)$ is formulated in (2).

$$r_i(t) = d^{\alpha}_{i,l}(t)\ (recv\_thres_j(t)/c) \quad (2)$$

$recv\_thres_j(t)$ is the receive threshold power of such a node n_j ($n_j \in DN_i(t)$, $DN_i(t)$ is the set of downlink neighbors of node n_i at time t) that for all $n_k \in (DN_i(t) - \{n_j\})$ the relation $recv\_thres_j(t) > recv\_thres_j(t)$ is true. In (2), $d_{i,l}(t)$ is the distance between the nodes n_i and such a downlink neighbor n_l at time t, that for all $n_k \in (DN_i(t) - \{n_l\})$ the relation $d_{i,l}(t) > d_{i,k}(t)$ is true. C is a constant and α is the path loss constant that takes a value between 2 and 5 depending upon the wireless medium. It is evident from (1) that $ef_i(t)$ takes a value between 0 and 1. It increases with increase in the remaining energy of n_i at time t (E_i - $E'_i(t)$) and decrease in the number of multicast packets to be transferred and estimated maximum amount of energy to transmit a multicast packet to one of its downlink neighbors. Values close to 1 indicate that the node n_i is very well prepared to participate in the multicast operation.

2. Link stability – Stability of the node n_j w.r.t. its predecessor n_i in the multicast route at time t is termed as stability of the link from n_i to n_j at that time. It Is denoted as $ls_{i,j}(t)$ and defined in (3).

$$ls_{i,j}(t) = mb_{i,j}(t)\ ((R_i - R_{min}) / (R_{max} - R_{min}))\ (1-d_{i,j}(t)/R_i) \quad (3)$$

where $mb_{i,j}(t)$ is the mobility component of the stability of the link between the associated nodes n_i and n_j, that depends on the relative velocities of the involved nodes. It is formulated in (4).

$$mb_{i,j}(t) = -(a'b'+c'd')+Q/(a'^2+c'^2) \quad (4)$$

where $Q = \sqrt{\{(a'^2+c'^2)R^2_i - (a'd'-b'c')^2\}}$ and,

$a' = v_i(t) \cos \theta_i(t) - v_j(t) \cos \theta_j(t)$
$b' = x_i(t) - x_j(t)$
$c' = v_i(t) \sin \theta_i(t) - v_j(t) \sin \theta_j(t)$
$b' = y_i(t) - y_j(t)$

The ordered pair ($x_i(t)$, $y_i(t)$) indicates geographical position of node n_i at time t in terms of x-coordinate and y-coordinate, respectively. Similarly, motion parameters (velocity, direction) of n_i at time t are ($v_i(t)$, $\theta_i(t)$). The formulation in (4) is based on the fact that if ($v_i(t)=v_j(t)$) and ($\theta_i(t) = \theta_j(t)$) then $mb_{i,j}(t) = 1$. $mb_{i,j}(t)$ varies between 0 and 1. Values close to 1 denote the fact that the relative velocities between n_i and n_j is small, contributing to increase stability of the link between them.

The ratio (($R_i - R_{min}$) / (R_{max} - R_{min})) acquires a high value if radio-range of node n_i i.e. R_i is close to R_{max} where R_{min} and R_{max} specify the minimum and maximum possible radio-ranges in the network. High radio-range of a node signifies its better encapsulation capability strengthening its bond with its downlink neighhbors.

It is evident that the upper limit of distance between a node n_i and any of its downlink neighbors, is R_i. Hence the ratio of R_i and the distance $d_{i,j}(t)$ between n_i and its downlink neighbor n_j at time t, takes a fractional value between 0 and 1. Lesser the value of this ratio, greater is the stability of the link.

3. Reliability – Let M be the set of multicast members. Assuming that for the multicast member $n_q \in M$, the router n_i has stored $p_{i,q}(t)$ number of routes (as much node disjoint as possible) till time t, established at timestamps $\tau s_{i,q}(1)$, $\tau s_{i,q}(2)$, … , $\tau s_{i,q}(p_{i,q}(t))$, in its route cache capable of storing at most C_i routes, reliability $rl_i(t)$ of the router n_i at time t is given by,

$$rl_i(t) = (1/|M|)\Big[\sum_{n_q \in M} (p_{i,q}(t)/ C_i)\Big\{ \prod_{1 \leq \phi \leq (p_{i,q}(t)+1)} (1 - \tau s_{i,q}(\phi)/t)\Big\}^{1/(p_{i,q}(t)+1)}\Big] \tag{6}$$

In the above formulation, it is assumed that if n_i has not stored a route to a multicast member n_q then the value of ϕ will be limited to 1 only and $\tau s_{i,q}(\phi)$ will be 0. Hence, if n_i doesn't already have any stored path to any multicast member, then its reliability will be 0. Please note that, for any router n_i, $rl_i(t)$ lies between 0 and 1. Reliability of a router acquires a high value if a large number of recent routes are stored in route cache of n_i at time t corresponding to a huge number of multicast members belonging to the multicast group M. The utility of storing multiple paths, as much node-disjoint as possible, to a multicast member is that, if a path breaks in the middle of the multicast communication, another stored path may be tried instead of initiating a new route discovery session to newly discover a route to the multicast member. This helps to reduce the message cost in the network.

4. Fuzzy rule bases of Eligible Intermediate Node selector (EINS)

Crisp range division of the input parameters of EINS and the corresponding fuzzy variables are shown in table I.

Table I: Crisp range division of parameters and corresponding fuzzy variables

Range division of energy efficiency	Range division of other parameters	Fuzzy variable
0-0.40	0-0.25	A1
0.40-0.60	0.25-0.50	A2
0.60-0.80	0.50-0.75	A3
0.80-1.00	0.75-1.00	A4

According to the study of discharge curve of batteries heavily used in ad hoc networks, at least 40% of total battery power is required to remain in operable condition (represented by the fuzzy variable A1), 40% to 60% is satisfactory (represented by fuzzy variable A2), 60% to 80% is good (represented by fuzzy variable A3) and the next higher range (80%-100%, represented by fuzzy variable A4) is more than sufficient for the associated node to take part in multicast communication. The other two parameters link stability and reliability are uniformly divided within the range 0 and 1.

Table II combines energy efficiency (ef) and link stability (ls) producing temporary output t1. Both are given equal weight since they are equally indispensable for survival of the associated multicast link. t1 is combined with the remaining input parameter reliability (rl) in table III producing the output eligibility-status of the underlying node. t1 is given more weight in table III because it is a combination of two parameters both of which are more important from the perspective of link survival, than reliability of a node. Reliability is not critical for survival of a link, it is concerned with efficiency of the link.

Table II: Fuzzy combination of ef and ls producing temporary output t1

ef ⇒ ls ⇓	A1	A2	A3	A4
A1	A1	A1	A1	A1
A2	A1	A2	A2	A2
A3	A1	A2	A3	A3
A4	A1	A2	A3	A4

Table III: Fuzzy combination of t1 and rl producing eligibility-status

t1 ⇒ rl ⇓	A1	A2	A3	A4
A1	A1	A1	A2	A3
A2	A1	A1	A2	A3
A3	A1	A2	A3	A4
A4	A2	A2	A3	A4

An intermediate node will be termed as an eligible intermediate node provided its eligibility-status is either A3 or A4.

5. Input Parameters of Route Performance Evaluator (RPE)

The input parameters of RPE are hop count quotient, eligible router cardinality and multicast member router impact. Detailed descriptions of these parameters are mentioned below:

1. Hop count quotient– Let the number of hops of a route RT be denoted as h_{RT}. Quite clearly, $h_{RT} \leq H$, where H is the maximum possible number of hops in any route in the network. Then, the hop count quotient hcq_{RT} of the route is mathematically expressed in (7).

$$hcq_{RT} = 1 - h_{RT} / H \tag{7}$$

   Please note that, hcq_{RT} takes a fractional value between 0 and 1. Lesser the number of hops present in a route, smaller with be the delay in communication through the route. Also the chances of link breakages will be small in a route with smaller number of hops than a route with large number of hops.

2. Eligible router cardinality – Eligible router cardinality er_{RT} of any route RT is defined in (8).

$$er_{RT} = N\_M_{RT} / h_{RT} \tag{8}$$

   where N_M_{RT} indicates the number of eligible routers in the route RT which are not multicast members. From (8), it can be seen that er_{RT} lies between 0 and 1. Higher the value of eligible router cardinality better will be performance of the route.

3. Multicast member router impact – Multicast member router impact mmr_{RT} of any route RT is defined in (9).

$$mmr_{RT} = \begin{cases} [(1 - ((|Q_{RT}|/h_{RT})\ (|Q_{RT}|/|M|\ ))^{0.5})\ fm_{RT}\ (1/\sqrt{|Q_{RT}|})\sqrt{\{\sum_{n_i \in Q_{RT}}(f_{RT}(i) - fm_{RT})^2\}}]^{1/3} & \text{if } Q_{RT} \text{ is not null} \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

where $f_{RT}(i) = \text{dist\_hop}(\text{first}(RT),i)/\ h_{RT}$ and $fm_{RT} = (1/|Q_{RT}|)\sum_{n_i \in Q_{RT}} f_{RT}(i)$

Significance of the symbols appearing in (9) are as follows:

- Q_{RT} is the set of all multicast member cum router nodes in route RT.
- first(RT) is identification number of the first node or source node in route RT.
- dist_hop(first(RT),i) specifies the distance between the source node of route RT and node n_i in terms of number of hops.

The mathematical expression of multicast member router impact is based on the fact that it is always desirable in case of multicast communication that all the multicast members receive the same multicast message at approximately same time. This is terribly hampered if the multicast members present in the same route are placed far apart. On the other hand if most of the multicast members are closely spaced in the same route then the delay suffered by the multicast packet during its journey from the multicast source to one multicast member won't differ much from the delay faced by the same packet during its journey from the source to another multicast member in the same route.

Also this kind of structure is beneficial from the point of view of lifetime of network nodes because otherwise separate routes (at most |M| routes) would have been needed to send the multicast message to all the multicast group members. From transmission delay point of view, the average distance from multicast source to the multicast members present in the same route, should be small.

From (9), it can be seen that mmr_{RT} lies between 0 and 1. Lesser the value of this input parameter of RPE, better will be performance of the route.

4. Router intersection – This parameter will be used to determine performance of a route when the first route to at least one multicast member is established. In order to formulate router intersection, assume that at time t, $\psi_M(t)$ denotes the set of routes that are active or presently being used for multicast communication in a group with set of members M. Considering all these paths, $\beta_M(t)$ denotes the set of routers that appear in more than one active path. Let a common router n_i be present in $\rho_{i,M}(t)$ number of routes. The router intersection $rn_M(t)$ at time t is given by,

$$rn_M(t) = (|\beta_M(t)| / (\sum_{RT \in \psi_M(t)} h_{RT}))\ \ [\prod_{n_i \in \beta_M(t)} (\rho_{i,M}(t) / |\psi_M(t)|)]^{1/|\beta_M(t)|} \quad (10)$$

$rn_M(t)$ ranges between 0 and 1. Lesser the value of router intersection, higher will be the advantage of storing multiple paths to the multicast members.

6. Fuzzy rule bases Route Performance Evaluator (RPE)

All parameters of the RPE are uniformly divided in the ranges between 0 and 1 (0-0.25, represented by the fuzzy variable A1, 0.25-0.50, by the fuzzy variable A2, 0.5-0.75, by the fuzzy variable A3 and 0.75-1.00 by fuzzy variable A4). Among these parameters, multicast member router impact is most important. Others are assigned equal weight. Table IV combines hop-count quotient (hcq) and multicast member router impact (mmr) producing temporary output t2. mmr is assigned more weight. Table V combines t2 and eligible router cardinality (er) generating another temporary output t3. Fuzzy combination of t3 and router intersection (rn) appears in table VI producing ultimate output route-performance. In tables V and VI, temporary outputs (t2 and t3) of the respective immediate previous tables (tables IV and V) are assigned more importance than the new parameters (er in table V and rn in table VI) since the temporary outputs are a combination of certain input parameters of RPE, all of which are equally or more important than the new parameters.

Table IV: Fuzzy combination of hcq and mmr producing temporary output t2

hcq ⇒ mmr ⇓	A1	A2	A3	A4
A1	A3	A3	A4	A4
A2	A3	A2	A3	A4
A3	A2	A2	A3	A3
A4	A1	A1	A2	A3

Table V: Fuzzy combination of t2 and er producing temporary output t3

t2 ⇒ er ⇓	A1	A2	A3	A4
A1	A1	A2	A3	A3
A2	A1	A2	A3	A3
A3	A2	A2	A3	A4
A4	A2	A2	A4	A4

Table VI: Fuzzy combination of t3 and rn producing output route-performance

t3 ⇒ rn ⇓	A1	A2	A3	A4
A1	A2	A2	A3	A4
A2	A1	A2	A3	A4
A3	A1	A2	A3	A3
A4	A1	A1	A2	A3

If RPE is presently evaluating performance of a route which is the first discovered route to any multicast member, then output of table V, i.e. temporary output t3 will represent route-performance. The parameter router intersection won't be applicable in this case. Otherwise, output of table VI will generate performance of the route. A route is elected for communication provided its performance, as evaluated by the RPE, is A3 or A4.

7. Simulation results

We have compared the performance of FPMR, against the performance of ODMRP [1] and MP-MAODV [10], ADMR [5] and PAMRRP [6], which are well-known representatives of state-of-the-art multicast routing protocols for ad hoc networks. Qualnet 3.5 has been used for the simulation purpose. Table VII describes the simulation environment. The metrics used for performance evaluation in the present article are packet delivery ratio, end-to-end delay per packet and control overhead. Packet delivery ratio is defined as the number of data packets successfully delivered divided by the total number of data packets actually transmitted. End-to-end delay per packet indicates the total time delay required to deliver packets to each multicast receiver divided by the total number of packets. Control or message overhead is defined as the as the number of control packets transmitted divided by the number of data packets transmitted. Figures 1-6 graphically illustrate the benefit of our model and emphasize that FPMR produces highly improved throughput and agility at much lesser message cost.

Table VII: Simulation environment

Parameters	Value
Total no. of nodes	100, 200, 300, 400, 500
Simulation time for each experiment	1000 sec, 2000 sec, 4000 sec
Simulation area	1000 m × 1000 m
Node placement	Random
Mobility model	Random waypoint
Radio-range	25m -100m, 100m - 350m, 5m - 500m
Channel capacity	66 Mbps, 100 Mbps
MAC protocol	IEEE 802.11g
Data packet size	512 bytes, 1024 bytes
Number of simulation runs	30

Among the above-mentioned competitors of FPMR none consider stability of the links connecting the multicast source to the multicast members. Hence, possibility of link failure and consequently, flooding of route-request packets is very huge for them. High message cost results in increased packet collision. Automatically, percentage of successful delivery of packets at the multicast destinations also reduces. Additional delays are introduced during repairing of broken links. Source-initiated tree-based protocols are, in general, better than the destination-initiated mesh-based protocols. The reason is that, tree-based protocols maintain only one route between the source and each multicast destination. On the other hand, in mesh-based protocols multicast destinations create a mesh and elect a core, which directly communicates with the source. More than one path generally exists between each receiver and the core due to the underlying mesh structure. Along with that, an additional route is required between the core and sender of the multicast message. If the multicast receivers are long distant from one another, then the mesh structure doesn't help. FPMR is power-aware. It takes care of remaining lifetime of nodes preserving network connectivity. Also it prefers the multicast routes blessed with highly stable links. The chances of link breakage is much less in FPMR and as a result the number of control packets like route-request, route-reply etc. is also lesser in this protocol compared to other state-of-the-art multicast algorithms available in literature. Considering reliability of the routers present in the path depending upon the number and performance of the alternative paths stored in the router to the multicast destinations, also help to reduce the number of these control packets. The reason is that, if a link breaks, then an alternative path stored in the router to that multicast destination may be tried instead of initiating a whole new process of route discovery to the same multicast destination. Multiple paths are used for load distribution purpose also. When the minimum of energy efficiencies or stability of the link with respective predecessors, of multicast routers in an established route, becomes a2 or a1, a backup route which is node-disjoint from other established routes, as much as possible, is used for communication. It may be noted that FPMR prefers the routes with less hop count and less variations in the distance of the multicast receivers present in the route from the multicast source. This significantly reduces the delay in multicast communication and also ensures that the at least the multicast receivers present in the same route receive a multicast packet at approximately same time.

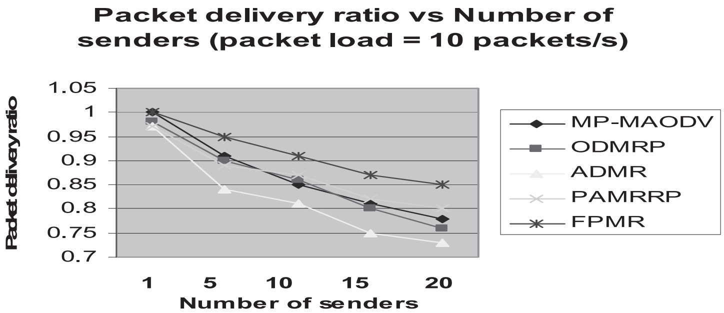


Fig. 1: Graphical demonstration of packet delivery ratio vs number of senders

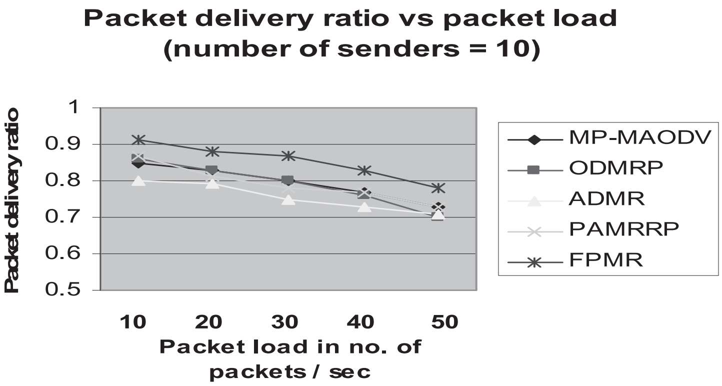


Fig. 2: Graphical demonstration of packet delivery ratio vs packet load

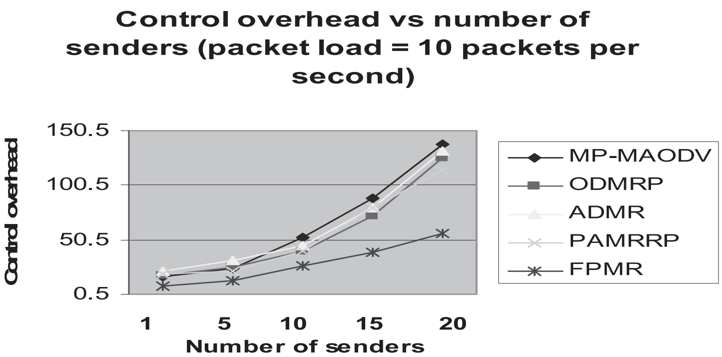
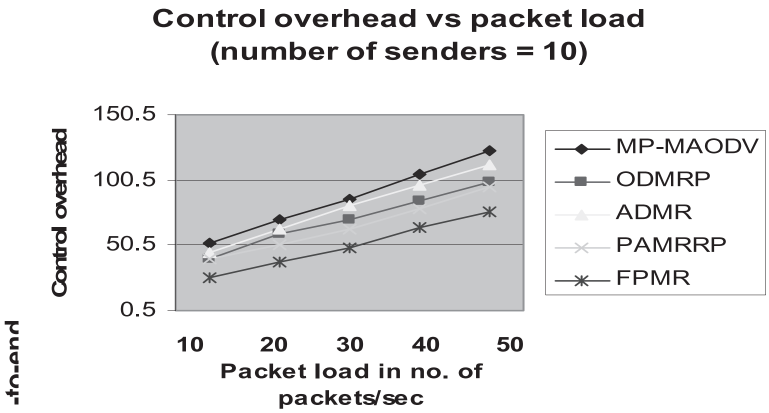
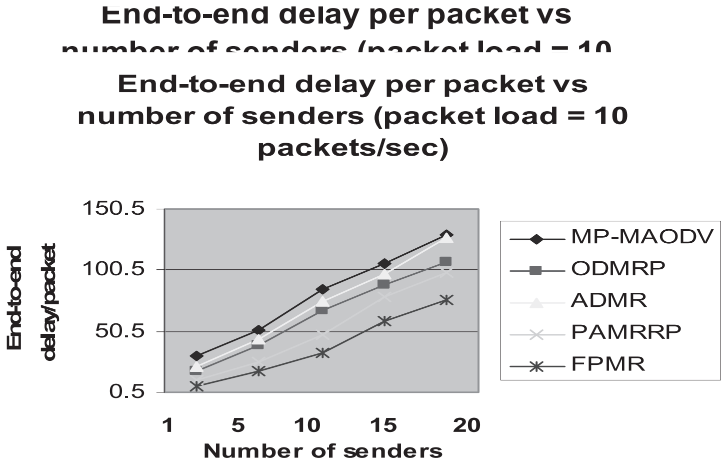


Fig. 3: Graphical demonstration of control overhead vs number of senders





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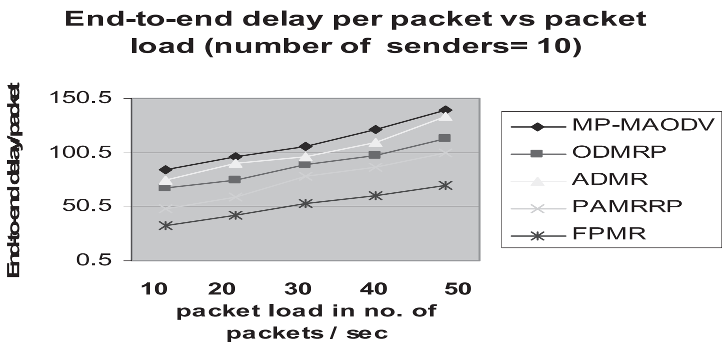

Fig. 6: Graphical demonstration of end-to-end delay per packet vs packet load

8. Conclusion

FPMR is an intelligent multicast protocol that incorporates intelligence in the nodes of the ad hoc network by embedding two fuzzy controllers EINS and RPE. EINS takes care of the fact that intermediate nodes in the multicast routes are eligible enough in terms of their residual energy, strength of connectivity with the predecessors and number of stored efficient routes to a huge number of multicast group members. On the other hand, RPE aims at estimating efficiency of the multicast routes with respect to the number of eligible intermediate nodes and the multicast members present in it. Impact of the geographical positions of the multicast members compared to one another, on performance of a multicast route, is also critically analyzed by RPE. Actually, FPMR tries to establish fast, stable and long-lasting routes to the multicast members so that they receive multicast packets at approximately same time, as much as possible.

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