A time-stepped and fluid simulation approach for mobile ad hoc networks

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Abstract: We propose a simulation approach which applies time-stepped and fluid simulation techniques to accelerate large-scale simulations of mobile ad hoc networks (MANETs). We described the simulation modelling and parameterizing process according to the dynamic characteristics of MANETs. We also introduce the simulator SSim developed by the authors and present the experiment results. This research demonstrates that time stepped and fluid simulation is a viable approach to realize efficient MANET simulation.

1. Introduction.

Mobile Ad Hoc Networks (MANETs) are of growing importance in networking. Performance evaluation for MANETs is difficult because of dynamic topology and often heterogeneous traffic. Moreover, meaningful experiments may involve hundreds or even thousands of mobile nodes. To develop an adequate experimental test bed would be very expensive. Analysis allows for faster solutions, while simulation is more flexible in the sense that arbitrary levels of detail are allowed. However the conventional means of simulation of packet-switched networks is not scalable because it uses a discrete event approach that models each packet level event through the network.

Contrast to the discrete event approach, fluid simulation [2] uses a packet rate rather than a packet-by-packet flow to represent traffic sources. Compared with discrete packet-level simulation, it requires fewer variables when describing a traffic flow and can save computation time. An extension of fluid simulation technique is the time-stepped simulation model which discretizes the time axis into fixed-length intervals called time-step and ignores the traffic variation within one time-step, assuming a constant arrival rate during that period.

We have developed a simulation facility specifically for multi-hop wireless communications using ad hoc networking or hybrid networks mixed with traditional fixed networks. The main objective of this research is to improve simulation scalability and efficiency and will be achieved mainly by using time-stepped and fluid simulation techniques. Section 2 provides an overview of the simulators for MANETs. Section 3 describes the modelling and section 4 gives the results of our experiments. Section 5 is our conclusion.

2. Related work.

Several general purpose simulators have been developed and reported in the literature, such as OPNET [3] Modeler, NS-2 [1] and GloMoSim [4]. NS-2 is a discrete event network simulator and was extended to support wireless networking such as MANETs and wireless LANs. A limitation of NS-2 is its large memory consumption and its lack of scalability as soon as a simulation of a few hundred to a few thousand nodes is undertaken. OPNET Modeler can simulate all kinds of wired networks, and an 802.11 compliant MAC layer implementation is also provided. Although OPNET is intended for companies to diagnose or reorganize their network, it is possible to implement one's own algorithm by reusing a lot of existing components. GloMoSim is a scalable simulation environment for wireless and wired networks systems. The scalability is achieved by using a parallel simulation language, *Parsec*. With GloMoSim, the difficulty was to describe a simple application that bypasses most OSI layers. The bypass of the protocol stack is not obvious to achieve since most applications usually lie on top of it.

In [5] John Heidemann et al described the trade-offs associated with adding detail to wireless network simulation models. The authors evaluated the effects of detail in five case studies of wireless simulations for protocol design. In [6] we proposed a hybrid approach which decomposes a MANET system dealing with each component accordingly. The identified components need to be analyzed or simulated only once. By using the evaluation results of these sub-components instead of simulation, acceleration can be achieved by avoiding unnecessarily repeating these parts of the overall simulation.

3. Simulation model.

The main objective of SSim is to provide a flexible simulation solution which is able to adjust the level of simulation detail for the performance evaluation and designing of MANETs. Different from fixed networks, the topology of a MANET tends to change from time to time. This means most of the simulation acceleration techniques developed for wired communication networks are not suitable for a MANET environment. These techniques need to be adjusted in order to be able to cope with the traffic characteristics and the dynamic topology of wireless communications. We specially focus on improving simulation speed for relatively large-scale networks, since detailed simulation results can easily be obtained by using the existing simulators, e.g. NS-2, OPENT and GlMoSim, etc.

3.1. Time-stepped model.

SSim keeps track of the current value of simulation time and advances it by a fixed period called a *time-step*. This is different from another principal approach of advancing simulation clock called *next-event time advance*. With the next-event time advance approach, the simulation clock is initialized to zero and then is advanced to the time of occurrence of the most imminent of these future events. Under time-stepped advance policy, the state of the system is updated periodically to account for the fact that a fixed period of simulation time (time-step) has passed. Note that the “simulation time” here refers to the virtual time represented by the simulation clock which is not necessarily pro rata to the actual simulation running time.

The time-stepped simulation technique provides SSim a framework for simulating the network behaviour at different time scales. Scalability can be achieved by trading off the granularity of the simulation for computational efficiency. Simulation time is discretizd as time-step of length *h*. At the instance of the end of each time-step, system state variables are updated according to the events in past period $(nh, (n+1)h]$. For a large-scale system, typically hundreds of nodes for MANETs, increasing the time-step length directly results in the reduction of simulation computation time. This will usually introduce some error and infidelity, but our experimental results have shown that if the time-step length is chosen properly the error can be made negligibly small.

3.2. Fluid traffic model.

The traffic in SSim is represented by using the fluid model and is modelled in terms of a continuous fluid flow, rather than discrete packet instances. A bunch of closely-spaced packets can be represented as a single traffic fluid with a constant fluid rate and the small time-scale variations in the packet steam are abstracted out of the model. Continuous flow can be modelled efficiently using linear equations of the form $(\text{flow rate}) \times (\text{time}) = (\text{total flow})$.

Though fluid simulation can avoid simulating tedious packet level events, it is not always true that fluid simulation outperforms discrete packet-level simulation. For a network system where different traffic flows meet and contend for limited resources, rate changes may be propagated and amplified and this is known as *ripple effect* [7]. In SSim, we assumed that the MAC layer protocol provides each transmission a collision free wireless channel with fixed bandwidth. Interferences caused by simultaneously transmitting by two or more sources are simplified as the wireless channel is shared among these transmissions if the total bandwidth demand is less than the channel bandwidth. Otherwise, bandwidth is shared evenly among these transmissions. Since rate change in one flow can affect the output rate of other flows contending for the same channel only when the total bandwidth demanding of all flows exceeds the channel bandwidth, the effect of rate change can be largely avoided in light-loaded or moderated-loaded MANETs.

3.3. Topology and mobility model.

SSim models a network as a directed graph with links representing direct network connections between nodes. The free space propagation model is used to decide whether two nodes are directly connected. Nodes in the simulation move according to a mobility model. We use the *Random Waypoint Model*, which has been widely used in modelling of MANETs.

In MANETs, the changing topology can cause re-routing and traffic rate changes. Since the topology updating is time-stepped, errors may occur if the interval between updates is too long so that some link breaks have not been captured. It will affect the fidelity of simulation results because the routing process and channel bandwidth allocation are relying on this periodical “snapshot” of network topology. To deal with this problem, we carefully choose the time-step to be a length that the probability of more than one link-break is insignificant for each link during a time-step.

Let $N(t)$ be the Markov counting process of the number of link-break occurring in $(0,t)$, with $P_j(t) = \Pr ob\{N(t) = j\}$. So the probability of no more than one link-break occurring in $[nh,(n+1)h]$ is $P_0(h) + P_1(h) = L(h)$. By resolving the function $L(h) \geq \lambda$, where λ is a probability $(\lambda \leq 1)$, we can find a proper time-step h so that the probability of an error is below λ. The distribution $P_j(t)$ depends on the mobility model being used. For the random waypoint model, an analytical result was given in [8] using the assumption that the distribution of each node’s mobility characteristics change slowly relative to the rate of link failure. In practice, we also use simulation to evaluate $P_j(t)$ referring to [9].

4. Experiments results.

Several scenarios have been implemented to evaluate the accuracy and speedup performance of SSim. In each case homogeneous constant bit rate or exponential on-off traffic sources are applied and a series of comparisons are carried out among various time-steps. All simulations were run on a workstation with Athlon XP 2000+ 1.4 CPU and 256 MB physical memory.

Figure 1 presents the wall-clock simulation time with different simulation lengths as a function of time-steps. We can see that the run-time of a simulation decreases almost linearly with the increase of time-step, and this holds true for all scenarios. It’s clearly shown that the speedup benefit is very obvious by simply increasing the time-step.

We assume the simulation results can be considered accurate with a time-step of 0.1 second. We adjust the *pause time* which in the Random Waypoint model defines the idle length of a node after each movement. A higher pause time corresponds to a higher level of mobility. Figure 2 and figure 3 show the delivery ratio and overall end-to-end throughput as a function of pause time under maximum node speed 2 m/s. We can see that with a lower rate of mobility (2 m/s of maximum node speed) increasing time-step causes a trivial effect on the traffic delivery ratio and overall end-to-end throughput. However when the rate of mobility becomes higher, the effect brought by increasing time-step becomes more obvious. This can be seen in figure 4, where the maximum node speed is 20m/s. The difference between the results of with time-step of 0.1 second and these of 100 seconds ranges from 1.1% to 6.4% in figure 3 and the maximum difference goes as high as 23.1 % in figure 4.

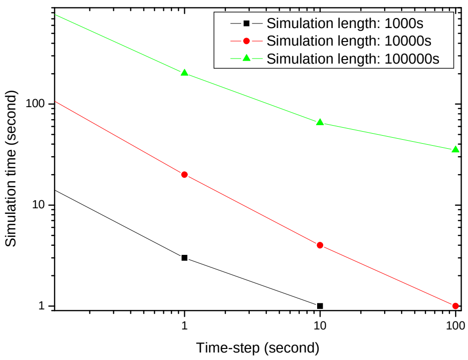

Figure 1 Comparison of simulation (wall-clock) time with increasing simulation length as a function of time-step.

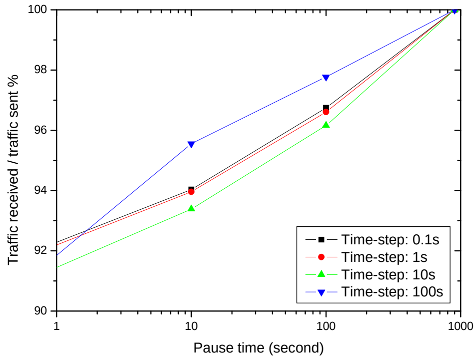

Figure 2 Comparison of the fraction (%) of traffic data successfully delivered as a function of pause time. Maximum speed is 2 m/s. Traffic sending rate is 50 Kbps.

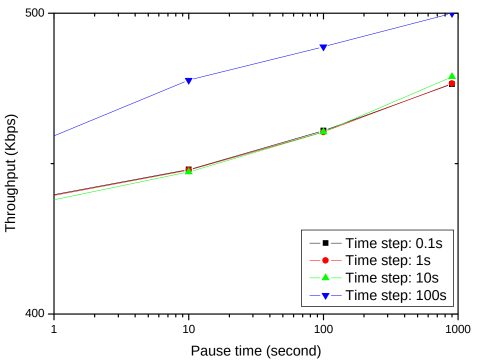

Figure 3 Comparison of the throughput (Kbps) as a function of pause time. Maximum speed is 2 m/s. Traffic sending rate is 50 Kbps.

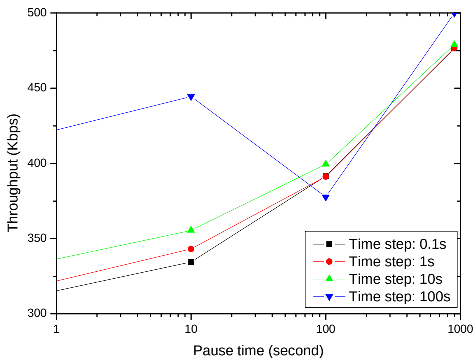

Figure 4 Comparison of the throughput (Kbps) as a function of pause time. Maximum speed is 20 m/s. Traffic sending rate is 50 Kbps.

5. Conclusions.

In this paper we propose a simulation solution using the time-stepped and fluid simulation techniques in MANET. We illustrate the effects of applying such techniques in the MANET environment and propose a hybrid solution using both analysis and simulations. Our results show that the combination of these techniques can accelerate simulations of complex systems like MANETs and keep the desired level of accuracy as well.

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