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Delivery ratio- and buffered time-constrained: Multicasting for Delay Tolerant Networks

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ABSTRACT

Almost all multicast routing algorithms for Delay Tolerant Networks (DTNs) mainly focus on improving routing performance, but hardly consider the constraints in actual DTN applications. In this paper, we investigate the constrained multicasting problems in social network scenarios. A pattern of constrained multicasting is defined, and then based on the node mobility in social network scenarios that the pair-wise inter-contact time is exponentially distributed, we propose a Delivery Ratio- and Buffered Time-Constrained Multicast routing algorithm, named as DBCM. DBCM considers the delivery predictability as utility value within the maximum buffered time, and makes routing decisions based on the utilities of current neighbors. To utilize contact more effectively, an enhanced scheme of DBCM, called E_DBCM, is introduced. E_DBCM can increase message delivery ratio without inducing additional overhead. The performance of DBCM is analyzed theoretically in terms of message delivery ratio, average number of hops and end-to-end delay. We also develop the RWP mobility model, and propose a social mobility based version (SM_RWP). Pair-wise inter-contact time in SM_RWP is proven to follow exponential distribution. Simulation results show that DBCM and E_DBCM outperform the most of the existing multicasting algorithms on delivery ratio and routing overhead.

1. Introduction

Delay Tolerant Networks are a class of emerging wireless networks, in which most of the time there does not exist an end-to-end path from source to destination (Kevin, 2003; Kevin and Stephen, 2008). Many real networks fall into this category, such as wildlife tracking and habitat monitoring sensor networks (Tovar et al., 2010), vehicular ad hoc networks (Li et al., 2008; Paulo et al., 2012), underwater sensor networks (Dunbabin et al., 2006), satellite networks (Carlo et al., 2008), and military networks (Lu and Fan, 2010). These networks experience frequent and long-duration partitions, and the end-to-end delay is usually quite long and unpredictable.

Multicasting service supports the dissemination of a message to a group of receivers. Many potential DTN applications operate in a group-based manner. For example, vehicles on the road expect to receive real-time traffic information from others and soldiers in the same battlefield need to share the information about their surrounding environment. Multicasting in the Internet and mobile ad hoc networks (MANETs) have been studied extensively in the past (Lee et al., 2002; Royer and Perkins, 1999; Xie, 2002). These proposed algorithms assume that network is connected most of the time. Thus, these multicastings fail to forward messages in DTNs. It is necessary to design efficient multicasting algorithms for DTNs, and this is a challenging work (Zhao et al., 2005; Zhang, 2006).

As a matter of fact, there always exist some constraints in the applications of DTN multicasting in social network scenarios. In some of these applications, message delivery ratio should be guaranteed, that is, should not be lower than a threshold. Considering such a scenario that some remote villages distribute in a region, in which there do not exist communication infrastructures. People who live in the same village can be regarded as a group of message receivers. Communication between these villages is relayed on some ferry nodes, which wander in these villages. Due to the long distance between these villages, messages carried by ferry nodes should be delivered with a considerable delivery ratio. In other cases, end-to-end delay may be more concerned. As an instance, in a vehicular ad hoc network, the traffic information is shared by drivers to help them to avoid some congestion points (Palma et al., 2012; Soares et al., 2012). It is obvious that such information is time-limited, since a driver has to decide which way to go in time according to the received information. When such messages are disseminated in a sparse network, end-to-end delay must be considered (Soares, 2009). Military networks also

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have a high requirement of end-to-end delay, in order to make deployments timely. Generally, message transmission delay between nodes can be ignored, and a message's end-to-end delay can be estimated as the sum of buffered time in relay nodes. Most of existing algorithms mainly focus on improving routing performance, but do not take these constraints into consideration. As a result, these algorithms may not perform well in specific DTN applications. A few other works, such as Farahmand and Rodrigues (2009), Lau and Yue (2007) and Li et al. (2010), take the constraints of energy and buffer resource into account, but rarely consider that of delivery ratio and buffered time.

In this paper, we are interested in delivery ratio and buffered time constrained multicasting problems for the application of DTN in social network scenarios. Our main contributions in this paper are the following:

- propose a Delivery Ratio- and Buffered Time-Constrained Multicast routing algorithm (DBCM). The goal of DBCM is to deliver a message within predefined buffered time, with a considerable delivery ratio. In addition, considering the tradeoff between delivery ratio and buffered time, DBCM also contains *Scheme A* to fit the cases that have a high requirement on latency, and *Scheme B* to cater to the scenarios where message delivery ratio is more concerned;
- propose an enhanced scheme of DBCM, named E_DBCM, which improves message delivery ratio without causing additional routing overhead;
- present a new social mobility based mobility model, called SM_RWP, and further in the *Appendix*, it is proven that the pair-wise inter-contact time in SM_RWP follows exponential distribution.

The performance of DBCM is analyzed theoretically in terms of message delivery ratio, average number of hops and end-to-end delay in this paper, and the lower bound performance of DBCM is derived. Performance comparison of DBCM, E_DBCM and several existing DTN multicasting algorithms is also discussed in our simulation studies.

The remainder of this paper is organized as follows. Section 2 reviews the existing multicasting algorithms for DTN. Problem definition and assumptions are provided in Section 3. Sections 4 and 5 describe the routing schemes in DBCM and E_DBCM respectively. DBCM's performance is analyzed in Section 6. Section 7 evaluates the performance of our algorithms by simulations. This paper is concluded in Section 8.

2. Related work

Ye et al. (2009) divide the existing DTN multicasting algorithms into three categories, which are unicast-based multicast (U-Multicast), static-tree-based multicast (ST-Multicast) and dynamic-tree-based multicast (DT-Multicast). U-Multicast is the simplest way to perform one-to-many data communication, in which a multicast message is sent via multiple unicast operations from source to each destination. Moreover, some unicast algorithms, such as Epidemic (Vahdat and Becker, 2000), Spray-and-Wait (Spyropoulos et al., 2005), can be used to deliver a message to multiple receivers directly. ST-Multicast and DT-Multicast are tree-based algorithms. In such algorithms, messages are forwarded along a multicasting tree. In ST-Multicast strategy, a multicasting tree is constructed at source node when a multicast session starts, and the topology of this tree will not be changed by intermediate nodes during the multicast session. STBR (Zhao et al., 2005) is a classic static-tree-based multicasting algorithm, in which source node constructs a shortest path tree to all the destinations, and messages have to be forwarded along this tree. STBR forbids intermediate nodes to forward messages along other better paths by utilizing more accurate information. In contrast, the construction of multicasting tree in DT-Multicast is not static. Each message is related to a tree that can be adjusted dynamically to adapt the current network conditions. DTBR (Zhao et al., 2005) and OS-Multicast (Ye et al., 2006) are two dynamic-tree-based multicasting algorithms. In DTBR, for a specific message, each of its relay nodes maintains a tree rooted at itself to all the receivers, and the message is forwarded along this multicasting tree. Every message duplicate has a receiver list. The list indicates that for which receivers an intermediate node should be responsible. Similar to DTBR, in OS-Multicast, there also exists a receiver list attached to a message. The difference is that each duplicate of a message always contains a full list of all the expected receivers. It means that in OS-Multicast, each relay node should be responsible to deliver the multicast message to all the receivers.

When applying the algorithms mentioned above in DTNs, some problems exist. Unicast-based algorithms usually create multiple copies for a message, so routing overhead is considerably high. Tree-based routing algorithms have to collect global information about link state and network topology, which is hard to be obtained in most DTN scenarios. With this in mind, a new category of DTN multicasting, called utility-based routing, is proposed (Appu et al., 2010). Utility-based multicasting algorithms use utility information to route multicast messages, and all the routing decisions are made based on the comparison of utility value between message carriers and encounter nodes. The definition of utility-based routing has been presented in (Spyropoulos et al., 2008), where the utility function is a monotone decreasing function of the time elapsed since the last encounter. Besides, utility can also be calculated based on the count of node encounters (Lindgren et al., 2004). Compared to unicast-based and tree-based multicasting algorithms, utility-based multicasting relies on neither the information about the whole network, nor redundant message copies. Thus, utility-based multicasting is more suitable for DTNs. EBMR (Xi and Chuah, 2009) is a typical utility-based multicasting algorithm, which utilizes history contact information and transitivity to select next-hops. The estimation of delivery predictability in EBMR is similar to that in Prophet (Lindgren et al., 2004), and EBMR prefers to pass messages to the node whose delivery predictability is higher than a threshold (P_{thresh}). In EBMR, the forwarding decisions are purely based on local information and encounter nodes, and the accuracy of delivery predictability has a great impact on the performance of EBMR.

Some other DTN multicast routing algorithms have also been proposed, including CAMR (Yang and Chuah, 2009) and SHIM (Ye et al., 2007). In CAMR, each node maintains a 2-hop neighborhood information, with which local node density can be estimated. If the local node density drops below a certain threshold, nodes are allowed to use high power transmissions. Furthermore, if the network is too sparse, nodes can act as message ferries. Simulation results in Yang and Chuah (2009) show that CAMR performs well in sparse networks. However, CAMR depends on the traditional routing process, and its ability to control node movement in DTNs is not strong enough. SHIM is a scalable hierarchical inter-domain multicasting approach to provide the inter-domain multicasting service in DTNs. In SHIM, each DTN domain has at least one leader, and the whole network is organized in two layers: the upper layer and the lower layer. The upper layer includes all the domain leaders, while the lower layer includes the other nodes. By this way, SHIM organizes the multicast structure hierarchically and effectively, and suppresses the management states by hiding the receiver information of the lower layer from the upper layer.

From the above statement, it can be seen that most of the described multicasting algorithms only focus on the improvement of routing performance, without taking some constraints in realistic DTNs into consideration. In our view, minimum delivery