Mobility Control for Reliable Transmission in Mobile Ad-hoc Networks

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Abstract—One of the challenges in the MANET is the evaluation and design of an effective Mobility Control protocol that works at low data rates and responds to dynamic changes in the network topology for different Mobility Models. Several ad hoc protocols have been designed for accurate, fast, reliable routing for a high volume of changeable network topology. Such protocols must deal with the typical limitations of changeable network topology, which include high power consumption, low bandwidth, and high error rates. In this paper, we proposed a new mobility control algorithm for improved route availability in highly dynamic safety critical environment where the Ad-hoc nodes may potentially move out of range from others. The Ad-hoc network is divided into clusters and a cluster head is selected from each cluster periodically using weighted cluster algorithm. Using extreme machine learning approach, these cluster heads predict the trajectories of all the nodes in its cluster and run mobility control function for all those nodes that may move out of range from other nodes. This mobility control function updates the future mobility states of the selected node. The simulation results report that the proposed approach yield better performance than state of art approaches.

Index Terms—Mobile Ad-hoc Networks(MANET),Weighted clustering algorithm(WCA),Extreme machine learning,Clusters,Cluster head,Coordinate node,Mobility state,mobility prediction,Overhead,routing,Topology.

1 Introduction

Mobile ad hoc networks (MANETs)[1] represent self-configuring and self-organizing multi-hop wireless networks with no centralized control. In Manet wireless connection and spontaneous interaction take place between many mobile nodes in a highly dynamic environment.

In the last few decades due to the advanced development of communication services, their availability and rapidly emerging deployment demands, researchers on Mobile Ad-hoc Networks in different areas has been increased. These research areas vary from acritical social networks to safety-critical domains such as battlefields, disaster rescue operations,etc[1]. As MANET is de-centralized Network, communication in MANET is the only means of data transmission over the open wireless medium[3].The use of node mobility in such cooperating communication environment is beneficial for desired service provisioning as well as improving communication performance [4]. Several reactive and proactive mobile ad-hoc routing protocols [5], such as AODV, OLSR, DSR, etc. have been proposed till the date for realizing necessary communication among nodes

MANETs are self-organizing networks[6] because, they do not use any infrastructure such as base station or router. This implies that every node performs as a host as well as a router, since it is in charge of routing information among its neighbors, contributing to and maintaining connectivity of the network. Thus, in a MANET, the mobility control approach used is of primary importance because it determines how a data packet is transmitted over multiple hops from a source node to a destination node.

The route formation should be performed rapidly, with minimal overhead. The routing protocol must also adapt to frequently changing network topologies caused by nodes mobility, as well as other network characteristics.

An example of mobile ad hoc networks can be described as a group of soldiers in a war zone, wirelessly connected to each other with the help of limited battery-powered devices and efficient ad hoc routing protocols that help them to maintain quality of the communication while they are changing their positions rapidly. Therefore, routing in ad-hoc wireless networks play an important role in a data forwarder, where each mobile node can act as a relay in addition to being a source or destination node.

A mobility control protocol is a convention or standard, that controls how nodes decide which way to route packets between computing devices in a mobile ad hoc network. In ad hoc networks, nodes are not familiar with the topology of their networks. Instead, they have to discover it. Typically, a new node announces its presence and listens for announcements broadcasted by its neighbours. Each node learns about others nearby and how to reach them and may announce that it too can reach them. A major class of research in MANETs is focused on developing several efficient mobility control approaches which incur minimum costs in terms of security, bandwidth and battery power Nodes in wireless sensor networks are low cost and economical to use. Hence there is no problem of limitation of resources. Battery drained nodes can be replaced by new nodes instead of replacing the only battery.

In addition to the autonomous nature of node mobility, the inherent resource constraints such as energy, bandwidth, radio range, etc. cause frequent route failures and critical packet loss in MANET. This, in turn, affects the reliability of data transmission along with the overall performance of the underlying routing protocol in the backbone ad-hoc network. The state-of-art routing protocols[7] can barely adapt to the frequently changing channel and network topology conditions.

Some of the researchers [8][9][10]those worked in the area of Mobility control in MANET focused and developed only localized versions of MANET and regulate the mobility of the nodes by adjusting their transmission range as desired. The reason this idea not being a practical one in the context of MANET is that there will be a heavy impact on the power degradation and mobile nodes are not possible to extend their transmission ranges without high power backup.Another limitation of this applicability of Topology control algorithms in the context of MANET is the restricted range of ad-hoc node to a certain level[11]. On the other hand, few researchers have contributed towards actually controlling the mobility of the nodes in MANET up to a certain level.

Most of the researchers on mobility control contributed only on optimizing the power level of each node and minimizing the network interference. In addition, a majority of the algorithms yield a minimally connected domain, which suffers from frequent link failures. Link failures result in critical packet loss and re-transmissions that have a huge impact on the network performance. Majority of the research activities focus on topology control approach [12][13] in specific application contexts in order to achieve better coverage and ensure higher connectivity. Hence, it is necessary to consider the effect of node mobility on the performance of In mobile ad-hoc networks. For a lower mobility scenario, the impact of mobility on delay, throughput, and PDR can be ignored. But, for higher mobility scenarios, the node may move out of the others radio range frequently and quickly so that the links become unstable leading to unexpected route failure. Hence, the transmission delay, throughput, and PDR gets affected significantly. Hence, the state-of-art topology and mobility control mechanisms fail in providing reliable end-to-end transmission along with improved overall performance in highly mobile tactical and safety-critical ad-hoc environments.

The motivation of developing an efficient and reliable mobility control mechanism in MANET has been driven due to all the above limitations in existing research works. In this paper, we have proposed a novel mobility prediction and control mechanism for MANET that ensures reliable end-to-end data transmission without compromising the performance of the underlying network. We have modeled and evaluated the network in a 3-D Cartesian coordinate system for realizing the proposed mobility control technique in real-world environments. The proposed approach is mentioned below.

1. We first considered the dynamically changing topology of the network into account. So predicting the mobility state of the nodes which may potentially move out of range from others is the first task. Using Weighted clustering algorithm, we divided the network into different clusters and a cluster head is selected from each cluster based on different criteria.

2. Nodes that are within the transmission range of two cluster heads are called gateways, and they usually handle inter-cluster communication. As all other nodes in the network, a gateway may belong to one cluster only. A cluster-head maintains a list of all its members along with their trust values, while a cluster member only knows its cluster-head and monitors continuously its trust value.

3. Once the Cluster heads are selected, it iteratively executes the extreme learning machine based one-hop prediction function to determine the future trajectories of those nodes which may potentially move out of range from others. Accordingly, the Cluster head sets flag in its routing table for the entries of those nodes which are predicted to move out of its range, so that it is not selected as the cluster head in near future.

4. In this phase, Cluster head detects the nodes in that cluster that may potentially move out of range from it. Cluster head runs mobility control function and sends appropriate packets to those potential nodes to change those trajectories.

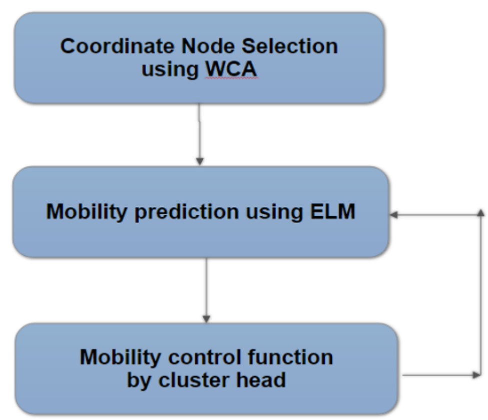

Fig. 1. Flowchart

The proposed mobility control protocol is implemented on the top of the routing protocol. The flowchart of the proposed mobility control as shown in Fig. 1 shows that the approach consists of 3 phases. They are described as follows.

The rest of the paper is organized as follows. Section II mentions related previous works. Section III presents the proposed mobility control protocol for highly dynamic mobile ad-hoc environments. Section IV contains simulation results of our proposed protocol. Section V concludes the paper.

2 Related Works

Many Mobility control algorithms are proposed in mobile ad-hoc networks but these do not guarantee connectivity among nodes all time. Probabilistic algorithms[14] maintain connectivity among nodes by adjusting transmission range along with balancing power consumption and contention level[15][16]. nodes which are deployed without the need for any fixed infrastructure. Centralized algorithms provide optimized solutions based on global view and, hence, are not feasible in infrastructure-less ad-hoc networks.

Mousavi et al. introduced an adaptive mobility prediction based distributed topology control mechanism with the aim to reduce power consumption of mobile nodes[15]. Later on, they proposed a mobility prediction method based on pattern matching in which each node predicts its future position through finding identical patterns in its movement history. This results in improved prediction accuracy and reduced energy consumption in MANET. In 2009[10], another group of researchers proposed a different approach to control speed and directions of the knowledge sharing agents based on genetic algorithms (GAs) to obtain a uniform distribution of the ad-hoc nodes over a geographical region. Using a simplified particle swarm optimization, Hunjet et al. reduced the interference and energy consumption placing additional nodes at crucial points simultaneously controlling nodes transmission range. As a security application, Patrick Tague in 2010[11], presented a mobility control framework in the adversarial ad-hoc network to reconfigure the nodes geometry to improve attack impact and protocol performance.

Another group of researchers proposed a distributed and adaptive power and position control algorithm based on the computation of mobile agents cost functions for non-cooperative robotic ad hoc and sensor networks. As an improvement to this work, Hee-Tae Roh, and Jang-Won Lee[17] formulated a joint mission and communication aware mobility control protocol converging to the Nash equilibrium for Mission-critical ad-hoc networks. Here, the individual nodes have their own specific missions and have a goal to achieve a certain degree of satisfaction as well as good communication quality that depends on the their locations. In 2013, Le et al.[18] proposed RoCoMARMoP (Robots Controllable Mobility Aided Routing with Mobility Prediction) that comprises of the link quality based route discovery and the link reinforcement process that provides high-quality data transmission in MANETs. Another work, i.e., B.A.T.Mobile, an extension of the B.A.T.M.A.N[19] routing protocol leverages the knowledge derived from mobility control process guiding the routing behavior of unmanned autonomous vehicles (UAVs) to accomplish a dedicated task in MANET.

From the literature survey, it is evident that the node mobility in MANET plays a key role in routing and effects the performance of the underlying routing protocol. The major class of researchers on topology and mobility control focused mainly on reducing the energy level of the nodes and the network interference. However, these are prone to suffer frequent link failures in a highly mobile environment with limited individual radio range and deteriorate the network performance, i.e., the Packet Delivery Ratio (PDR), throughput and End-to-end delay (E2E delay). In addition, the lack of high power backup and the limited transmission range of an ad-hoc node restricts the applicability of state-of-art topology and mobility control algorithms in a highly mobile tactical and safety-critical ad-hoc environments. Therefore, an adaptive mobility control approach is desirable in the context of MANET that ensures improved performance irrespective of the varying mobility level without affecting the overall performance.

3 Mobility control protocol

In this section, we presented a novel mobility prediction and control mechanism for MANET that ensures reliable end-to-end data transmission with improved overall performance of the underlying network.The overview of the proposed mobility control protocol is shown in the below figure.

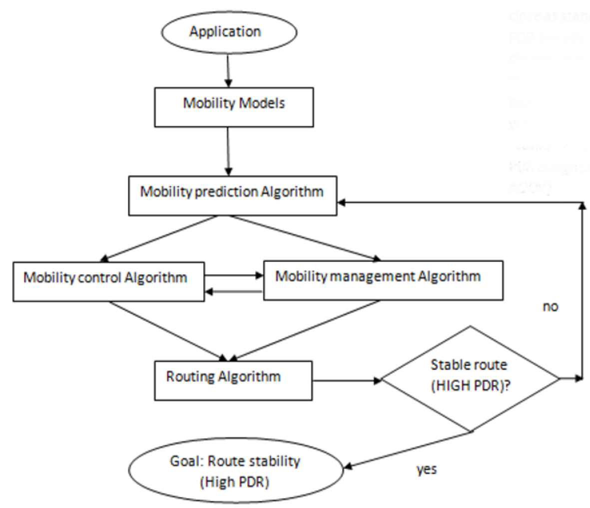

Fig. : Cross-layer solution: utilizing the mobility control in routing

3.1 Cluster head selection

Initially the entire MANET is logically divided into clusters and a cluster head is selected from each cluster using Weighted Cluster algorithm. In this way Logically dividing the clusters makes control process easier as MANET is a distributed and infrastructure-less network.

In our work, we have considered nodes in the network in 3-D Cartesian coordinate system which is significant in recent Mobile Ad-hoc Network application contexts. The cluster head selected by WCA is alternatively called as coordinator node in our work which iteratively executes the prediction and control function till convergence.

The clustering procedure considers several network parameters such as: the node degree, the battery power, transmission power, and mobility of the nodes. Depending on specific application and context, any or all of these parameters are used in the metric to elect the cluster heads to deal with the trade-off among a number of cluster heads, cluster size, latency, power consumption, and information processing per node. WCA elects a minimum number of cluster heads to support all the nodes in the network satisfying all constraints.

To decide the suitability of a node to be a cluster head, WCA takes into account its degree, battery power, transmission power, and mobility. We have considered the following features in our clustering algorithm:

i. Optimization of the degree of each cluster head to assure efficient medium access control (MAC) functioning.

ii.Selection of a node as cluster head that is not a target node in the past.

iii. Efficient use of the battery power within certain transmission range.

iv. Non-periodic execution reducing system updates thereby minimizing computation and communication overhead.

v. Selection of a node as cluster head that has low mobility frequency.

Weighted clustering algorithm (WCA)[20] effectively integrates the above network parameters with certain weights selected according to the requirements.It consists of following steps.

Step 1: Remaining power or battery left for each node $v$is computed B_v

Step 2: The neighbors of every node v is defined as its degree d_v and are determined as

$$d_v = |N(v)| = \sum_{v' \in V, v' \neq v} dist(v, v') < tx_{range}$$

Step 3: The degree-difference for every node v is computed as, $\triangle_v = |d_v - \delta|$

Step 4: For each node, the sum of the distances with all its neighbors is denoted as D_v and is determined as,
$D_v = \sum_{v' \in N(v)} dist(v, v')$

Step 5: Calculate the average of the speed for each node till current time instant T. This defines the measure of mobility which is denoted by M_v. It is defined as,

$$\frac{1}{T} \sum_{t=1}^{T} \sqrt{(X_t - X_{t-1})^2 + (Y_t - Y_{t-1})^2 + (Z_t - Z_{t-1})^2}$$

where (X_t, Y_t, Z_t) and (X_t1, Y_t1, Z_t1) are the Cartesian coordinates of the node v at time t and (t 1), respectively.

Step 6: Then the cumulative time, P_v, during which a node v acts as a cluster head, is computed. P_v indicates how much battery level has been consumed for being a cluster head as compared to an ordinary node.

Step 7: The total weight W_v for each node v is calculated as,
$W_v = w_1\Delta_v + w_2 D_v + w_3 M_v + w_4 P_v + w_5 B_v$
where w_1, w_2, w_3 ,w_4 and w_5 are the weights chosen for the corresponding network parameters.

Step 8: The node with the smallest W_v value is chosen as the cluster head. The neighbors of the chosen cluster head do not participate in the election procedure.

Step 9: Follow steps 2 - 7 for the remaining nodes those are not yet elected as a cluster head or are members a cluster.

3.2 Mobility Prediction

Extreme machine learning[21] based approach is used for mobility prediction. Cluster head selected from the above approach runs Mobility prediction function periodically execute to identify the nodes potentially going out of range.

This architecture is composed of three layers arranged in a feedforward fashion: The first layer is the input layer which represents the dynamic memory of network. This memory is originated by a feedback between the output layer and the input layer; as well as feedbacks between neurons themselves from input layer. The activation function used is sigmoid function and the total number of hidden layers is 1.

Unlike multilayer perceptrons (MLPs), extreme learning machine (ELM) [22] capture better the existing interaction/correlation between the Cartesian coordinates of the arbitrary nodes leading to more realistic and accurate mobility prediction based on several standard mobility models.

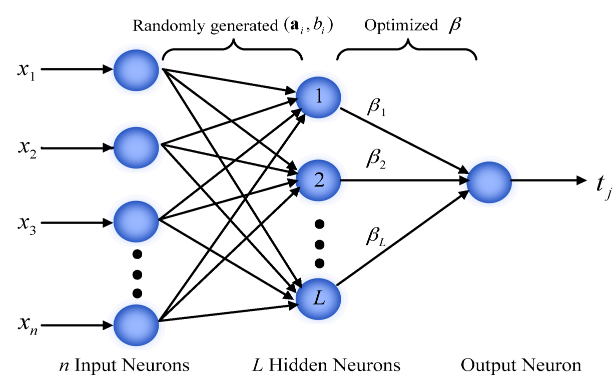

Fig. 2. Extreme Learning Machine Model

The Mobility state M_n of a node n is a two-tuple $< P_n, V_n >$, where $P_n = (X_n, Y_n, Z_n)$ is the current cartesian coordinate of the node n. In each cluster, the cluster head has the mobility information up to 2-hop neighboring nodes from it. The cluster head has mobility state information for a series of time sequence. Now the cluster head runs the Mobility prediction using extreme learning approach by passing mobility information for a series of time sequence.

3.3 Mobility control function

The Cluster head sets flag for the nodes that potentially move out of range from its range. Then the cluster head runs Mobility control function for those target nodes to change their trajectory and bring into its range.The following steps are followed.

1. The Cluster head sends a control packet to the target node to modify its next mobility state. Control packet contains cluster head IP address, port number, target node IP address, port number and the mobility information that it should change.

2. The target node updates its trajectory i.e mobility state accordingly as sent by its cluster head.

3. The Cluster head then calculates the communication quality of the link on the basis of energy consumption, end to end delay, packet delivery ratio.

4. If the Communication quality obtained is above the route stability threshold then exit, else go to step 1.

Hence, the mobility control process is terminated when the target nodes are placed appropriately for ensuring higher route availability and reliable data transmission. The target position of the nodes are fed back to the mobility prediction phase for recurrent mobility control execution. The in-depth simulation results are reported in the next section.

4 Simulation Results

Simulation is carried using Tetcos Netsim(Version 10.2.10) interlinked with Matlab(version 9.1) and Visual Studio in Windows 8.1 OS platform.

We have created network size from 10 to 30 nodes. Using cluster head selection the network is divided into 4 cluster as shown in the figure. Each cluster has a cluster head and selected as using the cluster head selection algorithm stated above.

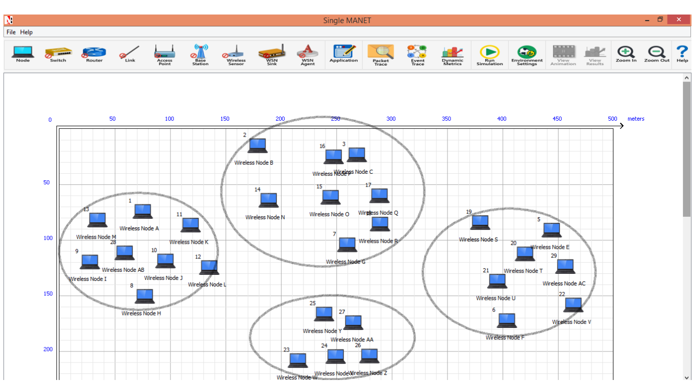

Fig. 3. Manet Model

Cluster Node 3D figure is shown. The simulation of the above network in tetcos network simulator using the steps stated above for cluster head selection gives the following result. Four peaks show that the network is divided into 4clusters and each cluster have a cluster head.It contains peaks which has information about cluster head coordinates.

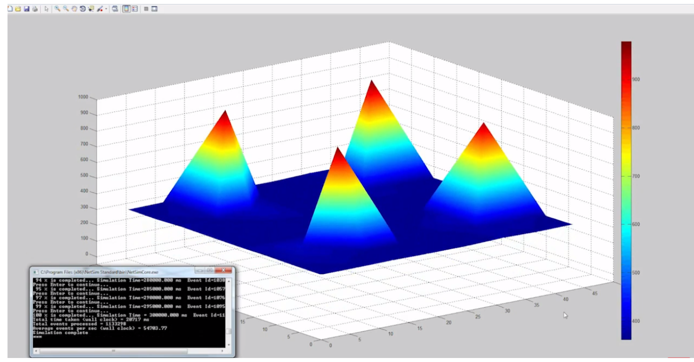

Fig. 4. Cluster head Selection results

After Cluster head is selected, Extreme machine learning approach is used for Mobility prediction. Figure 5 shows actual values of mobility state vs predicted values. Mobility states are takes as function values of $< X_i, Y_i, Z_i >$.

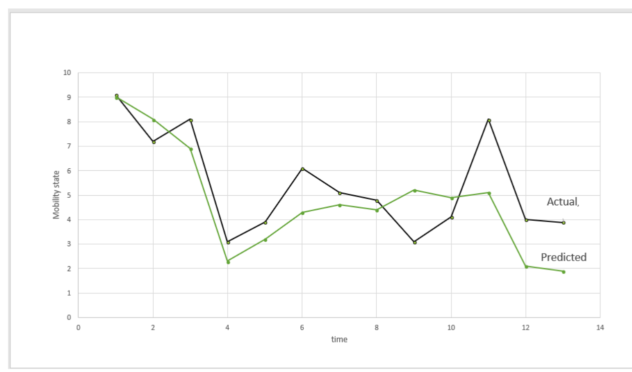

Fig. 5. ELM results

The results of Extreme machine learning approach gives that the function of predicted values of Mobility state is very close to the actual mobility state values.

We have Considered the following parameters for evaluating the Mobility control protocol. We have compared our mobility control protocol with AODV routing protocol based on the following parameters.

(a)Packet Delivery Ratio (PDR) : It is the ratio of Total packets successfully received to the total sent.

(b)Throughput: It is the rate at which information is sent through the network i.e it is the total amount of data received by all nodes per unit time.

(c)End-to-End Delay: Average of the delay (received time minus transmitted time) of every data packet. It is defined as the average time taken by data packets to propagate from source to destination across the network. This includes all possible delays caused by buffering during routing discovery latency, queuing at the interface queue, and re-transmission delays at the MAC, propagation and transfer times etc.

Fig. 6 presents the comparative result of Throughput of AODV routing protocol with and without using our proposed mobility control mechanism with respect to network size (i.e., the number of nodes). We observed that the AODV routing protocol with proposed mobility control mechanism yields better Throughput than the AODV routing protocol without mobility control technique. This is evident as mobility control avoids unexpected route failures by predicting and controlling the mobility of the nodes.

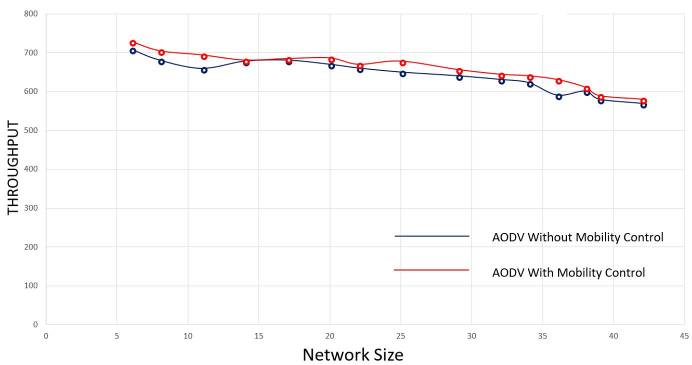

Fig. 6. Comparision of Throughput with respect to Network size

Fig. 7 presents the comparative result of End to End delay of AODV routing protocol with and without using our proposed mobility control mechanism with respect to network size (i.e., the number of nodes). We observed that the AODV routing protocol with proposed mobility control mechanism yields lower End to End delay than the AODV routing protocol without mobility control technique.

Fig. 7. Comparision of End to End delay with respect to Network size

Fig. 8 presents the comparative result of PDR of AODV routing protocol with and without using our proposed mobility control mechanism with respect to network size (i.e., the number of nodes). We observed that the AODV routing protocol with proposed mobility control mechanism yields better PDR than the AODV routing protocol without mobility control technique.

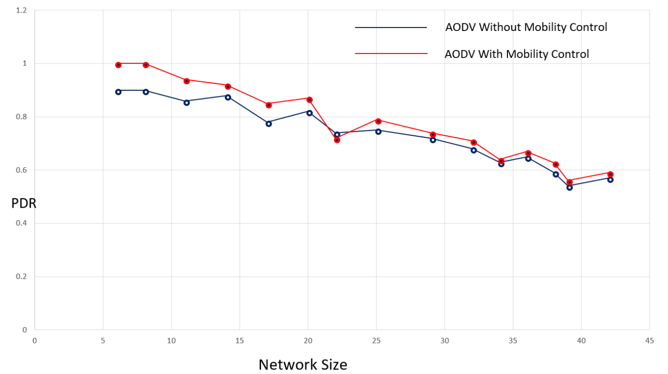

Fig. 8. Comparision of PDR with respect to Network size

5 Conclusion

It is evident from the above simulation results that our proposed mobility control protocol with all state-of-art routing as mobility control avoids unexpected route failures by predicting and controlling the mobility of the nodes.The proposed protocol also ensures the passage of packets through trusted routes only by making nodes monitor the behavior of each other and update their trust tables accordingly. The efficiency of the proposed mobility control mechanism is reported in-depth simulation results by varying network size and randomness in mobility. In future, we will consider the contextual and security features in the mobility control protocol for strengthening the security parameter in MANET.

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