TOPOSIM: WIRELESS AD HOC NETWORK TOPOLOGY SIMULATOR

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Abstract: An important task of an ad hoc network consisting of geographically dispersed nodes is to determine the characteristics of the topology which include connectivity, energy-effectiveness, throughput, and robustness to mobility. However, the widely used network simulators don't support topology simulations that result in an evaluation of the quality of the network topology. Thus, in this paper, we introduce a newly developed wireless ad hoc network topology simulator – TopoSim, that can be used for the purposes of simulating a topology of an ad hoc network, including its dynamical changes caused by the node's mobility, for the purposes of determining the main topology characteristics of the simulated network.

Keywords: ad hoc networks, topology characteristics, simulation, simulator

1   Introduction

Although one of the original motivations for ad hoc networks found in military applications still dominate the research needs in ad hoc networking, the recent rapid advent of mobile telephony and plethora of personal digital assistants has brought to the fore a number of potential commercial applications of ad hoc networks. An ad hoc network is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration [2]. The mobile nodes in the network dynamically establish routing among themselves to form their own network "on the fly". Due to the limited transmission range of wireless network interfaces, multiple network "hops" may be needed for one node to exchange data with another across the network, while each mobile node operates not only as a host but also as a router, forwarding packets for other mobile nodes in the network.

An important task of an ad hoc network consisting of geographically dispersed nodes is to determine the characteristics of the topology. The quality of the topology can be evaluated according to several criteria including connectivity, energy-efficiency, throughput and robustness to mobility [4]. Since the topology characteristics are one of the most important factors affecting the network efficiency, it's important to supply topology algorithms that will provide connectivity and energy-efficiency using a

"simple" topology that is "easy" to maintain. In addition to connectivity and energy-efficiency, it's imperative to have a topology with high capacity or throughput, that is, it must be feasible to route "about as much traffic" in the topology as any other topology, satisfying the desired constraints. Further challenge in the design of distributed topology control algorithms is to ensure some degree of robustness to the mobility of nodes measured by the maximum number of nodes that need to change their topology information as a result of the node movements.

Although the need of examining the network topology features is widely accepted, the existing network simulators, such as Network Simulator - NS2 [5] and GloMoSim [1], don't support simple and fast simulation that result in an overview of the ad hoc network topology. Thus, in this paper, we introduce a newly developed wireless ad hoc network topology simulator – TopoSim, that can be used for the purposes of simulating a topology of an ad hoc network, including its dynamical changes because of the node's mobility. TopoSim as scalable and open simulator allow many different types of topology simulations to be made. We have used TopoSim for gaining information regarding the number of common neighbors of two given nodes, the number of network connections depending on the transmission range and the nodes mobility, the connectivity matrix of the network, the hop distance between any pair of nodes in the network, the cluster coefficient of the ad hoc network that is being simulated, or the time each node spends in a given sub area during the simulation.

2   Wireless Ad Hoc Network Topology Simulator - TopoSim

TopoSim is a wireless ad hoc network topology simulator created for the purposes of simulations of purely topological characteristics of an ad hoc network, while incorporating its dynamical changes caused by the node's mobility. The simulator is built in Microsoft Visual C++ 6.0, and it operates in Windows environment. The TopoSim Static Structure UML Diagram is shown on Fig. 1. Generally, the simulator consists of the following classes:

- Class Log – base object class used for writing in the output file.
- Class Area – area in which mobile nodes are scattered using different types of scattering distributions.
- Class Node – base class for representation of the common properties of all mobile nodes in the ad hoc network which can have different nature.
- Class MobilityModel – base class for several implementations of different mobility models like Random Way Point, Random Walk etc.
- Class Calculation – base class for all types of calculations of the average output results.
- Class Simulator – simplifies the usage of the simulator.
- Class RNG – used for random number generation [3].

The Simulator class is the main packaging class for TopoSim. Simulator has associations with Area and Calculation classes that are used to perform simulations. The Ar-

ea class holds all the nodes scattered in it, while the Node class is connected to the node's mobility model which defines the node's current positioning in the area. The Random generator is used for the purposes of scattering the nodes within the simulation area and for the needs of the mobility models when calculating the next node position in the network area. Every class that holds any type of topology significant characteristic of the network can supply the log file located in the Log class with the necessary information.
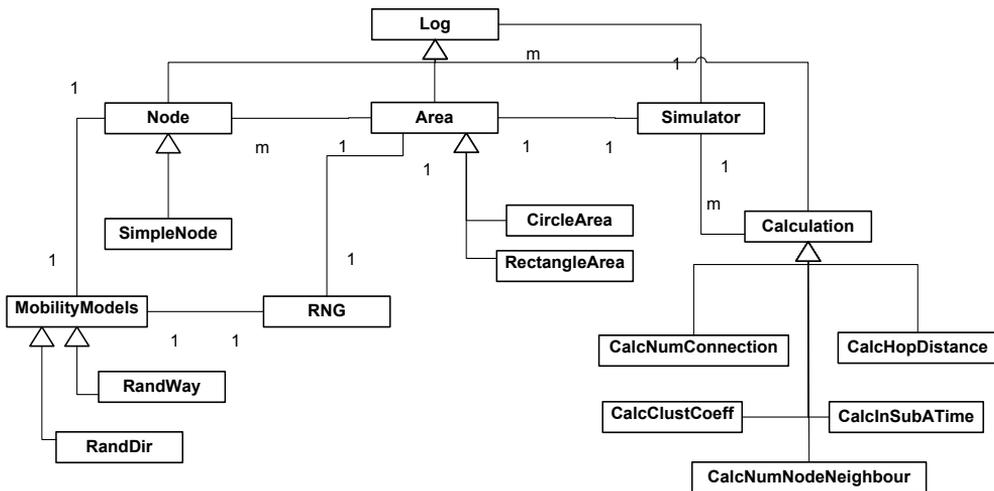

Figure 1: TopoSim Static Structure UML Diagram

TopoSim is very flexible when it comes to addition of any needed extensions. That is, the new area, node type, mobility model or type of calculation is implemented completely independently and, afterwards, only attached to its appropriate parent class. The rest of the object-oriented organization does not suffer from any structural changes, and the additional code changes are minor.

3   Implementation

In TopoSim, the ad hoc network is modeled as a collection of points in 2-dimensional space, where each point represents a mobile network node. The mobile nodes are scattered in an area with user defined shape and dimensions. The free space radio propagation model [7] is used to model the radio environment while assuming flat terrain and omni directional antenna for all mobile nodes. Thus the nodes have equal transmission range *r* and the node radio coverage is shaped as a perfect circle. The nodes are defined with the following parameters:

- Mobility model, speed range
- current position, node's coordinates
- node energy

- transmission range

The node scattering can be set by the user or made using random node position coordinates. If random values are chosen, the user only sets the type of distribution which can be uniform, exponential, normal or logarithmic. So far, the scattered nodes are one of kind, have the same nature. Once the parameters are set, and the nodes are scattered in the area, one can proceed to adding, deleting and moving the nodes.

The mobile nodes movement pattern is set according to a given Mobility Model (MM). There are several MM that are used in performance evaluations simulations for ad hoc networks [6]. The most commonly used models are Random Walk and Random Waypoint. In the Random Walk MM, a mobile node moves from its current location to a new location by randomly choosing a travel direction and speed. The new speed and direction are both chosen from pre-defined ranges, [*speedmin*; *speedmax*] and [0;2π] respectively. Each movement in the Random Walk Mobility Model occurs in either a constant time interval *t* or a constant distance traveled *d*, at the end of which a new direction and speed are calculated. If a mobile node, which moves according to this model, reaches the simulation boundary, it "bounces" off the simulation border with an angle determined by the incoming direction. The mobile node then continues along this new path. In Random Waypoint MM the mobile node chooses a random destination in the simulation area and speed that is uniformly distributed between [minspeed, maxspeed]. The MN then travels toward the newly chosen destination with the selected speed. Upon arrival, the MN pauses for a specified time period before starting the process again. In the both MMs linear motion and uniformly distributed speed is used.

TopoSim input parameters are the following: area type and dimensions, number of nodes scattered in it, node's transmission range, node mobility model to be used and type of distribution. The simulation is made in a given number of iterations, which represent discrete moments of time. In every iteration, every moment of time, each node is moved to its new position according the employed mobility model while all the necessary calculation regarding the topology characteristics that the user wishes to explore are made.

4   Example Simulations

Our main purpose for creation and use of TopoSim was to prove certain analytical models and inspect the topological performances and characteristics of the ad hoc networks.

4.1   Common neighbors calculation

By definition, two nodes are connected (neighbors) if one node is within the range of the other. Therefore, the node transmission radius and movement pattern have a great impact on the network connectivity. The following scenario is used for the simulations: rectangle area with dimensions 1400mx1400m, wherein 100 nodes are scattered on random positions using uniform distribution, Random Direction mobility model and transmission range r=250m.
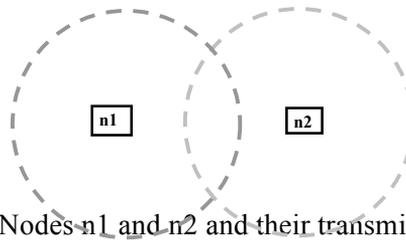
Figure 2: Nodes n1 and n2 and their transmission range

In order to obtain the number of common neighbors two referent nodes for which the calculation is performed (n1 and n2) are placed in the area (see Fig.2). The coordinates of the nodes are (500,500) and (750,500) respectively. During the simulation n2 is slowly drifting apart from n1. In each iteration the connectivity matrix is updated and, at the end, the average number of common neighbors is calculated.
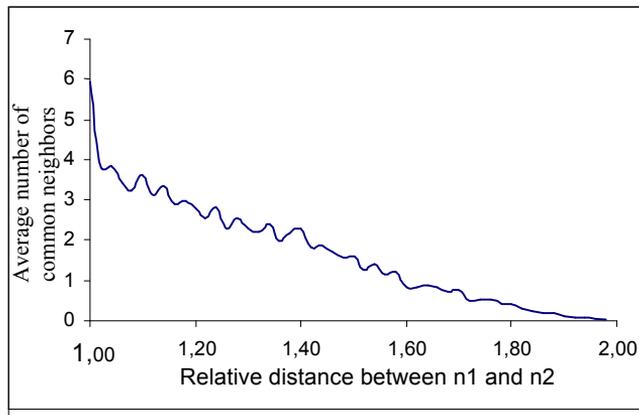

Figure 3: Average number of common neighbors

The obtained results shown on Figure 3 represent the average number of common neighbors depending on the relative distance between n1 and n2. With the increasing distance between nodes n1 and n2, the number of their common neighbors is decreasing.

4.2   Number of connections in the ad hoc network

Number of connections in the network while varying the transmission radius or the node is made for the same scenario characteristics like in previous example. The transmission range is vitiated from 280m to 20m. For each value of the transmission range 100 iterations are made.

On Figure 4 the dependence of the average number of network connection on the node transmission range is shown. It's obvious that the number of connections in the network increases with the increasing value of the transmission range since the nodes become more aware of their surrounding neighborhood.
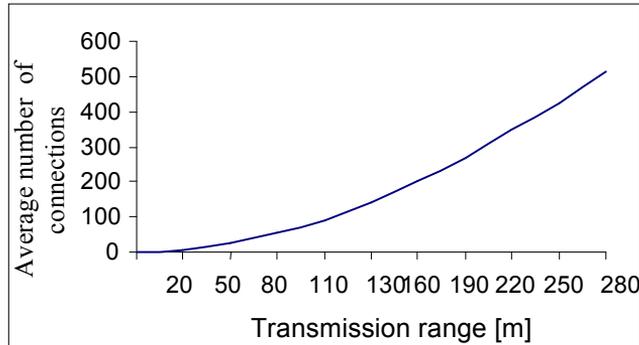
Figure 4: Average number of the network connections

4.3   Calculation of the average time each node spends in a given sub area

TopoSim can also be used for the purposes of calculation of the average time each node spends in a given sub area inside the area wherein the nodes are scattered which is obtained through the number of iterations for which the node is inside the sub area according to the following model [8]. If the node spatial probability density function for the given node movement model is f(x,y), the probability that a given node will be in the *B* area is given by $p_B = \iint_B f(x,y)dxdy$. When considering a long enough time interval *T*, the time spent in the *B* area for a given node is $T_B = p_B T$. If, during *T*, a given node makes *k* enter-leave cycles in area *B*, then the average time spent in each cycle is $\bar{t}_B = T_B / k$. Thus,

$$\bar{k}t_B = p_B T \tag{1}$$

Considering that these relations can also be written for the *C* area, we have

$$\bar{k}t_c = p_c T \tag{2}$$

Dividing (1) with (2), we obtain

$$\frac{\bar{t}_B}{\bar{t}_C} = \frac{p_B}{p_C}, \; \bar{t}_C = \frac{p_C}{p_B}\bar{t}_B \tag{3}$$

TopoSim was used in order to prove the above equation. Using the simulator we modeled several types of areas and sub areas and measured the portion of time each node spends in the sub areas with different shapes and sizes.

4.4   Average hop distance calculation

On of the most frequently used topological characteristics of the ad hoc networks is the average hop distance parameter defined as the average number of the shortest hop distances between all possible couples of nodes in the network. The shortest hop distance h_{ij} between nodes *i* and *j* is the minimum number of hops needed to send packet

from a node *i* to another node *j* ($h_{ij} = 1$ if there is a direct connection between node *i* and *j,* that is node *j* is in transmission range of node *i*) [9]. We used TopoSim for the purposes of calculation of the average hop distance for a given network. The calculation is implemented as a breadth first search through the network looking for directly connected nodes in each search level.

4.5   Clustering coefficient calculation

Real-world networks show strong clustering or network transitivity [10]. A network is said to show clustering if the, probability of two vertices being connected by an edge is higher when the vertices in question have a common neighbor. That is, there is another vertex in the network to which they both are attached. The clustering effect is measured by a clustering coefficient C, which is the average probability that two neighbors of a given node are also neighbors of one another. The clustering coefficient of the whole network is the average of all individual clustering coefficients

$$C = \frac{1}{N} \sum_{i=1}^{N} C_i \qquad\qquad (3)$$

where

$$C_i = \frac{E_i}{k_i(k_i - 1)/2} \qquad\qquad (4)$$

is the individual clustering coefficient for a node i in the network, having k_i edges which connect it to k_i other nodes and E_i edges that actually exist between these k_i nodes.

In addition, using TopoSim a user can obtain the clustering coefficient of a given network by specifying the network area, number of nodes and their positions in the area. From this information firstly the connectivity matrix of the network is being calculated, since the clustering coefficient calculation uses the connectivity matrix as a basis for the E_i detection.

5   Conclusion

Thus, in this paper, we introduced a new wireless ad hoc network topology simulator – TopoSim. It is important to emphasis the fact that, built to be flexible and scalable, TopoSim has many advantages. In this paper we presented only a part of the opportunities that TopoSim is able to offer. Toposim's object oriented nature allows easy and rapid implementations of newly introduced topological features of an ad hoc network. Namely, TopoSim can be easily changed and even more easily extended to support various different area types including, for instance, 3-dimensional areas. Also different types of nodes as well as different types of calculations can be implemented, while various structures can be simulated without modifying the source code and rebuilding the system.

Our future work involves extension of TopoSim in order to provide possibilities for simulations of various different types of topology characteristics that are found to be significant to the user.

6   References

1. *GloMoSim   (ver.   1.2)*, http://pcl.cs.ucla.edu/projects/glomosim/GloMoSimManual.html

2. Charles E. Perkins, *Ad Hoc Networking*, Addison – Wesley 2001

3. Stephen K. Park, and Keith W. Miller., "Random Number Generator", *Computing practices, Communications of ACM*, Oct. 1988

4. Rajmohan Rajaraman, "Topology Control and Routing in Ad hoc Networks: A Survey*", ACM SIGACT News*, Vol 33, Issue 2, June 2002

5. *The network simulator – NS-2*, http://www.isi.edu/nsnam/ns

6. Tracy Camp, Jeff Boleng, Vannesa Davies, "A Survey of Mobility Models for Ad Hoc Network Research", *WCMC: Special issue on Mobile Ad Hoc Networking*, vol. 2, no. 5, pp. 483-502, April 2002

7. T. S. Rappaport, *Wireless Communications: Principles and Practice,2nd edition*, Prentice-Hall, Inc., NJ, 2002

8. Dimitar Trajanov, S. Filiposka, J. Makraduli, A. Grnarov, "Impact of Mobility on Ad Hoc Networks Connection Availability", IEEE WCNC'04, USA, 2004 (submitted for publication)

9. M. E. J. Newman, *Random graphs as models of networks*, Santa Fe Institute Work. Paper, 2002

10. Duncan J. Watts: *Six Degrees: The Science of a Connected Age*, W.W. Norton & Company, New York, 2003