Short Paper: A Human Mobility Pattern-based Routing Protocol for Delay Tolerant Networks

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Abstract—Delay tolerant networks generally use the epidemic routing protocol, because stable routing paths can hardly be maintained. However, the epidemic scheme leads to much network overheads because the messages are delivered to all the devices. In this paper, we propose an efficient protocol based on the human mobility patterns. In the proposed protocol, a message is delivered to several devices that are expected to deliver well the message to the destination. The proposed protocol relies on the human mobility patterns that contain the regularity. The simulation demonstrates that the proposed protocol reduces the network overheads, while maintaining reasonable delay time.

Key words—routing protocol, DTN, mobility pattern, HCMM

I. INTRODUCTION

Efficient routing in the delay tolerant network (DTN) could be an appropriate test bed to implement a cost effective network system, because each device can communicate each other without a server [1]. However, it is difficult to route in DTN because DTN has intermittent connection due to the mobility of devices. The mobility of devices also implies that there is no guarantee on a stable and fixed path to route in DTN. To resolve the intermittent connection issue, one of the most popular schemes is the epidemic routing protocol [2]. This scheme can quickly deliver a message, but DTN suffers from too much network overheads because a device delivers the same message to all the devices encountered. Thus, in this paper, we propose a routing protocol called the human mobility pattern-based routing protocol (HRP) to reduce the network overheads. HRP attempts to exploit regular mobility patterns of users that they could be expected to encounter each other more predictably.

II. PROPOSED PROTOCOL: HRP

A. Storing Mobility Patterns in a Table

We explain how to store the mobility pattern information in a table at each node. The table consists of \( N \times N \) entries, where \( N \) is the number of nodes in the network. Each entry \((i, j)\) of the table contains \( P_{i,j} \) denoting the probability that a message is successfully delivered to the destination node \( n_i \) via \( n_j \). Initially each \( P_{i,j} \) is set to 0.5 as below because a node does not have any movement pattern information prior to the warm-up period. The higher the probability is, we get the better chance that a message can be sent to \( n_i \) via \( n_j \). The probabilities are stored and updated as in the table below.

In Table 1, \( n_1, \ldots, n_n \) in the first column are the destination nodes to whom the owner of the table wishes to ultimately send a message, and \( n_1, \ldots, n_n \) in the first row are ‘the bridge nodes’ that may deliver a message to the destination node. After the owner of the table sends a message to \( n_j \) in the hope that it is delivered to \( n_i \), \( P_{i,j} \) is updated as in Equation (1).

\[
\begin{align*}
P_{i,j} &= \begin{cases}
P_{i,j} \times (1 - \alpha), & \text{if the node sends a test message} \\
P_{i,j} \times (1 + \beta), & \text{if the node receives a return message}
\end{cases}
\end{align*}
\]

Equation (1).

In Equation (1), \( \alpha \) and \( \beta \) are the values for learning \( P_{i,j} \). \( \alpha \) decreases \( P_{i,j} \) when a test message is sent to \( n_j \), because we are not sure whether \( n_j \) successfully delivers the test message to \( n_i \) or not. We increases \( P_{i,j} \) through \( \beta \) when a return message is received via \( n_j \), because receiving a return message from \( n_j \) indicates that \( n_j \) successfully delivered the test message to the destination node \( n_i \).

B. Collecting Regular Mobility Patterns

In the warm-up period, each node sends a test message to all other nodes in the network in order to learn the mobility pattern information. Each node adopts the epidemic routing protocol to deliver its test message for obtaining the pattern information. The test message has the visiting history information that means the list of nodes in the order of being visited by the test message. We can exploit the delivery history of a test message for the regular mobility patterns from the fact that if some nodes appear frequently in the delivery history of the test message, they received the test message repeatedly and such receptions could mean regular mobility patterns.

Now we show how to get the mobility pattern information from the delivery history during the warm-up period. First, we assume that there are three nodes in the network. Among them node \( A \) is the source node, node \( C \) is the destination node. We also assume that \( \alpha = 0.1 \) and \( \beta = 0.2 \). As \( A \) moves, it encounters \( B \). At this moment, \( A \) delivers its test message and decreases \( P_{C,B} \) in its table through \( \alpha \). So, \( P_{C,B} = 0.45 \), because \( 0.5 \times (1 - \alpha) = 0.45 \). Next, \( B \) can finally finish this work by delivering the test message to the destination node \( C \). In this case, \( B \) does not modify anything. After \( C \) gets the message, it sends a return message to the source node \( A \) by
exploiting the delivery history information of the test message. The return message is kept by $B$ until $B$ meets $A$.

C. Analyzing Regular Mobility Patterns

When the test message is arrived at the destination node, the destination node sends a return message to the source node. The return message traces the route of the delivery history of the test message. We can infer the regular mobility pattern of the nodes from the return message. If the test message is sent to the destination node through the regular mobility patterns of the nodes associated with the delivery history, it’s much easier for the return message to come back to the source node. However, it would be difficult for the return message to get back to the destination if the test message is sent to the destination node by means of random mobility patterns. Thus, we can analyze users’ mobility patterns by collecting the return messages.

In the previous example, after $B$ meets $A$, $B$ delivers the return message to $A$, and then, in the table of $A$, $P_{C,B}$ is increased. Thus, $P_{C,B} = 0.54$ because $0.45 \times (1 + \beta) = 0.54$ according to Equation (1), indicating that it’s good for $B$ to send $C$ a message. The more we perform the analyzing process repeatedly, we get the more precise the regular mobility pattern information on the network. So, if a node delivers a message to some node with a higher associated probability, the message is highly likely to be delivered to the destination.

III. SIMULATION RESULTS

A. Simulation Environments

We used the NS-2 network simulator to evaluate HRP, because NS-2 is suitable for analyzing correlation between network overheads and delay time. We compared HRP with the epidemic and probabilistic routing protocols using history of encounters and transitivity (PRoPHET) [3] protocols to evaluate the performance of HRP. The scenario with Home-cell Community-based Mobility Model(HCMM) [4] has 45 nodes. Each community has five nodes of which only one is the traveler node. The speed of each node is 2–5 m/s. Each node in the network randomly selects a destination node. We measured the delay time and network overheads until all 45 messages arrived at each destination. The simulations were conducted 20 times to get the accumulate results.

B. Results

We measured the delay time of each protocol. HRP shows faster delivery than PRoPHET because HRP uses not only deliver predictability but also the mobility pattern of nodes. As we can see in Figure 1, the average delay time of HRP is 463.7% slower than that of the epidemic protocol, but 170.6% faster than that of PRoPHET. Next, we measured network overheads of each protocol. In Figure 2, the network overhead of HRP is 69.6% smaller than that of the epidemic protocol, because HRP utilizes the table information of the nodes effectively. In DTN, the transmission delay isn’t critical since DTN is devised to endure the transmission delay. However, too much network overheads in DTN could become a serious problem.

IV. CONCLUSION

We proposed a human mobility-based routing scheme in DTN to reduce the network overheads. The proposed routing scheme is designed to collect and analyze users’ mobility patterns in a warm-up period. The scheme calculates the probability of which a message is successfully delivered to the destination node. The simulation shows that the proposed scheme outperforms the epidemic routing protocol in terms of network overheads. We are currently working on the impact of different mobility patterns.

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