Self-organizing Mobile Medium Ad hoc Network

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***Abstract*— MANETs are mobile networks of wireless mobile devices capable of communicating with one another without any reliance on a fixed infrastructure. A Mobile Medium Ad hoc Network (M2ANET) is a set of mobile nodes forming a Mobile Medium and functioning as relays for facilitating communication between the users of this Mobile Medium. Movement of the nodes affects the performance of a M2ANET. We propose a scheme for controlling the movement of mobile nodes in a M2ANET based on an attraction/repulsion paradigm. The new node movement has an advantage over a random movement in keeping the nodes in an unbounded region in a sufficient density to allow for an efficient transfer of data over the Mobile Medium. Simulation results show tripling of the delivery ratio in a self-organizing M2ANET compared to a mobile network with all nodes moving randomly, in one experimental scenario.**

Keywords-mobility models; self-organizing mobile network; M2ANET; Mobile Medium; MANET; NS-2; AODV

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]. Mobile devices are linked together through wireless connections without infrastructure and can change locations and reconfigure network connections. During the lifetime of the network, nodes are free to move around within the network and node mobility plays a very important role in mobile ad hoc network performance. Mobility of mobile nodes significantly affects the performance of a MANET [2].

A Mobile Medium Ad Hoc Network (M2ANET) is a particular configuration of a typical MANET proposed in [3], where mobile nodes are divided into two categories: (i) the forwarding only nodes (shown in black in Fig. 1) forming the so called Mobile Medium, and (ii) the communicating nodes (shown in red in Fig. 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 drones released over an area of interest facilitating communication in this area. 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].

Controlling the movement of all forwarding nodes forming a Mobile Medium is a problem in deploying M2ANETs in real world scenarios like emergency or disaster recovery. While movement of each node is most easily directed independently there is a need for keeping the nodes in relative proximity to maintain their connectivity one with another. In practical terms, the nodes may move on closed paths (e.g., circular), or at random. With randomly selected trajectories maintaining the nodes in one area becomes a problem.

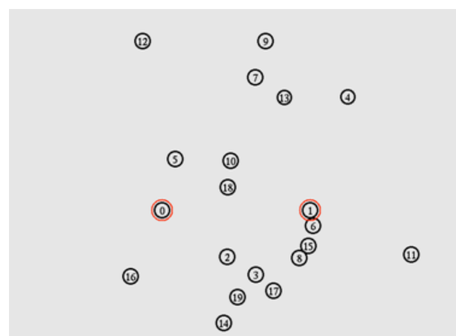

Figure 1. ns2 simulation screen of a M2ANET

The problem is simple to handle in MANET simulation: simulators typically allow setting the simulation area defined as a bounded region which guarantees that the nodes do not disperse any further. If any node tries to move too far away it hits the boundary and then moves in another direction, but still in the same area together with the other nodes. The same cannot be said about the real world scenarios.

In this paper, we propose a solution for controlling the Mobile Medium nodes for M2ANET deployments in an unbounded region. The mechanism is based on an attraction/repulsion paradigm for controlling the movement of mobile nodes in a region without boundaries while providing means for maintaining all nodes in the same area. In principle, when a node moves too far away from other

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nodes it should detect the separation and turn back. While the decision making in our simulation is based on the actual distance between the nodes, in a practical deployment the same can be done based on the radio signal strength.

In Section II, we present background on MANETs and mobility patterns. The new movement pattern based on the attraction/repulsion principle for MANETs is discussed in Section 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]. Another class is the mobility models with geographic restriction. 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 [10]. 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. ATTRACTION/REPULSION MOVEMENT

One of the most incredible sights in nature happens when animals form a group and move together in a flock. How exactly do these individuals do it? A group, such as a herd of land animals or flock of birds, consists of individuals but exhibits some characteristics of team collaboration in the population. While it seems that the group is under a centralized control, in reality what is observed is an aggregated behavioral performance of independent individuals, each of which is acting on the basis of its own local perception [11].

Similar principles can be applied to controlling node movement in our self-organizing M2ANET. The objective of the proposed approach is to control the collective movement of locally interacting nodes similar to the behavior observed in flocks of birds or swarms of insects. Our goal is to keep randomly moving nodes (similar to RWP model) in a limited area without imposing a hard constraint of an external boundary. Our approach is based on an attraction principle to keep the nodes together in a flock (we use the name "flock" or a "cloud" when referring to a number of mobile nodes moving together) and on a repulsion mechanism to keep them sufficiently far apart so that they cover a large area. Though the actual simulation we conducted is based on the distance calculation, in practice the attraction/repulsion principles can be implemented based on the received signal strength at each node.

A. *Attraction*

The main deficiency of the RWP model for controlling the movement of nodes in a MANET is that, aside from the border effect [12], the nodes tend to fill the entire available space. If there is a boundary limiting the node movement, like in the case of most simulation environments, ns2 included, the nodes tend to disperse approximately evenly resulting in the node density and the average distance between the nodes determined by the available area and the number of nodes in the network. The situation becomes worse in an environment with no boundaries where nodes would disperse completely and lose any connectivity over time.

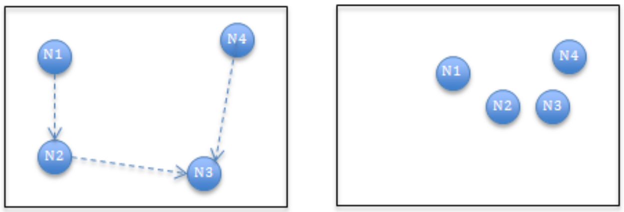

Figure 2. Attraction keeps nodes in a flock.

Attraction between the nodes, when used in addition to the RWP model, can remedy this problem. In our proposed approach, nodes normally move following the RWP model, but when the distance to the nearest neighbor becomes too large they turn towards the nearest neighbor (Fig. 2) rather than choosing a random direction.

B. *Repulsion*

While the attraction mechanism would be sufficient for a set of randomly moving nodes to form a flock (or a cloud) and remain connected and stay over a limited area without imposition of a hard boundary, the network coverage could be improved with an added mechanism, also based on watching the distance to the nearest neighbor. The coverage of a M2ANET is where the Mobile Medium nodes are, so keeping the nodes apart assures a larger area of coverage by preventing the nodes from congregating in only one place.

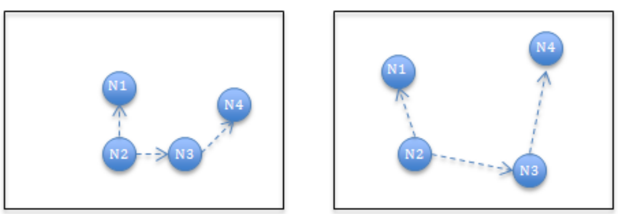

Figure 3. Repulsion prevents the nodes from collapsing into one point.

In our proposed approach, nodes normally move following the RWP model, but when the distance to the nearest neighbor becomes too small they move away from the nearest neighbor (Fig. 3) rather than choosing a random direction.

C. *Implementation*

Nodes normally follow RWP model movement pattern, with the next move direction determined by parameters stored locally at each node. Attraction and repulsion mechanisms can be implemented based on the received signal strength at each node. We could assume that each node periodically sends a beacon signal (possibly as a part of functioning routing mechanism like in the Destination-Sequenced Distance Routing (DSDV) protocol [13]). The received signal strength determines the identity, and possibly the direction towards, the nearest neighbor. Alternatively, the direction towards the nearest neighbor could be determined by querying the nearest neighbour for the location information (assuming it has a Global Positioning System (GPS), or similar, built in).

In ns2 simulation, nodes move piecewise linearly with each movement of a node specified with the *setdest* command [10]. In our simulation experiments we use the distance between the current node and its nearest neighbor D and define two thresholds: Th_1 to mark when nodes are too far apart, and Th_2 when nodes are to close. The next move is specified:

i. *towards* the nearest node, when $D > Th_1$,
ii. *away* from the nearest node, when $D < Th_2$, and
iii. in a *random* direction, when $Th_1 > D > Th_2$.

The distance covered is chosen randomly (in cases (i) and (ii), uniform distribution $U(0,D)$), but within the bounds of the simulated area.

D. *Simulation environment*

Each simulation of a network consists of a different number of nodes roaming in a square 1000 x 1000 meters with a reflecting boundary. The 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 (CBR) process [10]. The source and destination nodes are stationary and located at coordinates (300, 500) and (700, 500). The summary of the simulation parameters used in ns2 is shown in Table 1.

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 1000
Source Type	(UDP) CBR
Simulation Time	900 sec
Routing Protocol	AODV

The forwarding nodes are mobile and move according to the attraction/repulsion algorithm. In each experiment, the designated source node transmits to one designated destination node for 900 seconds.

V. RESULTS

Four sets of simulation experiments were conducted: one set with all forwarding Mobile Medium nodes moving randomly, and three sets with the forwarding nodes moving based on the attraction/repulsion principle using three different threshold levels:

i. Low threshold: $Th_1 = 60, Th_2 = 30,$
ii. Medium threshold: $Th_1 = 120, Th_2 = 60,$
iii. High threshold: $Th_1 = 200, Th_2 = 120.$

In each experiment, data regarding the node location and the delivery ratio were collected.

A. Node movement behavior

Topologically, the purpose of the attraction/repulsion mechanism is to keep the nodes together while allowing them to move independently. To measure the togetherness of the nodes we collected samples of node coordinates (every 10s) over the duration of each experiment and calculated the standard deviation of all X coordinates, for all the samples.

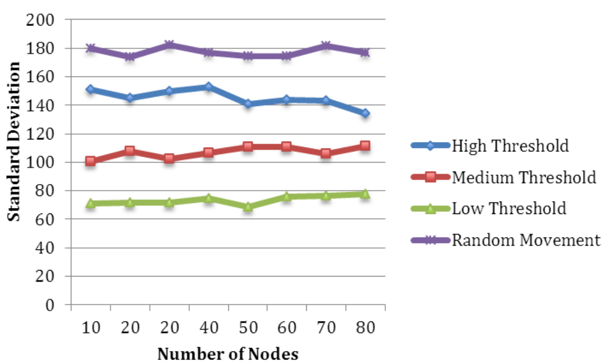

Figure 4. Node location standard deviation: X axis

Fig. 4 shows a measure (standard deviation of *X* coordinates of all mobile nodes, sampled every 10 seconds) of the spread of all the nodes in four sets of experiments. The results show that the lower the threshold the tighter the flock (cloud) formed by the mobile nodes. Also, the nodes of the proposed self-organizing M2ANET stayed closer together than they normally would if all the nodes just moved randomly over the 1000 by 1000 m simulation area.

B. Network delivery ratio

The main goal of a self-organizing M2ANET is to avoid node dispersion and to provide enhanced communication over the area covered by the Mobile Medium (forwarding nodes). Fig. 5 shows the comparisin between the delivery ratios in a self-organizing M2ANET versus a M2ANET with Mobile Medium nodes moving randomly over the entire simulation area. The graph shows that decreasing the treshold values and thus keeping the Mobile Medium nodes closer together improves the delivery ratio. In our experiments, all self-organizing networks do better than a network with nodes moving totally randomly. The improvement is most signifincat for experiments with small number of nodes: in a M2ANET with only 10 nodes in an area 1000 by 1000 m the delivery ratio of 9% for a random movement scenario was improved threefold to almost 30% in a self-organizing M2ANET when a low threshold settings of $Th_1 = 60$, $Th_2 = 30$ were used.

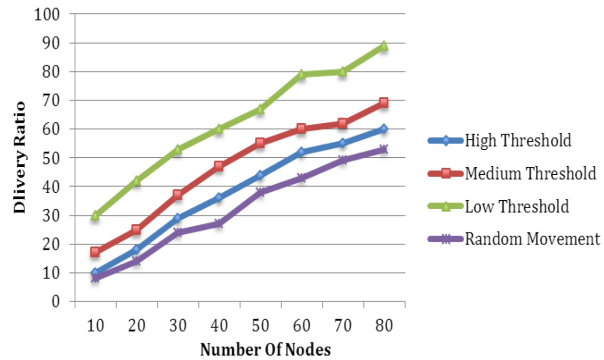

Figure 5. Delivery ratio.

The improved performace is due to keeping the nodes closer together (Fig. 1), which increases a likelihood of forming a route from the source to the destination.

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed a 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 an attraction/repulsion principle: the Mobile Medium nodes normally move randomly, but they turn back when they get too far from their neighbors. This mechanism keeps all the nodes in a “flock”, with the flock (or cloud) density controlled by two thresholds, and thus allowing the M2ANET creator to control the performance of the Mobile Medium: the lower the attraction/repulsion thresholds the closer the nodes of the Mobile Medium remain and the higher the delivery ration of the resulting M2ANET network.

Based on our results, we suggest further testing self-organizing M2ANET networks using different routing algorithms. Also the role of the lower threshold Th_2 needs to be investigated: it is not clear which protocols might benefit form maintaining the minimum distance between the mobile nodes.

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