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Energy Aware Stable Multipath Disjoint Routing Based on Accumulated Trust Value in MANETs

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Abstract: Conserving energy and finding the stable path are the two vital issues in Mobile Ad Hoc Networks (MANETs) as the prior increases the network lifetime and the later increases the network throughput. The nodes which are not legitimate in terms of residual energy and packet forwarding history might be a threat to the path thereby making the path unstable. Thus, it results in frequent link failure, reduced throughput, reduced network and path life time. In order to reduce these hazards, authors have proposed an energy efficient, reliable path selecting protocol referred to as *Trust Based Energy Aware Multipath Disjoint Routing Protocol (TEA-MDRP)* for MANETS in this article. TEA-MDRP finds the optimum route between the source and the destination nodes using two parameters namely, the *Accumulated Trust Value (ATV) and the node's residual energy* (N_{res}). *ATV* is calculated based on the packet forwarding status of the node which shows how good the node is in terms of packet forwarding point of view. TEA-MDRP allows only the nodes which have a good *ATV* and sufficient residual energy. A good *ATV* shows loyalty in forwarding the packets while a sufficiently large residual energy node avoids frequent path breakups and packet drops. Thus, the TEA-MDRP not only increases the network and path lifetime but also increases the throughput of the communication. Further, with the legitimate nodes in the paths, the TEA-MDRP considerably reduces the control packet overhead which might occur because of the frequent route re-discovery process. An extensive simulation is carried out using Network Simulator-2.35 for the quantitative and qualitative analysis of TEA-MDRP. The results obtained are compared with classical AOMDV and the results are satisfactory.

Index Terms: Energy Efficiency, Stability, Node Residual Energy, Multipath Disjoint, Accumulated Trust Value (*ATV*).

1. Introduction

The Mobile ad hoc networks (MANETs) is a foundation less, self-configurable, simple deployable organization in which the nodes go about as hosts just as routers. The MANETs applications include [1] war-field operations, rescue operations, emergency actions and many more. One of the most challenging issues in MANETs is the routing process. The same can be classified into two categories, depending on when and how the paths are found: proactive (table-driven) and reactive (on-demand). For the table-driven route convention, steady and most recent data are kept up with at every versatile mobile host. Consequently, for the table-driven conventions every portable host keeps at least one table containing routing data to each and every versatile mobile host in the network. At the point, when a network topology changes, the versatile mobile hosts engender the refreshed messages all through the network to keep up with the routing data about the entire network. Unlike table-driven routing protocols, reactive or on-demand routing protocols [2,3], do not maintain all up-to-date routes at each mobile host. Rather, routes are built only when they are needed. When a source host wants to deliver a packet to a destination, the route discovery method is used to locate the best way. In continuation to these two classifications, the routing in MANETs can further be of single path and multipath routing [4,5]. In the former case, there exists a single path between the source and the destination, it makes the route setup and maintenance of the route easier although it suffers from fault tolerance. Whereas in the latter case, there will be multi different paths between the source and the destination nodes. Routinely, an ideal primary path or optimal path will be used to transmit data packets and the other paths which are sub optimal, will be kept as standby for the worst case scenarios. Multipath routing again can be of two types; node disjoint and link disjoint. In the former case, no node will be common (apart from the source and destination nodes) in a path. Whereas in the latter case, nodes may be common but no link will be common in the path. Multipath routing is more fault tolerant [6] when compared to single path routing; thus, it is good to use multipath routing for providing reliable and stable data communication, especially when the application is time critical. Multipath routing also possesses stability.

However, because of the distinguishing characteristics of MANETs [7] (radio link quality, mobility, frequently changing and unpredictable topology, energy scarcity etc.) the optimal path found during the route discovery phase becomes unstable. Further, the unguessing network topological progress and the non-centralized control makes the route (re)discovery process more exigent. Thus, designing a routing protocol for MANETs [8-11] faces a lot of problems such as node unavailability, frequent link breakage, energy depletion, mobility, dynamic topology etc. The nodes of the MANETs operate on a limited battery power thus, node's energy is a scarce resource in MANETs. Energy efficiency [12,13] is regarded as the supreme factor and its awareness is considered to be the vital requirement for the MANETs lifespan.

Thus, Energy awareness, path stability and path reliability are the topic of interest for a large number of researchers in recent days. Few researchers have calculated the trust value of a node in a direct and indirect way; this causes overhead in the network. Efficient residual energy usage at each node in order to enhance the path durability is the prime focus of all routing protocols in today's research. By keeping all these factors, authors have proposed a novel on demand routing protocol in this article referred to as *Trust Based Energy Aware Multipath Disjoint Routing Protocol (TEA-MDRP)* which works on dual parameters referred to as trust value and residual energy of a node.

The main objective of TEA-MDRP is to design, develop an energy efficient and stable multipath routing mechanism in such a way that the node's trustiness and residual energy are taken together. To the best of the authors knowledge, no work by any individual addressed trustiness and residual energy of a node together to make a protocol energy efficient and stable multipath. However, these parameters were considered in isolation for their protocol design. Most of the researchers have taken the trust value of a node for the integrity purpose.

The proposed trust and stable multiple path routing protocol estimates the trust value of a node based on its packet forwarding capability. With reference to the words "node trust", authors mean a trust value based on the packet forwarding capacity of a node and it does not relate to the integrity part of the node. At the time of route discovery, the calculated trust value along with the residual energy of a node will be used to select the nodes in the path. The condition here is the trust value as well as the node's residual energy should be more than the threshold value in order for a node to be involved in the routing process. Furthermore, the nodes which fail to forward packets correctly eventually are detected and isolated.

Rest of the article is standardized as follows; in section 2, an article briefs about the work related. The proposed work is presented in section 3. Section 4 presents the simulation results and the quantitative and qualitative analysis of the proposed work. Finally, in Section 5, the article is concluded with a forethought about the proposed work.

2. Related Work

Increasing the operational durability of ad hoc networks [14] is going to be the prime concern for many leading researchers in these recent days. Multipath routing has been explored to different extents by different researchers. Various researchers have proposed different schemes to obtain energy efficiency and stability enhancement in the routing process [15-18]. The following section discusses the majority of the work which focuses on minimum energy consumption, and stable route selections with node disjointedness in multipath routing.

M. Rajashanthi and K. Valarmathi [19], have proposed a work which considers an issue of energy consumption in MANETs. In their work, nodes in the network are gathered by the K-medoid bunching calculation, which limits the expense of steering of information in populated networks. The parameters used are network lifetime, PDR and QoS. The NS-2 simulation results yield better energy efficiency and lifetime of the network to that of the Fish swarm optimization (FSO) algorithm.

B. S. Rani and K. Shyamala [20], have proposed an energy proficient burden adjusting approach for AOMDV alluded to as EELB-AOMDV, which recognizes three routes through source and destination. A path with minimum hop count will be chosen as the essential path and all other paths as treated as auxiliary paths. The protocol is simulated using NS-2 and the results of EELB-AOMDV is contrasted with AOMR-LM, FF-AOMDV and to AOMDV for boundaries, for example, packet delivery ratio, throughput, e2e delay, energy utilization and control overhead. EELB-AOMDV protocol outperformed the above protocols with respect to the parameters considered.

A. Rama Rao et. al., [21], proposed a multipath selection scheme for providing Quality of Service (QoS) in MANETs based on a "fractional cuckoo search algorithm (FCS-MQARP). Multiple QoS constraints such as energy, link lifetime, distance and delay" are considered as the routing parameters for route discovery. Authors have simulated proposed QoS aware routing protocol in MATLAB by considering the metrics such as "normalized delay, throughput and energy". The proposed protocol produces better results compared to existing AOMDV with utmost energy of 99.1501 and meagre delay of 0.0554.

A. Pal, et. al., [22], have proposed a method to identify stable neighbors in order to find stable multi-path routes in MANETs considering various mobility patterns. The proposed work also deals with data packets with minimum transmission time. Recurrent neural network is used to choose stable neighbors which uses earlier neighborhood information as input and finds out if a node will be next neighbor or not. The correctness of the proposed methodology has been proved with the analytical model. Simulation results help authors to prove that the proposed model takes less time to pass the same amount of data packets. Also, authors claim that the proposed method simulated in MATLAB yields better packet delivery ratio, lower route recovery time when compared to existing multipath routing protocols.

Varalakshmi et al., [23] proposed a scheme, which helps in selection of highly trusted nodes to pass the data to the destination. The node in the network is first checked for its identity (normal or not) by applying the bottom-up parser approach and also the node is checked for its trust level by shift-reduce operations. To determine the detection ratio, the method uses energy, node's trust value as its parameters. The work is simulated in NS-2 to prove its efficiency.

Thirunavukkarasu et al., [24] proposed a Node Reputation based Energy Aware Directing (NREAR) contrivance. The NREAR solution is done with two stages like node conduct checking and node's energy esteem observing. First stage incorporates distinguishing proof of conviction nodes with the assistance of node practices (hopeful and negative). Second stage ascertains the energy worth of the trusted (idealistic) nodes subsequently information is disregarded the idealistic nodes. The authors have proved the protocol efficiency by simulating it in NS-2.35.

Khan, B. U. I et al., [25] proposed an Intelligent Packet Forwarding Approach with Trust Model (IPFATM) in view of the game hypothesis, here trust assessment assumes a fundamental part as far as node notoriety viewpoint. The methodology implements an impetus displaying to convey the participation methodology between versatile nodes. The utility of packet sending strategy is enhanced by trust-based games. Authors have evaluated the numerical modelling using the MATLAB environment.

D. Zhao et al., [26] have proposed a methodology referred as "Distributed and Adaptive Trust Evaluation Algorithm (DATEA)", in which the trust evaluation is divided into communication trust and energy trust. The number of packets transferred between nodes is used to calculate communication trust, whereas, the residual energy of nodes is used to calculate Energy Trust. Direct trust is determined by communication and energy trust, but indirect trust is determined by a variety of factors such as reliability and familiarity. Final trust of a node is calculated by merging direct and indirect trust. Authors have performed the simulation using MATLAB.

S. Krishnaveni and N. Angel [27], have presented a protocol called "Energy Efficient Ad hoc On Demand Distance Vector Routing (EE-AODV)" which identifies the trusted nodes for effective communication through parameter optimization. The authors have also proposed "a new clustering model referred to as Virtual Link Weight based Clustering (VLWBC)" to group the random nodes for parameter optimization. An algorithm called Improved Harmony Search Optimization (IHSO) is used to identify trusted nodes from each cluster. Through simulation in NS-2 it has been shown that the presented algorithm optimizes QoS, energy utilization and lifetime of the network.

Though authors are able to find plenty of research work in the literature which focuses attention on energy aware multipath routing and the node trust-based energy aware multipath routing in MANETs in an isolated way. Authors could not find enough work in the literature on the energy efficient multipath routes based on the trustiness of the nodes; which could make routing in MANETs more efficient and effective. Thus, authors have proposed a node disjoint multipath routing protocol in this article, which satisfies energy awareness as well as stable path, pertaining to residual energy and trust value of the nodes in the routing process.

3. Proposed Methodology

Various energy efficient protocols were proposed [28-30] previously (as in the literature) to find the stable and energy efficient routes in MANETs which equipped different parameters such as *residual energy, link expiration time, probabilistic link lifetime estimation, link usage* etc. Energy efficient and stable multipath is proposed in this article by calculating the trustiness of a node in the network. In the proposed work, the authors have used two parameters, for determining the best path between the source and the destination namely, the *Accumulated Trust Value (ATV) of a node and the node's residual energy (* N_{res}*)*. The nodes in MANETs are energy constrained and which are to be retained to prolong the network lifetime. The rest of the subsections explains the proposed algorithm in detail.

3.1. Basic Knowledge and Theory

It is understood that not all the nodes of the MANETs are reliable, stable and energy aware. A suitable strategy has to be established to pick the most appropriate node for data routing. The trust value plays a significant and vital role for ensuring a stable and energy efficient route between the source node and the destination node. The trust value is a value associated with every node of a MANETs environment for measuring reliability among the nodes of the network. In the work carried out, trustiness is estimated for all the nodes who make an entry into the network. These mobile nodes further assigned *ATV_Init,* an initial value required for calculating the accumulated trust value *(ATV)* and accordingly, the routing protocol utilizes the same for deciding the participation of the mobile nodes into the routing process.

When a new node enters the network, its ATV will be set to the initial value that is *ATV_Init* using the trust module. The *ATV* of the newly joined node will be updated periodically in the update phase of the proposed algorithm. As the nodes will have mobility, a node may move out of the vicinity at time *t1* and may re-enter the radio range at time *t2* after a small-time gap of *Δt (Δt = t2-t1)*. In such case, the proposed algorithm re-computes *ATV* and N_{res} as soon as the node re-enters the radio range.

3.2. Node Selection Scheme

In the proposed algorithm, the *ATV* will be calculated for every node based on its packet forwarding status and N_{res} is calculated based on the energy consumed by the node. Both *ATV* and N_{res} are calculated at regular intervals (for each session) and will be stored in each node's routing table and accordingly, the routing table structure is changed to accommodate both the values. The nodes whose *ATV* is greater than the *ATV* Threshold (*ATV_Thresh*) and whose N_{res} is greater than N_{res_min} can participate in the route setup procedure. Thus, the proposed algorithm makes sure that only nodes which have good packet forwarding records and whose residual energy is relatively greater are selected in the optimal path. The first parameter, *ATV*, ensures higher network throughput while the second parameter, N_{res} ensures the extended path lifetime during the communication.

A. Accumulated Trust Value

In the proposed algorithm, initially, all nodes will be initialized with the initial Trust Value *ATV_Init*. Then, the *ATV* will be updated for each session based on the number of packets that the node has successfully transmitted for that particular session. Where, the session is the successful packet transmission scenario till the first packet drop as shown in Fig. 1. Based on the number of successful transmitted packets in the session, the session trust value *STV* will be derived from Table 1 and it will be used in Algorithm 1 for updating *ATV*.

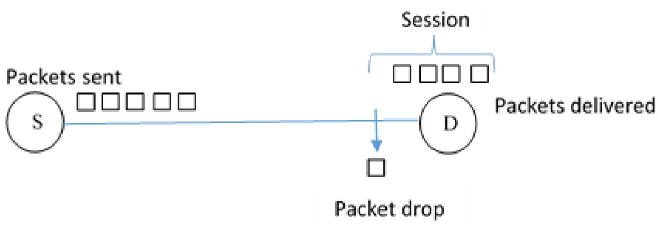


Fig.1. Network scenario of a session.

Table 1. STV based on the number of Packets Successfully Transmitted in the Session.

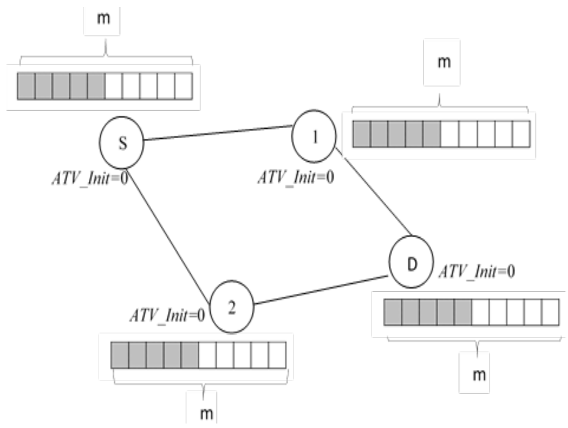
Range (in Packets)	Session Trust Value *(STV)*
<=5	0.5
<=7	0.7
<=9	0.9
<=10	1.0

The below algorithm indicates the procedure for updating the *ATV* of a node.

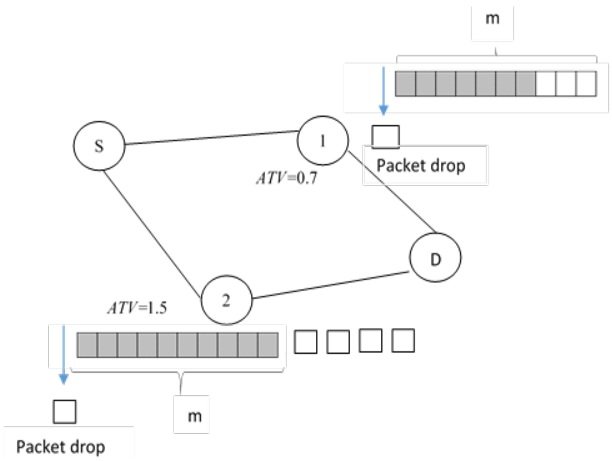
Algorithm 1. Calculating and updating ATV

a) Initialization
 1. Initialize Accumulated Trust Value (ATV) of all the nodes to ZERO
 2. Initialize the ATV_Thresh to 100
 3. Initialize m to 10, where m is size of the queue
b) For each session update the ATV
 If total successfully transmitted packet is = 0 then
  ATV = ATV - 0.5
 else if total successfully transmitted packet is <= m then
  Find the STV from Table 1 based on the session details.
  ATV= ATV + STV
 else
  ATV = ATV + (total successfully transmitted packets in the current session/m)
 end if
c) Node Selection criteria
 If (ATV < ATV_Thresh) then
  Neglect the node
 else
  Treat node as legitimate node
 end if

Fig. 2(a) shows the topological scenario of a network in which all the nodes are initialized to ATV_Init i.e zero. Each node will have a fixed queue size of 'm'. With respect to Fig. 2(b), two cases have been considered and are discussed below.



(a) Initial setup of network



(b) Showing ATV calculation and Session

Fig.2. Topological scenario in a network of nodes.

Case Studies (Considering value of m = 10).

Case 1. For node 1, the correctly transmitted packets in a session is 7. Since, 7 is less than *m*, the corresponding *STV* value for 7 will be taken from Table 1 which is 0.7. Then, the *ATV* will be updated as *ATV* = 0 + 0.7, which results in *ATV= 0.7*

Case 2. For node number 2, if the correctly transmitted packets in a session is 15. Since, 15 is more than *m* the ATV will be updated as *ATV = 0 + (15/10)* which results in *ATV* = 1.5.

B. Energy Aware Model

The different attributes used to frame up the energy model are *transmission energy, reception energy, idle time energy and energy spent during sleep*. Energy consumption for a node can be calculated using Equation (1).

$$\sum_{i=0}^{n} N_{ec}(i) = \sum_{i=0}^{n} N_{Tx}(i) \times t_{Tx}(i) + \sum_{i=0}^{n} N_{Rx}(i) \times t_{Rx}(i) + \sum_{i=0}^{n} N_{ILx}(i) \times t_{ILx}(i) + \sum_{i=0}^{n} N_{SLx}(i) \times t_{SLx}(i) \quad (1)$$

Where, N_{ec} is the energy spend by node N $at\ time\ t$. Energy spend by a node for transmission and reception is indicated as N_{Tx} and N_{Rx}. While N_{ILx} and N_{SLx} represents energy spent by a node during its idle and sleep state.

The total remaining energy of a node N_{res}can be calculated using Equation (2), by subtracting the total energy consumed from the initial energy.

$$\sum_{i=0}^{n} N_{res}(i) = \sum_{i=0}^{n} N_{ini}(i) - \sum_{i=0}^{n} N_{ec}(i) \quad (2)$$

A node's energy plays a crucial role in the path as well as in network lifetime. A low-energy node in a path can cause path breakups, resulting in route re-selection and latency. Furthermore, a less energy node might hinder the path throughput as it may drop the packets because of N_{res_min} criteria. Thus, in the proposed algorithm, a raider is put on the node selection criteria with respect to node's residual energy. Each node after passing the ATV criteria, should pass the N_{res_min} criteria as well.

Fig. 3 shows the different stages of a node's N_{res_min}, where a node's battery life is divided into three different stages, Green stage (> 20%), Warning stage (<20% and >10%) and the Danger stage (< 10%) [31]. The proposed algorithm makes sure that no path will contain Danger stage nodes. Warning stage nodes might soon move to the danger stage which is a threat to the ongoing communication which may lead to path breakup and reduced throughput. Thus, the proposed algorithm will also ensure that the primary path does not include any nodes which are in the Warning stage.

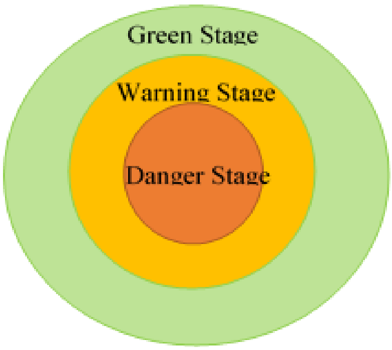


Fig.3. Energy status of a node

The Algorithm 2 chooses the node for the paths based on the ATV as well as the above said criteria.

Algorithm 2. Node and Path Selection.

Node Selection Criteria

During Route Discovery phase
When a node receives RREQ Packet
    If destination node then
        Send RREP
    Else If (ATV > ATV_Thresh && N_{res_min} > Danger Stage) then
        Forward the RREQ Packet.
    Else
        Discard the RREQ Packet.
    End if

Path Selection Criteria

At the point, when the source node gets RREP packet,
    If AOMDV_max_paths_ have been reached then
        Discard RREP.
    Else If the path contains Warning stage nodes then
        Neglect the path
        Discard RREP and wait for the next RREP
    Else
        If !Primary Path
            Make the path as the optimal/primary path.
        else
            Store the path as the suboptimal path.
        End if
    End if

Fig.4 shows the workflow of the proposed TEA-MDRP algorithm which depicts how the *ATV* of a node will be calculated by the algorithm based on the session value and subsequently, how an energy efficient and legitimate node will be included for route discovery phase.

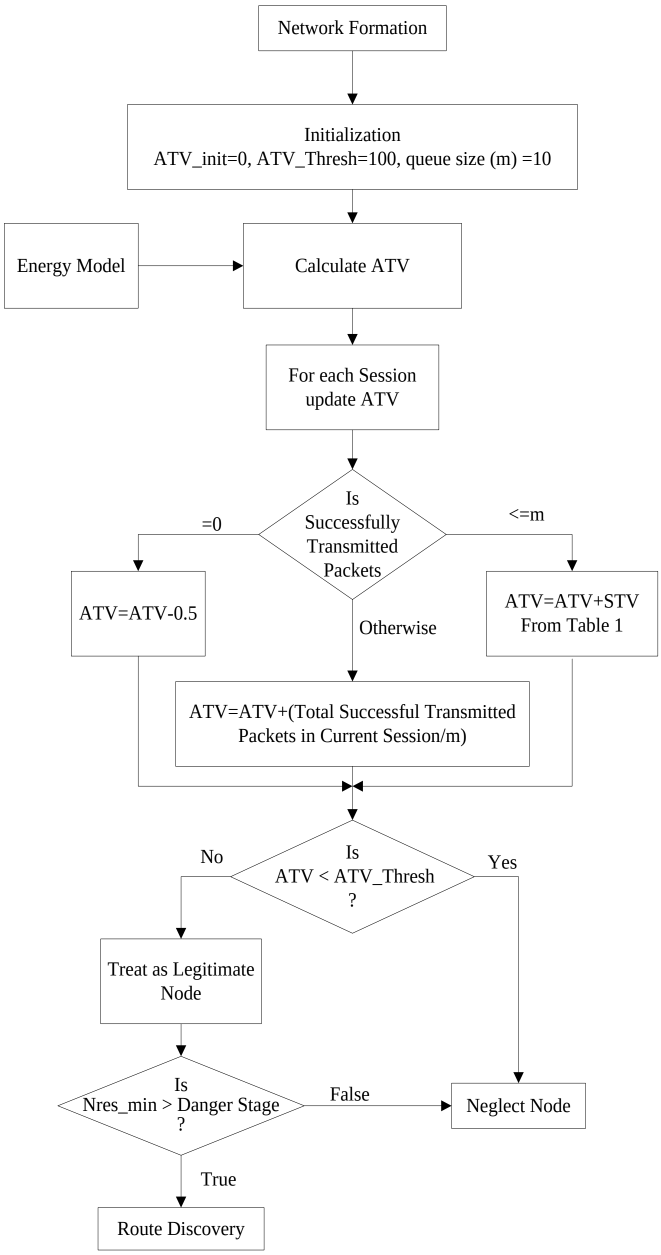


Fig.4. Working of proposed protocol TEA-MDRP based on Accumulated Trust Value (ATV)

3.3. *Stability Study*

AOMDV is an on-request routing convention which communicates a Route request packet (RREQ) to every one of its neighbors to discover the route. Intermediate nodes verify the destination address and accordingly, they rebroadcast RREQ to their neighbors. A RREQ packet traversing from various paths arrives at the destination. A Route reply (RREP) packet will be sent at the destination node against receiving of RREQ packet [32]. The classical multipath routing algorithm, for example AOMDV [33-35] finds multiple paths for a single source destination pair and these routes may have non-legitimate nodes (less energy and a bad packet forwarding record) which may tend to unstable paths. Unstable paths cause link breakage and that leads to frequent route failures and reduced throughput. Frequent route failure leads to a number of route re-discoveries and finally increases the routing overhead. Keeping routing overhead of the network at minimum is the primary task of the stability enhanced routing protocol.

The proposed algorithm uses the trust value and node’s residual energy while selecting the node for the path. The algorithm allows only the nodes which have a good trust value and a sufficient residual energy. The good trust value node shows loyalty in forwarding the packets while a sufficiently large residual energy node avoids frequent path breakups and packet drops. Thus, the proposed algorithm not only increases the network and path lifetime but also increases the throughput of the communication. Further, with the legitimate nodes in the paths, the proposed algorithm considerably reduces the control packet overhead which might occur because of route re-discovery.

4. Performance Evaluation

The Network Simulator-2 (ver.2.35) is used to test the proposed algorithm [36] for the qualitative and quantitative analysis. For the simulation, an area of 900m x 900m is considered with a node density ranging from 25 to 200. All node's transmission range has been set to 250 meters and the mobility model is set to Two Ray Ground mobility model. Each node's initial energy is set to 100J and the packet size is considered as 512 bytes. Further, 0.6w and 0.2w are assigned as transmitting and receiving powers respectively. The traffic mode used is User Datagram Protocol (UDP)/Constant Bit Rate (CBR) for multiple node creation and establishing communication among nodes. The total simulation duration is set to 200 seconds. The results obtained from the simulation for the proposed algorithm are compared with AOMDV protocol for different QoS parameters like throughput, packet overhead, packet delivery ratio, and energy efficiency.

Fig. 5 shows the graph for energy consumption vs. node density of the TEA-MDRP and AOMDV as the energy consumption is an important metric to analyze the performance of the network. The energy consumed at lower network density is 85.78j and 82.02j by AOMDV and TEA-MDRP, whereas the energy consumed at higher density networks is 97.18j and 92.26j by AOMDV and TEA-MDRP respectively. The TEA-MDRP is consuming less energy when compared to standard AOMDV, because of the stable and most legitimate nodes involved in the path. The path's stable nodes avoid frequent path breakups which in turn avoids route rediscovery. Thus, TEA-MDRP burns less energy when compared to AOMDV. Furthermore, TEA-MDRP reduces control packets with stable nodes in the path which also contributes to the less consumption of the energy in the proposed algorithm.

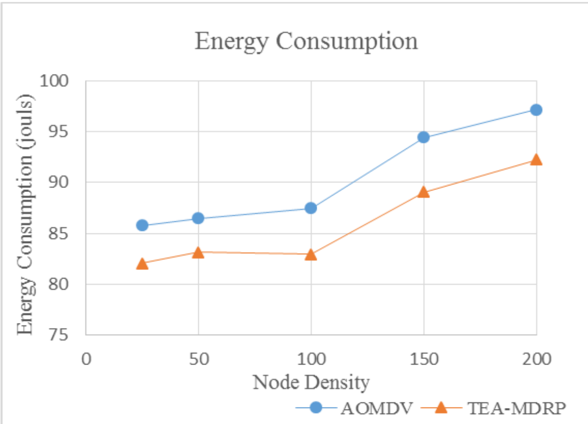


Fig.5. Energy consumption Vs Node density

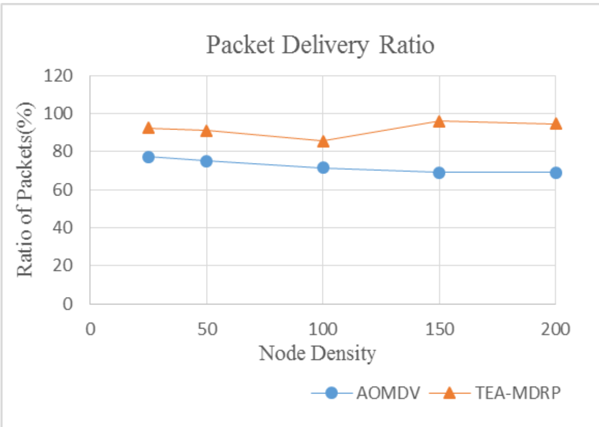


Fig.6. Ratio of packets Vs Node density

The packet delivery ratio (PDR) is measured as the total number of packets sent from source to that of the packets received at the destination and the same is shown in Fig. 6, where for the low node density 77.25% and 92.28% of packets were reached to the terminus by AOMDV and the TEA-MDRP respectively. When the network grew, the packet delivery percentage decreased to 68.87% with AOMDV and it increased to 94.51% with the proposed TEA-MDRP. This is mainly due to the reasonably higher energy nodes in the path which avoids path failures and packet drops. The TEA-MDRP could manage to deliver a good number of packets to the destination though the network tends to be congested. Further, as the control packet overhead is reduced in TEA-MDRP, the nodes can completely focus on the data packet transmission without wasting much of its time thus increasing the throughput.

The end-to-end delay is the time that a data packet experiences while traversing from the source node to the destination node and the same can be seen in Fig. 7. The proposed protocol managed 0.5ms with the lower node density against 0.82ms delay incurred by AOMDV. The delay of 0.76ms for TEA-MDRP against the 1.02ms delay produced by AOMDV at the higher density of the network. The overall delay of the TEA-MDRP is less when compared to standard AOMDV because of the trustiness nodes in the path which makes sure that the packets are forwarded without hiccups.

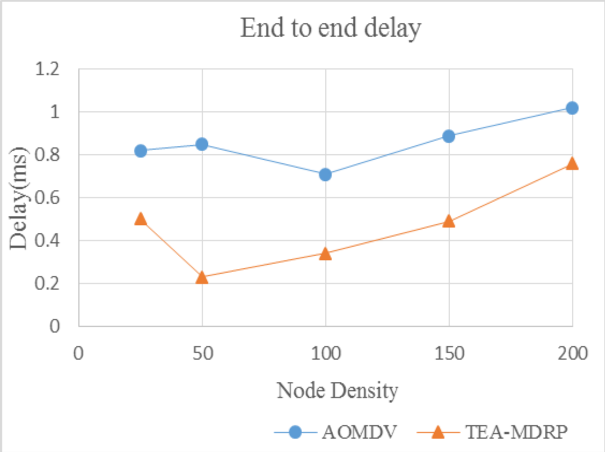


Fig.7. Delay(ms) Vs Node density

Throughput is the total number of bits received by the receiver node per unit time. Fig.8 shows the graph of throughput Vs node density for both AOMDV and proposed protocol at lower and higher network density. The proposed protocol managed to get good throughput for two reasons. The first being its low bandwidth and power consumption. The other reason is the presence of most stable and energized nodes in the selected path. The proposed protocol has a throughput of 1215.21 kbps against 870.6 kbps of AOMDV at lower density of the network. TEA-MDRP produced 1429.83 kbps of throughput against 671.78 kbps of AOMDV protocol at higher high density. Overall, the proposed protocol, TEA-MDRP, managed to produce 85% better throughput to that of the conventional routing protocol AOMDV.

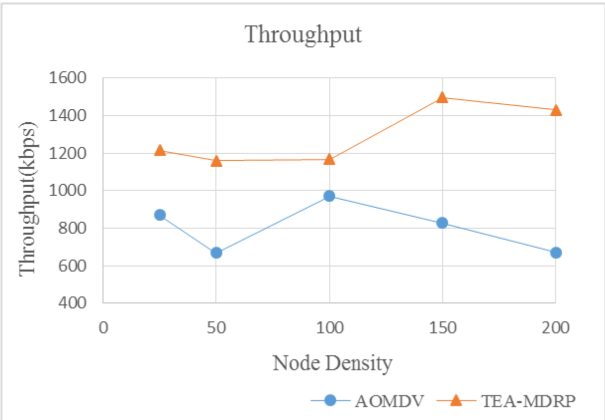


Fig.8. Throughput Vs Node density

In Fig.9, control packet overhead Vs node density has been plotted. It can be observed that, when compared to the overhead of the existing AOMDV protocol, the proposed protocol TEA-MDRP, has a lower control overhead of 13% less. We can notice that the overhead grows as the number of nodes grows in the network. Overhead packets are generated to maintain the paths for the protocols. The AOMDV protocol undergoes path breakups more frequently, hence the control packets generated are more when compared to the proposed TEA-MDRP. The stable nodes that are present in the path of TEA-MDRP, in terms of higher energy, reduces the frequent path breakups which in turn lessen the frequent re-route discovery process.

Fig.10 shows the node density vs. network lifetime of the TEA-MDRP and AOMDV protocols. The network lifetime is also an important metric to measure the network performance. The increased network life is recorded from inception till the end in the case of proposed protocol compared to standard AOMDV. The proposed protocol assures a better network lifetime during the routing process to that of the lifetime of standard AOMDV. It is because of more stable and trustworthy nodes in the network which always possess sufficient energy to take part in the data transmission process.

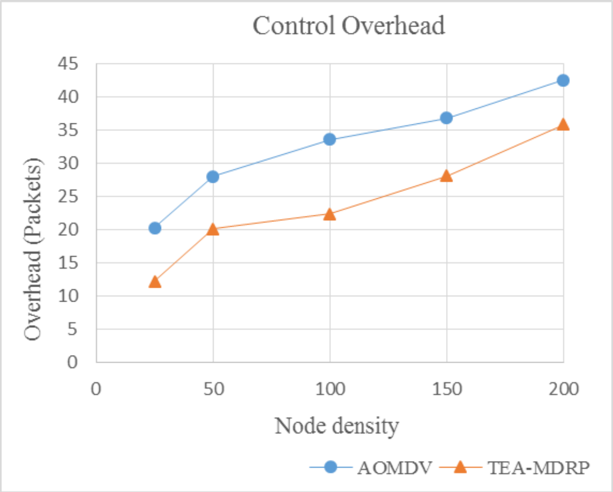


Fig.9. Overhead Vs Node density

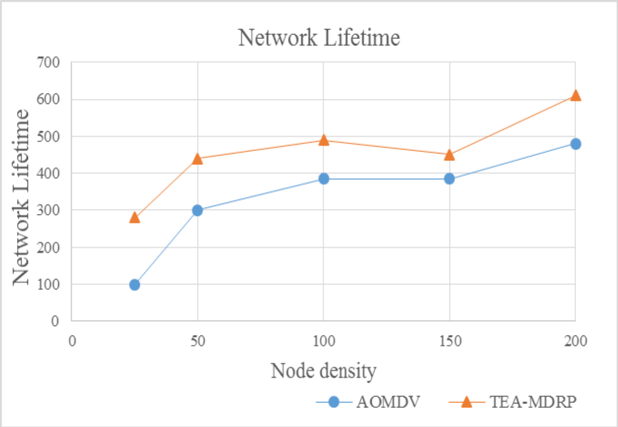


Fig.10. Network lifetime Vs Node density

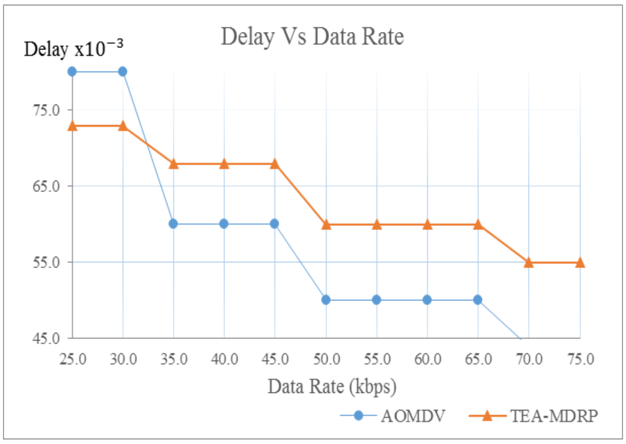


Fig.11. Delay Vs Data Rate

Fig.11, shows the graph of delay Vs data rate which exhibits that initially the delay with AOMDV is more and for the subsequent data rate the delay becomes less compared to the proposed protocol. Energy efficient Vs. Data rate has been plotted in Fig. 12, initially, when the data rate is at low, the energy efficiency is also low, but when the data rate keeps on increasing the energy efficiency is also increasing and it is almost more than 90% at the end; whereas, for AOMDV has got efficiency of almost 73%. This behavior of the TEA-MDRP is observed only because of its distinguishing factors related to routing and queuing process.

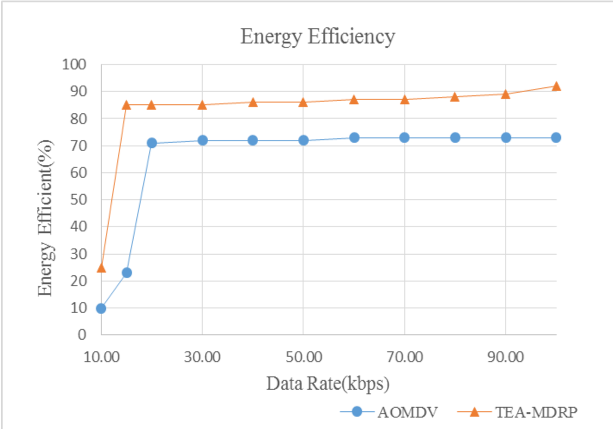


Fig.12. Energy Efficiency Vs Data Rate

4.1. TEA-MDRP Efficiency

As for the validity and the efficiency is concerned, the proposed protocol TEA-MDRP remains valid till the destination node is reachable or until all the discovered routes are utilized/expired. Whenever the node enters the network area, every node gets its initial ATV and further, the initialized ATV will get updated as and when the nodes' packet forwarding capacity is recorded. Later, the node residual energy is also administered to decide whether the node can contribute enough in the path or not. These nodes with trustiness are allowed to build the route setup. A good *ATV* shows node's loyalty in forwarding the packets while a considerably large residual energy node avoids frequent path breakups during the communication which in turn avoids packet drops. Thus, the TEA-MDRP increases the network and path lifetime (because of sufficiently large residual energy) and the throughput (because of TEA) of the communication. Further, with the legitimate nodes in the paths, the TEA-MDRP considerably reduces the control packet overhead which might occur because of the frequent route re-discovery process.

The above-mentioned points can be seen in the simulation results where TEA-MDRP shows good performance over classical AOMDV in terms of energy efficiency, delay, throughput, network lifetime and overhead parameters.

5. Conclusion and Future Work

In this article, our trust node and energy based multipath routing protocol TEA-MDRP is a useful framework for MANETs. TEA-MDRP updates the trust value of the nodes based on its packet forwarding capacity and also, the node's residual energy is used to find the stable paths in MANETs. The proposed TEA-MDRP uses reasonably higher energy nodes in the path which reduces the number of route failures, which will in turn minimize the route re-discovery and meanwhile, the control packet overhead too. Due to the reduced control packet overhead, the TEA-MDRP achieves a better throughput of 93% and packet delivery ratio of 85% than standard AOMDV. The proposed stable trust value protocol includes nodes in the path which exhibits trustiness in forwarding the packets, thus, further increasing the throughput. In Addition, TEA-MDRP also shows less energy consumption when compared to standard AOMDV because of trusted nodes' involvement in the routing process. The advantage of TEA-MDRP is that the trustiness can be calculated based on actions and tasks, hence this can be applied in any network. On the other hand, the disadvantage is that it does not use either recommendations or the past observations. Hence, the trustiness is measured in totally instantaneous and node dependent. The quantitative and qualitative analysis has been carried out using Network Simulator-2 (NS-2.35) to simulate TEA-MDRP and the findings were compared to classical AOMDV. The comparison results were found in favor of TEA-MDRP and are very encouraging.

The future work is to implement the proposed algorithm for highly dense networks with heterogeneous nodes and for higher mobility rate and also to address the link trust issues taking *ATV* as the prime parameter. The trust value of all nodes will not be calculated using the same functional descriptions; hence, an investigation is needed on incorporating network dynamics and heterogeneity while calculating trustiness.

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