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MEDMR: Fuzzy based Marginal Energy Disbursed Multicast Route Discovery for Mobile Ad Hoc Networks

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Abstract

Objective: An ad hoc network is formed with set of nodes and each operated by limited energy level and able to connect and transmit to other nodes within the specified geographical range. To transmit data from source node to target it make use set of intermediate nodes with maximal life span and minimal energy consumptions such as Residual and Battery Deflection. **Methods/Analysis:** To achieve the route should have intermediate nodes with sufficient reserve energy resources and ability to transmit by minimal energy consumption without compromising at other quality factors like minimal end-to-end delay, maximum packet delivery ratio and minimal transmission. **Findings**: There is a lot of need to propose a new multicast Tree based model Fuzzy based Marginal Energy Disbursed Multicast Route (MEDMR) which uses a set of heuristics along with Fuzzy reasoning in discovering energy consumption for multicast route with maximizing life span for mobile ad hoc networks. **Applications/Improvements:** Performance metrics shown to its best like end-to-end delay, packet delivery ratio and battery depletion ratio that were estimated with other fuzzy based energy efficient multicast routing for mobile ad hoc networks.

Keywords: Battery Deflection, Energy Efficient, Multicasting, Opportunistic Multicast Range, Residual Energy

1. Introduction

Multicast routing is the process of transmitting data that initiates by one or more nodes, said to be source nodes and transmitting to multiple nodes, said to be destination nodes that are referred with unique address[1-3]. The optimal multicast route discovery is a significanttask[4]. The majority of the models found in the literature are based on the shortest path as critical factor[5], which leads to routing intricacy[6] that often causes extreme energy disbursement and further route devastation owing to intermediate node unavailability due to lack of energy resource[7]. Hence the contemporary researchers intricate to ascertain efficient multicast routing topologies under divergent quality constrictions like minimal energy consumption, trifling end-to-end delay and utmost packet delivery ratio.

Energy consumption is overlooked in the many of existing Quality centric multicast routing discovery models[8]. Hence the route destruction is found often due to the nodes with maximal energy disbursement[9]. In order to this improvising the routing quality in the context of minimal energy disbursement is considered as the objective of this contribution. One of the critical objectives of QoS aware multicast routing in mobile ad hoc networks is achieving minimal energy conserved route discovery. The contemporary literature evincing the significant research efforts to discover energy efficient routing strategies. This section briefs the set of energy efficient multicast route discovery strategies found in recent literature. The model devised in proposed[10] an energy efficient multicast routing strategy for ad-hoc network build by wireless smart badges. This model is aimed to discover routes with suf-

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ficient energy in the context of data transmission rates. In order to this, iterative function[11] was used. The constraint of the model is process complexity and it is not aiming to diver the route that consumes minimal energy, rather it obtains route with sufficient energy for data transmission rate.

A multicast routing model that limiting the overall energy consumption by selecting nodes based on their mobility speed and direction. This is a cross model of mesh and tree architectures. The density of neighbor count also considered in order to select nodes for multicast route building. The metrics node mobility speed and direction, neighbor count and residual energy of each node are used as critical factors by this model to devise energy efficient multicast route. Switching the idle nodes into sleep state is also boosting this model to minimize the energy consumption. The empirical study[12] signifies that the model is optimal as the packet delivery ratio is high, energy consumption and end-to-end delay is low that compared to the On-Demand Multicast Routing Protocol (ODMRP). The constraints are, control flow overhead and process overhead. The overall energy consumption observed for data packets and control packets transmission is not optimal.

Multicast routing strategy to achieve minimum energy consumption[13]. The devised model is using Particle Swarm Optimization (PSO) technique to discover the route with maximum residual energy, minimal energy consumption and end-to-end delay. The initial multicast tree that includes all nodes in the network is built by PRIMS algorithm and further optimal multicast tree is discovered by applying PSO. The nodes involved in initial tree are considered as particles with the properties called mobility speed, position and direction of mobility. The PSO traverse these particles in order to select qualified particles. Further the optimal nodes are being selected from these qualified nodes through the fitness function, which is assessing the node fitness by their residual energy levels, energy consumption ratio. The experimental study evinced that the PSO model is the best fit model to derive energy efficient multicast tree that compared to traditional GA approach[14]. The computational overhead observed for PSO is considerable constraint of the model, which is also lagging to achieve energy efficiency in noisy channels[15].

To achieve maximum link stability and minimal energy consumption. This proposed model[16] relied on two factors called residual energy of the battery and maximal relay scope. The establishment of route with the nodes having high residual energy and high relay capacity evinced reliable communication. This model is not considering the minimizing the energy consumption to enhance the network life span, which is found to be critical constraint of this model and other constraint is process load due to additional control traffic.

Multicast routing model, which is to achieve minimal energy consumption and minimal end-to-end delay. The route discovery strategy is an evolutionary model that uses genetic algorithm in route selection. In order to obtain the optimal multicast tree path, the proposed model is applying genetic evolutions on possible multicast trees discovered in route request phase. The cost function estimating the energy consumption ratio and end-to-end delay in order to notify the fitness of the resultant multicast trees of the GA crossovers. The empirical study of the model evinced the discovery of optimal multicast tree with minimal energy consumption and least end-to-end delay. The critical constraint of the proposal is computation overhead, since the genetic algorithm[17] process complexity is not linear; hence the process complexity is complimented if network size is increased. The other constraint of the model is, it is not considering the overall multicast tree lifespan as a factor route selection.

The review of contemporary multicast routing with minimal energy consumption and maximal network lifespan models was done here in this section. The review evincing that the all of these models are found to be fit under the specific factors considered. All of these models are divergent at multicast route discovery process in order to achieve minimal energy consumption and maximal network lifespan. The common constraints of these models observed is limiting the performance if transmission influenced by noise, computational overhead observed in route discovery phase and process overhead observed at route maintenance phase[18].

1.1 The fuzzy based modified Search Results

Ad hoc On-Demand Distance Vector (AODV) (FMAR) protocol for multicasting is proposed in[19]. The model initially obtaining all possible routes through route request strategy and then the optimal route in the context of minimal energy consumption is selected by fuzzy reasoning. The objective function of the fuzzy logic is assessing the optimality of the route through weighted multi-criteria. This model also capable to balance the restricted bandwidth levels of hop level links. The constraint of the proposal is the objective function used in fuzzy reasoning, which is adapting the optimal route by first come first serve basis. Hence the discovered optimal route may with link stability, but not significant to select a route with minimal energy consumption.

The objective of this contribution is to establish an optimal tree based stable multicast route with nodes that are having maximum residual energy and using minimal energy to transmit data. But the proposed model is an extension to our earlier contribution called Heuristics to Multicast Route Discovery (HMRD)[20] that estimating the energy consumption by signal strength and also multicast opportunity.

In order to this, HMRD for Energy Efficient Multicast Routing Topology were devised in our earlier contribution. The HMRD found to be best to estimate the energy disbursal efficiency of the nodes in order to establish the multicast route. But the model is probabilistic to identify best fit nodes if the nodes are having proximately similar energy disbursal scope. Hence to overcome this limit we introduced a fuzzy based optimal node selection strategy in this contribution. The proposed fuzzy reasoning relied on a membership function that uses the heuristics explored in HMRD along with signal to noise ratio as other heuristic.

2. Fuzzy Based Marginal Energy Disbursed Multicast Route Discovery

The initial step to discover the energy efficient multicast route by the proposed heuristics is to locate all possible routes to transmit data between selected source and multiple destination nodes by using the qualified diffusion of the route request[21]. Let $R = \{r_1, r_2, \ldots r_{|R|}\}$ be the set of routes selected in route request process.

2.1 Route Discovery Strategy

The nodes involved in all possible routes R are further organized as a tree structure with source node s as root, all target nodes $T = \{t_1, t_2, \ldots t_{|T|}\}$ as leaf nodes and other intermediate nodes found in all possible route R as non-leaf nodes. This act is done in breadth first strategy that explored in following description. All possible hop level nodes of the target nodes those involved in routes R said to be non-leaf nodes of hierarchical order h_1 of the tree. The hierarchical order h_2 contains the hop level predecessor nodes of the hierarchical order h_1 nodes those found in routes R. Similarly the hierarchical order n contains the hop level predecessor nodes of the hierarchical order h_{n-1} nodes those found in routes R. The last hierarchical order $h_{|H|}$ contains the nodes those are hop level successor nodes to source node. Let $H = \{h_1, h_2, \ldots . h_{|H|}\}$ set of all hierarchical orders found the tree structure defined. Then the optimal nodes from each hierarchy $\{h_i \exists h_i \in H\}$ will be selected by using the fuzzy reasoning applied on heuristics considered. The optimal node selection process is done in the sequence of hierarchical orders found in H as follows:

The selection of optimal nodes in hierarchy h_1 is done such that there will be optimal routes to all nodes in T from minimal number of nodes in h_1 those meets the criteria of heuristics proposed. Similarly optimal node selection for h_i is done such that there will be routes to all selected optimal nodes in h_{i-1} from minimal number of nodes in h_1 those meets the criteria of heuristics proposed. Finally the optimal nodes discovered for hierarchy $h_{|H|}$ will connected to source node s under no constraints.

2.2 Heuristics to Multicast Route Discovery

The heuristics proposed to select optimal nodes in each hierarchy of the set $H = \{h_1, h_2, \ldots . h_{|H|}\}$ are

2.2.1 Battery Depletion Ratio

Battery Depletion Ratio: This heuristic signifies the mediocre energy required to transmit the unit of data for node involved in routing path. The average energy required to transmit a frame by a node in hierarchy h_i to all optimal nodes selected in consecutive hierarchy h_{i+1}. The Battery Depletion bdr_{nd_p} of each node $\{nd_p \exists p = 1, 2, \ldots |h_i|\}$ of hierarchy h_i of size $|h_i|$ can be measured as follows:

$$bdr_{nd_p} = \frac{\sum_{q=1}^{\|h_{i+1}\|} \rho\left(\frac{u_{nd_p \to hnd_q}}{dc}\right) \otimes \tau \otimes bd + (obd \otimes \tau)}{\|h_{i+1}\|} \quad (1)$$

//Here in Eq 1

- The outcome bdr_{nd_p} is the battery depletion ratio observed for node nd_p of hierarchy h_i
- $u_{nd_p \to hnd_q}$ represents the Euclidian distance of the nodes nd_p and hnd_q
- ρ is the required frequency to a frame to travel distance capsule dc
- dp is battery depletion observed to transmit a frame with frequency ρ.
- τ is the retransmission factor
- obd is the obligatory battery depletion due to the overhead of other factors.

2.2.2 Foreseen Residual Battery Life

Foreseen Residual Battery Life: This metric forecast the possible residual life of a node nd over the completion of the scheduled routing process. The sum (aec) of Battery Depletion (bd) estimated for transmissions between the node nd and its hop level successor nodes, battery depletion at node's idle time (ibd) and obligatory battery depletion (obd) that indicates the energy consumption due to the factors such as jitter, control packets, retransmissions. Further the resultant sum aec will be subtracted from the present residual battery life ($prbl$). The resultant value must be the positive and greater than the given threshold. The foreseen residual battery life of a node $\{nd_p \exists p = 1,2,...,|h_i|\}$ of hierarchy h_i of size $|h_i|$ can be measured as follows:

$$aec_{nd_p} = bd_{nd_p} \otimes fc + ibd_{nd_p} + obd_{nd_p} \dots \qquad (2)$$

Here in this equation (Eq2),

- fc is the number of frames to be transmitted
- ibd_{nd_p} is the battery depletion observed for node nd_p at idle time while transmitting fc number of frames.
- obd_{nd_p} is the obligatory battery depletion observed for node nd_p to transmit fc number of frames.

$$frbl_{nd_p} = prbl_{nd_p} - aec_{nd_p} \dots \qquad (3)$$

Here in this equation (Eq3),

- $frbl_{nd_p}$ is the foreseen residual battery life of the node nd_p
- $prbl_{nd_p}$ is the present residual battery life of the node nd_p

2.2.3 Assessing Opportunistic Multicast Range

Opportunistic multicast range is a heuristic that signifies the hop level multicast link between optimal nodes of hierarchy h_i to number of optimal nodes in continual hierarchy h_{i+1}. The opportunistic multicast range of each node in each hierarchy $\{h_i \exists h_i \in H \wedge i = 1,2,...,|h_i|\}$ assessed as follows.

Initially the opportunistic multicast range of nodes in hierarchy h_1 is assessed as follows:

For each node $\{nd_p \exists nd_p \in th \wedge p = 1,2,...,|h_1|\}$ collect all hop level target nodes as set $l_{nd_q \to T}$ that represents the opportunistic multicast range of node nd_p of the hierarchy h_1

2.2.4 Assessing Signal to Noise Ratio

Usually the Signal to Noise Ratio (snr) of a node n_i is the average loss of signal ratio against the noise observed at links between the node n_i and all its connected successive nodes, which will be assessed as follows:

Let sf_{n_i} be the carrier signal frequency of node n_i

Let SN_{n_i} $\{sn_1, sn_2, \dots sn_{|SN_n|}\}$ be the set of successive nodes connected to node n_i in the multicast route

Let $sf_{sn} = \{sf_{sn_1}, sf_{sn_2}, \dots sf_{sn_{|SN_{n_i}|}}\}$ be the set of receiver signal frequencies observed at respective successive nodes connected to node n_i.

The '$sf_{n_i} - sf_{sn_j}$' represents the signal loss observed at successive node sn_j that connected to node n_i, this signal loss is further considered as noise at the link between node n_i and node sn_j

The average noise $\langle J_{n_i} \rangle$ observed for all links between node n_i and all successive nodes will be calculated as

$$\langle J_{n_i} \rangle = \frac{\sum_{j=1}^{|SN_{n_i}|} (sf_{n_i} - sf_{sn_j})}{|SN_{n_i}|}$$

The average receiver signal strength $\langle S_{n_i} \rangle$ observed for all links between n_i and all successive nodes will be calculated as

$$\langle S_{n_i} \rangle = \frac{\sum_{j=1}^{|SN_{n_i}|} (sf_{sn_j})}{|SN_{n_i}|}$$

Then the Signal to Noise Ratio snr_{n_i} observed for node n_i will be assessed as follows:

$$snr_{n_i} = \frac{\langle S_{n_i} \rangle}{\langle J_{n_i} \rangle} \begin{cases} > 1 \therefore signal\ is\ good \\ \leq 1 \therefore signal\ is\ bad \end{cases}$$

2.3 Selecting Optimal Nodes by Fuzzy Logic

The soft computing technique called Fuzzy logic[22] is promising model to perform the logical reasoning beyond the Boolean logic. Many of the ad hoc networks routing models[23-25] are based on fuzzy logic. The definite reasoning from the vague or ambiguous input is the objective of fuzzy logic. In the context of ad hoc network route discovery, the definite conclusion of the combinatorial factor of hop count, residual energy, packet transmission, signal strength and energy consumption is critical to achieve quality aware routing, hence the fuzzy logic is adaptable in this regard that converts complex representation of these factors to simple rules based representation[26-29].

The selection optimality of a node is assessed using fuzzy logic applied on battery depletion ratio, foreseen residual battery life, Signal to Noise Ratio and opportunistic multicast range as shown in Table 1.

The membership function that used for fuzzy reasoning is defining range of values for heuristic notations are as follows:

- The mean m of the low l and high h values of a heuristic is estimated initially as follows

$m = \frac{(l+h)}{2}$ then the lower value l to $\frac{m}{2}$ is considered as the range of very low,

- $\frac{m}{2}$ to $3 \otimes \frac{m}{4}$ will be considered as the range of low,
- $3 \otimes \frac{m}{4}$ to m is considered as the moderate,
- m to $m \oplus \frac{m}{2}$ is considered as range of high
- and $m \oplus \frac{m}{2}$ to h is considered as range of very high.

Table 1. Heuristics proposed notations

	Battery Depletion Ratio (bdr)	Foreseen Residual Battery Life ($frbl$)	Signal to Noise Ratio (snr)	Opportunistic Multicast Range (omr)	Node Optimality ($Nopt$)
Very Low	BDVL	FBLVL	SNRVL	OMRVL	NOVL
Low	BDL	FBLL	SNRL	OMRL	NOL
Medium	BDM	FBLM	SNRM	OMRM	NOM
High	BDH	FBLH	SNRH	OMRH	NOH
Very High	BDVH	FBLVH	SNRVH	OMRVH	NOVH

In regard to select the optimal nodes in each hierarchy the nodes will be order by the fuzzy reasoning that applied in multiple phases.

The nodes reflecting same fuzzy notation for all heuristics are referred as nodes inferred by same notation impact. The nodes reflecting divergent fuzzy notations for different heuristics are referred as nodes inferred by divergent notation impact

Further the nodes in each hierarchy will be ordered according to their inference reflected by the fuzzy notations of the selected heuristics, which is as follows

The nodes having fuzzy notation $BDVL$ for bdr and inferred by same notation impact are selected as first order nodes

The second order nodes are selected as nodes having fuzzy notation $BDVL$ for bdr and inferred by divergent notation impact such that

- The heuristic $frbl$ with $FBLH$ or $FBLM$
- The heuristic snr with $SNRH$ or $SNRM$
- The heuristic omr with $OMRH$ or $OMRM$

Then the nodes having fuzzy notation BDL for bdr and inferred by same notation impact are selected as third order nodes

The next order nodes are selected as nodes having fuzzy notation BDL for bdr and inferred by divergent notation impact such that

- The heuristic $frbl$ with $FBLH$ or $FBLM$
- The heuristic snr with $SNRH$ or $SNRM$
- The heuristic omr with $OMRH$ or $OMRM$

Further order will be with nodes having fuzzy notation $BDVL$ for bdr and inferred by divergent notation impact such that

- The heuristic $frbl$ with $FBLL$ or $FBVL$
- The heuristic snr with $SNRH$ or $SNRM$
- The heuristic omr with $OMRL$ or $OMRVL$

The last order will be with nodes having fuzzy notation BDL for bdr and inferred by divergent notation impact such that

- The heuristic $frbl$ with $FBLL$ or $FBVL$
- The heuristic snr with $SNRH$ or $SNRM$
- The heuristic omr with $OMRL$ or $OMRVL$

The leftover nodes if any in the hierarchy will be considered as obsolete

The Battery depletion ratio is the prime heuristics among all the heuristics proposed, which is since the prime objective of the proposal. Hence the fuzzy notation for bdr are considered only very low and low. In order to achieve the promising data transmission, the signal to noise ratio must be high, hence the fuzzy notation for snr are considered only $SNRVH$, $SNRH$ and $SNRM$ as shown in Table 2. The foreseen residual battery life is considered to confirm the route stability, which must not be the negative. Further the heuristic called opportunistic multicast range follows the order of priority.

2.4 Forming the Multicast Route by Fuzzy Logic

Further Form a tree based multicast route between source node and all target nodes T . In order to this, initially selects optimal nodes of each hierarchy by fuzzy logic and connects optimal nodes of each hierarchy to the hop level optimal nodes of the successive hierarchy.

Table 2. Fuzzy inference rules notations

Node Optimality ($Nopt$) is	If Battery Depletion Ratio (bdr) is	If Foreseen Residual Battery Life ($frbl$) is	If Signal to Noise Ratio (snr) is	If Opportunistic Multicast Range (omr) is
NOVL	BDVH	FBLVL	SNRVL	OMRVL
NOL	BDH	FBLL	SNRL	OMRL
NOM	BDM	FBLM	SNRM	OMRM
NOH	BDL	FBLH	SNRH	OMRH
NOVH	BDVL	FBLVH	SNRVH	OMRVH

In regard to this, initially the each optimal node of the hierarchy h_1 in the order defined by fuzzy logic will be linked to the target nodes, such that all target nodes connected to hierarchy h_1 and discard the leftover nodes in that hierarchy. Follow the same procedure to establish links between optimal nodes of the hierarchy h_2 to all selected optimal nodes of the hierarchy h_1. This process continues till the last hierarchy and then the source node will be linked to all selected optimal nodes of the last hierarchy.

3. Empirical Analysis and Results Exploration

The empirical study was done by using NS2 simulation of the mobile ad hoc network with MAC specification MAC 802.11 DCF. The specifications of the simulation are explained in Table 3. The initial energy levels, noise, signal strength and the factors were initialized by the Gaussian distribution strategy. The possible multicast routes were discovered by the traditional MAODV[30]. Then these discovered routes were used to identify the optimal multicast tree by MEDMR. The performance of the proposed model was explored by comparing with the benchmarking fuzzy based model called *Fuzzy Based* Energy Efficient Multicast Routing (FBEEMR).

Table 3. Network simulation constraints

Count of Nodes in network are in the range of 30 to 240
The node mobility speed in the range of 0.2 to 2.4 meters per second
The nodes spanned to 1200 X2400 square meters
Each node's transmission frequency range is 5 square meters
The load used in the range of 1.25 to 1.75 MB per second
Bandwidth is 2 MB per second
Packet type is CBR
Simulation time is 360 sec

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The performance advantage[31] of the MEDMR is evinced by the experimental study. The advantage of the MEDMR is scaled by comparing with other benchmarking model called FBEEMR. The performance of MEDMR and FBEEMR is estimated by the metrics end-to-end delay, packet delivery ratio and residual energy. These metric values were collected at different pause times from network simulation with different number of nodes that differs with topology[32]. The MEDMR is scalable and robust since the stability at end to end delay, packet delivery ratio and residual energy is evinced (Figures 1, 2 and 3).The MEDMR evinced the minimal end-to end delay that compared to FBEEMR (Figure 4), and packet delivery ratio is promising factor that compared FBEEMR (Figure 5). The main objective of the proposal is minimizing the battery depletion, which is finding to be best with MEDMR for dense networks that compared to FBEEMR (Figure 6).

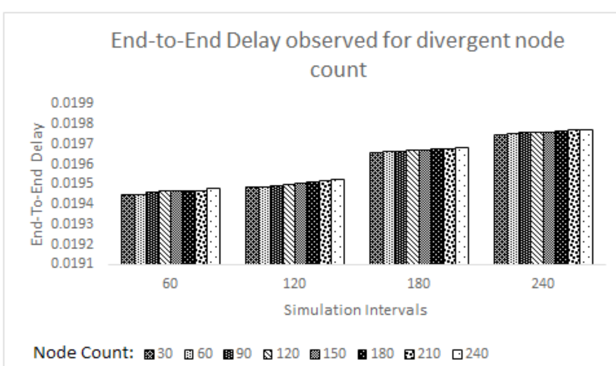

Figure 1. End-to-end delay at different intervals

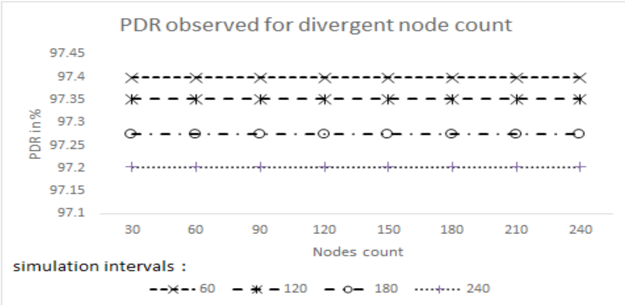

Figure 2. PDR observed for divergent node count

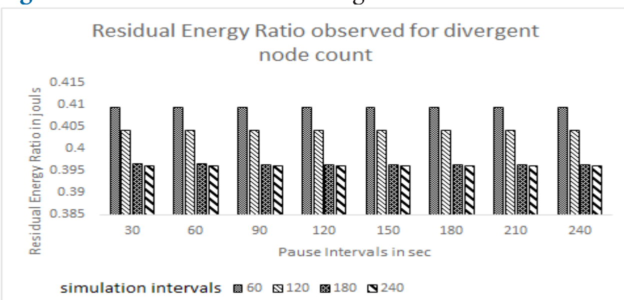

Figure 3. Residual observed for divergent node count

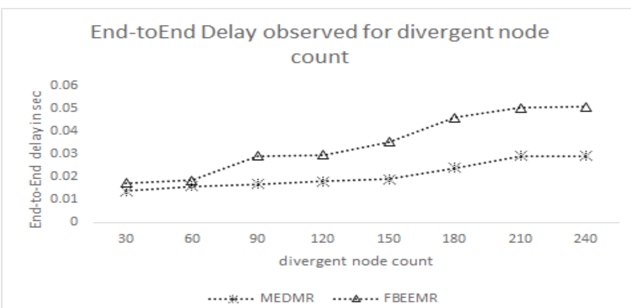

Figure 4. End-to-end delay observed for divergent node count

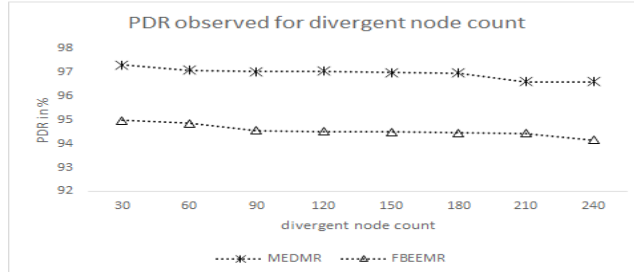

Figure 5. PDR observed for MEDMR and FBEEMR

4. Conclusion

The contribution of this manuscript is Fuzzy Based Minimal Energy Disbursed Multicast Route Discovery (MEDMR) for mobile ad hoc networks is to estimate the optimality of the nodes by applying fuzzy reasoning with membership function in order to form energy efficient multicast tree based route. The simulation study was conducted using NS2 and the performance results obtained for different quality metrics from the outcomes of the MEDMR with FBEEMR were evincing that MEDMR proven that it is scalable and robust. The confidence gained from the model devised would drive the further research to define combinatorial QoS factors aware and energy efficient multicasting for mobile ad hoc network that uses other evolutionary strategies.

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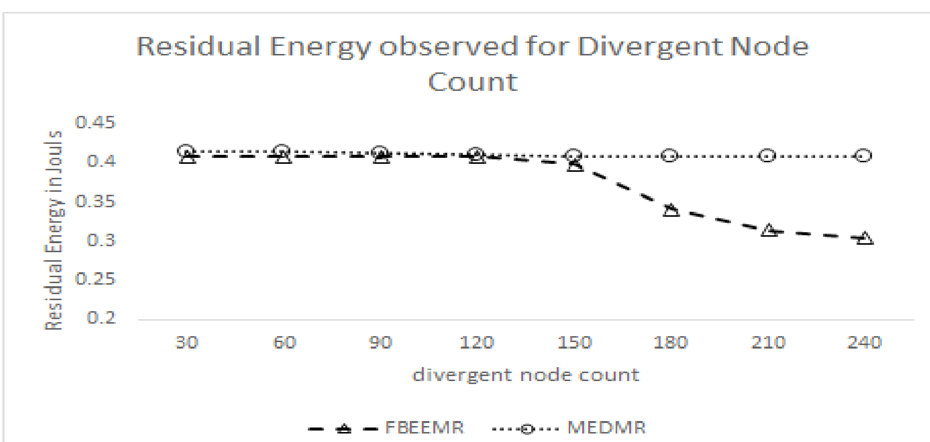

Figure 6. Residual energy ratio observed for divergent node

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