Geo-Routing with Angle-Based Decision in Delay-Tolerant Networks

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***Abstract*—Delay-tolerant networks consist of mobile nodes that communicate in unscheduled opportunity without network infrastructure support. When mobile nodes move in highly dynamic networks, they suffer from many challenging issues such as broken network topology and transient connectivity among nodes. In this paper, we propose a geo-routing scheme with an angle-based decision policy (GRAD) for message delivery in delay-tolerant networks. This scheme can select relay nodes in geographic proximity to perform message delivery towards a destination. After a definite number of relays, the message can be destined to a destination. Simulation results show that GRAD can attain a higher rate of successful message delivery and lower communication cost as compared with a classical Spray and Wait scheme under area-confined random waypoint and SLAW mobility patterns in delay-tolerant networks.**

***Index Terms*—Message delivery; routing; geo-routing; delay-tolerant networks; wireless and mobile networks.**

I. Introduction

Data networking in challenged and unstructured networks suffers long transmission delay, path uncertainty and maintenance cost. Traditional store-and-forward routing schemes, like AODV and SDR, which resort to end-to-end connections in wireless and mobile ad hoc network [1], now become infeasible. Instead, recent research addresses delay-tolerant networking (DTN) architecture [2] which supports the store-carry-and forward routing model. In this model, message delivery depends on unscheduled connections among mobile nodes in a network. Nodes hand over messages in buffer as encountering other nodes during movement, or continue to carry messages till the next encounter. After a number of message relays among mobile nodes, those messages will reach their destinations.

The chance of reaching the destination is the goal on performance of message delivery in DTNs. To enhance the successful message delivery, data replication is often used to increase the number of copies of an original message so as to increase the probability of a message received by its destination. Nevertheless, abundant copies of messages by Flooding- or Epidemic-based replication [3][4] can be unbeneficial due to limited storage space and energy on nodes, thereby increasing traffic overhead and maintenance cost and even decreasing delivery ratio by buffer overflow.

A practical solution to many replication-based routing paradigms is to bound the message workload and communication cost in a network. Spray and Wait (SnW) [5] is a typical solution that maintains a fixed quota of message copies with respect to each distinct message in DTNs. A binary spray mode of SnW, for example, is usually applied to expedite the distribution of copies. At each time, a node with the message can hand over half the quota to an encountered node till its quota equals to one. A number of nodes corresponding to the quota will keep this message till it meets the destination or the lifetime of this message expires. On the other hand, geographical routing (geo-routing) paradigms exploit geographic information of nodes to find a routing path or direction from a source node to the destination in a network. Greedy perimeter stateless routing [6] is classical, and runs in a greedy forwarding way to find a route in a network. Shortest path based geographical routing [7] tends to find the minimum path for relay nodes to deliver data along an Euclidean line between a pair of source and destination. Though most geo-routing schemes originate in wireless sensor networks and mobile ad hoc networks, the geo-routing rationale conforms to DTN applications in large-scaled communication environments.

In this paper, we take both data replication and geographic information among nodes in a large-scaled DTN. We propose a Geographical Routing scheme with Angle-Based Decision, abbreviated as GRAD, which consists of three design functions. First, GRAD combines the advantages of SnW with a *binary* spray-and-wait mode. Second, GRAD takes account of moving direction, velocity and angle of each relay node corresponding to a baseline between a data-carried node and a destination. Third, GRAD can select an appropriate relay node which is moving toward the destination, and iteratively hand over message copies to relay nodes in a network. We examine GRAD in comparison to Flooding, Epidemic and SnW schemes under Random Waypoint (RWP) [8] and SLAW mobility models [9]. The performance result is derived using The One Simulator [10]. Simulated results show that GRAD can outperform other strategies for that it transmits in lower overhead or it maintains higher delivery ratio. Therefore, we introduce a new routing GRAD which not only keeps in high delivery ratio but also maintains in low amount of message copy compare to those classic methods.

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The rest of the paper is organized as follows. Related work is presented in Section II. Then, we present the design of GRAD in Section III, and simulation and performance results in Section IV. Finally, the conclusion is given in Section V.

II. Related Work

Routing in DTNs often resorts to replication-based message delivery schemes, e.g., Flooding, Epidemic, Quota-based SnW, which are mentioned below. Specifically, mobile nodes using Flooding or Epidemic schemes [3][4] can broadcast message copies in buffer to all neighbor nodes within reciprocal transmission ranges and then re-broadcast received message copies again in the same way. In spite of high data delivery ratio and low latency, the flooding-based scheme may consume energy dramatically due to an unscaled quantity of redundant messaging load in a network. Spray and Wait (SnW), i.e., quota-based replication, has been shown effective for message distribution in a network. SnW can perform using the *source spray* or *binary spray*. By the source spray, only a source node that generates the original message is allowed to scatter messages. It hands over a message copy to each encountered relay node during movement till only one copy is left in its buffer. By the binary spray, a source node sends out half the quota of copies to any encountered relay node. Likewise, a relay node will continue to send out half the quota of copies to the next encountered relay node, unless there is only one copy left in its buffer. SnW is simple to implement and also achieves high data delivery ratio, which is suitable in DTNs.

Regarding relay node selection, prior works mainly used the prediction model to select relay nodes in a network. The delivery probability of a node to meet a destination is estimated according to the inter-contact history of all nodes in a network. [11] used a replication-based efficient data delivery (RED) protocol by referring to a node's past successful transmission rate to each if other nodes. [12] used a FAD protocol that calculates the delivery probability with the way same as RED, but it further concerned fault tolerance about how it could restrict the amount of replicas to each message. Nevertheless, [11] and [12] still resulted in very high overhead.

Some previous works considered location and mobility as calculating delivery probability and delivery time in DTNs. For example, [13] took predications, mobility patterns and locations of mobile nodes to the destination, all which are used to make a decision of whether to replicate a message to nearby nodes with higher probability of meeting the destination. Moreover, recent works extended geographic routing paradigms to support large-scaled message distribution in DTNs. [14] proposed a geographic multi-copy routing scheme, named TBGR, which limits the number of copies to maintain low routing overhead. [15] contributed a geographic-based spray-and-relay (GSaR) scheme that efficiently sprays a limited number of message copies toward to the node with higher opportunity to meet the destination. In summery, previous research results indicated that those routings schemes can perform more efficiently and reduce energy consumption on nodes in a network after they adopt specific node-selecting and message-limited functionalities.

III. Approach Design

This section develops the GRAD scheme for message distribution in DTNs. Assume that all mobile nodes move independently in a square area of size $K \times K\ m^2$ as referring to a geographic-scaled network environment whose geographic scope is relative to the settings of node speed, population, and map size instead of a physical geographic distance. For simplicity, a source node and destination are set to be stationary or not move far from their home locations. In addition, relay nodes are set to move in different confined areas, and every node has its own moving path and moves at constant speed inside. The maximum transmission range of every node is set to R. Moreover, all relay nodes are equipped with GPS to obtain current locations. With the above, our study can concentrate on analyzing the effect by message forwarding among all relay nodes in a network.

The proposed GRAD scheme jointly employs the binary-spray replica distribution and the geographic angle-based relay node selection, as mentioned below.

A. *binary-spray replica distribution*

The former aims to take advantage of considerable performance that SnW attains as a result of quota-based replication. Specifically, every message is assigned M replicas in total. When a relay node carries a message in buffer and encounters another relay node during movement, this node can replicate this message to another if the remaining quota of this message is still more than one.

In light of SnW with the naive spray, any node A that has $M > 1$ message copies, i.e., source or relay node, will hand over 1 copy to any encountered relay node B if B has no copy of this message, and then itself keeps $M - 1$.

In light of SnW with the binary spray, by contrast, when A encounters B, A hands over $M/2$ copies and keeps $M/2$ for itself. When it is left with only one message copy in buffer, it switches to direct transmission. According to different conditions, GRAD can have different decisions on applying nave- or binary-spray type. To obtain more efficiency, we design the source node that initially sprays $M/2$ copies to every relay nodes it met because messages should be widely sprayed apart from where the source node stays.

B. *geographic angle-based relay node selection*

The decision of geographic angle-based forwarding strategy depends on the *degree* of whether the moving direction of a relay node is close to a destination indicated by the source node. Any mobile nodes that carry messages will iteratively determine suitable relay nodes to hand over message copies to next relay nodes that are going on the "closer" way to the destination.

Illustratively, Fig. 1 presents the geographic angle-based computation. For a relay node n_i with a destination n_d, such a degree α_i can be calculated by the measure of a geometric

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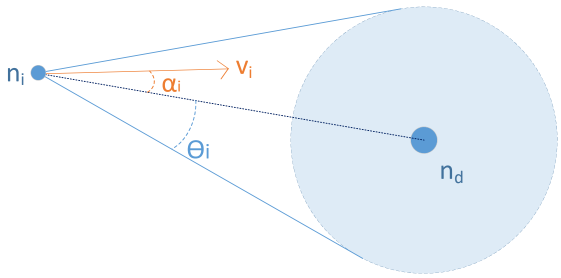

Fig. 1. Geographic angle-based computation.

angle with respect to a vector of moving direction $\vec{v_i}$ and a straight line $l_{i,d}$ between n_i and n_d. In addition, let θ_i be the angle between $l_{i,d}$ and the tangent line of n_i to the transmission range of n_d. Then, the closer extent of moving in the locality can be presented by a relative factor p_i below.

$$p_i = \frac{\theta_i - \alpha_i}{\theta_i}, \quad \alpha_i < \theta_i \, . \tag{1}$$

Suppose that a node n_i possesses a message m_i with a replicated quota of M_i and $M_i \leq M$, n_i is obligated to transfer this message to a destination d_i while it meets another node n_x. Observing the comparisons between α_x and θ_x as well as between p_i and p_x, it will be able to decide whether to transfer a portion of message quota from n_i to n_x or not. In what follows, there are five cases as the GRAD scheme operates the node selection in DTNs.

1) If n_i meets n_x that now appears in the transmission range of the destination n_d, p_x is set by 1 because n_x directly contacts n_d. Then, n_i delivers the message to n_x, and responsively n_d receives messages from n_x.
2) If n_i meets n_x that is static and not in the transmission range of n_x, p_x is set by 0.

Other than above cases, n_i and n_x will compare their values of relative factors with (1).

3) If $p_x > p_i$, it indicates that $\vec{v_x}$ is closer to $l_{i,d}$ than $\vec{v_i}$ is. That is to say, n_x has higher probability to meet n_d. By the binary-spray replication, n_x receives a half of message quota $M_i/2$ from n_i.
4) If $p_x \leq p_i$, it indicates that $\vec{v_x}$ likely deviates from $l_{i,d}$ as compared with $\vec{v_i}$. Herein, the deviation extent can be reflected by the difference between α_x and θ_x. Explicitly, in case of $\alpha_x < \theta_x$, n_x may still move in the transmission range of n_d. In case of $\alpha_x > \theta_x$, n_x may still move out the transmission range of n_d. Because n_x has some probability to meet n_x somehow, a naive replication is used, instead of a binary-spray replication, subject to the condition below:
If $\theta_x < \alpha_x < \theta_x \times 3$ where 3 is controlled as a tunning factor empirically, then one message quota out of M_i will be allocated to n_x.
5) If $\alpha_x > \theta_x \times 3$, obviously it is considered that n_x has a rare chance to meet n_d, so no message quota will be allocated to n_x.

Accordingly, the above gives a procedural description for geographic angle-based relay node selection, where closeness and deviation extents among three roles of relay, neighbor and destination nodes are relatively quantified. To this end, the proposed GRAD can be implemented, and its functionality will be investigated in the next section.

IV. Performance Results

This section shows the performance of GRAD compared with SnW under two mobility models, e.g., Random Waypoint (RWP) and SLAW. We execute simulation on The ONE stimulator which is commonly used for DTN routing research. Table 1 shows a list of parameters and their values during simulation. Performance results are compared by the aspects of delivery ratio and average transmission overhead.

- Delivery ratio equals to the value of the total of messages received by any destination nodes divided by the total of original messages generated by any source nodes.
- Average overhead: The average times of a message that has been forwarded between relay nodes till this message is received by the destination.

A. RWP Model

The comparison of delivery ratio between GRAD and SnW is shown in Fig. 2 where the cases are given with the quota of message copies as 4 or 8 with respect to each original message. It is clear to see that, under the RWP model, GRAD obtains better performance than SnW given that each message is assigned with the same time-to-live (ttl) period, i.e., the maximal lifetime in local buffer. This is because relay nodes move in confined ranges, yet GRAD can take advantage of geographic information to distinguish which node is moving toward the destination and then select suitable relay nodes to transmit messages with the angle-based decision.

Meanwhile, GRAD achieves lower transmission overhead in Fig. 3., by limiting the number of copies when replicating. GRAD prefers to keep most of message copies, and it only sends them out as soon as encountering suitable relay nodes. By contrast, SnW simply sprays message quotas to neighbor nodes but does not have any effective selection method. This manner may case messages to be barely transmitted to any nearby nodes nearby.

Therefore, the GRAD outperforms SnW when the messages of both have the same ttl values in the RWP model. It can be understood that GRAD is effective when nodes move in regional areas. It utilizes a certain method to select relay nodes as considering the directional vector in moving space. However, SnW does not have any node selection strategy, so it cannot ensure the message will be delivered to the area near a destination.

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TABLE I
SIMULATION PARAMETERS UNDER RANDOM WAYPOINT MODEL

Parameter	Value
Map size	1000×1000 m^2
Number of nodes	22
Transmission radius	100 m
Node speed	2 m/s
Quota of a message	4 or 8
Message size	5 KB
Maximum buffer size	100 KB
Message generation interval	60 seconds

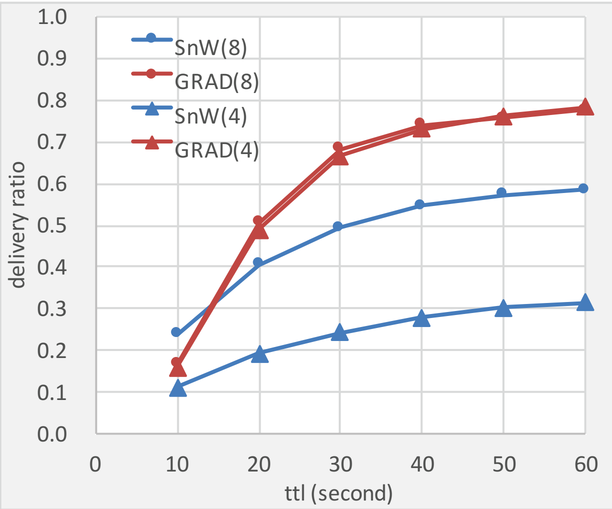

Fig. 2. Delivery ratio between GRAD and SnW under the Random Waypoint model.

B. SLAW Model

We further examine GRAD under the SLAW mobility model. This model adopts the behavior of fractal way-points, driven by similar techniques of fractional Gaussian noise and Brownian Motion generation, in order to resolve the premise of mobility attraction by popular places in the human society. SLAW leverages fundamental properties of fractal points to generate power-law flights on top of them. A power law distribution is then applied to emulate node movement patterns according to human social contexts.

Compared with the results in the RWP, it is interesting to notice that SnW itself can perform better with higher delivery ratio in the SLAW. As Fig. 4 illustrates, for example, the cases of SnW(4) and SnW(8) conform to such an observation. This can be explained in that message copies can be delivered to popular places where most nodes stay and it is of higher chance to meet the destinations. However, there is another interesting point that SnW itself can slightly increase transmission overhead, as illustrated in Fig. 5. The additional overhead likely arises from the more of message forwarded times n popular places. Relatively, GRAD still results in satisfactory performance in both metrics: better delivery ratio and similar overhead in comparison with SnW under the SLAW model.

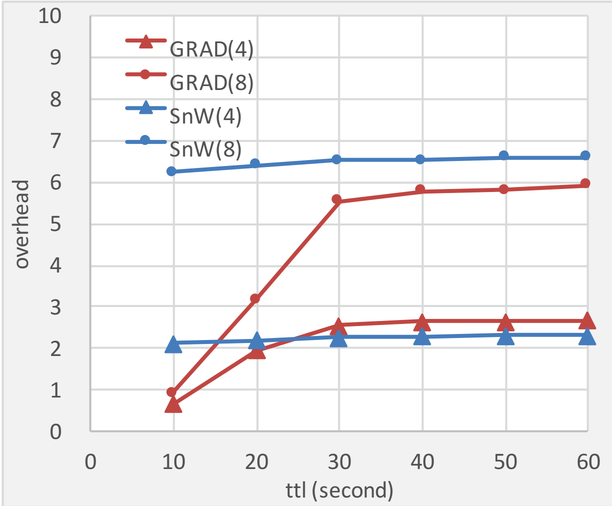

Fig. 3. Transmission overhead between GRAD and SnW under the Random Waypoint model.

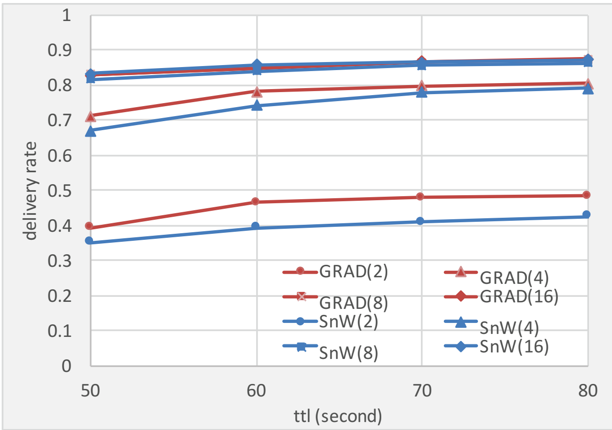

Fig. 4. Delivery ratio between GRAD and SnW under the SLAW model.

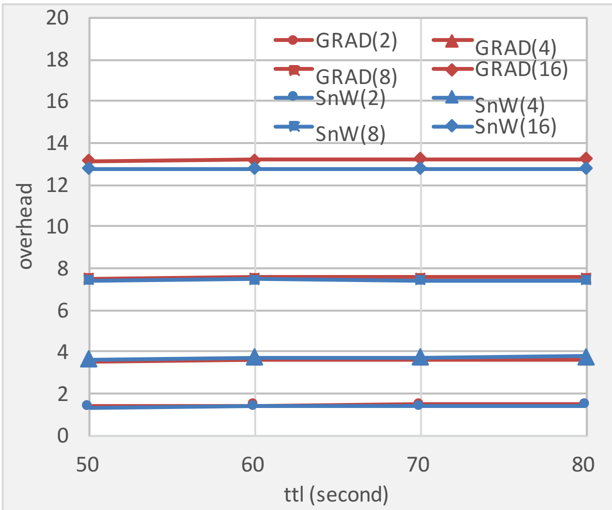

Fig. 5. Transmission overhead between GRAD and SnW under the SLAW model.

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TABLE II
SIMULATION PARAMETERS UNDER SLAW MODEL

Parameter	Value
Map size	1000×1000 m^2
Number of nodes	22
Transmission radius	100 m
Node speed	2 m/s
Quota of a message	2, 4, 8,or 16
Message size	5 KB
Maximum buffer size	100 KB
Message generation interval	60 seconds
Number of clusters (popular places)	3

V. CONCLUSION

This paper accounts for in DTN techniques for mobile data dissemination in dynamic network environments. We have proposed a geo-routing with angle-based decision (GRAD) scheme which uses the moving direction and the angle deviation between relay nodes and destinations in a network. By exploiting geographic locality information, the GRAD is able to select appropriate relay nodes during movement, so as to improve the percent of messages received by destination as well as to mitigate possible transmission overhead, thereby resulting in a cost-effective message delivery solution in DTNs. Simulation results under both RWP and SLAW mobility models show that GRAD performs better than SnW.

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