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A location aided controlled spraying routing algorithm for Delay Tolerant Networks

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ABSTRACT

Delay Tolerant Networks (DTNs) often suffer from intermittent disruption and variable long delay due to factors such as mobility and energy. In this paper, a Location Aided Controlled Spraying (LACS) routing algorithm is proposed to deal with the challenging issues in DTN routing. Only the routing information carried by the contacted nodes is needed in this algorithm, and there is no need for global networks knowledge and hardware support. The routing process is divided into two stages, i.e., controlled spraying routing stage and single-copy routing stage. The maximum transfer throughput of the contact is checked before each message is forwarded. During the controlled spraying stage, the current node adjusts spraying strategy according to the encounter angle of the contact nodes. During the single-copy stage, a location prediction model based on the semi-Markov process (SMP) is introduced, and the node's behaviors can be captured both in the temporal and spatial domains with this model. The current node predicts the destination node's location, and then decides whether to forward the message to target node based on the time used for meeting the destination node. Simulation results show that the proposed algorithm can achieve better performance than the traditional routing schemes of DTNs in terms of delivery ratio, network overhead and transmission delay under both random node movement model and realistic trace scenario.

1. Introduction

Delay Tolerant Networks (DTNs) [1] are designed to cope with the challenging conditions in the restricted networks with sparse density, intermittent disruption and limited energy. DTNs have features such as multiple hops, self-organization, and no central administration. In DTNs, an end-to-end path between a source node and a destination node does not exist most of the time, and the messages are opportunistically routed. Therefore, routing is an extremely challenging problem due to the characteristics of DTNs and the traditional network routing techniques cannot work effectively in DTNs [2].

There have been different kinds of routing schemes proposed for DTNs in recent years, and typical schemes include epidemic routing and probabilistic routing. The epidemic routing can achieve high delivery ratio and small delay at the cost of network bandwidth and buffer space by flooding messages to all the nodes encountered. To reduce the consumption of network resource, it uses different ways to limit the number of message copies forwarded, but it is hard to distinguish between nodes with regard to their probabilities of delivering the messages. The probabilistic routing tries to reduce message overhead and buffer contention by forwarding messages to nodes with high delivery probabilities. Its difficulty lies in the determination of reasonable delivery probability and the applicability in different scenarios.

In this paper, a novel routing algorithm called Location-Aided Controlled Spraying (LACS) is proposed. Despite the fact that a number of existing protocols have used location-aided methods, there are few routing schemes that consider rational assumptions for DTNs and have low complexity [3,4]. The proposed scheme combines the advantages of both spraying routing and probabilistic routing. The scheme consists of two stages according to the amount of the message copies: the controlled spraying stage and the single-copy location aided routing stage. If message copies are more than one, the message is forwarded by the spraying method, and the spraying process is controlled by node encounter angle instead of binary mode. By this, the copies can be spread to the whole region more quickly and avoid the slow start problem [5]. When only one copy is left, the LACS will trigger the single-copy

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routing stage aided by the location information. The location prediction model is based on the SMP, and all the needed information can be obtained from the two contact nodes. The last copy of the message will be forwarded to the node which can reach the destination within the shortest time.

The major contributions of this paper are as follows. (1) A method to estimate the throughput of node contact is proposed. It can help avoid transmitting such messages that could not be finished within the contact time. (2) An angle related adaptable spraying strategy is developed to increase the message propagation efficiency. (3) A location prediction model based on the SMP is devised to find the superior relay node in the one-copy routing stage. (4) Simulations are implemented in both synthetic movement models and realistic traces to demonstrate the superior performance of the proposed LACS scheme over several representative routing algorithms.

The remaining sections of this paper are organized as follows. In Section 2, the state-of-the-art routing algorithms in DTNs are briefly reviewed. In Section 3, the location-aided spraying routing algorithm is proposed and analyzed. The simulation results under different nodes mobility models are presented in Section 4. Finally, Section 5 concludes the paper and points out the future work.

2. Related work

There are many kinds of DTN routing schemes and different ways to categorize them [6]. In this paper, they are categorized into two types: coding-based routing and copy-based routing.

2.1. Coding-Based routing protocols

Motivated by transmitting large size data, for example, big files in DTNs, coding-based routing protocols are proposed against the limited transmission opportunities by relaying buffers in realistic network settings. In the coding-based routing protocols, the source node converts one generated message into multiple coding blocks and transmits them in the DTNs, and the destination node restores the original message after receiving the certain amount of coding blocks. There are mainly two kinds of coding-based routing protocols: erasure coding and network coding.

In [7], an erasure coding based forwarding algorithm is proposed, which spreads the forwarding responsibility over many nodes while maintaining a fixed network overhead. However, this scheme increases the transmission delay in most cases. In [8], the adaptive erasure coding routing schemes are proposed for interplanetary networks, which are effective even in case of imperfect transmission channel knowledge. The incremental redundancy adaptation (IRA) and partially observable Markov decision process (POMDP) approaches are analyzed in the coding round, and the appropriate decision about coding strategy selection can be taken based on incomplete knowledge. In [9], an erasure coding framework integrated within the DTN architecture is introduced, which extends the bundle protocol specification. In this scheme, the transmission robustness against link interruptions and disruption is improved by the joint use of a packet level coding approach with the custody transfer option. In [10], a routing algorithm is proposed by combining the erasure coding and replication to handle the path failures in DTNs. Both Bernoulli path delivery model and Gaussian path delivery model are discussed to solve the underlying optimization problem. The erasure coding based scheme is robust to failures of a few relay nodes, but it also results in underperformance because of the limited storage capacity and long transmission delay in DTNs.

The network coding is defined as allowing intermediate nodes to not only forward but also combine their incoming independent information flows. The network coding based probabilistic routing is proposed in [11], which can reduce the overhead of probabilistic routing algorithms. The nodes do not simply forward packets which they overheard, but may send out information that is coded over the contents of several packets they received. The network coding based epidemic routing (NCER) scheme is proposed in [12], which transmits a batch of data packets with network coding. In [13], an efficient network coding based protocol (E-NCP) is proposed to optimize packet transmission efficiency, achieving similar transmission delay but with much fewer transmissions. In this scheme, the source node transmits slightly more coded packets such that these coded packets are sufficient to decode the original packets with high probability. The coded packets are referred to as pseudo source packets and disseminated by binary spraying. In [14], an efficient context-aware network coding (CANCO) scheme for DTNs is proposed, in which the nodes move according to non-homogeneous mobility models. The friendliness metric is used to measure how popular a node is while the delivery predictability estimates the probability of reaching another node. The most compelling benefits of network coding may be its robustness and adaptability, which can significantly increase throughput for different traffic patterns. However, network coding also increases communication complexity and is not suitable for the resource constrained DTNs nodes. Therefore, in our scheme, the coding-based method is not used because we are trying to find a simple but effective method which has low demand for node performance and network resource.

2.2. Copy-Based routing protocols

In the copy-based routing, the source node generates one message and then injects one or more copies into the networks. The relay nodes will forward this message to the destination node by different routing algorithms. The copy-based routing protocols can be classified into single-copy routing and multi-copy routing, and the latter type is in the majority.

In the single-copy routing schemes, a prediction assisted algorithm is proposed for underwater DTNs [15], which uses the aggressive chronological projected graph (ACPG) to capture the network mobility properties and the common characteristics of near optimal routes. Then based on the guidance from ACPG, the online heuristic protocol is devised by choosing appropriate historical information and forwarding criteria. In [16], several basic single-copy routing protocols are discussed such as direct transmission, randomized routing, utility-based routing with 1-hop diffusion, utility-based routing with transitivity, seek and focus routing, oracle-based routing and so on. In [17], a predict and relay routing algorithm is presented in which the nodes determine the probability distribution of future contact times and choose a proper next hop to improve the end-to-end delivery probability. It assumes that the nodes move around a set of well-visited landmark points and their mobility behaviors are described by time-homogeneous semi-Markov process model. The single-copy routing scheme has excellent performance at the expenditure of network resource, but performs poor at other aspects such as message delivery ratio, delay and so on. This kind of routing scheme is appropriate for the scenario where nodes and networks are extremely resource constrained, so it is not applied in our proposed scheme.

The multi-copy routing is the most discussed case in recent years. The epidemic routing is a typical one, in which nodes exchange all different messages they carry and try their best to transmit messages to destination nodes. However, this will lead to too much network resource expenditure. There are some kinds of methods to avoid message flooding: probabilistic routing, social based routing and controlled epidemic routing.

The probabilistic routing determines whether a message between two contacted nodes is transmitted by a certain algorithm.