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A novel forwarding scheme for adaptive anycasting in delay/disruption-tolerant networks

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Abstract
Delay/disruption-tolerant networks (DTNs) are characterized by frequent and long duration partitions and end-to-end connectivity may never be present between the source and the destination at the message origination time. Anycast is an important service used for many applications in DTNs such as information exchange in hazards/crisis situation, resource discovery etc. In this paper, we propose classification of DTNs into three subcategories, namely: networks utilizing message ferries (MFN), interplanetary networks (IPN) and intermittently connected mobile Ad hoc networks (ICMAN). Further, we propose a novel anycasting scheme for ICMANs called receivers based forwarding (RBF), which considers the number of anycast receivers available through a link as well as the path length to the nearest receiver through that link in deciding the next hop while forwarding an anycast bundle. Simulation results with respect to link availability, group size and buffer size show that the RBF performs better than the shortest path forwarding (SPF) in term of data delivery ratio, average end-to-end delay and overall data efficiency.

Keywords: Delay-tolerant networks, anycast, routing.

Introduction
The transmission control protocol over internet protocol (TCP/IP) suite, used widely in internet, may deliver poor performance in scenarios called “challenged” networks where connectivity among nodes is intermittent. Fall (2003) describes the peculiar connectivity behavior of terrestrial mobile networks and exotic media networks and proposes architecture for interoperability among challenged networks called delay-tolerant network architecture. This architecture operates as an overlay above the existing transport layer protocol stack. The packets called bundles in delay-tolerant networks are forwarded in store and forward fashion. The connectivity among the nodes is periodically predictable. Another breed of ‘challenged networks’ exhibit opportunistic connectivity, examples are partially connected ad hoc networks as discussed by Pelusi *et al*. (2006), Ye *et al.* (2006) and Ming-Jun *et al.* (2009). Delay-tolerant network is characterized by frequent and long duration partitioning of the network. Thus end-to-end delay may become too long to be supported by the TCP/IP model. Further, often owing to frequent partitioning, end-to-end connectivity between the source and destination nodes may not be present at the time of message generation. In previous literatures we found little agreement among researchers over labels used to refer to different kinds of networks which fall under the category of delay/disruption-tolerant networks. For example Fall (2003) named terrestrial mobile networks as delay-tolerant networks; Ming-Jun *et al.* (2009) talk about partially connected networks; while highly partitioned networks are studied by Davis *et al.* (2001), Hanna *et al.* (2003) and Zhao *et al.* (2004). Zhao *et al*. (2004) discuss what they refer to as message ferrying. Researchers have also studied similar phenomena under the title of intermittently connected mobile networks (Spyropoulos *et al.,* 2005), delay-tolerant mobile networks (Harras *et al.,* 2006), challenged networks (Harras *et al.,* 2007), disruption-tolerant networks (Burns *et al.,* 2008) and ad hoc relay wireless networks (Chen *et al.,* 2001). After studying the salient features and distinguishing characteristics of the example networks referred to in the literature as DTNs, we propose that the broad category of delay/disruption-tolerant networks may be further classified into the following three subcategories:

1. *Message ferries:* In this category of delay-tolerant networks there are special nodes called message ferries that move in the region on well defined paths and are responsible for data transfer among the regular nodes who do not take part in data transfer among the nodes. Message ferries are equipped with more functions and capabilities, like bundle storage capacity, longer battery lifetime etc. Some authors described the sparse mobile ad hoc networks with message ferries (Zhao *et al.,* 2004); similarly the concept is also studied by Juang *et al.* (2002), Shah *et al.* (2003), Small *et al.* (2003), Pentland *et al.* (2004) and Gong *et al.* (2006).
2. *Interplanetary network:* These kinds of networks are characterized by very long propagation delay due to long distance (Burleigh *et al.,* 2003), not supported by TCP/IP suite. For example, the round-trip time of a bundle from Earth to Mars is between 8 and 40 min depending on the orbital positions of the planets (Lindgren *et al.,* 2006). The connectivity may be periodically predictable (scheduled) using position and speed.

Intermittently connected mobile ad hoc networks: In these kinds of networks, the mobile nodes communicating via limited radio range, experience frequent partitions and the end-to-end route may not be present at the time of message generation. Their difference from the message ferries is that each node in it acts as router, source or receiver and message carriers are not fixed. Examples of these networks are Ye et al. (2006), Ming-Jun et al. (2009) and Spyropoulos et al. (2005). The connectivity among the mobile nodes is often opportunistic which clearly distinguishes them from periodically predictable nature of interplanetary networks. In this paper we studied the anycast protocols for the DTNs subcategory of intermittently connected mobile ad hoc networks (ICMANs), various applications of this category are inter-vehicular communication (Chen et al., 2001), mobile sensor network, disaster recovery and military deployment etc. (Ming-Jun et al., 2009). Anycast means to deliver a packet to any of the members in a group (Zegura et al., 2000). There are various applications of anycast in DTNs like, in disaster rescue field and battle fields. Since ICMANs have limited resources such as link bandwidth, storage capacity and connectivity among the nodes; an efficient anycast service is necessary for supporting the aforementioned applications. Anycasting in the Internet and mobile ad hoc networks (MA-NETs) has been studied by Katabi & Wroclawski (2001) and also studied by Zegura et al. (2000), Park & Macker (1999), Peng et al. (2004) and Wang et al. (2003) where routing is based on the assumption of the guaranteed end-to-end connectivity but anycasting in DTNs is more challenging owing to the frequent partitions, long end-to-end delays and end-to-end connectivity may not be guaranteed. For Internet and MANETs anycasting, in case more than one shortest path to the receivers are available, the packet can be forwarded on any one of them, without concern to the number of receivers (Wang et al., 2003; Peng et al., 2004) because end-to-end path is guaranteed, we name it as shortest path forwarding (SPF), however in DTNs end-to-end path is not guaranteed due to frequent and long duration partitions.

We propose a novel forwarding scheme named receivers based forwarding (RBF) for anycasting in a specific type of DTNs where the mobile nodes are sparsely distributed, communicating via low radio range, experiencing frequent and long duration partition and end-to-end path may not be present at the time of message generation (Hadi *et al.,* 2007). In this scheme, if there is more than one shortest path available, a node forwards the packet to the next hop of that shortest path from which more receivers are reachable. That is forwarding is based on the path length as well as number of receivers reachable from that next hop. Due to this scheme the probability of receivers' availability increases so the packet delivery ratio is increased because in the absence of one receiver the packet can be forwarded to the next receiver. As the partition delay is long as compared to transmission and propagation delay, so the end-to-end delay is also decreased.

The rest of the paper is organized as follows: Section II describes the related work while section III describes the proposed adaptive anycast algorithm. Section IV describes the simulation results and finally section V concludes the study.

Related work

Anycast routing has been studied extensively for internet and mobile ad hoc networks. Zegura *et al.* (2000) proposed a selective anycast service to choose best mirror server among the many available servers, depending upon some application-specific metrics, like path length and server load. This is an application layer anycasting on the internet, where the connectivity is guaranteed and the end-to-end delay is within the range of TCP/IP protocol suite. Katabi & Wroclawski (2001) has designed an IP anycast protocol. They have divided inter-domain anycast into 2 components. The first component builds inexpensive default anycast routes that consume no bandwidth or storage space. The 2 component, controlled by the edge domains, generates enhanced anycast routes that are customized according to the beneficiary domain's interests. This is an internet based protocol, where the end-to-end path is guaranteed. Park & Macker (1999) discusses the anycast routing in context of mobile ad hoc networks. They illustrate how several different classes of unicast routing protocols can be extended to provide efficient construction and maintenance of anycast routes. Extensions to link state, distance vector and link reversal unicast routing protocols are all conceptually realized through the representation of an anycast service as a "virtual node". They show that anycasting approach instead of unicasting is efficient in such scenario. Park & Macker (1999) describe potential applications of anycast routing technology in military networks. Wang *et al.* (2003) present the anycast routing protocol for MANET on the basis of ad hoc on-demand distance vector (AODV) protocol. For each entry in the routing table, Wang records anycast group number, if the corresponding destination is member of an anycast group. Forwarding of anycast bundles at a node is done as follows: it retrieves the entries from its routing table for the desired anycast group and selects the one having shortest path in term of hop count. Peng *et al.* (2004) propose anycast algorithm on the basis of dynamic source routing protocol (DSR) for mobile ad hoc network that returns route-error message to the source in case of link failures. Xie *et al.* (2003) propose an efficient way for handling link failures in MANETs. If link failure occurs at the intermediate node, then the intermediate node discovers an alternate route to the destination instead of sending route error to the source, causing reduction in control overhead.

Choudhury and Vaidya (2004) propose a MAC layer anycasting with consultation of unicast routing protocol, if there is more than one route to the destination available at routing layer then MAC layer forwards to one of the neighbors on either path according to signal strength. They have also discussed in detail its effect on various categories of unicast routing protocols. Recently, Gong *et*

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al. (2006) discussed the DTNs with message ferries where correspondent nodes in the network are stationary. The connectivity among the nodes is provided by mobile devices that act as carriers to deliver messages to the destination nodes. Specifically, the mobile devices do not generate messages themselves and the moving patterns of these mo-bile carriers are well defined.

Fig. 1. A simple example of DTN.

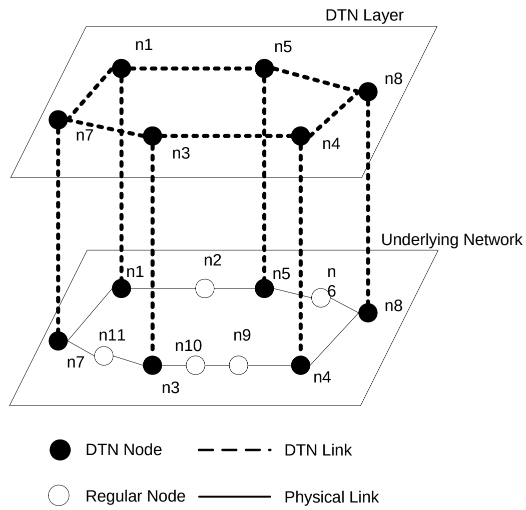


Fig. 2. Bundle layer (DTN layer).

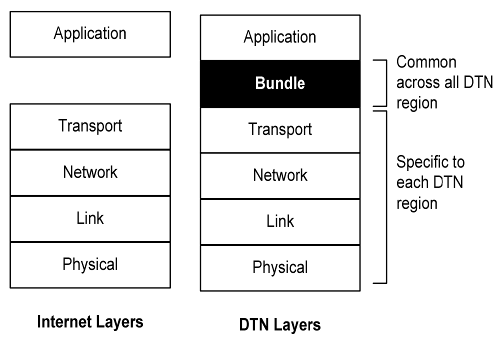
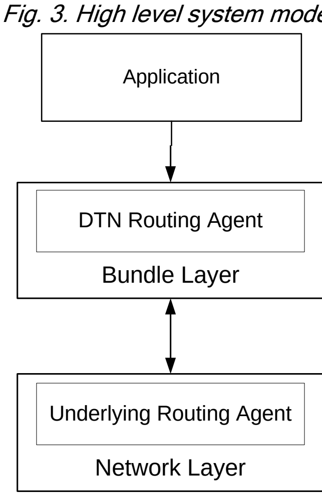


Fig. 3. High level system model.



Proposed adaptive anycast algorithm

In the following discussion, we suppose that the underlying network is an intermittent connected mobile ad hoc network, ICMAN, where the mobile nodes are sparsely distributed and communicating via limited wireless radio range. These networks experience frequent and long duration partitions. Nodes move with limited storage capacity and connectivity among the nodes is opportunistic. A node may be a source, receiver or the carrier which carries the message and forwards the message when the opportunity arises. We also propose a novel packet forwarding mechanism named received based forwarding (RBF), which improves the performance of anycasting when compared to the widely adopted shortest path forwarding (SPF). For efficient implementation, we use the situation awareness mechanism as proposed by Ye *et al.* (2006). The network model and anycast model of DTNs are given below.

Network model: As presented by Fall (2003) the DTN is an overlay network built upon the underlying network, working above the transport layer based on asynchronous message forward. Among the other nodes, the nodes on which the DTN agent is implemented are the DTN nodes; the two neighbor DTN nodes may be multi-hops away, the packet, and known as bundle in DTNs, are transmitted at DTN layer (bundle layer) in store-forward fashion. Fig.1 shows a simple DTN example presented in Ye *et al.* (2006). The storage capacity of each DTN node is limited and the packet may be dropped on the intermediate nodes due to buffer overflow. We have ensured the custodian hop by hop transfer, proposed in Fall (2004) in which reliable packet delivery is ensured between two hops.

Anycast model: Anycast means to deliver the packets to any of the members in a group. Anycast in DTN is defined as bundle transmission to any of the members in a group of DTN nodes. Every DTN node has a name and the translation between DTN name and underlying network is done by DTN routing agent, which is responsible to buffer the bundles, routing at bundle layer and other functionalities at bundle layer which operates above the transport layer and below the application layer of the network. Below the transport layer, protocol of own choice can be used depending on the network environment while a single DTN layer is used across all the networks (regions) of DTNs as shown in Fig. 2. Anycast source uses the explicit names of the anycast receivers as the destination address. We also propose packet forwarding mechanism named RBF, which improves the performance of anycasting in DTNs. Our improved design also includes placement of the DTNs into three categories, timeline for retransmission, and also extensive simulations to check the effect of buffer size, effect of link availability percentage and group size on the proposed algorithm.

Situation awareness: As DTNs experience frequent and long duration partitions. The underlying network is operational for a long time so that caches are built up and sufficient knowledge about the network topological condition is available. To achieve situational awareness, each DTN routing agent periodically sends request to underlying routing agent (responsible to perform appropriate routing in underlying networks) for the current network condition, we use dynamic source routing (DSR) (Johnson & Maltz, 1996) as an underlying routing agent. The underlying routing agent responds to the DTN routing agent with the current topological condition of the underlying network, includes the paths from current node to the intended destinations, the high level system model shown is Fig. 3.

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Group formation: Any DTN node that wants to join anycast group sends a join request (JRqt). The join request is flooded so that it can reach the anycast source as early as possible. Each DTN anycast source updates its members list on receiving the join request. The group joining model also confirms the temporal interval membership model (TIM) proposed in (Katabi & Wroclawski, 2001). Members per unit area (group size) plays an important role in DTN anycasting; which varies in different scenarios, like in PDAs (personal digital assistants) networks the anycast group size can be larger such as the people having PDAs or cellular phones and want to share the audio/video or other files within a cluster. In military battle field/sensor network, the anycast group may comprise a small number of nodes. The effect of group size has been on the proposed scheme by varying the group size (Hadi, 2007).

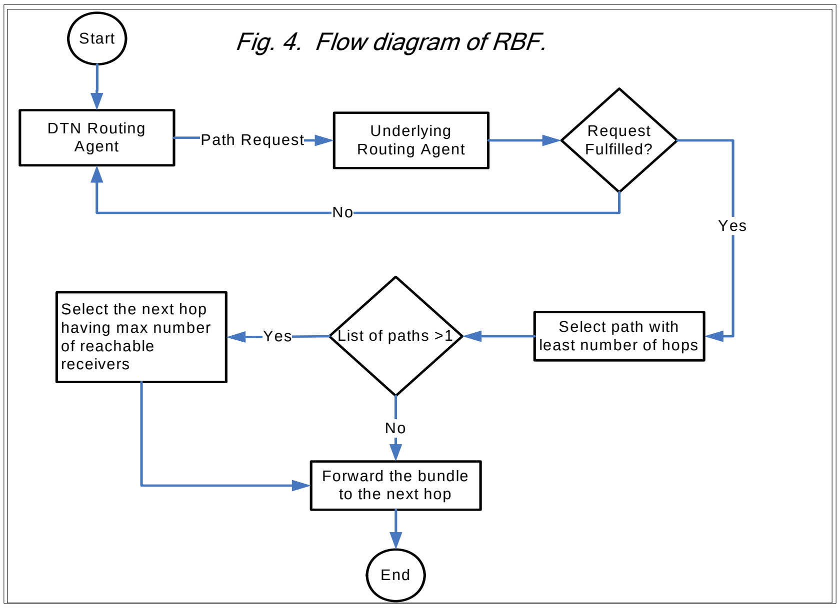
Message buffering: Each DTN node has a limited buffer to store the in transit packets. The packet is forwarded to the next hop and is removed from the buffer on receiving the acknowledgment from the next hop i.e., the custodian transmission is enabled to ensure the reliable delivery between two hops. When the buffer is about to overflows, the DTN node sends the buffer information to the sender for flow control. In different scenarios the buffer size varies like in wireless sensor networks the nodes have a very limited buffer while in vehicle ad hoc networks the nodes have a larger storage capacity. We have tested the proposed scheme by varying the buffer size, results shown in section 5.3.

Forwarding state

Each anycast bundle has the explicit list of receivers. So each DTN node forwards the packet according to its local knowledge about the underlying network provided by DSR.

Receiver based forwarding (RBF): When a node wants to forward the bundle, it gets the current topological information from the underlying routing agent. The DTN routing agent sends a rout request to the underlying routing agent (RoutRqt); the route request contains the anycast receiver list. The underlying routing agent sends the discovered paths information (from the current node to the receivers in the list) to the DTN agent. The DTN routing agent removes the currently unavailable outgoing links. The DTN routing agent finds the path to the closest anycast member. In a situation, when there is more than one such path available to the anycast receivers, earlier approaches take the first discovered shortest path (Wang *et al.,* 2003; Peng *et al.*, 2004); we refer to this scheme as the shortest path forwarding scheme. In contrast, our proposed scheme works in the following way. For each link find the number of anycast receivers accessible through it; also, find the path length to the nearest anycast receiver accessible through this link, we call it minimum path length. Choose the next hop as the node across that link which has the shortest minimum path and through which largest number of receivers are reachable. The flow diagram of RBF is shown if Fig. 4. We believe this increases the probability of the bundle to reach some member of the anycast group. We support this assertion by extensive simulation that shows an increase in the delivery ratio and decrease in the end-to-end delay. Thus, our scheme achieves higher overall efficiency without any additional control overhead.

Fig. 4. Flow diagram of RBF.



The pseudo code of the RBF is as follow:

//DTN routing agent is working above //the transport layer which requests //the underlying routing agent for //path information to the anycast//receivers.

DTN_routing_agent
Do{
Paths_Info = handler_underlying_routing_agent (list_of_anycast_recievers)
If (Paths_Info)
{
//Choose the paths with least number //of hop.
Shortest_Paths = Select_Shortest_Paths (Paths_Info)
If (Shortest_Paths >=1)
{
Forward the bundles to the next hop of the shortest path through which more receivers are reachable
}}}
Until (No Path_Info)
//the underlying network is //operational and the underlying //routing agent will give the paths to //the DTN routing agent

Fig. 5. Working of receiver based forwarding (RBF).

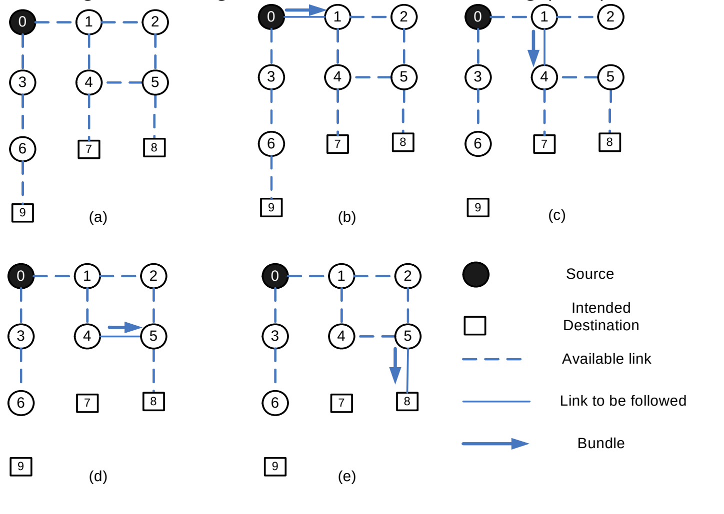


Fig. 6. Packet delivery ratio of SPF & RBF.

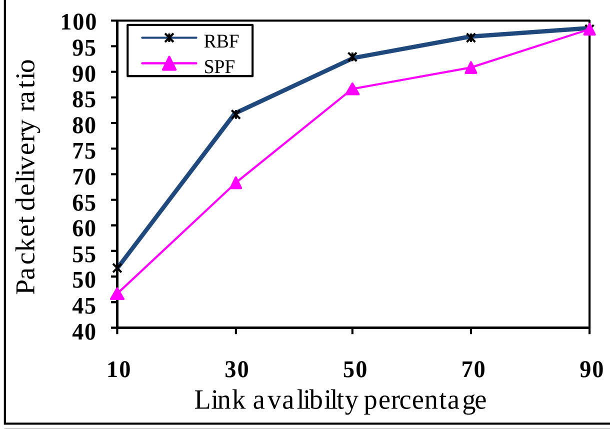


Fig. 7. Overall efficiency of SPF & RBF.

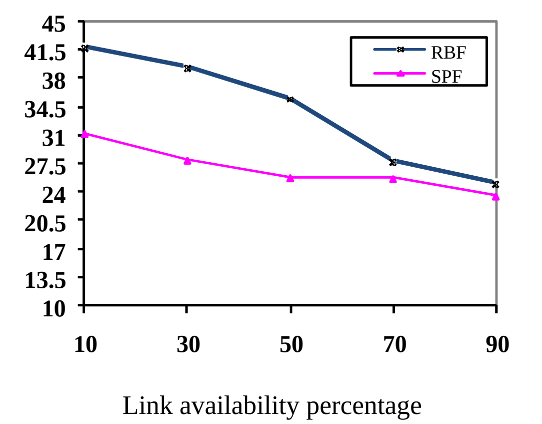
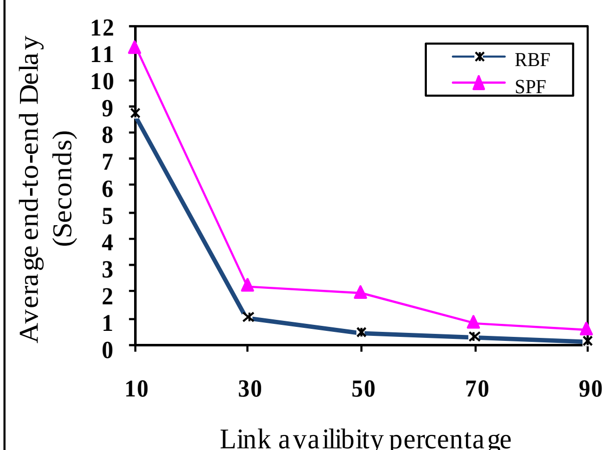


Fig. 8. Average end-to-end delay of SPF & RBF.



Bundle retransmission:

DTN node checks periodically its local buffer for unacknowledged packets, provided its existence, they are retransmitted according to anycast receiver list. In order to reduce the overhead there are controlled retransmissions for a threshold. Once the acknowledgment is received, the packet will be deleted from the buffer.

Working of RBF is depicted in Fig. 5. Node 0 is a source node and node 5, 7 and 9 are members of anycast group. When node 0 wants to send anycast bundle to any of the anycast members then node 0 will send request message to underlying routing agent in order to trigger the network condition to the specified anycast receivers. Node 0 will come to know about the paths to anycast members. Now node 0 will make mesh by combining these discovered paths to anycast members as shown in Fig. 5a. The dashed lines show available links. The node 0 will delete all those outgoing links that are currently not available, as shown in Fig. 5b.

The node 0 has two shortest paths of equal length so it has two choices to forward the bundle, either to node 3 or to node 1. The Shortest Path Forwarding algorithm solves the tie situation by forwarding the bundle to the first one or randomly. But RBF selects the node through which more anycast receivers can be reached, so the probability of available receivers will increase. Therefore, node 0 forwards the bundle to node 1 as shown in Fig. 5c. Along the message, the list of anycast receivers is also included. Similar operation will be done at each DTN node for each bundle. Node 1 gets paths to node 5 and node 7 and then forwards the bundle to node 4 as shown in Fig. 5d. Node 4 finds the path to node 5 so it will forward the bundle to node 5 as shown in Fig. 5e. We have noticed that when the packet is forwarded to the next hop from which more receivers are reachable, according to RBF, then the packet can be delivered earlier to a receiver having longer path, if the receiver of the shortest path is not available.

Performance evaluation

For performance evaluation we implemented the adaptive anycasting in DTNs with both SPF and RBF using the famous network simulator-2 (ns-2). Performance parameters are: 1) Message delivery ratio: It

Fig. 9. Packet delivery ratio of SPF & RBF.

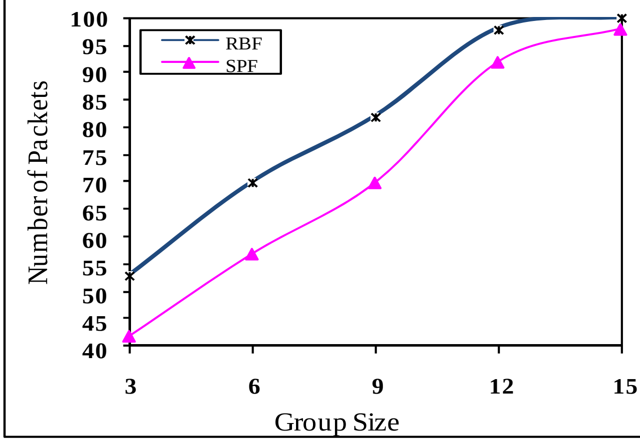


Fig. 10. Overall efficiency of SPF & RBF.

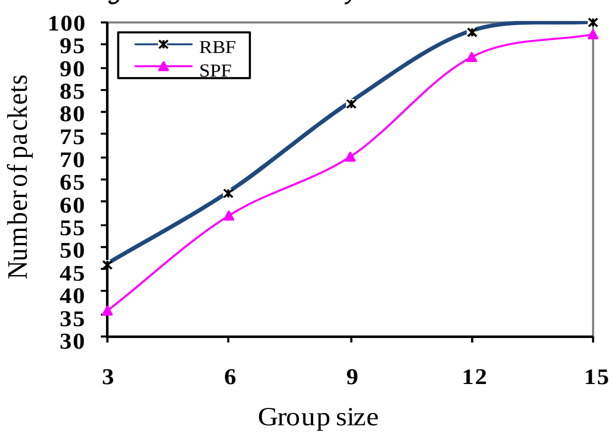
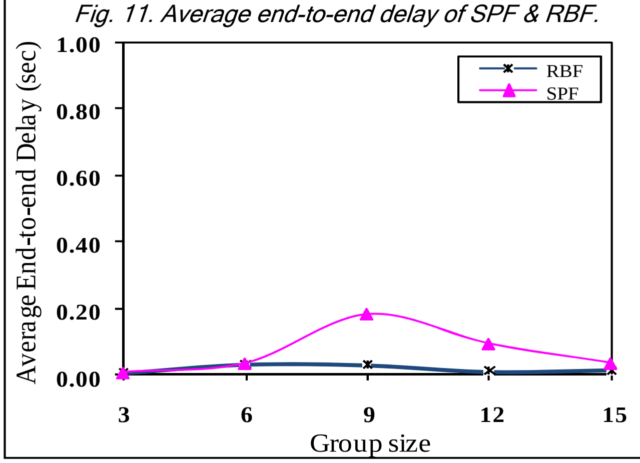


Fig. 11. Average end-to-end delay of SPF & RBF.



is defined as the ratio of total number of unique anycast bundles received by any anycast group member to the total number of bundles transmitted by the anycast source. 2) Data efficiency: It is defined as the ratio of total number of unique anycast bundles received by any group member to the total traffic generated, both data bundles and control packets. 3) Average message delay: It is defined as the ratio of total delay for received anycast bundles to the total number of anycast bundles. We simulate a specific type of DTNs; in simulation we have used 20 nodes over 800 x 800 m area with 110 m transmission range. DSR is used as routing approach for underlying routing in network. For situation awareness, we collaborate between DTN routing agent and underlying routing agent. MAC layer is IEEE 802.11. We study one anycast session for 60 sec. Node 1 is fixed as the anycast source. While the other DTN nodes randomly join the anycast group by sending join request. The anycast source sends the bundle at the rate of 1 bundle per sec. At every 2 sec each DTN agent checks its buffer to see bundle waiting for retransmission. We have studied the performance of the proposed scheme with respect to: (i). Varying link availability, (ii). Varying group size and (iii). Varying buffer size.

Varying link availability

We study the performance by varying the link availability of each link uniformly for 10%-90%. The buffer capacity of each DTN node is 30 bundles. Fig. 6 shows the average delivery ratio of adaptive anycast algorithm with both SPF and RBF schemes. Varying the link availability from 10%-90% increases the delivery ratio. When the availability is low, RBF achieves better delivery ratio because, the probability of receivers availability increases. The delivery ratio of both schemes SPF and RBF are almost equal at 90% or more link availability. Fig. 7 shows that when link availability is low the overall data efficiency of RBF is high because the probability of number of receivers is high and if one receiver is not available, the bundle may be forwarded to another receiver, and no extra traffic is generated for retransmission and checking the underlying network condition. At high link availability the difference between SPF and RBF data efficiency decreases. Fig. 8 shows the average end-to-end delay performance using both SPF and RBF. At low link availability the average end-to-end delay of both schemes abruptly increases due to the long duration partitions, which causes packets to be buffered for longer time. Similarly we noted that RBF experiences comparatively low delay due to the alternate receivers' availability and that the propagation delay is less than the long duration partition delay. At high link availability the average end-to-end delay of both schemes is minimal. Above the 90% link availability the average end-to-end delay of both schemes is almost equal.

Varying group size

We have studied the effect of group size on the proposed scheme for anycasting in DTN. Group size varies in various applications like in PDAs (personal digital assistants) networks. The anycast group size can be larger such as the people having PDAs or cellular phones and want to share the audio/video or other files within a cluster. In military battle field/sensor network, the anycast group may comprise a small number of nodes.

Fig. 9 shows the average delivery ratio of adaptive anycast algorithm with both SPF and RBF schemes for various group sizes. Varying the group size from 3-15, the delivery ratio increases. When the group size is small, the RBF achieves better delivery ratio as compared SPF because the probability of receivers' availability increases. The difference between delivery ratio of SPF and RBF decreases as the group size increases because the availability of receivers increases in both schemes. Fig. 10 shows that overall efficiency of shortest path forwarding (SPF) is lower than the receiver based forwarding (RBF) for all group sizes; however, the difference grows smaller for larger group sizes. Fig. 11 shows that the average end-to-end delay of receiver based forwarding (RBF) is better than shortest path forwarding (SPF) however, the difference is not appreciable.

Varying buffer size

The size of buffer plays an important role in the disruption tolerant network. It varies in different applications. For example in wireless sensor networks sensor nodes have limited storage while in vehicle ad hoc networks the nodes have larger storage. We have studied the performance of the proposed scheme from 6-30 bundles. Fig. 12 shows that when buffer size is limited, the RBF performance is better than SPF. This is because of increased probability of anycast receivers' availability. However when buffer size grows larger the difference between RBF and SPF performance decreases. Fig. 13 shows that overall efficiency of RBF and SPF decrease due to retransmission of in transit packets. It is also shown that the overall efficiency of RBF and SPF is slightly different on average by varying buffer size. There is no significant difference between the performances of RBF and SPF by varying the buffer size. It is due to the implementation of custodian transfer, reliable hop by hop transfer which introduces more traffic while the packets reside in the buffer. Fig. 14 shows the average end-to-end delay of RBF and SPF by varying the buffer size. It is shown that increasing buffer size leads to increase in the end-to-end delay. This is because the packets are buffered for longer time. However it increases the delivery ratio.

Fig. 12. Packet delivery ratio of SPF & RBF.

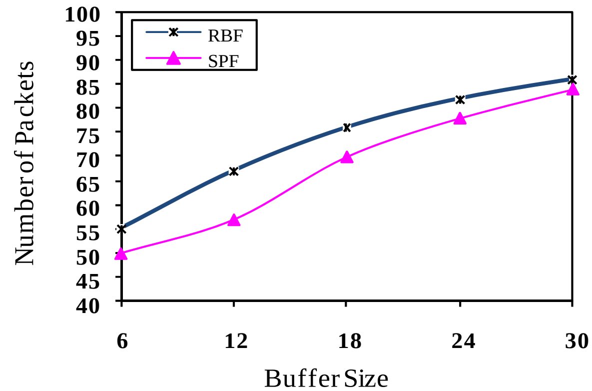


Fig. 13. Overall efficiency of SPF & RBF.

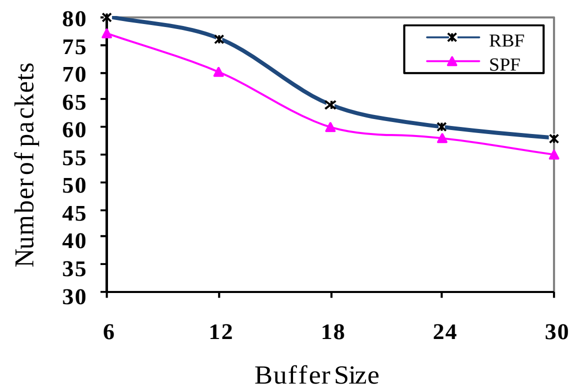
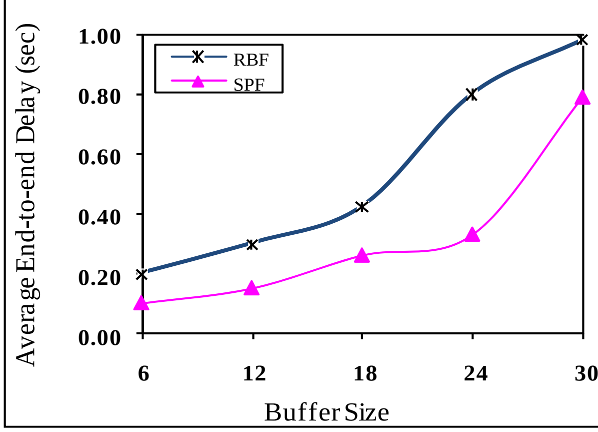


Fig. 14. Average end-to-end delay of SPF & RBF.



Conclusion

In this paper, we have proposed classification of delay/disruption-tolerant networks (DTN) into 3 subcategories by identifying their distinguishing characteristics. Firstly, DTNs with special nodes working as message ferries; secondly, DTNs with periodic/scheduled connectivity and finally, the intermittently connected mobile ad hoc networks-each class has unique routing/buffering requirements of its own. Further, after presenting detailed discussion of anycasting schemes proposed in literature for the intermittently connected mobile ad hoc networks, we have proposed a receiver based forwarding (RBF) scheme, which considers the number of anycast receivers accessible through a link as well as the path length to the nearest receiver through that link in forwarding the anycast bundle to the next hop. Extensive ns-2 simulation results with respect to link availability, group size and buffer size show that the RBF performs better than SPF in terms of data delivery ratio, average end-to-end delay and overall data efficiency. Currently, we are evaluating a novel technique for geocasting i.e. delivering a message to all hosts in a geographical location in DTNs. Here, we first use anycast overlay network to reach to a particular geographic region and then let routing protocol of the underlying network to accomplish the job within that particular region.

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