A Qualitative Survey on Multicast Routing in Delay Tolerant Networks

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Abstract. Delay Tolerant Networks (DTNs) are a class of networks that make communication in stressed and challenging environments possible. DTN is characterized with a number of unique features by virtue of which a working environment is achieved in situations where traditional networking paradigms fail to deliver satisfactorily or entirely. The utility of multicasting in DTNs extends to numerous potential DTN applications i.e., crisis environments, battlefield situations, deep space communications, dynamic data size management, etc. In this paper, we propose taxonomy for the different multicast routing strategies and thereafter, we present a comprehensive up to date survey of these strategies. Further, we perform a qualitative comparison between the different multicast strategies with respect to important performance issues in DTN. We also highlight some unexplored areas in DTN multicasting that could inspire research in the near future.

1 Introduction

Personal communication devices like as cellular phones have made voice and data communications possible by achieving global connectivity through infrastructure networks such as cellular and WLAN [1]. Additionally, local connectivity can be achieved through ad-hoc networks since mobile devices are nearly always turned on and possess the necessary attributes to act as routers. The classic TCP/IP-based communications necessarily require end-to-end connectivity. However, sparse ad-hoc networks do not support this due to frequent disruptions and partitions caused due to node mobility. Delay tolerant networks (DTNs) are a class of emerging networks that experience frequent and long-duration partitions. There is no end-to-end path between some or all nodes in a DTN [2]. These networks have a variety of applications in situations that include crisis environments like emergency response and military battle-fields, deep-space communication, vehicular communication, and non-interactive internet access in rural areas.

Multicast involves the distribution of specific data to a group of users. While multicasting in the Internet and mobile ad hoc networks has been studied extensively, multicasting in DTN is a considerably different and challenging problem. It not only

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requires new definitions of multicast routing algorithms but also brings new issues to the design of routing protocols. According to the best of our knowledge, our qualitative survey on multicasting in DTN is the first of its kind, and it includes even the most recently proposed multicast strategies.

The remainder of our paper has been structured as follows. Section 2 discusses about the importance of multicasting in DTN and associated challenges. In section 3, we discuss the basis of our classification. Section 4 presents the proposed taxonomy tree by classifying various routing strategies. Section 5 concludes our paper and focuses on future work.

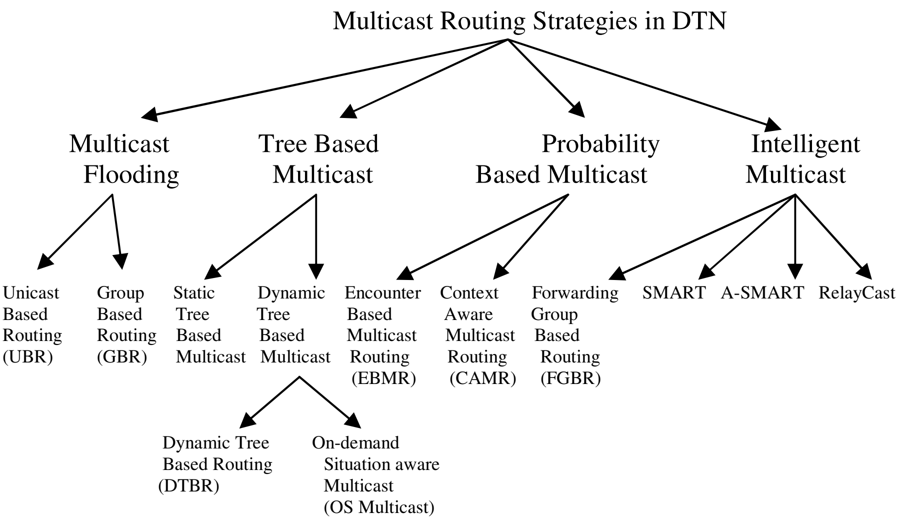

Fig. 1. Classification of Multicast routing strategies based on a new taxonomy

2 Challenges and Applications of Multicasting in DTN

Unicasting in DTNs has been researched upon to a large extent as opposed to multicasting. As mentioned before, multicast routing in DTN is a relatively fresh topic; however, the massive range of its applications makes its study an important one. Besides, because of its fundamentally different working principle with respect to unicast, multiple challenges are encountered while making headway with this topic. Some of the applications and challenges have been discussed below:

2.1 Identical Challenges between Unicast and Multicast in DTN

While implementing multicasting in DTNs, due to large transfer delays, group membership of a particular multicast group may change during a message transfer, introducing ambiguity in multicast semantics. Under these situations, it is necessary to make a distinction between group members and the intended receivers of a message, i.e., endpoints to which the message should be delivered. Group members may change with time as endpoints join and leave the group. The intended receivers, on the other hand, should be fixed for a message, even though they are defined based on group membership. In order to overcome the aforesaid challenges, various multicast routing strategies have been introduced by researchers, which we have tried to classify taking into consideration their working principles.

2.2 Applications of DTN Multicasting

Multicast service supports the distribution of data to a group of users. Many potential DTN applications operate in a group-based manner and require efficient network support for group communication. For example, in a disaster recovery scene, it is vital to disseminate information about victims and potential hazards among rescue workers. In a battlefield, soldiers in a squad need to inform each other about their surrounding environment. Although group communication can be implemented by sending a separate unicast packet to each user, this approach suffers from poor performance. The situation is especially acute in DTNs where resources such as connectivity among nodes, available bandwidth and storage are generally severely limited. Thus efficient multicast services are necessary for supporting these applications.

3 Classification of Multicast Routing Strategies

We have attempted to classify the proposed multicast routing strategies in DTNs on the basis of their basic working mechanisms. Multicasting can be implemented in DTNs in a variety of ways (as in Fig. 1). We classify them as follows: 1) Messages are flooded throughout the network, 2) Messages are forwarded along a multicast tree that stores node information leading to the destinations, 3) A probabilistic approach is used which employs history of encounters to select the best route, 4) An intelligent combination of flooding and forwarding techniques is used to make better use of available resources. Each of these techniques can be further classified into more specific ones (Fig. 1): multicast flooding can be achieved by using unicast transfer [3] [4], or by the broadcast strategy; tree-based multicast can be accomplished by using a static tree or dynamic tree to decide the shortest path to a destination; probability-based multicast can be implemented using the encounter-based technique that records history of node encounters to decide best route or by using the context-aware multicast-routing (CAMR) [11] which allows for excess power usage in extremely sparse networks; intelligent multicast can be achieved by segregating the entire message delivery process into two segments, each implementing either the flooding or the forwarding technique to achieve better performance, as in case of the forwarding group-based, SMART, A-SMART [12], and RelayCast [13] routing strategies. We discuss the above mentioned strategies in detail in the section that follows.

4 Proposed Taxonomy

Based on the above mentioned bases of classification, we propose taxonomy for the various multicast routing strategies (as shown in Fig. 1). Each routing strategy has been discussed in brief and probable conclusions have been drawn on their performances.

4.1 Multicast Flooding

Multiple copies of the messages are flooded into the network so that the message gets transferred to the intended receivers of the multicast group. The techniques that fall under this category are as follows.

4.1.1 Unicast-Based Routing (UBR)

This can be considered to be the simplest way of implementing multicast in DTN. Here, the source sends multicast bundles to the destination through multiple unicast operations [6], [7]. Any existing DTN unicast scheme can implement this strategy by modifying its bundle header to include group information. Unicast routing schemes like Epidemic Routing [18] and Spray-and-Wait algorithm [15] already implement this strategy to achieve multicasting. Apparently, this strategy accomplishes least implementation overheads [7]; however, as number of receiver nodes in a multicast group increases, there is a chance that an intermediate node will forward the same bundle several times, thus decreasing delivery efficiency dramatically.

4.1.2 Broadcast-Based Routing (BBR)

BBR [14] or Epidemic Routing [18] uses the technique of flooding in disruption-tolerant networks**.** In this routing scheme, flooding of messages throughout the network is carried out with the intention of reaching intended receivers [14]. BBR performs better when it has access to long-term information about the network topology, i.e., average interval between node contacts, etc. BBR generates redundant messages, a property which renders it inefficient in mobile networks where power supply for individual nodes is limited.

It is probably safe to say that flooding based routing should work better in Random Walk/Waypoint models since node movement predictability is negligible. Delivery ratio must be very high with significantly low latency, although buffer overhead will be quite large.

4.2 Tree Based Multicast

In tree-based multicast routing, a DTN graph is considered which consists of all the nodes present in the network [14]. The messages are forwarded along a tree in this DTN graph that has the source as its root and is connected to all the receivers in the network. The message passing technique is essentially *forwarding*, as messages are duplicated at a node of the tree if and only if it has more than one outgoing paths [4], [6], [7]. Tree-based multicast can be categorized into the following two strategies:

4.2.1 Static Tree Based Multicast

As discussed earlier, a multicast tree is created at the start of a multicast session, with its root at the source [7]. The source first gathers information about discovered routes to all the intended receivers and then constructs a smallest cost tree using Djikstra's algorithm based on this information [14]. As we can understand from the name, the topology of the intermediate nodes of this tree does not change until the multicast session is complete. Bundles are replicated according to the number of downstream neighbours, i.e., number of messages coming out of a node equals the number of its downstream neighbours. Its demerit comprises of the fact that it loses flexibility of adjusting multicast routing decision according to variations in the topology during the course of a particular multicast session. This strategy is most appropriate where disruptions happen periodically in a scheduled pattern, e.g., data communication via LEO satellite. We can intuitively conclude that this strategy is supposed to work best in the Working Day mobility model where the node mobility follows a periodic pattern.

4.2.2 Dynamic Tree Based Multicast

Contrary to the static tree, dynamic tree based multicast allows for dynamic adjustment of the multicast tree to incorporate changes in the network topology during the course of a particular multicast session. In this strategy, each bundle has an associated tree [7] that may change hop-by-hop depending upon up/down variations of DTN links. Each node having a bundle performs the three common steps: collection of information regarding availability of DTN links, computation of smallest cost tree and forwarding bundles using discovered multicast tree [14]. In addition, this strategy can take advantage of newly available routes to receiver nodes and can avoid forwarding messages through links that are now disconnected due to outward movement of nodes. Though this strategy is characterized with high overheads, it is better adaptive to topology variations in DTNs. We discuss two variations of this strategy in the text that follows.

4.2.2.1 Dynamic Tree Based Routing (DTBR). Each DTN node has knowledge oracle containing schedule or statistical summary of link up/down information in DTN overlay and thus the source computes a multicast tree for each bundle and forwards the current message along the tree [7]. Based on this, source computes a multicast tree for each bundle and forwards current message along tree. Thus, once a message leaves the source for a destination node, the strategy remains static virtually since it does not incorporate the changes in the topology thereafter. This will fail to work efficiently in networks where disruptions are random and frequent.

4.2.2.2 On-Demand Situation-Aware Multicast (OS-Multicast). It also builds up a dynamic multicast tree hop-by-hop for each copy of bundle [9]. However, contrary to DTBR, it doesn't rely on any global knowledge of network such as node position, or link up/down schedule. It assumes that underlying networks is able to record discovered routing information and report current availability of outgoing links to DTN multicast agent. It contains full list of intended receivers and thus each intermediate node that has a bundle is responsible for delivering multicast message to all receivers. This improves on DTBR since the intermittent topology changes are evaluated dynamically, thus optimizing performance. However, delivery latency is quite high.

4.3 Probability Based Multicast

Here nodes deliver messages to the other nodes only when its delivery predictability is higher than the certain threshold value.

4.3.1 Encounter Based Multicast Routing (EBMR)

It is a scheme that is purely based on node encounters. EBMR scheme is built on top of PRoPHET Scheme [8]. Each node doesn't pass bundle to a next hop node unless the next hop node has delivery predictability higher than a certain delivery threshold (P_{thresh}) value [10]. For multicast delivery each node will pick as many nodes as needed with highest delivery predictability to each of the multicast receivers.

4.3.2 Context Aware Multicast Routing (CAMR)

Nodes are allowed to use high power transmission when locally observed node density drops below a certain threshold. Each node maintains 2-hop neighbourhood information and hence can deliver traffic without invoking a route discovery process if all receivers are within its 2-hop neighbourhood [10] [11]. Its advantage constitutes of the fact that it can achieve higher multicast delivery ratio than DTBR and OS-multicast. However it still relies on route discovery process and ability to control node movement. CAMR can be considered a special case of multicast routing where power resources can be exploited to achieve high delivery ratio in very sparse networks.

4.4 Intelligent Multicast

Here dynamic intelligence is used by the algorithm to decide between flooding and forwarding techniques of delivering messages to the receivers. This strategy is based on a two-phase algorithm with each phase implementing flooding or forwarding to achieve optimal performance. Flooding technique is implemented to achieve high delivery ratio and low latency since all the intermediate nodes receive single or multiple copies of the message thus increasing the chances of message delivery to an intended receiver. Forwarding, on the other hand, achieves better efficiency and works with a significantly reduced buffer space since message replication is not allowed beyond the number of intended receivers. Intelligent multicast is able to take advantage of the merits of both these techniques.

4.4.1 Forwarding Group Based Routing (FGBR)

FGBR implements the concept of a forwarding group [4] within which the message is flooded. The forwarding group is created by computing a shortest path tree (as in case of tree based multicast) to the intended receivers. The group consists of those nodes which are present in the shortest path tree, including the receiver nodes. Within this forwarding group, the message is flooded, thus decreasing latency and increasing delivery ratio. Performance of this strategy is better than in cases where only flooding is implemented.

4.4.2 SMART

SMART uses travel companions of the destinations to increase the delivery opportunities. Here, routing is divided into two phases: 1) a fixed number of copies of the message are injected into the network to propagate the message to the companions of the destination by Binary Spray algorithm [15], and 2) a companion of the destination only transmits the message to other companions of the destination until the message is delivered to the destination.

4.4.3 A-SMART

In A-SMART, companion nodes are organized to form an anycast group [12] and periodically broadcast its group identifiers and hops to build the routing table. Routing is divided in two phases: 1) an anycast scheme is used to forward the message the companion node of the destination; 2) the companion node only transmits the message to other companions of the destination until the message is delivered to it.

Anycast is virtually a unicast, for the reason that source node just sends the message to any one member of a destination group which is the best receiver according to the current environment. In addition, the message will be routed to an alternative member of the destination group when the previous path to a member disappeared, so anycast is a more reliable routing mechanism.

4.4.4 RelayCast

RelayCast [13] is a routing scheme which extends 2-hop relay algorithm used in unicast to multicast in DTNs. In this strategy, a source forwards a single message to all the relay nodes, each of which in turn transmits the message to all intended multicast receivers. Mathematical analysis shows that the throughput achieved is better than in case of conventional multi-hop relay. Thus, RelayCast is able to achieve maximum throughput bound of DTN multicast routing.

FGBR and A-SMART seem to perform well in most mobility models due to an efficient balance between flooding and forwarding techniques. Due to the partial flooding, delivery ratio and latency are taken care of, whereas buffer usage is somewhat controlled by the partial forwarding character. Recent reports show that use of multicast tree results in poor scaling behaviour which is efficiently dealt with using RelayCast algorithm.

Table 1. Performance Comparison among Multicast Routing Strategies based on Performance Metrics

Routing Strategies	**Routing Algorithms**	**Performance Metrics**			**Remarks**
		Delivery Ratio	***Delivery Latency***	***Buffer Usage***	
Multicast Flooding Based	UBR	Low	Highest	Lower than BBR	Higher delivery ratio is achieved at the cost of high buffer overhead and low efficiency. Should work well in Random Walk/Waypoint mobility models.
	BBR	High	Low	Highest	

Table 1. (*continued*)

Routing Strategies	Routing Algorithms	Performance Metrics			Remarks
		Delivery Ratio	*Delivery Latency*	*Buffer Usage*	
Multicast Forwarding Based	Static Tree Based	Higher than UBR	Less than GBR	Less usage	Buffer usage reduced significantly; however, delivery ratio and latency are compromised with. Compatible with most mobility models.
	DTBR	Higher than UBR	Less than GBR	Less usage	
	OS-Multicast	Higher than DTBR when network is sparse	Higher than DTBR	Less usage	
Probability Based	EBMR	Very high when node mobility is predictable	High	Medium	Ideal for networks where node mobility is periodic and/or predictable. CAMR compromises heavily with power usage. Should work best with Working Day mobility model.
	CAMR	Highest, 8 times more than DTBR or OS-Multicast	Low, almost identical to DTBR and OS-Multicast	Medium	
Intelligent Multicast	FGBR	High	More than Tree Based	Medium	Highly efficient; uses intelligent combination of flooding & forwarding techniques to achieve optimal performance; Designed to work well with most mobility models.
	SMART	Higher than A-SMART	Low	Slightly lower compared to multicast flooding techniques	
	A-SMART	High	Higher than SMART	Lower than SMART	
	RelayCast	Higher than EBMR	High	Comparable to A-SMART	

5 Conclusion and Future Work

Multicasting in DTNs is a fresh area of research and there is a limited amount of research information on it. The information, however, is growing in volume as researchers realize the importance of multicast routing in challenging environments.

In this paper, we have tried to identify the reasons of considering multicasting an essential tool for routing in disruption-tolerant networks. We have presented a classification comprising the multicast routing schemes that have been proposed and have performed a comparative survey on their performances. The advantages and otherwise of each of the strategies have been studied with an eye for novelty.

Though research in the field of DTN multicasting has made some headway in the recent past, there are many important areas that remain unexplored. We highlight some of those areas that can prove to be fodder for future research work. Firstly, security in DTNs is an area of huge concern, especially in those cases where the networking deals with personal information (such as in social networking) or classified information (such as in the battle-field scenario). Major practical contributions regarding security are yet to come up. Secondly, efficient usage of power is another aspect that needs to be considered. More power usage will lead to higher cost, which is both impractical and unsustainable. Another area of significant importance could be dynamic buffer management in DTNs. Data packets can range in size from a few KBs (such as text files) to some GBs (such as multimedia files). There is a need to provide for dynamic addition and reduction of buffer space in nodes depending upon the size of the data packet at being transmitted at a particular instant of time. This provision could contribute significantly in the reduction of buffer usage and thus make routing in DTN more sustainable. Last but certainly not the least; we should focus on the issue of scalability in DTN environment, i.e., sustainability of a particular routing strategy with increasing node density. The practicality of a strategy will depend hugely on its scalability.

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