Dynamic Node Movement Control in a Mobile Medium Ad hoc Network

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***Abstract*—A Mobile Ad hoc Network (MANET) is a network of wireless mobile devices capable of communicating with one another without any reliance on a fixed infrastructure. A Mobile Medium Network is a set of mobile forwarding nodes functioning as relays for facilitating communication between the users of this Mobile Medium. The performance of the Mobile Medium depends on the Mobile Medium node density, distribution and movement. In the proposed dynamic node movement, the movement is determined based on whether the node is on a forwarding path for a data flow or not. Simulation results show that slowing down the speed of mobile nodes when they are forwarding significantly affects the delivery rates in Mobile Medium networks. For networks with a few forwarding nodes dispersed in a large region reducing the mode movement speed by 50% results in an approximately 20% improvement in the delivery ratio, with even higher improvements possible at lower speeds.**

Keywords-mobility models; Mobile Medium; self-organizing mobile network; M2ANET; SMMANET; MANET; AODV; DSDV; ns2 simulation

I. INTRODUCTION

A Mobile Ad hoc Network (MANET) is a set of mobile devices that cooperate with each other by exchanging messages and forwarding data [1][2]. A Mobile Medium Ad hoc Network (M2ANET) proposed in [3] is a particular configuration of a typical MANET where all mobile nodes are divided into two categories: (i) the forwarding only nodes (shown in black in Figure 1) forming the so called Mobile Medium, and (ii) the communicating nodes (shown in red in Figure 1), mobile or otherwise, that send data and use this Mobile Medium for communication. The advantage of this M2ANET model is that the performance of such a network is based on how well the Mobile Medium can carry the messages between the communicating nodes and not based on whether all mobile nodes form a fully connected network. An example of a M2ANET is a cloud of autonomous drones released over an area of interest facilitating communication in this area. The movement of nodes in a M2ANET can be predefined by the user, selected at random or purposefully controlled for the best performance. When the mobile nodes select themselves their movement we refer to such a network as a Self-organizing Mobile Medium Ad hoc Network (SMMANET). Recently, a number of projects that match the M2ANET model have been announced; they include Google Loon stratospheric balloons [4] and Facebook high altitude solar powered planes [5] for providing Internet services to remote areas, and the Swarming Micro Air Vehicle Network (SMAVNET) project where remote controlled planes are used for create an emergency network [6].

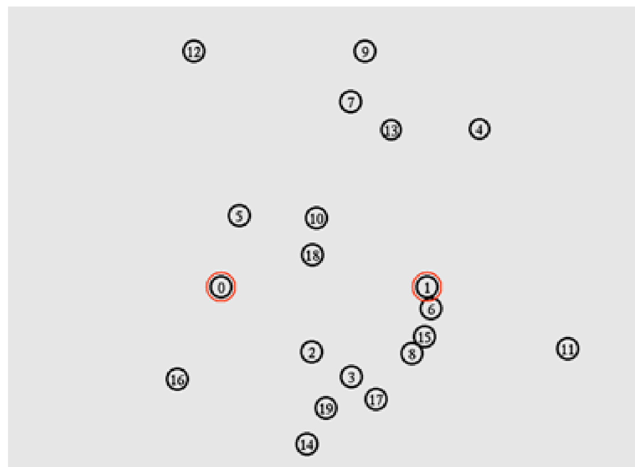

Figure 1. ns2 simulation screen of a M2ANET

Controlling the movement of the forwarding nodes forming the Mobile Medium is a problem in deploying M2ANETs. Random movement, while easy to implement, suffers from the difficulty of how to keep nodes in a sufficient density over the area of interest where the communication infrastructure is to be supplied by means of a Mobile Medium. A Mobile Medium with low mobile node density suffers from frequent disconnections and rerouting, resulting in a low delivery ratio. In this paper, we propose a solution for controlling the movement of the Mobile Medium nodes for M2ANET (SMMANET) deployments. The solution is based on the following observation: In a typical M2ANET only a few (if any) mobile nodes are actively forwarding the network traffic for a given flow at any given time. The longer the forwarding path is maintained the better the delivery ratio. We therefore propose to slow down the movement of the nodes that are actively forwarding data in the M2ANET. The new approach is then compared against the standard Random Way Point (RWP) movement.

In Section II, we present background on Mobile Medium networks and mobility patterns. The new movement pattern based on changing the speed of mobile nodes that happen to be on the forwarding path for a flow is discussed in Section

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III. Simulation experiments of this movement under different scenarios are in Section IV. Finally, we present the experimental results in Section V, followed by the conclusion and future work.

II. State of the Art

A MANET is comprised of interconnected mobile nodes, which make use of wireless communication links for multi-hop transmission of data. They offer distinct advantages over infrastructure based networks and are versatile for some particular applications and environments. There are no fixed or prerequisite base stations or infrastructures; therefore, their set up is not time consuming and can be done at any time and in any place. MANETs exhibit a fault-resilient nature, given that they are not operating a single point of failure and are very flexible. The deletion and addition of new nodes, forming new links are a normal part of operation of a MANET [1][7][8]. A group of nodes can facilitate communication between distant stations by forming a Mobile Medium, as introduced in [3].

Many mobility models have been proposed for recreating the real world application scenarios of MANETs. A mobility model attempts to mimic the movement of real mobile nodes that change speed and direction with time. There are two main types of mobility models currently used in simulation of MANETs [2][9]: trace and synthetic. A trace uses actual node movements that have been observed in a real system. In the absence of traces, synthetic mobility models can be used. The synthetic models attempt to realistically mimic the movements of mobile nodes in mobile networks [2]. The categorization of synthetic models is based on interactions between the nodes and the environment in a mobile network [2]: we can distinguish between individual node movements and group node movements. Based on specific mobility characteristics these models can be further classified into four categories: models with temporal dependency, models with spatial dependency, models with geographic restriction, and random models [2]. In the mobility model with temporal dependency the movement of a mobile node is affected by its movement history. A node's current movement is affected by past movement such as in the Gauss Markov Model and the Smooth Random Mobility model [2]. In mobility models with spatial dependency, the mobile nodes tend to travel into a group and are interdependent one on another. The movement of a node is affected by surrounding nodes in group mobility such as in the Reference Point Group Model [2]. One implementation of a group mobility model uses the attraction/repulsion principle to maintain the connections between the mobile nodes: when nodes get too close (e.g., signal strength is high) they select the next move with a preference in the opposite direction to the incoming signal and conversely, when the signal gets weak, they turn back [10]. Another class is the mobility models with geographic restriction. There, the mobile node movement is limited to certain geographical areas, such as streets or freeways, as for example in the Pathway Mobility Model and the Obstacle Mobility Model [2].

In simulation, a random mobility is often used as a reference case scenario, mostly because of the relative ease of implementing it in a simulator. One of these popular models is the Random Way Point (RWP) model available in ns2 [11]. Nodes are moved in a piecewise linear fashion, with each linear segment pointing to a randomly selected destination and the node moving at a constant, but randomly selected speed.

III. Dynamic movement control in Mobile Medium

Recall that the Mobile Medium is a particular type of a mobile network that is used for providing communication services to mobile or stationary users. It consists of a cloud of mobile nodes whose sole function is to forward data. Users of this Mobile Medium connect to it by establishing a link to one of its nodes and then send data to other users connected through this medium (Figure 2). Our interest here is to assure the best delivery ratio for the data sent form one user to another through the Mobile Medium.

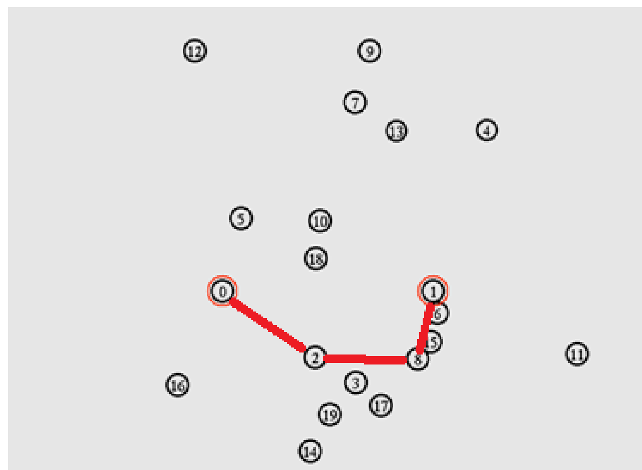

Figure 2. Nodes on the forwarding path

We start with a common reference scenario where a number of Mobile Medium nodes move in a restricted region (a rectangle) in random directions according to the RWP model. The two user stations (nodes) that wish to communicate are placed in the same region, remain stationary and send data one to another through the Mobile Medium (Figure 2). Because the Mobile Medium nodes move in and out of range of the communicating stations the connections break and the routing path changes, affecting the delivery ratio.

The Dynamic Movement Control in Mobile Medium is an attempt aimed at reducing the (number of) changes in the routing path during the data transfer between the users. Normally, the nodes in the RWP model move in random directions and at random speeds independent of whether they are forwarding packets or not. The faster they move the quicker they get out of range and the sooner the connection path breaks. In the proposed Dynamic Movement Control for the Mobile Medium, the nodes that forward data are slowed down. Note that this decision to slow down does not require any global information or location data; it is solely based on the forwarding status of the node. The easiest way to determine if the node is in the forwarding state is to check if it had forwarded a data packet recently: for example, for the scenario with a Constant Bit Rate (CBR) traffic source a node would maintain its forwarding status, and move at a reduced speed, for at least the time defined by the inter packet interval of the CBR source. For other scenarios, like the exponential traffic sources, multiples of the average inter packet interval can be used for determining the forwarding status maintenance period for a node. In the ns2 simulation we used the actual path determined by the simulator to determine which nodes are in the forwarding state.

The evaluation of the proposed Dynamic Movement Control for Mobile Medium was performed in the ns2 simulator. The simulator is implemented in c++ and each simulation is controlled by an Object Oriented Tool Command Language (OTCL) script. Unfortunately, the OTCL scripting language does not provide any access to the routing information used in the simulation. To access the routing information used by the Ad hoc On-Demand Distance Vector (AODV) protocol we modified the

```
void forward (aodv_rt_entry *rt,
      Packet *p, double delay);
```

function in `aodv.cc`, and to get routing for the Destination-Sequenced Distance Vector (DSDV) the function

```
void forwardPacket (Packet *p);
```

in `dsdv.cc` was modified.

IV. Simulation experiment

A set of simulation experiments was conducted to evaluate the proposed Dynamic Movement Control for the Mobile Medium networks. Each simulation of a network consists of a different number of nodes roaming (RWP movement, average speed 4 *m/s*) in a square 1000 x 1000 meters. The node transmission range is 250m. The link data rate is 1 Mbps. Every packet has a size of 512 bytes. The buffer size at each node is 50 packets. Data packets are generated following a Constant Bit Rate process [11]. The source and destination nodes are stationary and located at coordinates (50, 400) and (950, 600). The summary of the simulation parameters used in ns2 is shown in Table 1. In each experiment, the designated source node transmits to one designated destination node for 500 seconds. For each node density and speed, the experiment is run three times and the average delivery ratio is reported.

TABLE I. SIMULATION PARAMETERS

Parameters	
Simulator	NS-2.34
Channel Type	Channel / Wireless Channel
Network Interface Type	Phy/WirelessPhy
Mac Type	Mac/802.11
Radio-Propagation Type	Propagation/Two-ray ground
Interface Queue Type	Queue/Drop Tail
Link Layer Type	LL
Antenna	Antenna/Omni Antenna
Maximum Packet in ifq	50
Area (n * n)	1000 x 1000m
Source node location	(50, 400)
Destination node location	(950, 600)
Source Type	CBR over UDP packetSize_ 512 interval_ 0.05
Simulation Time	500 s
Routing Protocol	AODV and DSDV

A. *AODV performance*

Reducing the speed of the forwarding nodes running the AODV routing protocol results in an improved delivery ratio for all but the very low node density (5 nodes over 1000x1000m region) scenario, Fig 3. The networks with a very few nodes in the Mobile Medium, i.e., with 5 and 10 nodes, as expected show very low delivery ratio. Under normal operating conditions for the Mobile Medium, with 20 or more mobile forwarding nodes, the performance improves gradually. Networks with a large number of nodes, more than 30 in a 1000x1000m area, as expected work well at any node speed with delivery ration ranging from 75% to almost 100%. The most interesting case is the network with a moderate number of nodes, 20 nodes over the area 1000x1000m. This scenario demonstrates best the benefits of the Dynamic Movement Control for Mobile Medium networks. In this scenario the delivery ration is very low 30% for nodes moving at the original speeds, but the performance improves significantly to 85% when the speed is reduced to 10% of the original speed.

The benefits are the highest in the low to medium range of node densities, 10 to 20 nodes moving in a 1000x1000m region, as depicted in Figure 4.

B. *DSDV performance*

DSDV performance improvement is similar to AODV: low improvements at low node densities (5 to 10 nodes) and a gradual improvement with the reduction of the speed of the forwarding nodes at higher node densities, as shown in Figures 5 and 6. In our experiments, the overall delivery ratio is lower for DSDV than for AODV. This is a common situation for the DSDV protocol when used in the ad hoc networks with a dynamically changing topology [12] and can be attributed to the proactive nature of the DSDV protocol where distributing the routing information to all the nodes and detecting a valid route can take a considerable time.

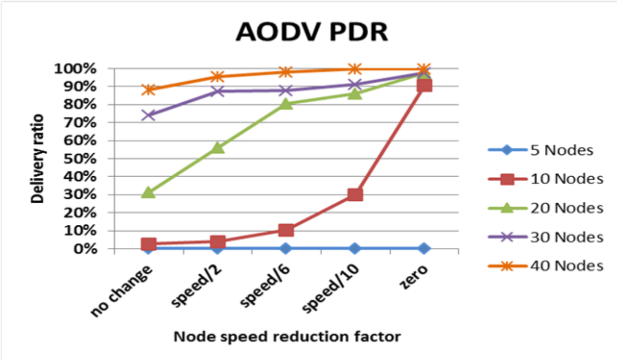

Figure 3. AODV delivery ratio.

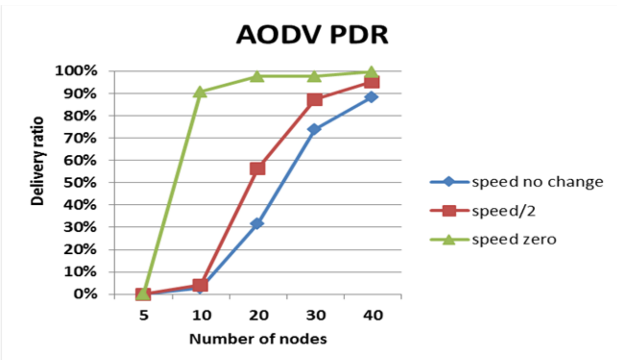

Figure 4. Delivery ratio for AODV at three speeds: no change, with 50% reduction and zero.

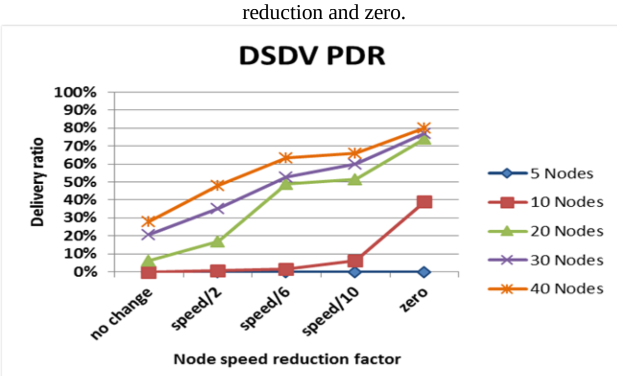

Figure 5. DSDV delivery ratio

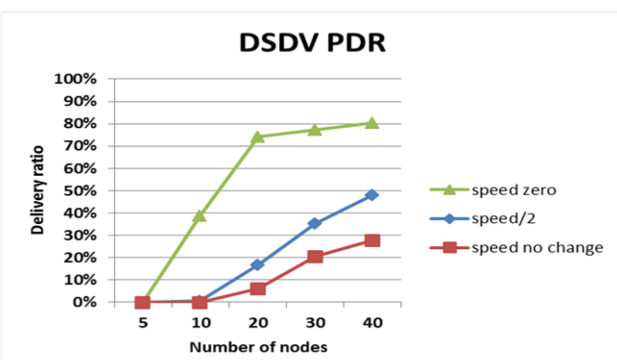

Figure 6. Delivery ratio for DSDV at three speeds: no change, with 50% reduction and zero.

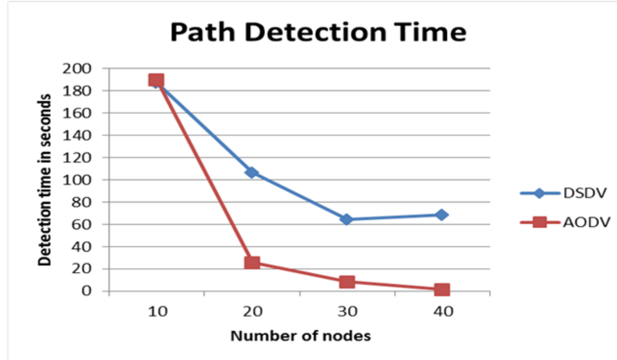

Figure 7. Time to detect the first path, for two different protocols.

In our experiments, no routes were detected in networks with 5 nodes and it took approximately 80 seconds to detect the first route in the networks with 20 or more nodes running DSDV, which is considerably slower than the path detection delay observed for the AODV protocol, see Figure 7.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed a new node movement control paradigm for a self-organizing MANET network. The approach is particularly attractive for M2ANETs where the goal is to create a Mobile Medium out of mobile forwarding nodes, and use this Mobile Medium to facilitate data communication between other users. The new mobility control mechanism is based on slowing down the nodes that are on the forwarding path for a flow. The performance of the M2ANET/SMMANET increased significantly with the lowering of the speed of the nodes actively forwarding the data, with a higher relative improvement for the networks with moderate node densities. The improvements were observed in the networks running two different routing protocols AODV and DSDV.

Based on our results, we suggest further testing self-organizing M2ANET/SMMANET networks using different experimental scenarios. In particular while our experiments involved two stationary communicating nodes it might be more realistic for some application scenarios to model them as mobile. Combining the attraction/repulsion mechanism proposed in [10] with the new Dynamic Control may also result in further improvement of the performance of a SMMANET.

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