Performance Comparison of Geographic DTN Routing Algorithms

Misako Seki*, Kazumine Ogura†, Yasuhiro Yamasaki†, and Hiroyuki Ohsaki*
* *Department of Informatics*
School of Science and Technology
Kwansei Gakuin University
Hyogo 669-1337, Japan
E-mai: {misako,ohsaki}@kwansei.ac.jp
† *Cloud System Research Laboratories*
NEC Corporation
Kawasaki, Kanagawa 211–8666, Japan
E-mail: {k-ogura,y-yamasaki}@ay.jp.nec.com

***Abstract*—In this paper, we compare the performances of geographic DTN (Delay/Disruption-Tolerant Network) routing algorithms through simulation experiments. We compare message delivery times in five geographic DTN routing algorithms — Random, Nearest, Farthest, Distant and AOD (Angle Of Deviation) — while varying the number of mobile agents on the field and the capacity of wireless communication. Our finding includes that AOD algorithm, which prioritizes message loading and unloading according to the deviation of node's mobility vector and message's destination vector, outperforms other four geographic DTN routing algorithms.**

***Keywords*-DTN (Delay/Disruption-Tolerant Networking); geographic DTN routing, store-carry-and-forward communication, simulation**

I. Introduction

Delay/disruption-tolerant networking (DTN), which allows end-to-end node communication even when communication links between nodes are not functioning normally, has recently been regarded as a promising communication technology for realizing communication infrastructure at the time of disaster and low-cost communication infrastructure [1]. DTN aims to achieve reliable end-to-end data transfers in communication environments where internode communication links can be temporarily severed, or the transmission delay between nodes can temporarily increase.

In the literature, extensive researches on DTN routing based on store-carry-and-forward communication with mobile nodes have been actively performed [1]. DTN routing communication between mobile nodes generally utilizes the characteristics of mobile nodes, which autonomously and independently move on the field, and also adhoc wireless communication among mobile nodes for realizing end-to-end message delivery. DTN routing is classified into two types, *unicast* and *multicast (or broadcast)* according to the number of nodes involved in transmission and reception of a message. Also, according to the number of message replicas, DTN routing algorithms are classified as either *single-copy* algorithms or *multi-copy* algorithms. Another classification is based on message forwarding strategy: *flooding-based* algorithms and *forwarding-based* algorithms.

To the best of our knowledge, most of existing DTN routing algorithms are designed for message delivery between mobile nodes (i.e., message transmission from a mobile node to one or more other mobile nodes). However, in practical applications of DTNs in several fields, endpoints of communication might not be necessary *mobile* nodes. In other words, endpoints might also be *fixed* nodes, so other types of communications between mobile and fixed nodes and also between fixed nodes should be required. In this paper, a class of DTN routing utilizing mobile nodes for store-carry-and-forward communication among *fixed* nodes is called *geographic DTN routing*.

In the literature, there exist a great number of studies on DTN routing such as design, analysis, and performance evaluation of several DTN routing algorithms (see, for example, [2]–[4]). However, to the best of our knowledge, there is little research on geographic DTN routing.

In this paper, we therefore investigate fundamental properties of geographic DTN routing algorithms. The class of geographic DTN routing algorithms studied in this paper is *single-copy* and *unicast-based*. We compare the performances of five geographic DTN routing algorithms — Random, Nearest, Farthest, Distant and AOD (Angle Of Deviation) — through simulation experiments. We compare message delivery times of those geographic DTN routing algorithms while varying the number of mobile agents on the field and the capacity of wireless communication. Our finding includes that AOD algorithm, which prioritizes message loading and unloading according to the deviation of node's mobility vector and message's destination vector, outperforms other four geographic DTN routing algorithms.

Note that this paper focuses on simple single-copy algorithms to investigate the fundamental properties of geographic DTN routing algorithms. Investigation of more complex single-copy algorithms and also multi-copy algorithms is of great importance, but it is beyond the scope of this paper.

The primary contributions of this paper are summarized

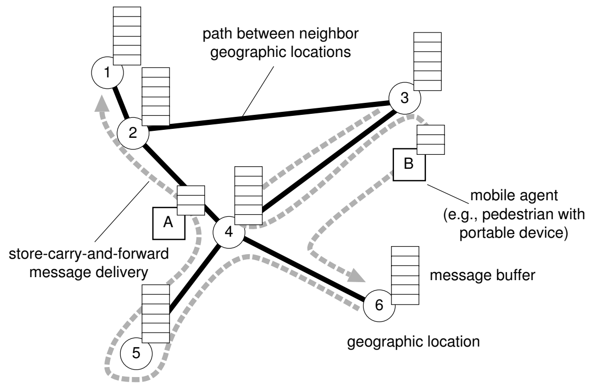

Figure 1. An overview of geographic DTN routing with mobile agents

as follows.

- We formulate a problem of geographic DTN routing among fixed nodes, which is essentially different from existing DTN routing among mobile nodes.
- We reveal the fundamental properties of five geographic DTN routing algorithms though simulations under different node densities and capacities of wireless communication (i.e., the maximum numbers of message movements per geographic location).
- We show that in geographic DTN routing, utilization of the deviation of node's mobility vector and message's destination vector is effective rather than utilizing the distance between the origin and the destination of a message.

The organization of this paper is as follows. Section II explains the concept of geographic DTN routing and defines terminology used throughout this paper. Section III formulates a problem of geographic DTN routing. Section IV introduces five geographic DTN routing algorithms. Section V compares message delivery times of those five geographic DTN routing algorithms through simulations. Section VI concludes this paper and discusses future works.

II. Geographic DTN Routing

A geographic DTN routing aims at realization of message delivery among multiple (generally, geographically-dispersed) *geographic locations* on a field without necessity of specific communication infrastructure by utilizing mobility of *mobile agents*. There exist multiple geographic locations and also multiple mobile agents (i.e., mobile nodes) on the field, and messages are carried by mobile agents for *message* delivery among geographic locations.

Every geographic location continuously generates *messages* destined for other geographic locations. We assume that multiple mobile agents autonomously and irregularly visit geographic locations one and another. A mobile agent can *load* a message at its visiting geographic location, carry multiple messages while it moves, and *unload* one or more carrying messages at its visiting geographic location.

There exist a huge number of possible geographic DTN routing algorithms depending on the combination of various factors: message generation patterns and buffer sizes of geographic locations, mobility, mobility controllability, buffer sizes of mobile agents, type and capacity of wireless communications between a geographic location and a mobile agent, and availability of positional information of mobile agents (e.g., GPS (Global Positioning System)).

In this paper, we focus on a case where people carrying portable devices such as smartphones autonomously move among geographic locations. Therefore, we assume that mobile agents' mobility are uncontrollable (i.e., a geographic DTN routing algorithm has no control over people's mobility), and the capacity of wireless communication is limited (i.e., the bandwidth for message transfer between a geographic location and a portable device is finite). On the contrary, we assume that the buffer sizes of geographic locations and mobile agents (e.g., portable devices) are sufficiently large. We also assume that the positional information of mobile agents are available to a geographic DTN routing algorithm.

III. Problem Formulation of Geographic DTN Routing

Let N be the number of geographic locations on the field. We assume that the geometry P_v of geographic location v is known and stationary (i.e., the geometry does not change over time). Every geographic location is provided with a fixed node, which is equipped with a wireless communication device and a buffer (i.e., storage for storing messages). A mobile agent can exchange messages with the fixed node using wireless communication. For brevity, in this paper, the fixed node in a specific geographic location is simply called *geographic location*. We assume that the buffer size of a geographic location (i.e., the buffer size of a fixed node) is sufficiently large.

At a geographic location, messages destined for other geographic locations are generated. The destination of message s is denoted by $d(s)$. The message generation rate from geographic location v is denoted by λ_v. For simplicity, the sizes of all messages are assumed to be identical. Let $\mathbf{B}_v(t)$ be a set of messages stored in the buffer of geographic location v at time t.

The number of mobile agents is denoted by M, which is assumed to be a constant for simplicity. We assume that mobile agent m accurately and immediately obtains its geometry P_m on the field. A mobile agent irregularly visits geographic locations one and another. We assume that buffer sizes of mobile agents are sufficiently large (e.g., portable devices have large storages). Let $\mathbf{B}_m(t)$ be a set of messages stored in the buffer of mobile agent m at time t.

When a mobile agent visits a geographic location, (1) the mobile agent and the geographic location can exchange their lists of messages stored in their buffers, (2) at most the number K of messages can be copied or moved from the buffer of the geographic location to the buffer of the mobile agent, (3) at most the number K of messages can be copied or moved in the opposite direction (i.e., from the buffer of the mobile agent to the buffer of the geographic location), and (4) the mobile agent can eliminate an arbitrary number of messages in the buffer of the geographic location. In our problem formulation, the capacity constraint in wireless communication is represented as the maximum number K of message copies/movements.

In general, performance metrics for such a geographic DTN routing include (1) message delivery time (i.e., time elapsed from a message generation at an geographic location to completion of message delivery at its destination), (2) throughput (i.e., the number of deliverable messages per unit time), and (3) fairness among geographic locations (i.e., equality in the number of message deliveries among geographic location pairs).

IV. Five Geographic DTN Routing Algorithms

Geographic DTN routing algorithms can be roughly classified by their *message loading* mechanism (i.e., how messages are copied/moved from *a geographic location*) and *message unloading* mechanism (i.e., how messages are copied/moved from *a mobile agent*).

In this paper, we focus on the following five single-copy algorithms.

A. Random algorithm

Random algorithm is the minimal and the simplest algorithm, which randomly performs both message loading and message unloading.

When mobile agent m visits geographic location v, the number K of messages, $s_1 \dots s_K \in \mathbf{B}_v(t)$, are randomly chosen from the buffer of geographic location v. Those messages are moved to the buffer of mobile agent m.

If mobile agent m has one or more messages destined for geographic location v in its buffer, the number K of messages, $s_1 \dots s_K \in \mathbf{B}_m(t)$, are randomly chosen from its buffer. Those K messages are moved to the buffer of geographic location v.

B. Nearest algorithm

Nearest algorithm gives higher priority to messages destined for closer geographic locations in message loading, hoping that quickly delivering messages to closer geographic locations leads higher throughput.

When mobile agent m visits geographic location v, it selects the number K of messages, which have the shortest distance between the current geometry and the geometry of the message destination, $|P_{d(s)} - P_v|$, from the buffer of geographic location v. Those messages are moved to the buffer of mobile agent m. Other operations of Nearest algorithm is the same with those of Random algorithm.

C. Farthest algorithm

Contrarily to Nearest algorithm, Farthest algorithm gives higher priority to messages destined for further geographic locations in message loading, hoping that quickly delivering messages to further geographic locations leads to the smaller average delivery time.

When mobile agent m visits geographic location v, it chooses the number K of messages from the buffer $\mathbf{B}_v(t)$ of geographic location v with the longest distance between the current geometry and the geometry of the message destination, $|P_{d(s)} - P_v|$. Those messages are moved to the buffer of mobile agent m. Other operations of Farthest algorithm is the same with those of Random algorithm.

D. Distant algorithm

Distant algorithm gives higher priority to messages that have been carried further by the mobile agent, hoping that disseminating messages in the field contributes to a shorter message delivery time.

Message loading in Distant algorithm is identical to that of Random algorithm, but message unloading is performed as follows. First, if mobile agent m has one or more messages destined for the currently-visiting geographic location v in its buffer, those messages are unloaded. Second, mobile agent m moves messages with *longest traveling distance* from its buffer to the buffer of geographic location v. Traveling distance for message s is defined as the Euclidean distance between the geometry $P_{l(s)}$ of the geographic location where message s was loaded and the geometry P_v of geographic location v, i.e., $|P_{l(s)} - P_v|$.

E. AOD (Angle Of Deviation) algorithm

AOD algorithm performs message loading and unloading based on AOD (Angle of Deviation) between the mobility vector of an mobile agent and the destination vector of a message, but message unloading is performed as follows.

When mobile agent m visits geographic location v, it calculates AOD $\theta(s)$ for every message s in the buffer of geographic location between its mobility vector and the destination vector, $P_{d(s)} - P_v$, of the message. Mobile agent m then selects the number K of messages with the smallest AOD's from messages with AOD's within the range of $[-\pi/2, \pi/2]$. Those messages are moved to the buffer of mobile agent m.

First, if mobile agent m has one or more messages destined for the currently-visiting geographic location v in its buffer, those messages are unloaded. Second, mobile agent m calculates AOD $\theta(s)$ for every message s in its buffer between its mobility vector and the destination vector, $P_{d(s)} - P_v$, of the message. Mobile agent m then selects messages with the largest AOD's whose AOD's are *not* within the range of $[-\pi/2, \pi/2]$. Those messages are moved from the buffer of mobile agent m to the buffer of geographic location v.

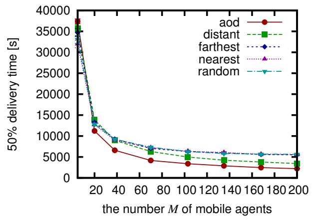

Figure 2. 50% delivery time for $K = 1$ with different numbers M of mobile agents

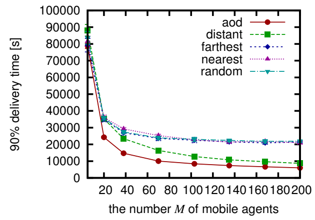

Figure 3. 90% delivery time for $K = 1$ with different numbers M of mobile agents

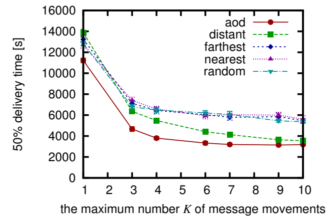

Figure 4. 50% delivery time for $M = 20$ with different maximum numbers K of message movements in message loading and unloading

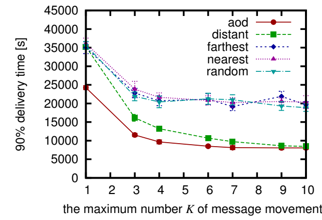

Figure 5. 90% delivery time for $M = 20$ with different maximum numbers K of message movements in message loading and unloading

V. Simulation

We used a 5×5 grid topology, which is composed of 25 geographic locations and 40 edges between geographic locations, each of which has 100 [m] length. In our simulations, the number M of mobile agents and the maximum number K of message movements in message loading and unloading are varied.

We used the CRWP (Constrained Random WayPoint) mobility model [5] for all mobility agents. The velocity of mobile agents was given by a uniform distributed of $[2, 4]$ [km/h]. The pause time of mobile agents was given by a uniform distributed of $[0, 300]$ [s].

At the initial state (i.e., $t = 0$), every geographic location had messages toward all other geographic locations. Hence, 600 ($= 25 \times 24$) messages were initially placed on the field. In our simulation, processing times for message loading and unloading are simply neglected.

Figures 2 and 3 show 50% and 90% delivery times for $K = 1$ with different numbers M of mobile agents. p% delivery time is defined as the time elapsed from the beginning of simulation to the successful delivery of p% messages on the field. These figures indicate that the performance of geographic DTN routing is significantly affected by the choice of a routing algorithm. In particular, AOD algorithm outperforms other geographic DTN routing algorithms regardless of the number of mobile agents. The performance with Distant algorithm is close to those with AOD algorithm. Performances with other three algorithms (i.e., Random, Nearest, and Farthest) are almost indistinguishable.

Also, Figs. 4 and 5 show 50% and 90% delivery times for $M = 20$ with different maximum numbers K of message movements in message loading and unloading. Again, AOD algorithm outperforms other geographic DTN routing algorithms, but the difference between AOD and Distant algorithms becomes marginal as the maximum number K of message movements increases.

VI. Conclusion

In this paper, we have investigated fundamental properties of five algorithms for geographic DTN routing among *fixed* nodes, which is essentially different from conventional DTN routing among *mobile* nodes. We have compared performances of five geographic DTN routing algorithms — Random, Nearest, Farthest, Distant and AOD (Angle Of Deviation) — through simulations under different node densities and capacities of wireless communication. We have found that AOD algorithm, which utilized the distance between the origin and the destination of a message, outperformed other geographic DTN routing algorithms regardless of the number of mobile agents.

As future work, we are planning to perform more extensive simulations by taking account of the distribution of geographic locations on the field and unbalanced workload (i.e., unbalanced message generation rates from geographic locations) and by examining other performance metrics than the message delivery time (e.g., efficiency and fairness).

Acknowledgements

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