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Development of a Test Environment (based on SAHNE) for Network Protocols in MANETs
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Work Package 2.4: Integrated Application Testbed (IAT)
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1 Introduction

When studying algorithms for complex networks it is not always possible to include all important aspects in a mathematical model. Often, many abstractions are necessary for formulating a theoretical model. To give an example, network topologies can be represented in a graph theoretical model: Nodes are the participants, communication links are modeled by edges. In the real world there are effects like interference, multi-path fading, obstruction etc. which influence the communication significantly. All these effects that can observed in practice cannot be adequately expressed by a theoretical model. Simulation models cannot replace reality, but simulation can bridge the gap between theoretical model and real-world applications.

We have developed the network simulator SAHNE (Simulation Environment for mobile Ad Hoc Networks) for simulations of wireless networks with a large number of nodes. We used this simulator to study topology control algorithms in the directional communication model, where each participant is equipped with a fixed number of directional transmitters, as well as in the omni-directional model, where an isotropic antenna is assumed. In [MSVG02] (see also [MSVG04]) the measures Congestion, Energy and Dilation for wireless networks were introduced. SAHNE provides methods for the assessment of network topologies based on these measures. The quality of the network topology is not only a quality criterion for the topology control algorithm, it also shows potentials or limitations for the routing algorithm, which uses the topology.

2 State of the art

There are various simulations environments such as ns-2\textsuperscript{1}, OMNet++\textsuperscript{2}, GloMoSim\textsuperscript{3} etc. These network simulators are capable of simulating wireless networks, but they were designed for the simulation of omni-directional communication. We are also interested in directed communication, which can be realized by infrared diodes or directional antennas. Our goal was the development of topology control algorithms for power-variable MANETs, i.e. wireless networks, where the participants may adapt their transmission power. Therefore we developed the network simulator SAHNE [Vol02].

2.1 The Simulation Environment

SAHNE is designed for simulations of wireless networks with a large number of nodes. It is characterized by a lean model of the physical layer and can simulate directional communication (infrared or directional antennas) as well as omni-directional communication. It’s data structures enable efficient range queries in order to determine the nodes that possibly receive a packet. It provides a graphical user interface based on LEDA. We investigate topology control protocols for directional communication, which are based on sector graphs (see [MSVG02]) and for omni-directional communication with variable transmission ranges, based on the Hierarchical Layer Graph [MSVG04].

Properties of SAHNE:

- directional as well as omni-directional communication model
- lean physical layer with focus on signal attenuation and signal-to-interference ratio
- efficient data structures for range queries, which are used for identifying possible receivers in a large set of participants.

\textsuperscript{1}http://www.isi.edu/nsnam/ns
\textsuperscript{2}http://www.omnetpp.org
\textsuperscript{3}http://pcl.cs.ucla.edu/projects/glomosim
• automatic computation of quality measures for network topologies
• graphical user interface (see Fig. 1)

2.2 Simulation Models

SAHNE was mainly developed for simulation of topology control algorithms using a directional communication model, where signals are propagated unidirectionally according to the directional characteristics of an infrared diode (see [KB97]). This model is motivated by an infrared communication module for a mini-robot that was designed by the System and Circuit Technology Group of the University of Paderborn. A graph-theoretical representation of directional transmission in different sectors leads to sector graphs: In a sector graph the plane around a node is divided into a fixed number of sectors. Then, in each sector a neighboring node is chosen, e.g. the nearest one. We have simulated topology control algorithms that build up these sector graphs using the directional communication model in [RSVG03].

2.3 Measures for Network Topologies

The quality of a routing algorithm depends on the quality of the network topology. If we can find an efficient routing scheme based on a certain topology, then we can regard it as good topology. Instead of focussing on one specific routing algorithm we consider path systems that use the topology and investigate the quality of the paths systems using the measures congestion, dilation, and energy which have been proposed in [MSVG02, GLSV02]: The dilation is given by the maximum of the lengths of all paths in a path system $P$. The energy used for maintaining a communication link $e$ is proportional to $|e|^{\alpha}$, where $|e|$ denotes the Euclidean length of $e$ and $\alpha$ the path-loss exponent. Then, the unit energy is defined by $\sum_{e \in E(P)} |e|^{\alpha}$. If we take the load of an edge $\ell(e)$ (i.e. the number of paths in $P$ using this edge) into account we obtain the flow energy, which is defined by $\sum_{e \in E(P)} \ell(e)|e|^{\alpha}$. Unit energy reflects the power consumption of maintaining the edges, and flow energy reflects the power consumption of using the paths for communication.

The load of a path system is the maximum load of an edge: $L(P) := \max_{e \in E(P)} \ell(e)$ (for wired networks this is often called congestion). The definition of congestion for wireless networks contains also the load which is induced by interfering edges. The congestion of an edge $e$ is given by $C(e) :=$
\[ \ell(e) + \sum_{e' \in \text{Int}(e)} \ell(e') \] where \( \text{Int}(e) \) is the set of edges \( e' \) that interfere with \( e \). The congestion of a path system is defined by \( C(\mathcal{P}) := \max_{e \in \mathcal{E}(\mathcal{P})} C(e) \).

The motivation for modeling interference this way is that communication in networks usually includes the exchange of acknowledgements, so that interference is also a problem for the sender who expects to receive an acknowledgement. Beside this model, we use a more realistic model in the simulation, including the power attenuation according to the free space propagation model and the signal-to-interference ratio. This consideration leads to the definition of realistic congestion \( C_r(\mathcal{P}) \) that we introduced in [RSVG03]. The realistic congestion includes load, interference, and properties of the propagation model. The definition is the same as for congestion, but for counting the interfering edges, we take the power attenuation and the signal-to-interference ratio (SIR) into account: An edge \( e' = (v_1, v_2) \) interferes with an edge \( e = (u_1, u_2) \) if the transmission on \( e' \) causes a received power \( p' \) at \( u_1 \) or \( u_2 \) that is higher than the received power \( p \) caused by a transmission on \( e \) divided by the SIR (i.e. \( p/p' < \text{SIR} \)).

SAHNE contains functions to assess the quality of the network topology, based on the measures congestion, dilation and energy (see [MSVG04]). For the computation of congestion, SAHNE calculates hop-optimal and energy-optimal paths systems based on the current topology. This calculation is done offline for the topology consisting of the communication links that are currently established. It is based on solving an all-pairs-shortest-paths problem w.r.t. hop-optimal and energy-optimal paths.

### 3 Main contributions

Our extenstions of the network simulator SAHNE comprise the propagation model, the statistics module and the mobility models. Furthermore, we have performed experiments of hierarchical network topologies.

#### 3.1 New Propagation Models

For the simulations with SAHNE we have extended the propagation models, such that besides the infrared propagation model for directional communication we can use a propagation model for omni-directional communication with variable range and variable path-loss exponent. These parameters are also evaluated in the statistics module, where the interference between wireless links is calculated in order to compute congestion and energy of routing path systems. Furthermore a propagation model for helical antennas has also been implemented.

For omni-directional communication, the propagation model is based on the well-known free space propagation model (see [HM04]). The received power \( P_r \) is calculated by

\[
P_r = \frac{P_t G_t G_r}{d^\alpha} \left( \frac{\lambda}{4\pi} \right)^2
\]

where \( P_t \) is the transmitted power, \( d \) the distance between sender and receiver and \( \alpha \) the loss exponent, \( G_t \) the transmitter gain, \( G_r \) the receiver gain, \( \lambda \) the speed of light.

The calculation of the measures congestion and energy is also based on this propagation model. Different environments, where e.g. reflections or multi-path fading exist, can be modeled by different path-loss exponents [HM04]. With a higher path-loss exponent, a higher transmission power is necessary. This influences unit energy and flow energy of the network topology and has also an effect on congestion, because the interference depends on the power attenuation and on the signal-to-interference ratio.

In the statistics module the functions for the calculation of congestion and energy were adapted to the parameters of the propagation model, such that these measures are calculated in accordance to the particular parameters of the propagation model.
3.2 Mobility Models

SAHNE includes various random mobility models which are the Brownian motion model and variants of the random waypoint model \cite{JM96}. We have extended the mobility models by a scenario mobility model, which provides a high flexibility for the user: One can define different trajectories for each participant. The trajectories are polygons, which are specified by waypoints. Between the waypoints the speed of each node can be determined or chosen randomly. Nodes can be stopped and switched off (to simulate node failures or communication failures) at certain time steps. The description for the scenario is read from a file.

3.3 Experimental Evaluations

In \cite{RSV05} we have investigated a hierarchical network topology, called hierarchical layer graph (HLG), which can be used to approximate congestion-optimal networks \cite{MSVG04}. The HLG was first introduced in \cite{GLSV02}. The basic concept of the HLG is based on layers which are subsets of the set of nodes (see Figure 2). The lowest layer contains all nodes. This node set is thinned out in the next layer by a leader election process, i.e. only the leaders of one layer become members of the next layer. On the highest layer a single node remains. The idea is to establish many short edges on the lower layers, that constitute an energy-optimal path system, and create only a small number of long edges on the upper layers, that ensure connectivity and allow short paths, i.e. paths with a small number of hops. The HLG has two parameters: the publication radius and the domination radius. These parameters affect the amount of interference in the network. These parameters also determine whether the HL graph is a c-spanner, which implies an energy-efficient topology.

The HLG can be constructed by a distributed protocol that uses only local information. In our simulations we used the performance measures dilation, energy and congestion and simulated the protocol on random node sets. We compared HLGs with different values for the publication radius and domination radius and could identify a good choice for these parameters. We also compared the HLG with the Unit Disk Graph (UDG). The unit disk graph contains an edge between two nodes if and only if the Euclidean distance between these nodes is at most 1. The topology of a wireless network with fixed transmission ranges (normalized to 1) corresponds to the unit disk graph. Our

\footnote{In a c-spanner there is at least one path between two arbitrary nodes u and v of length at most c \cdot ||u - v|| (see \cite{SVZ04} for more details).}
simulation results show that the HLG contains very energy efficient path systems compared to the UDG.

4 Summary

We have extended our simulation environment SAHNE, such that besides the infrared propagation model for directional communication we can use a propagation model for omni-directional communication with variable range and variable path loss exponent. These parameters are also evaluated in the statistics module, where the interference between wireless links is calculated in order to compute congestion and energy of routing path systems. Furthermore a propagation model for helical antennas has also been implemented. Besides the random mobility models, the movement of the participants can be specified by trajectories, which provides a high flexibility for the user.

We have investigated a hierarchical network topology, called hierarchical layer graph (HLG), which can be used to approximate congestion-optimal networks. The HLG can be constructed by a distributed protocol that uses only local information. In our simulations we used the performance measures dilation, energy and congestion and compared the HLG with the Unit Disk Graph (UDG). Our simulation results show that the HLG contains very energy efficient networks compared to the UDG.

References


