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A Simple Scheme for Relative Time Synchronization in Delay Tolerant MANETs

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***Abstract*—In mobile ad hoc networks (MANETs), time synchronization can be achieved by distributing time information among nodes. This type of time synchronization, however, does not work well under considerable long delay caused by sparse population. In this paper, we propose a simple yet effective scheme for relative time synchronization. When two mobile nodes meet, they exchange their clock information and adjust their own clocks to the average. Through simulation experiments, we show that the variance of the difference between the local and reference times remains within a certain finite range that depends on the frequency of nodes' meetings.**

***Keywords*-Time synchronization; DTN; MANETs;**

I. INTRODUCTION

Time synchronization is a critical issue in network systems composed of numerous distributed nodes. In general, a computer clock drifts away from real time by 10^{-6} to 10^{-4} seconds per second [1]. In the Internet, NTP is commonly used for rigid time synchronization. Each node synchronizes its local clock with UTC (Coordinated Universal Time) by periodically retrieving time information from an NTP server attached to special devices such as atomic clocks and GPS clocks.

Note, however, that NTP may not be suitable for wireless networks, especially, mobile ad hoc networks (MANETs) and sensor networks, because communication between two arbitrary nodes can be unstable. If each node is attached to GPS clock, time synchronization can be easily achieved. However, it is not desirable in terms of battery consumption and introduction costs. Moreover, each node cannot obtain time information from satellites when there are obstacles between the satellites and itself. To tackle these problems, there are several studies on rigid time synchronization in MANETs and sensor networks [2], [3]. To the best of our knowledge, all of existing time synchronization schemes require reference nodes distributing information through one- and/or multi-hop communications.

It is clear that such information distribution is difficult under challenged networks called delay tolerant networks (DTNs) [4], e.g., networks in deep space, underwater fields, and disaster areas. Since DTNs have sparse population, they suffer from long end-to-end delay due to lack of continuous connectivity. In such a situation, the end-to-end communication can be achieved by a store-carry-forward paradigm where mobile nodes fill the role of relaying messages. RFC 4838 [4] specifies the architecture of DTNs, where the importance of time synchronization is emphasized in terms of routing and message lifetime. It does not mention, however, how to achieve time synchronization among nodes in DTNs. If the existing synchronization methods [2], [3] are applied to DTNs, each node may have to wait for a long time to receive the reference time and/or cannot select correct one from multiple reference times received through different paths generated by the store-carry-forward paradigm

In this paper, we propose a simple yet effective scheme for *relative* time synchronization among nodes in sparsely populated MANETs: When two mobile nodes meet, they exchange their clock information and adjust their own clocks to the average. Therefore the proposed scheme does not need either reference nodes for time synchronization or distribution of time information.

II. RELATIVE TIME SYNCHRONIZATION

Suppose that there are N mobile nodes in a closed region and each node i ($i = 1, 2, \ldots, N$) has clock rate ρ_i and clock offset ϕ_i. We also assume that node i's clock $c_i(t)$ at time t is right-continuous and has a left-hand side limit.

When nodes i and j meet at time $t = \tau$, they instantaneously exchange time information and adjust their local clocks to the average:

$$c_i(\tau) = c_j(\tau) = \frac{c_i(\tau-) + c_j(\tau-)}{2}. \tag{1}$$

This scheme can be incorporated into the store-carry-forward paradigm without extra communication overheads. Note that we ignore transmission delay between the pair of nodes because it is the order of micro second which is relatively smaller than the accuracy of synchronization aimed by the proposed method.

We now define the reference time $c^*(t)$ as

$$c^*(t) = \overline{\rho} \cdot t + \overline{\phi}, \tag{2}$$

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where

$$\overline{\rho} = \frac{1}{N}\sum_{i=1}^{N}\rho_i, \quad \overline{\phi} = \frac{1}{N}\sum_{i=1}^{N}\phi_i.$$

Note that when nodes i and j meet at $t = \tau$, we have

$$c_i(\tau-) + c_j(\tau-) = c_i(\tau) + c_j(\tau).$$

Thus the sums of clock times of two nodes immediately before and after their meeting are identical. In addition, the sum of clock times of all nodes increases with rate $\rho_1 + \rho_2 + \cdots + \rho_N$. It then follows that

$$\frac{1}{N}\sum_{i=1}^{N} c_i(t) = c^*(t), \quad \forall t \geq 0,$$

where $c^*(t)$ is given in (2). Therefore the sum of the differences $d_i(t) = c_i(t) - c^*(t)$ of all nodes is always zero. We call $d_i(t)$ the *time difference* of node i hereafter.

III. SIMULATION EXPERIMENTS

We use NetLogo [5] in our time-driven simulation experiments with a 25×25 grid area. Initially, each of N nodes is located independently and randomly on one of grids. At each time step, every node first identifies adjacent grids (i.e., the above, below, left, and right grids, or some of them) and move to one of them with equal probability. After the movement, each node conducts time synchronization with each of neighboring nodes on the same and four adjacent grids. We set $(\rho_i, \phi_i) = (1 - 10^{-4}, 0)$ for randomly chosen $N/2$ nodes and $(\rho_i, \phi_i) = (1 + 10^{-4}, 100)$ for the rest, so that $\overline{\rho} = 1$ and $\overline{\phi} = 50$. Each simulation experiment runs for 10^9 time steps.

We define the meeting ratio as the average number of meetings per time step. Fig. 1 shows the variance of time difference, i.e., $N^{-1}\sum_{i=1}^{N}\{d_i(t)\}^2$, at the 10^9th time step and the meeting ratio for $N = 2$, 10, and 100. Without time synchronization, the variance of time differences would be greater than 9.99×10^9 at the 10^9th time step. We observe that the time difference is small in any case and the synchronization accuracy improves with the increase of N, because the meeting ratio also increases with N. Fig. 2 shows the transient behavior of the variance of time differences. We observe that the large initial variance due to offsets steadily decreases and reaches the steady state.

IV. CONCLUSION

In this paper, we proposed a simple yet efficient relative time synchronization scheme. Simulation results demonstrated that the proposed scheme looks promising. We are now working on the analysis of the time difference and the result will be reported somewhere else.

We also plan to extend the proposed method by taking account of the history of meetings. For example, it seems that nodes which encountered other nodes recently and/or many times are more reliable. We expect that extending Eq. (1) to weighted average using these information contributes the improvement of synchronization accuracy.

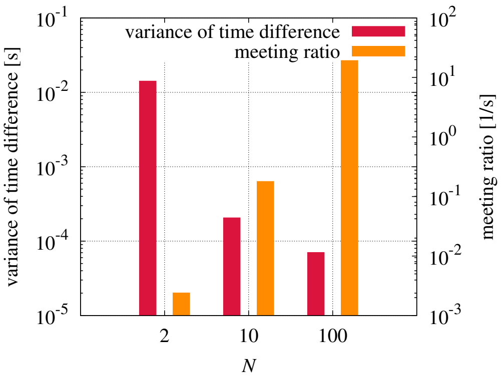

Figure 1. Variance of time difference at the 10^9th time step and meeting ratio.

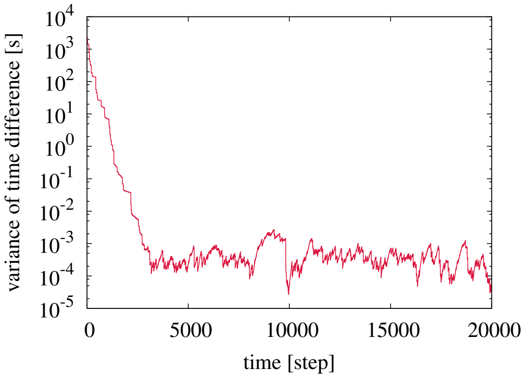

Figure 2. Transient behavior of the variance of time difference ($N = 10$).

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