Applied Computing and Informatics 15 (2019) 120–128

Contents lists available at ScienceDirect

Applied Computing and Informatics

journal homepage: www.sciencedirect.com

Original Article

EELAM: Energy efficient lifetime aware multicast route selection for mobile ad hoc networks

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ARTICLE INFO

Article history:
Received 2 August 2017
Revised 15 December 2017
Accepted 24 December 2017
Available online 26 December 2017

Keywords:
Ad hoc networks
Multicast routing
Adaptive genetic evaluation

ABSTRACT

MANET (Mobile Ad hoc Network) consists the nodes that are self-energized and shall be able to accommodate limited energy levels, and usually the nodes transmit the data using the intermediate nodes to the ones that are not in hop levels. In such conditions, the lifetime of the intermediary nodes turn out to be a critical factor, and hence only when the routes are having maximum residual energy and the ones that have high, spend minimal energy for transmitting the data is very important. In terms of route selection, the emphasis is much on multicast routing and the route discovery, and the efficient nodes selection has to take place with emphasis on QoS. Hence, the energy efficient multicast route discovery process has gained significant importance, and there are many potential solutions depicted in the process. Energy Efficient Lifetime Aware Multicast (EELAM) Route Selection strategy for MANETs is the proposed multicast route discovery approach that is developed using the adaptive genetic algorithm. EELAM works based on tree topology that differentiates to other tree based on multicast routing topologies by adapting evolutionary computation strategy defined as genetic algorithm, which shall play a critical role in terms of selecting optimal intermediate nodes with maximal residual energy and minimal energy usage. The fitness function that devised for the adaptive genetic algorithm targeted for improving the energy consumption ratio, improving the residual batter life and towards improving the multicasting scope. The process and the methods that are adapted are contemporary and is different to the traditional genetic algorithms, and still the outcome as depicted in the experimental results reflect the fact that the EELAM is the best of in its class that can support in addressing the limitations in the current solutions and towards managing improved route discovery.

1. Introduction

MANETs the mobile ad hoc networks constitutes usage from varied range of computing devices like the laptops, mobiles and other computing solutions. The network connects of the mobiles take place in the form of node connects and predominantly used in the current scenario. Alongside the classified range of communication, even in the routine communication too, the role of mobile communication has become an integral part. Network partition results as a part of network topology being classified in the MANET [1].

Among the key factors that depict the outcome for a system, energy-efficient-multicast plays a very vital role for MANETs. One of the critical issues that envisaged in the process is that as the mobile nodes usually operated on limited batteries, often switching is leading to more battery consumption, and it could lead to affecting the nodes in a significant manner, as the data transmission between the nodes might get impacted and it could lead to more challenges.

There are numerous studies that have been carried out earlier in terms of solutions for nodes that are aware of energy consumption, in the routing protocol for MANETs [2]. In MANET, there are varied was of power-aware algorithm solutions that are proposed to ensure that node energy is saved [3].

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.aci.2017.12.003
2210-8327/

Power aware metrics are critical objective of majority of the studies, which focused on increasing the node and lifetime of the network [4]. The power aware routing metrics, those depicted in [5] are resourceful for transmitting data to the destination from the source.

In another model that has been depicted in a study on conserving energy in the transmission, MTPR has been projected which works on minimizing the utilization of power for transmission from the nodes to the participating nodes in a path. From the inputs depicted in the study, it is imperative that the required power for transmission is relative to the distance between corresponding two nodes. This model reflects on multicast routs with large number of nodes, and the crux is that it is not considering the leftover energy of the battery of the nodes involved in the route, hence it lasts the focus on lifetime of each node.

In the other model of MBC [6], the solution is about minimizing the path cost and hence worked on the reverse modeling of the residual energy of the nodes depicted in corresponding path.

Compared to the wired networks, the complexity of multicasting in the wireless networks are much higher because of the interferences and mobility related issues. Multicast is an active communication and the concerted correspondence process between various nodes. Flooding based multicasting is one predominant strategy that evinces control packet overhead as high, and emphasized to generate minimal levels of data traffic in the network. However, the challenge is that the issue of scalability is a major constraint in the case of both the solutions. In the case of multicast protocols, there are varied factors that influence the solutions for MANETs, and categorically the issue of node mobility, is a key issue. The crux in the process is about the need for more bandwidth in terms of updates, by taking more of control message packets and high consumption of power.

In the proposed paper, the focus is on developing an energy efficient multicast algorithm for MANETs. In the proposed solution, the factor is that the data packets transmitted from source to the group destinations using a node, and such nodes relies on the path with higher efficiency of residual battery powers and relay-capacities. The other objective of the proposal is to minimize the process overhead to select possible multicast routes between source and destination. In regard to this, the depicted model is concluding the routes from destination to source, which is novel that compared to other contemporary models.

The proposed model explained in detail in the further sections constituting Section 2 as the related work, followed by Section 3 as discussion of outline of the proposed algorithm. In terms of experimental setup and the related performance analysis, Section 4 depicts the process outcome, followed by Section 5 depicting the conclusion and the scope of further research work.

2. Related work

In the process of increasing the network lifetime, the power-aware routing plays a vital role, and there are certain solutions that developed earlier for the same. In the case of Broadcast Incremental Power (BIP) algorithm [7], the process is that the system exploits the nature of wireless communication environments and the addresses that are essential in the process of handling the energy efficient operations in the system. Emphasis in the model is depicting multicast tree that broadcasts with minimal energy consumption. This model is fundamentally designed on the basis of Prim's algorithm [7].

Genetic Algorithm based multicast routing [8,9] are focused towards achieving the stability and energy efficient outcome in terms of mobile ad hoc network routing is an effective system that can make significant difference in terms of energy consumption. The key purpose of this model is towards evaluating the signal strength for stable levels in the hop links and shall be used further towards concluding the fitness in terms of stability and energy usage in the multicast tree. One of the significant constraints in this process is that though it aims at reducing the cost of battery life, still in terms of complexity observed in the process could be attributed to Genetic Algorithm. The other GA based multicast tree routing protocol [10] for HAP-satellite architecture [11] is depicted in contemporary literature. The QoS metrics called cost, bandwidth, and delay are consider to assess the fitness of the newly formed multicast trees (chromosomes). The cost metric denotes the energy consumption. The other contemporary model [12] that builds over Genetic algorithm is aimed to detect dynamic shortest path, and dynamic multicast route. The Link-stability, and energy efficiency is two critical objectives of the model depicted in [13], which is also based on genetic algorithm.

The probabilistic evolutions and evolutions complexity are the constraints of these GA based models, which are carried from traditional GA evolution process. Henceforth probabilistic route accuracy in regard to routing quality factors is often evinced, which is due to the probabilistic evolutions of the traditional Genetic Algorithm.

The evolutions carried in GA are probabilistic, since the initial chromosomes (multicast routes) are formed randomly. In addition, the parent chromosomes those were used as input to crossovers also being retained along with newly formed chromosomes due to crossover process.

In regard to overcome this, and to achieve route discovery deterministic process, this manuscript is preparing initial chromosomes using the route discovery process called EACNS [14]. Later the process of the genetic algorithm is using these chromosomes in crossover process. Moreover, among the parent chromosomes and newly formed chromosomes, the best fit will be survive and rest will be pruned from the chromosome list, which is progressive evolution strategy. Due to this the number of evolutions are deterministic and limits the evolutions process complexity.

Profoundly the algorithms that are designed with intension of power efficiency was based on cluster-based or by adapting the tree-based models. In the later model, emphasis is on developing tree-based solutions that are highly efficient in power management, and depending on source, they further classified as multicast-source or single-source algorithms. Some of the power efficient single-source multicast models defined are MIP, S-REMIT and RBIP [15].

In [16] G-REMIT was proposed as an alternative tree-based multicast to enable routing between multiple sources and sinks. The critical objective of the model is to achieve multicasting with minimal energy consumption. REMiT is another model with emphasis towards reducing the consumption levels of energies and improving network lifetime. L-REMit model proposed with objective of refining the lifetime of the network for the source-based trees. G-REMiT model is more about reducing the energy consumption amidst the group-shared trees.

In [17,18], the study has discussed contemporary solutions those enables multicasting. The emphasis of these models is to enhance the network life time. The MLMH [18] depicted a metric called EEM (Energy Efficiency Metric), which is the result of aggregate hop-count values and relative levels of increment of lifetime.

Lifetime-Aware-Multicast-Tree (LAM) works on maximizing the lifetime by identifying a route with minimal levels of energy consumption and exploits the multicast lifetime [19]. The other method of Prioritized-overlay-multicast algorithm shall work towards improving the effectiveness and efficacy of the superimpose multicast in MANET, by ensuring that there is effective role –based-prioritized trees [20].

The other method MAODV proposed in [21] is an extended version of AODV that targets improvisation of the process, where all multicast group constituted as a tree that leads by the root node that broadcasts the data packets to the nodes involved in corresponding tree. Any corrections, rectifications and repairing of the tree carried out using the MAODV protocol core. MP-MAODV discussed in [22] is an extended model of *MAODV* and works on multipath selection and establishment, and handling the process of multipath route maintenance along with other functions like load distribution. The MP-MAODV is capable to build multicast tree with multiple sources and multiple sinks that enables bidirectional sharing. In addition, the MAODV is one of the shortest routing with least levels of hops routing, however, the MP-MAODV is much rigorous in terms of establishing the maximum possible number of multicast routes between so node and multiple sinks that is adapted in the backup route.

Multicasting via the application of time reservation, as well as adaptive control for energy efficiency (MC-TRACE) [23] is generally an energy efficient real-time multicast routing procedure for data communication in MANETs. It is worth pointing out that MC-TRACE is generally the extended MH-TRACE [24] that generally supports multicasting routing ability.

Efficiency in the consumption of energy gained through allowing the nodes, which are idle and can be switched to sleep node frequently and through the elimination of majority of redundant data receptions. The MC-TRACE depicts significance to minimize the transmission delay and battery dissipation, whereas the bandwidth efficiency is similar that compare to ODMRP [25]. The ability of minimal energy consumption appeared in MC-TRACE evincing the greater possibility of significant QoS in multicast routing, as well as bandwidth efficiency. However, the lack of robust architecture is the main challenge.

High stable power conscious multicast algorithm (HSPMA) [26] which is mainly aimed at improving the lifespan of the network and the node, considering the two main metrics, residual battery-capacity as well as the relay-capacity which is vital for carrying out multicasting. Lowering the energy dissipation at nodes corresponding to multicast route leads to maximal lifespan of the network. Multicast group size may become a huge challenge when it comes to the determination of the performance of the network. In addition, the additional control information is vital when comparison done between the power conscious routing protocols and the regular protocols that do not take into consideration energy as one of the main concerns. The network's life span increased by about 20 percent on average. However, there is the creation of added control traffic.

Lu and Zhu [27] addressed a novel multicast routing protocol called EDCMRA that aimed to achieve Energy-efficiency and delay sensitive data transmission. The EDCMRA is based on Genetic Algorithm that is considering the energy dissipation and delay as fitness metrics in objective function to select optimal routes. The algorithm uses the Possible Multicast trees those traced in route request process as initial input chromosomes, and uses the common subtree of the any of given two multicast tress as crossover point. It is a highly efficient and effective algorithm, but the process time is inversely proportionated to the network size.

EGMP (Efficient geographic multicast protocol) [28] petitions the network into set of virtual zones to achieve effective management of group membership. In order to this, a network wide zone oriented bidirectional tree is formed in each virtual zone. The experimental study that compared the ERGMP with ODMRP and SPBM evincing that the ratio of packets delivered through EGMP is considerably high that compared to OBMRP and SPBM. The minimal control packet overhead is observed in multicasting process of the EGMP than the other two protocols. However, there is generally less efficiency with regards to the usage of energy.

The fuzzy oriented demand on multicast routing protocol (FBODMRP) [29] has been proposed as a highly efficient means of delivering information from the node at the source to different nodes, which are the receivers. The main objective of FBODMRP mainly entails establishing small, high quality as well as highly efficient forwarding group. When FBODMRP is compared to ODMRP, it is worth pointing out that fuzzy based approach results into higher packet delivery ratio, very low control information utilization as well as delays in the environment, which is highly dense. In addition, power saving option is greater if there is need for low control overhead. As future work, the fuzzy rules may use over the cognitive networks. This depicted model plays a role in increasing the rates of packet delivery by 40 percent, and the ratio of delay and energy dissipation reduced relatively to 35 and 45 percent. However, the loss rate is proportionating to network density.

MANETs uses omni directional antennas. At the same time, they are having limited energy resources in the protocol, which have been proposed. In the suggested distributed minimum energy multicast (DMEM) [30] focus is mainly on the reduction of the total RF energy which is highly vital for multicast communication. It is worth pointing out that the DMEM algorithm is highly effective in performance and in the delivery of the results. In an environment of low mobility, the protocol generally accomplishes the best of medium, as well as a huge volume multicast groups. For the higher mobile networks, it is worth pointing out that DMEM is generally regarded to be highly effective efficient and effective with regards to saving energy, as well as when it comes to ensuring that the overheads are adequately and effectively controlled. This model is highly efficient both with regards to saving energy and also operation overhead. However, In case there is link breakage, there is the dwindling of process' performance.

Least energy for every bit for multicasting [31] in the MANET generally concerns linear program in which the least energy for every bit achieved through the adoption of network coding. The process time required for an optimal network coding solution is 30th part of the time taken by an optimal routing strategy. Future research should characterize with an average gain. Generally, network coding is having a number of benefits when a comparison is done between it and optimal routing with regards to energy, as well as computational efficiencies. However, the characterization of admissible rate region is highly complex.

In the case that multicast transmission from multiple sources to multiple sinks, the main challenge, which is faced generally, entails the development of MEM tree to enable the conveyance of multicast data. This results into the minimization of the whole consumption of power for packet conveyance within the tree. There is the building of least energy multicast tree. However, it is only appropriate to the ad hoc networks that build by symmetric placement of the nodes.

The model depicted in [32] is a multicasting process that entails the all-to-all transmission. Critical objective of the model depicted is multicast sessions, which is framing the multiple sessions from the overall transmissions required. The nodes related to each multicast session contains a message for sharing with the other node. There is a reduction in the total energy that consumed, however, it demands exclusive construction of multicast routing tree.

The model depicted in [33] is considering the node mobility and energy dissipation as critical objectives, which is referred as mobility based energy efficient multicasting (M-EEMC). M-EEMC is coupled with tree, as well as mesh based routing techniques for the minimization of the levels of consumption of energy. Performance assessment of the protocol, which proposed with ODMRP generally points out that M-EEMC is delivering better ration of packet delivery and brings about lesser energy dissipation as well as lesser packet delay. There is the dissipation of minimal amounts of energy. However, it involves a complicated set of algorithm.

The limits observed in regard to these benchmarking models is that the multicast scope of a node is not considered and no evidence of accurate selection of multicast route with minimal energy consumption and maximum lifetime, which are significant in establishing stable route.

Hence, the contribution of this manuscript aimed to establish a best-fit multicast route that consumes minimal energy to transmit and retains maximum lifetime of the route. In order to this, the proposal relied on adaptive genetic algorithm that uses multicast scope, energy consumption ration and reserve battery ratio in fitness assessment. The adaptive genetic algorithm adapted for optimal multicast route selects the sub-trees with dynamic number of nodes and optimal fitness as crossover points to perform mutations, which is significant to reduce the computational overhead that usually found in traditional Genetic Algorithm strategies.

The suggested protocols EEMPMO in [34] makes use of the idea of zone building and they generally construct a multicast tree with alternative root node that replaces the primary root node as and when required. The depicted tree is capable to perform bidirectional transmissions [35]. Because the root node charged with the responsibility of routing, there is the dire need for more energy consumption in comparison to the other nodes. Performance and reliability, which pertains to reduced overhead, as well as usage of lesser power, as well as lesser bandwidth is gathered though the use of the protocol which was proposed. The scalability, as well as less control overhead are the critical strength of the EEMPO. However, the procedure involved in selection of highly appropriate node as the standby node may result into various kinds of delay in performance, however, it may enhance the protocol's overall efficiency.

3. Adaptive genetic algorithm based multicast route selection

An adaptive genetic algorithm (GA) is a method for solving both constrained and unconstrained optimization problems based on a natural selection process that mimics biological evolution. The algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm randomly selects individuals from the current population and uses them as parents to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution.

Generates a population of points at each iteration. The best point in the population approaches an optimal solution.

Adaptive Generic Algorithms (AGAs) is one of the affluent algorithms, and pc (probabilities of crossover) and the mutation (pm), certainly determines the level of accuracy and the quantum of speed that the genetic algorithms can attain. Rather than taking any fixed values in to account, in the case of the adaptive algorithms, the emphasis is on gathering inputs from the population diversity as well as in terms of sustaining the convergence capacity. In the AGA model [36], the fitness values of the solutions are vital in terms of determining pc and pm values for the solutions, whereas, in the case of CAGA [37], the decision of pc and pm depends more on the optimization states of the population. The scope of combining GA with the other set of optimization methods shall be more proficient as the GA is very effective in finding good global solutions, but the challenge is about its limitations in terms of finding the absolute optimum using the last few mutations. Some of the other techniques like the hill climbing method and other such solutions are certainly effective and efficient in finding the most favorable in a confined region, but in the case of alternating GA and the hill climbing methods can result in more effective outcome.

Of the adaptive genetic algorithm properties explored, the genetic algorithm used here in this manuscript evinces the adaptability at cross over point selection, such that maximum number of nodes in sequence having fitness more than the given threshold. This strategy of crossover point selection defuses the number of evolutions, hence the computational complexity will be evinced minimal that compared to traditional GA [37]. The Energy efficient and lifetime aware multicast route discovery strategy that proposed here in this manuscript explored following.

3.1. Formation of chromosomes (Genotype)

All possible Multicast Routes to transmit data between selected source and multiple destination nodes has to be discovered initially. The multicast routes formed as tree structures, which built from the selective nodes. Let $MT = \{t_1, t_2, \ldots, t_{|MT|}\}$ be the set of Multicast Routes selected by route request process adapted from MAODV [21]. Further, these set of Multicast Routes used as initial chromosomes for adaptive genetic evolution. In order to identify the fitness of the newly formed chromosomes from the crossover process, the fitness function is derived, which uses proposed heuristics derived in our earlier contribution called EACNS [14] that briefed in following section.

3.2. The metric used to estimate the fitness of the multicast tree

The Metrics used to estimate the fitness of the multicast tree $MT = \{t_1, t_2, \ldots, t_{n-1}, t_n\}$ are

- Ratio of Energy Consumption: Metric defines usual energy consumption per unit of transmission at the egress node levels. The metric value derived based on mean of consumed energy for unit of transmission amidst nodes to the nodes that connected at successor levels, and the values expected to be minimal.
- Reserved Battery Life: It details the lifetime of a node that is part of the routing process. The metric estimates battery life essential for routing and the idle time value of battery life, battery life impacted because of contingency like max battery consumption (mbc), which deducts mbc based on the estimated battery life (ebl). Resulting value of the assessment has to be positive and higher that the defined threshold.
- Multicast Scope: It defines the feasible quantum of child nodes.

The combination of these metric values such that a node having max number of child nodes with minimum energy consumption and maximum reserve battery life represents corresponding node is optimal.

Similarly the combination of these metric values such that the average of child nodes is maximum with average of energy consumption is minimum and average of reserve battery life is maximum represents the corresponding multicast tree is optimal.

The assessment of these metrics at each node carried out as follows.

3.2.1. Assessing energy consumption ratio

The energy consumption at every node is the average of energy consumption observed to transmit a unit of data to all child nodes from the corresponding node.

$ec(t_i) \leftarrow \phi$ // is vector contains the energy utilization ratio of all nodes in multicast tree t_i

1. For each Node $\{n \exists n \in t_i\}$ Begin
$ec_{n \to CN_n} \leftarrow \varphi$ // a vector denoting energy utilization essential for transmission of a frame to all child nodes denoted as set CN_n
2. For each child node $\{cn \exists cn \in CN_n\}$ Begin
$\rho\psi = \psi^{(\frac{\upsilon_{n\to cn}}{\delta}) \otimes \lambda}$ // desired frequency $\rho\psi$ is exponential of the number of frequency ranges, the number frequency ranges from the Euclidian distance $\upsilon_{n\to cn}$ observed between node n and corresponding child node cn is $\frac{\upsilon_{n\to cn}}{\delta}$, here δ is the frequency range observed at node n and notation λ is the exponential loss of the frequency.

$$ec_{n\to cn} = (\rho\psi \otimes \varepsilon) + (\varepsilon' \otimes \lambda) \quad (1)$$

//Here in Eq. (1)
- The notation $ec_{n\to cn}$ represents the energy consumed for transmission of a frame from node n to corresponding child node cn
- ε is energy essential for transmitting a frame under frequency ψ
- ε' is the energy consumption resulting because of overhead of other factors [27].

$ec_{n\to CN_n} \leftarrow ec_{n\to cn}$
// energy consumption between node n and corresponding child node cn is added to the set $ec_{n\to CN_n}$
End //End of loop in line 2
$nec_{t_i} \leftarrow \langle ec_{n\to CN_n} \rangle$ // mean energy consumption amidst n and all corresponding child nodes CN_n is moved to the set nec_{t_i} that contains usual energy consumption observed for all nodes in multicast tree
End // end of loop in line 1
$ec_{t_i} = \sum_{j=1}^{|nec_{t_i}|} \{e_j \exists e_j \in nec_{t_i}\}$// the energy consumption to transmit a frame by multicast tree t_i

3.2.2. Assessing reserve battery life

The reserve battery life of a given node estimated as follows.

Initially, the product of energy consumption ratio, max quantum of frames to be transmitted and aggregate number child nodes will measure and further the resultant value of this product will deduct from the actual battery life of the corresponding node.

For every Node $\{n \exists n \in t_i\}$ Begin

$$rbl_n = mbl_n - (\langle ec_{n\to CN_n} \rangle \times fc \times |CN_n|)$$

//The product of energy consumption ratio node n, max number of frames to be transmitted, and the aggregate of child nodes is diffused from the max battery life mbl_n of node n that referred as preserved battery life rbl_n of the node n.
End
Further, the average of reserve battery life observed for all nodes in given multicast tree considered as the tree level reserve battery life rbl_{t_i}

3.2.3. Assessing multicast scope

$rbl(t_i) \leftarrow \varphi$ //A vector comprises the information of reserve battery life of all the nodes in L_i
$nnl(L_i) \leftarrow \varphi$ // A vector which constitutes size of all probable neighbor nodes from $sl(L_i)$ interlinked to every node $\{snd \exists snd \in L_i\}$ based on defined metric constraints
$mcs_{t_i} \leftarrow \phi$// is an empty set contains the multicast scope of each node in the given tree
1. For each Node $\{n \exists n \in t_i\}$ Begin
$mcl_n = 1$
// max possible nodes to connect as child nodes to the node n that initialized with 1
2. For each child node $\{cn \exists cn \in CN_n\}$ begin
if $((mbl_n - (\langle ec_{n\to CN_n}\rangle \times fc \times mcl_n)) > rbl_n)$ Begin
$mcl_n + = 1$
End
Else Begin
$mcl_n - = 1$
$mcs_{t_i} \leftarrow mcl_n$
Go to loop in line 1
End
3. End // of loop in line 2
4. End // of loop in line 1

The given tree level multicast scope is the average of multicast scope observed at each node of the corresponding tree $\langle mcs_{t_i} \rangle$.

3.3. Fitness function

This section explores the process of estimating the tree level fitness in regard to energy efficiency and route longevity, which is as follows.

For given parent trees t_p, t_q and the resultant child trees t_i, t_j, assess the values for metrics, energy consumption ratio (see Section 3.2.1), reserve battery life (see Section 3.2.2 and multicast scope (see Section 3.2.3)

1. *if* $(rbl_{t_i} > rbl_\tau)$ Begin
// if the reserve battery life of the multicast tree t_i is more than the threshold rbl_τ given
i. *if* $(ec_{t_i} < ec_{t_p} \vee ec_{t_i} < ec_{t_q})$ Begin
The energy consumption ratio of the tree t_i is less than the energy consumption ratio of target tree t_p or t_q then the fitness of tree t_i is optimal
End // of if in line i
ii. Else
$(ec_{t_i} = ec_{t_p} \vee ec_{t_i} = ec_{t_q}) \wedge (mcs_{t_i} > mcs_{t_p} \vee mcs_{t_i} > mcs_{t_q})$
Begin
Confirm that the tree t_i is with optimal fitness
iii. End //of else in line ii
2. End // end of if in line1
3. Else Begin
The fitness of the tree t_i is not optimal, hence tree t_i is not prone to select for routing
4. End // of else in line 3

In the similar passion explored above find the fitness of the t_j

3.4. Adaptive GA for multicast route selection

The optimal energy efficient multicast route among the possible multicast routes discovered done by using evolutionary computation strategy called Adaptive Genetic Algorithm (GA) [36]. Selection of distinct range of nodes in sequence as crossover points reduces the computational overhead of GA, which applies set of initial multicast routes as $MT = \{t_1, t_2, \ldots, t_{|MT|}\}$. The algorithm description follows and the same is visualized in flowchart (see Fig. 1).

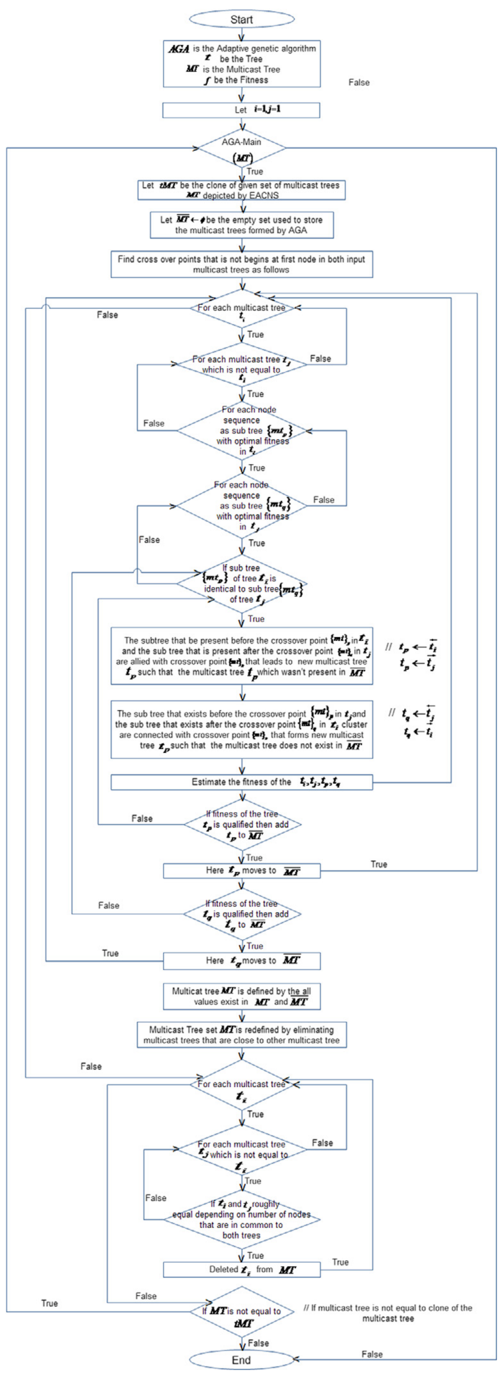

Fig. 1. The optimal multicast route discovery function.

3.4.1. The optimal multicast route discovery function

AGA-Main (MT) Begin

Let tMT be the clone of given set of multicast trees MT depicted by EACNSLet $\overline{MT} \leftarrow \phi$ be the empty set used to store the multicast trees formed by AGAFind cross over points (common node sequence with fitness greater than the given threshold in given both multicast trees) that is not begin at first node in both input multicast trees as follows.

1. $\forall_{i=1}^{|tCL|}\{t_i \exists t_i \in tMT\}$ Begin // for each multi cast tree t_i
2. $\forall_{j=1}^{|tMT|}\{t_j \exists t_j \in tMT \wedge i \neq j\}$ Begin// for each multicast tree t_j, which is not the other tree t_i
3. $for\, each\{\{mt\}_p \exists \{mt\}_p \in t_i \wedge p = 1\, to\, |t_i|\}$Begin //node sequence as sub tree $\{mt\}_p$ with optimal fitness in multicast tree t_i
4. $for\, each\{\{mt\}_q \exists \{mt\}_q \in t_j \wedge q = 1\, to\, |t_j|\}$Begin //node sequence as sub tree $\{mt\}_q$ optimal fitness in multicast tree t_j
5. If $(\{mt\}_p \equiv \{mt\}_q \wedge p \neq 1)$ Begin// if subtree $\{mt\}_p$ of tree t_i is identical to subtree $\{mt\}_q$ of tree t_j
   - The subtree that be present before the crossover point $\{mt\}_p$ in t_i and the sub tree that is present after the crossover point $\{mt\}_q$ in t_j are allied with crossover point $\{mt\}_p$ that leads to new multicast tree t_p such that the multicast tree t_p which wasn't present in $\overline{MT}$

     $t_p \leftarrow \overleftarrow{t_i}$

     $t_p \leftarrow \overrightarrow{t_j}$
   - The sub tree that exists before the crossover point $\{mt\}_p$ in t_j and the sub tree that exists after the crossover point $\{mt\}_p$ in cluster t_i are connected with crossover point $\{mt\}_p$ that forms new multicast tree t_q such that the multicast tree t_q does not exist in $\overline{MT}$

     $t_q \leftarrow \overleftarrow{t_j}$

     $t_q \leftarrow \overrightarrow{t_i}$
   - Estimate the fitness of the t_i, t_j, t_p, t_q (see Section 3.3)
   - If $(f_{t_p} \equiv 1)$ //if fitness of the tree t_p is qualified then add t_p to $\overline{MT}$

     $\overline{MT} \leftarrow t_p$
   - If $(f_{t_q} \equiv 1)$ //if fitness of the tree t_q is qualified then add t_q to $\overline{MT}$

     $\overline{MT} \leftarrow t_q$

   End If // of step 5
6. End For //of step 4
7. End For //of step 3
8. End For//of step 2
9. End For//of step 1
10. $MT \leftarrow MT \cup \overline{MT}$
11. Multicast Tree set MT is redefined by eliminating multicast trees that are close to other multicast tree if any, using the following steps
12. $\forall_{i=1}^{|MT|}\{t_i \exists t_i \in MT\}$ Begin
13. $\forall_{j=1}^{|MT|}\{t_j \exists t_j \in MT \wedge i \neq j\}$ Begin
14. If $(t_i \triangleq t_j)$ then // t_i and t_j roughly equal depending on number of nodes that are in common to both trees

    $MT \leftarrow MT \setminus t_i$ // delete t_i from MT
15. End If //of step 14
16. End For //of step 13

(*continued on next page*)

17. End For //of step 12
18. If ($MT \neq tMT$) then AGA-Main (MT)
19. End Function AGA-Main

This signifies each stable and optimal clusters, and then select the multicast tree from *MT* under contextual requirements.

3.4.2. Selecting best fit multicast route

Upon completion of the adaptive genetic algorithm process, the resultant multicast trees can be ordered in the priority of descending order of energy consumption and ascending order of multicast scope in sequence and then the best fit Multicast Route among the *MT* will be selected.

4. Empirical analysis and results exploration

In terms of conducting the experimentation of the process, in an area of 1000 mts × 1000 mts, set of nodes placed in a random manner, and using the Network Simulator [38] the testing process has been carried out. In the testing process, an ad hoc network simulated with randomly placed nodes with pause time of 2 s interval during their mobility from present location. Metrics that considered for the simulation depicted in Table 1.

In the placement of each node, with 25%, 50%, 75% and broadcast range with four distinct multicast groups are spawned, which can lead to process that is more emphatic. Also, the power sum is normalized in order to reduce the minimum heuristic solution to 1. The results that discussed about average numbers over 100 sets and routes formed with the range of nodes between 10 and 45.

4.1. Performance analysis

Many metrics like energy consumption, thorough put delay, and the network lifetime processes are adapted, which could affect the network performance to great extent. Also, the outcome from the experimental results is depicted for the five models, and the comparative analysis of all the five models has also been depicted in the experimental results.

4.2. Network lifetime

For the experimental study, nodes in the range of 10 to 45 chosen, and the nodes have been deployed within the defined area. Around 5–20 packets/sec has been sent between the nodes, and all the nodes moved at 2 mts/sec. The group quantum and the age of network depicted in Fig. 2, while engaged, the results affirm the performance of EELAM in keeping most of nodes alive for longer tenure, than the other models. When the group size has been managed to 40, the output from EELAM is about managing the nodes alive for a period of 8530 sec, which is significantly high that compared to the other benchmarking models (see Fig. 2). Fig. 3 reflects the kind of nodes that are alive during the simulation time (indicating in the multicast routes selected under each of the benchmarking models). The outcome from EELAM results has been depicting the better performance among the models that observed at different time intervals (see Fig. 3).

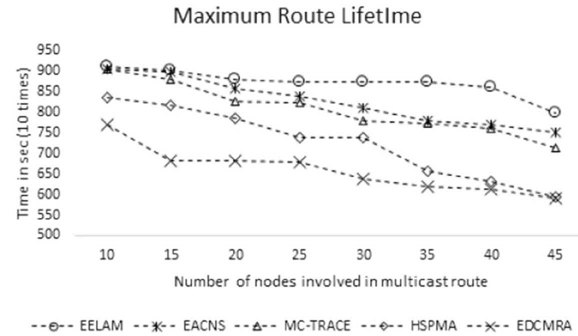

Fig. 2. Max life time of the routes with divergent number of nodes observed for EELAM and benchmarking models.

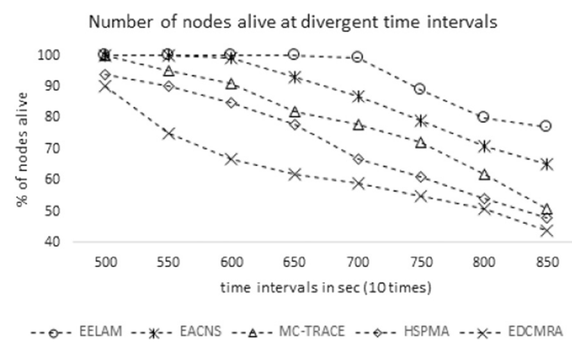

Fig. 3. Percentage of nodes alive in selected route observed for EELAM and benchmarking models at different intervals.

4.3. Energy consumption

In Fig. 4, the emphasis is on Energy Consumption ratio for varied time instances that presumes no energy consumption occurs initially. The results depicted n Fig. 4 evincing that EELAM is optimal that compared to other benchmarking models. The node level energy dissipation in EELAM is linearly proportionate to transmis-

Table 1
Metrics and the related values adapted for simulation.

Metric	Value
Simulation time	2000 s
Network Range	1000 × 1000 mts
Transmission power	1400 mW
Voltage	5 V
Traffic type	CBR
CBR packet size	512 bytes
Mobility	model Random waypoint
Frequency	2.4 GHz
Channel capacity	2 Mbps
Transmission range	150 mts
Idle power	830 mW
Node mobility	0–20 mts/sec
Receiving power	1000 mW
Pause time	1 sec
Group size	3, 6, 9, 12, 15

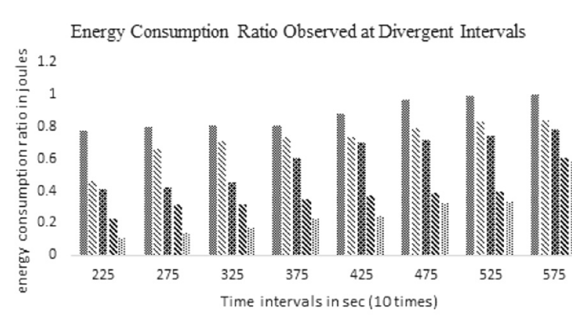

Fig. 4. Comparison of Energy Consumption Ratio observed for EELAM and benchmarking models at divergent time intervals.

sion time. Hence, the EELAM evinced the less consumption that compared to the other models.

4.4. Throughput

When dense number (here in experiments 45) mobile nodes are involved in route with varied node mobility speeds in range of 0 to 30 mts/sec and transmitting 5 packets per second, it is imperative that the mobility is vice versa to throughput. In the tests, results EELAM has worked well in the range of node mobility ranges 0–30 mts/sec and other models considered evinced significant downfall in throughput proportionate to the increase in speed (see Fig. 5). From the review of the experimental results, it is imperative that the minimal fall in throughput along with the increasing mobility of the nodes evinced for EELAM.

4.5. End-to-end delay

End-to-end delay can be termed as time consumption for a packet to travel amidst source to destination. In the test condition with mobile nodes positioned in various locations in the defined areas, and with the node mobility capability of 8–30 mts/sec, transmitting the data at 5 packets/sec. Fig. 6 depicts the delay at different time intervals observed for multicast routes traced by EELAM and other benchmark models. The EELAM has transmitted the data at significantly low that compared to the other (see Fig. 6).

Using the metrics of Reserve Battery Life, Packet Delivery Ration and End-to-End delay ratio, the EELAM performance also analyzed for multicast trees formed by divergent number of nodes. From the metric volumes that are obtained in the networks build with divergent count of nodes reflecting the fact that EELAM is scalable and robust. Inputs and metrics observed depicted in Figs. 7–9.

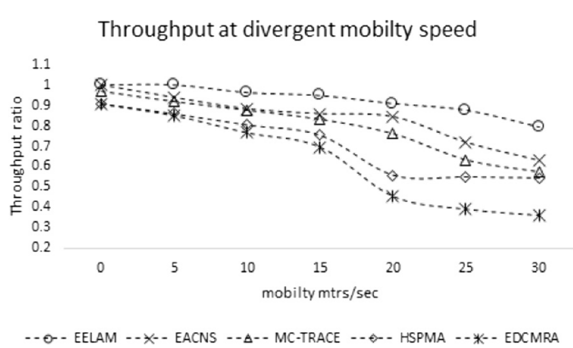

Fig. 5. Comparison of throughput observed for EELAM and benchmarking models at divergent mobility speed.

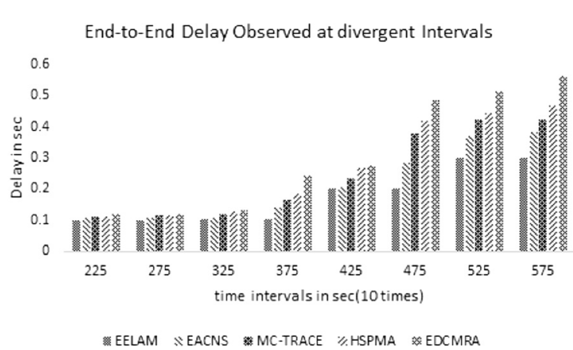

Fig. 6. Comparative analysis of end-to-end delay observed for EELAM and benchmarking models at divergent time intervals.

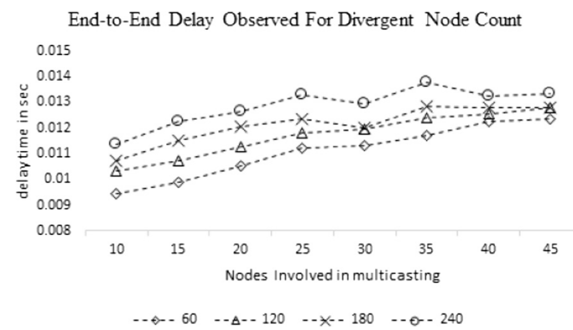

Fig. 7. Comparison of End-to-End Delay observed for routes formed by divergent count of nodes.

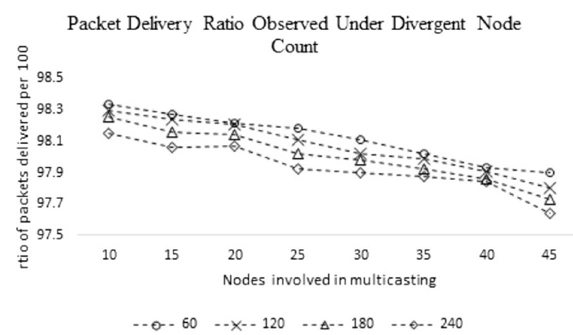

Fig. 8. Comparative analysis of Packet Delivery Ratio observed for routes formed by divergent count of nodes.

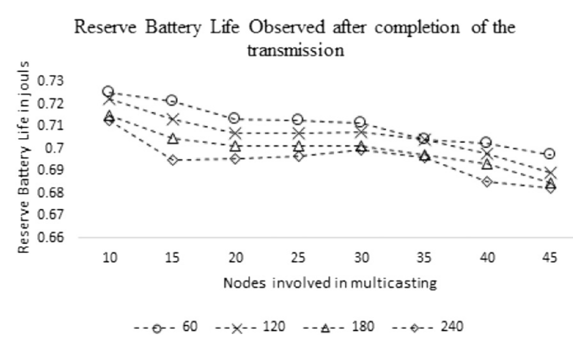

Fig. 9. Energy Reserves Ratio observed at different simulation intervals.

5. Conclusion

Energy Efficient and Lifetime aware Multicast (EELAM) route discovery for mobile ad hoc networks is the model that designed to address the issues pertaining to curtailing the consumption of energy and maximizing the route lifetime. The proposed topology EELAM is effective in terms of assessing the optimality of the multicast tree by ensuring that three crucial metrics Reserve Battery Life, Energy Consumption Ratio and multicast scope evaluated. The adaptive genetic algorithm is used to identify energy efficient lifetime aware multicast tree, which is balancing the process overhead by selecting sub-trees having dynamic number of nodes with optimal fitness as crossover points and further refining input chromosomes by comparing the fitness with child chromosomes formed. The significance of the EELAM assessed through the simulations build by network simulator called NS2. In order to this, the routing performance metrics, such as packet delivery ratio, end-to-end delay, throughput versus mobility, and energy consumption ratio used. The results obtained for these metrics from the multicast route discovered by EELAM compared to the other bench marking models such as EACNS, EDCMRA, HSPMA, and MC-TRACE. These metrics were also compared between the multicast routes formed with divergent count of nodes those discovered by EELAM, which is in order to evince the scalability and efficacy of the proposed model. Insights learnt from this model motivating us to redefine the Adaptive Genetic Algorithm, such that the fitness function can use fuzzy reasoning to estimate the fitness of the given multicast route.

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