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Simulation Study of Connectivity Performance in MANET Using Random Waypoint Mobility Model

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***Abstract-* This paper evaluates the connectivity performance of a dynamic mobile ad hoc network (MANET) with the help of introducing agent nodes in the network. Although agent nodes are similar to user nodes, their movements and locations with respect to other nodes in MANET improves network connectivity. The simulation result reveals that a better network performance is achieved with the use of agent nodes. However, increasing the number of agent nodes is a trade-off between cost and network connectivity. This simulation study shows that one can obtain good connectivity by using a limited number of agent nodes.**

***Key Words:* Network Connectivity, Random Waypoint, User node, Agent node**

I. INTRODUCTION

An infrastructure-less, self-organizing, computing devices play a vital role in wireless communications. These types of autonomous networks are typically called mobile ad hoc networks (MANETs). It includes heterogeneous devices like lap top, palm top, PDA, notebook, mobile phone or hand-held device, etc. Every device in a MANET is free to move independently and randomly in any direction, and will therefore change its links to other devices often resulting in a frequent topology changes. This dynamic behavior of nodes makes connectivity management challenging in MANETs.

In MANET, packets are transmitted in a multi-hop fashion as there is no central administration in the network. Thus, a source node reaches the destination node on the behalf of other nodes. Military communications including combat, emergency response, and search/rescue manoeuvres are some of the most commonly cited application of MANETs.

The reliability and performance of such network is highly affected by its connectivity. This network connectivity, which will directly affects routing of packets, depends on the links between mobile nodes. Links between the mobile devices sometimes exist, and sometimes do not, depending on the devices' locations relative to each other, their transmission power and the surrounding environment. At any time t, not only the existing mobile nodes may leave the network due to many reasons such as loss of battery power and/or radio signal strength, but also new mobile devices can enter the system. Therefore, it is very likely that one or more users will lose connectivity with the network or with the parts of the network depending on their positions relative to other mobile nodes. In case a mobile node is outside the transmission range of its nearest neighbour in terms of signal strength and/or distance, then its access to the rest of the network is unavailable and hence the node is isolated/disconnected from the network.

There has been very limited work in the literature to improve network connectivity through mobile agents. Orhan Dengiz [1], have proposed connectivity management in mobile ad hoc networks using particle swarm optimization where agent nodes are controlled through GPS system. In this work, multiple mobile agents are considered and no restrictions are imposed on the movement of nodes. The proposed approach is applicable to all user movement models and scenario. The objective function is a network connectivity which is a measure of how the user nodes are connected with each other [1].

In this paper, we proposed a dynamic connectivity management system to maintain connectivity of a MANET by using agent nodes. Agent nodes are designed to move freely each time-step during the operation of the network to optimize network connectivity among user nodes. User nodes are crucial nodes in the network that transmit and/or receive information while agent nodes are only for relaying packets. Practically, this can be achieved using a Global Positioning System (GPS), where each node is equipped with a receiver. Networks may operate in continuous time, however we used random waypoint mobility model where pause time is applied during simulation. The mobile nodes (both user nodes and agent nodes) move randomly and freely without any restrictions in the simulation area. The destination, speed and direction of nodes are all chosen randomly and independently of other nodes. Finally, we have also evaluated the performance of the network with and without using agent nodes quantitatively.

The rest of this paper is organized as follows. Review of relevant literature works are presented in Section II. Section III defines problem statement. Network model is given in Section IV. Simulation and performance evaluation is discussed in Section V. Lastly, Section VI contains our conclusion and future work.

II. BACKGROUND

In [2], the researchers proposed agent nodes to maintain connectivity where some are stationary while the rest are mobile in the network. The user nodes are considered to be stationary here. Each agent node can give service for only a single node at a time. Mobile agents are expected to randomly move between neighbouring nodes periodically. However, this may not represent the dynamic nature of MANETs as source and destination nodes are stationary. Only the mobile agents

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move to deliver messages from source to destination nodes. Hence, this algorithm is best suitable if applied in wireless sensor network scenario where nodes are stationary.

In [3], they introduced the idea of Message Ferrying (MF) and studied its benefit in networks with stationary nodes. The algorithm is focussed on conveying data packets in sparse networks where the MF node moves in a pre-destined route while nodes are stationary. As need arises for a node to send out or receive its own data packet, it must wait for the MF node to approach its vicinity. In [4], they introduced improvements with nodes being mobile. The MF scheme is used to deliver data depending on the prior information by introducing non-randomness to node mobility to provide connectivity among nodes. The two variations of the MF schemes were depending on the initiator a pre-defined movement: ferries or nodes. In the Node-Initiated MF scheme, ferries move around the nodes according to pre-defined routes and communicate with reachable nodes on their way. On the other hand, mobile nodes are expected to move periodically close to a ferry route and communicate with it when a need arises. In the Ferry-Initiated MF scheme, ferries move proactively in order to communicate with nodes. When a node wants to send/receive packets to/from other nodes, it sends a service request to a chosen ferry using a long range radio. Upon reception of a service request, the ferry will adjust its trajectory to meet up with the node and exchange packets using short range radios. Multi-hop communication is achieved by using ferries as relaying node. Thus, nodes are expected to wait for ferries to be around in order to transmit/receive data. This may create unnecessary delays which might affect the performance of the network. Thus, the algorithms might be good if used in non-delay sensitive applications.

In [5], the researchers proposed a system of message transmission by changing the hosts' trajectory. The trajectory modifications can be carried out regardless of the information about the movement of mobile nodes in the system. In the case of known mobile networks, they developed an algorithm for message transmission that assumes the routes of all the nodes in the network are already known. When any host needs to transmit message to another host located in multi-hop distance, it then moves to the nearest node and deliver its message than directly moving towards the destination host which may cost a lot. The nearby host on receiving the message destined to other nodes conveys to another nearby host and continues like this till the destination node is reached. On the other hand, hosts are required to inform all the other hosts about their current position in the case of unknown mobile networks. When a host should send out information about its location update, to whom it should send out this information, and how it should send out this information are the main issues considered. However, in a dynamic MANET where network topology changes frequently, it may not be effective to apply this algorithm. It also generates huge communication overhead to gather and update the location of the individual mobile nodes.

In [6], the researchers suggested an approach that tries to eliminate or delay partitioning by identifying critical links in the network and then reinforcing them either to avoid or delay their failure. It is a proactive approach that works before partitioning has happened. Critical link failures can be avoided or delayed by making local topology changes which can be attained by adjusting the trajectory of a node forming the link or changing the trajectory of less-significant nodes. This will affect only a small fraction of node movements and have little effect on the global scenario. On the other hand, in order to delay the critical link failure, they proposed an external node to strengthens the critical link. The flexible nature of the helper node enables it to constantly adjust its position so as to maintain the connectivity of critical nodes avoiding network partitions.

In [7], [8], the researchers proposed transmission power based topology control. Every node increases its transmission power by a small amount until it reaches a minimum number of neighbours starting from zero. Whenever another node, which so far does not belong to the neighbourhood list, hears the hello message of the original node for the first time, it realizes that the latter has too few neighbours, either sets its power equal to the transmission power of the hello-sending node or leaves it as before, whichever is larger, and answers the hello message. Now the original and new node are able to communicate by establishing a new connection. The original node adds one new node to its neighbourhood list. Only once the required minimum link degree is reached, the original node stops increasing its power for its hello transmissions. At the end each node has at least a minimum number of neighbours. However, increasing transmission power to maintain network connectivity is expensive in case the nodes are far apart.

III. PROBLEM FORMULATION

Connectivity and coverage area are the two key performance metrics in MANETs as the former is the essential requirement for functionality [9], [10] and the latter is one of the primary criteria for effectiveness [11], [12]. Ideally, MANETs are supposed to cover a broad area with sound connectivity among the nodes during movement. These are challenging to achieve practically due to limitations in transmission power and the node spatial distribution resulting from the employed mobility model [13].

Every node in MANET is categorized into either user node or agent node. The former are nodes demanding network connectivity while the later are free nodes for helping the user nodes so as to experience the best possible network service. That means, agent nodes are a kind of nodes used to maintain the connectivity of a node (user node) to its neighbouring node(s) that could have been disconnected otherwise. The user nodes in the MANET move at their own will with random speed and direction in which their future positions are unpredictable. However, by incorporating GPS, it is possible to get the location data of users and agents at central agent control system [1]. Each node has a definite wireless radio transmission range and a limited maximum velocity. Mathematically;

At any time t and set $XY^t = \{(x_i^t, y_i^t) : i \in V^t\}$, MANET can be represented by $G^t = (V^t, E^t)$ and formed as;

$$C_{(i,j,t)} = \begin{cases} 1 \text{ if } S_{ij}^t \leq R_i^t \wedge S_{ij}^t \leq R_j^t \\ 0 \text{ Otherwise} \end{cases} \dots\dots\dots\dots\dots\dots (1)$$

$$S_{ij}^t = \sqrt{\left[\left(x_i^t - x_j^t\right)^2 + \left(y_i^t - y_j^t\right)^2\right]} \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

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Where $i, j \in V^t$ and V^t is the set of nodes available in the network at time t, XY^t is the set of x and y coordinates of a node at time t, R_i^t, R_j^t is the maximum distance between the two nodes beyond which link does not exist, $C_{(i,j,t)}$ is the element of network matrix formed at time t to check the mutual connectivity of user nodes, S_{ij}^t is the Euclidean distance between nodes i and j at time t.

The ultimate objective is to see the impact of agent nodes on the overall connectivity of the MANET. Theoretically, there ought to be at least one path that exists between every user node pair in the network. Consequently, the principal objective is to help connect each user node to every other one and then to mitigate network partition. Mathematically, this overall connectivity objective can be expressed as in [1] follows;

$$C_o^t = \frac{2\sum_{i,j \in N_u^t; j>i} P_{ij}^t}{N_u * (N_u - 1)} \dots\dots\dots\dots\dots\dots\dots (3)$$

Where C_o^t the overall objective connectivity of MANET at any time t, N_u the number of user nodes in the network, P_{ij}^t indicates the status of path between nodes i and j at any time t. Its value is 1 if there is a path between the i^{th} and j^{th} user nodes at time t and 0, otherwise

Similarly, the average connectivity of the network can be obtained by adding all the objective connectivity, C_o^t, calculated at different times during simulation and dividing this by total simulation time. Mathematically expressed as;

$$C_{av} = \frac{1}{T}\sum_{t=1}^{n} C_o^t \dots\dots\dots\dots\dots\dots\dots (4)$$

Where C_{av} the average connectivity of the network, T is the total simulation time taken and n is the number of simulations conducted.

IV. NETWORK MODEL

We assume that each node has the same transmission range, power and distributed randomly in a MANET. Let a MANET is represented by the set of undirected graph G, the set of mobile hosts (user nodes and agent nodes) and the set of edges that link them together be represented by V and E respectively. Then, the network can be modelled as $G = (V, E)$. For every node $i, j \in V$, $(i, j) \in E$ if and only if they are within the same radio coverage in the network or there exist an agent node(s) between the two linking them together. Now let $N_1(n_u)$ be the user node within the transmission range of node $n_u \in V$, and $N_k(n_u)$ be those user nodes out of transmission range of node n_u. There exists a link between the two user nodes, $N_1(n_u), N_k(n_u) \in E$, if an agent node $n_a, n_a \in V$, exists between the two user nodes, but there should not be a user node(s) $n_u \in V$, with the capability of reaching them.

In this paper, we introduced Agent nodes to move randomly and freely in the network so as to convey packets (messages) between user nodes incapable of reaching each other. They do not have any information to transmit by themselves. Rather, they are used only to relay any information/packet/message that they received without processing it. In doing so, they simply help the user nodes to experience the best network connectivity.

User nodes are a type of mobile nodes used to transmit or receive packets. They are also used to relay on packets to their destination and roam freely and randomly in the network without restrictions. More specifically, the destination, the speed and the direction of nodes are all chosen randomly and independently of other nodes in the network.

The random waypoint model is a commonly used mobility model for simulations of wireless communication networks. It is one of the most popular and "benchmark" mobility model to evaluate other mobile ad hoc network (MANET) because of its simplicity and wide availability. The random waypoint mobility model includes pauses between changes in direction and/or speed. A Mobile node begins by staying in one location for a certain period of time (i.e. pause). Once this time expires, the mobile node chooses a random destination in the simulation area and a speed that is uniformly distributed between *[min-speed, max-speed]*. The mobile node then travels toward the newly chosen destination at the selected speed. Upon arrival, the mobile node pauses for a specified period of time starting the process again.

In this paper we have used a random way point model to study the network connectivity of MANET. The various input parameters that are required to create the network are supplied through the structure “s_input”. This s_input structure is used as the input for function Generateu_Mobility and Generatea_Mobility for generating the mobility of user nodes and agent nodes respectively. The two structures su_mobility and sa_mobilty generated by function Generateu_Mobility and Generatea_Mobility respectively is now used in the function test_animate along with s_input and time step to create an animation showing the movement of user nodes and agent nodes in the given simulation area and for the given total simulation time. The animation clearly shows how user node and agent nodes move randomly in the network which is the most basic feature of any mobile ad hoc network consisting of a given number of user and agent nodes.

V. SIMULATIONS AND PERFORMANCE EVALUATIONS

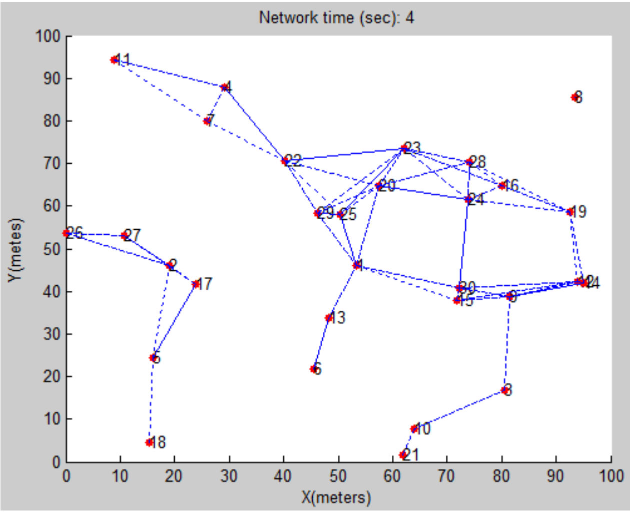
The simulation parameters used in our study is depicted in table 1.

Table 1. Simulation parameters

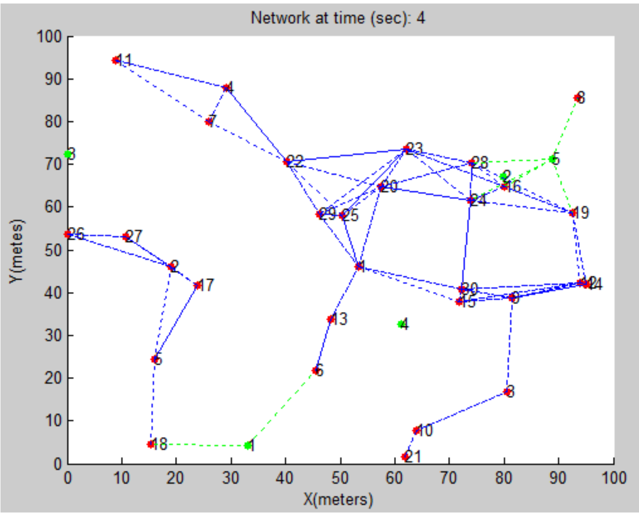
Input parameters	Values
Simulation area	100*100 (m2)
Speed of User node	Interval [0 10] (m/s)
Speed of Agent node	Interval [0 10] (m/s)
Number of User nodes	20 to 60 (increases by 10)
Number of Agent nodes	5 to 20 (increases by 5)
Transmission range	2.5 to 50 (m) (increases by 5)
Pause time	Interval [1 10] (s)
Walk time	Interval [0.1 3.0] (s)
Simulation time	15 (s)
Node direction	-180 to 180 (degree)

We simulate N number of nodes(user nodes and agent nodes) in an area of a100x100 grid [Yang]. Both nodes can randomly move around with a varying speed uniformly between the minimum and maximum values on the pre-defined basis(maximum speed in our case is 10m/s). Once a node reaches its destination, it selects the next target randomly and moves towards it based on the pre-defined pause time. The speed and direction of node is uniformly and randomly assigned without any criteria. We measure the connectivity performance of both user nodes and agent nodes thoroughly. The metrics used for evaluations are: i) transmission range, ii) maximum speed of nodes and iii) number of nodes.

In this simulation study, user nodes vary from 20 to 60 while agent nodes vary from 5 to 20. The maximum speed varies uniformly between 0 and 10m/s. The transmission range varies uniformly from 2.5 to 50. The increment is not sudden rather in steps of 0.25 from 1.0 to 2.0 times the respective transmission range. Fig. 1 shows a snap shot of the network connectivity without using agent nodes and with using agent nodes at instant of time t=4 second. In Fig. 1(a), node 8 is an isolated node while node 18, 5, 17, 2, 27, and 26 are partitioned from the main network. This may degrades the network performance. By using agent nodes as indicated in Fig. 1(b), the isolated node 8 is connected to the main network via agent node 5 while the partitioned group is connected through agent node 1 forming a large connected network thereby improving performance.



a) Without Agent node



b) With Agent node

Fig. 1 A snap shot of network connectivity

A. Simulation Results

Fig. 2 depicts the average connectivity of a network versus the number of user nodes where transmission range and maximum speed are 10m and 2m/s respectively. The results are shown for varying the number of agent nodes. We observe that the average connectivity of the network increases with increasing the number of nodes. This is due to the fact that within a given area, increasing the number of nodes means adding more neighbour to a mobile node which in turn increases the connectivity and vice versa. Although increasing the agent nodes increases the connectivity of the network, it incurs a cost. Thus, connectivity and number of agent nodes in the network are a kind of trade-off between them.

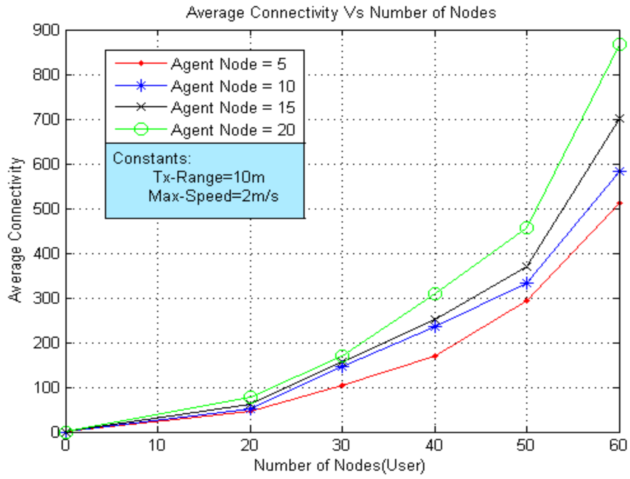


Fig. 2 Average connectivity versus number of nodes

Fig. 3 shows the average connectivity versus transmission range. The maximum speed and number of nodes are kept constant as indicated in the Fig. 3. The results are shown for varying transmission range by a constant factor so as to obtain the higher transmission range. The constant factor is varied from 1.0 to 2.0 with increments of 0.25. The simulation result clearly reveals that the average connectivity increases with increasing transmission range, fastly between 7.5 and 27.5 beyond which it becomes constant. This is due to the fact that a mobile node with a large transmission range will cover a large area. On the other hand, within a restricted area, increasing the transmission range beyond a limit(27.5m in our case), will not increase the network connectivity anymore.

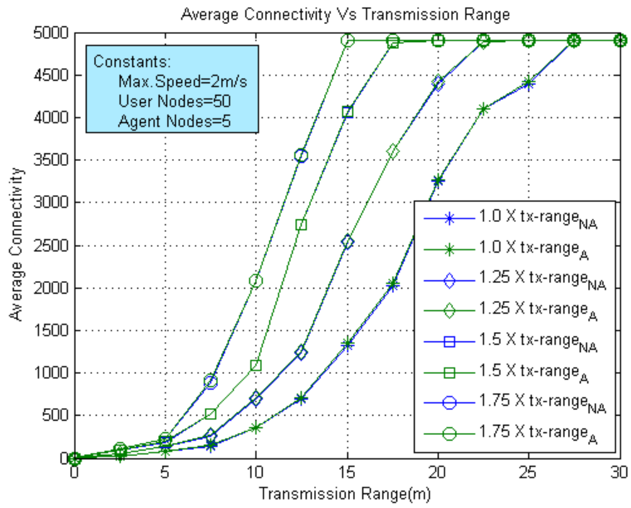


Fig. 3 Average connectivity versus transmission range

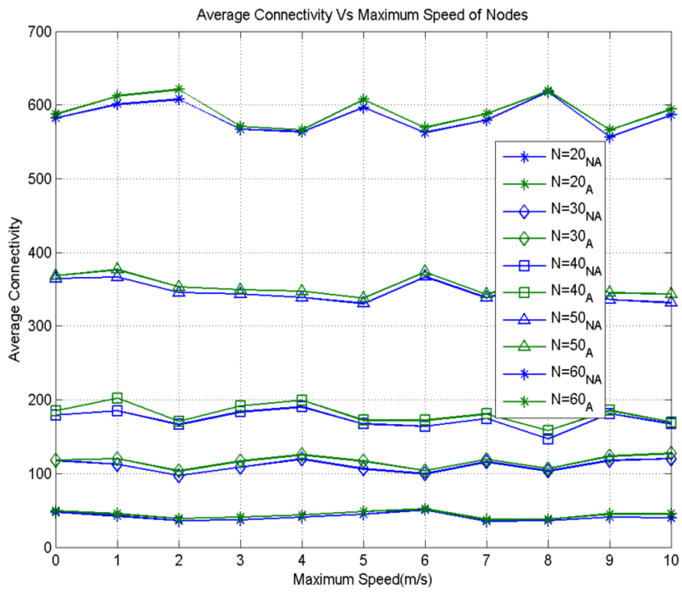


Fig. 4 Average connectivity versus maximum speed of nodes

In Fig. 4, the average connectivity versus maximum speed of nodes are shown. The transmission range and number of agent nodes are constant, 10m and 5 nodes respectively. The results are shown with varying number of user nodes. It is observed that increasing the maximum speed does not have any effect on the network connectivity. This is because of the fact that as far as the node is within a transmission area (coverage range), its speed does not matter on the instant connectivity. However, it increases the rate of change of a node to be attached and detached to/from a neighbouring node, degrading the overall performance. Average connectivity increases as the number of nodes increases with a relatively better performance in the case of using agent nodes(A).

Fig. 5 shows the average connectivity versus pause time. The maximum speed, transmission range, and number of agent nodes in the network are kept constant as depicted in the Fig.. The results are shown for varying number of user nodes. The simulation result shows that as the pause time increases, the connectivity performance of the network is almost identical for low number of user nodes. However, as the number of nodes and pause time increases in the network, its performance slightly increases. This might be due to the instant position of the nodes during pause time regardless of mobility. It can either be in a good position or bad position resulting in a better or worse network connectivity respectively. On the other hand, as the pause time increases, the mobility of nodes decreases which in turn reduces the rate of link breakage resulting in a different performance. Moreover, the network connectivity performance with agent nodes(A) is slightly higher than without using agent nodes(NA) as indicated below.

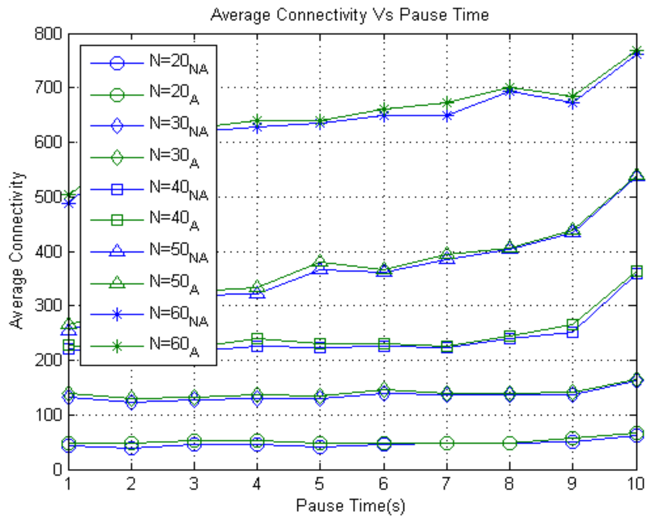


Fig. 5 Average connectivity versus pause time

VI. CONCLUSIONS AND FUTURE WORKS

In this paper, we have studied the network connectivity with a random waypoint mobility model by using agent nodes and without using agent nodes. The simulation result confirms that the network connectivity with agent node is relatively better than without using agent nodes. Since the movement of agent nodes are random, they may not reach the isolated and/or partitioned nodes sometimes. Thus, in the future we want to device a mechanism how to control agent nodes so as to move towards the disconnected and/or isolated node(s) and help them in connecting back to the main network for better performance.

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