Node Density-Based Adaptive Routing Scheme for Disruption Tolerant Networks

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Abstract— *Traditional ad hoc routing protocols do not work in intermittently connected networks since end-to-end paths may not exist in such networks. Hence, routing mechanisms that can withstand disruptions need to be designed. A store-and-forward approach has been proposed for disruption tolerant networks. Recently, several approaches have been proposed for unicast routing in disruption-prone networks e.g. the 2-hop relay approach, delivery probability based routing, and message ferrying. In our earlier paper, we have evaluated a combined multihop and message ferrying approach in disruption tolerant networks. In that paper, we assume that a special node is designated to be a message ferry. A more flexible approach is to let regular nodes volunteer to be message ferries when network dynamics mandate the presence of such ferries to ensure communications. Thus, in this paper, we design a node-density based adaptive routing (NDBAR) scheme that allows regular nodes to volunteer to be message ferries when there are very few nodes around them to ensure the feasibility of continued communications. Our simulation results indicate that our NDBAR scheme can achieve the highest delivery ratio in very sparse networks that are prone to frequent disruptions.*

Keywords-disruption tolerant networking; adaptive routing; node-density; 2 hop relay

I. INTRODUCTION

Packet-switched network communication has been studied for decades. Important progress has been made in robustness and scalability in the TCP/IP protocol suite based primarily on principles of end-to-end protocols and services [9]. However, there are many scenarios in which an end-to-end connection is not guaranteed or even possible, and so an intermediary is needed, perhaps to translate between protocols or to provide temporary storage (e.g., in mail servers). In these cases, without such intermediaries, communication would fail. In other cases, communication may fail not because of a lack of instantaneous connection, but because the connection properties fall beyond the expected bounds (excessive round-trip-time or high packet loss probability).

Solutions have been proposed to deal with some specific situations, e.g., using link layer retransmissions to deal with high packet loss probability in wireless environments [4]. However, these solutions still do not work in situations where there are no end-to-end paths. DakNet [3] deploys physical transport devices, e.g., buses and motorcycles, to carry mobile access points between village kiosks and hubs with Internet connectivity so that the data carried by the physical transport devices can be automatically uploaded and/or downloaded when the physical transport devices are in the wireless communication range of a kiosk or a hub. Similar techniques are proposed in [1],[2]. In the past year, considerable amount of research focusing on delay/disruption-tolerant networking and communications has been published (e.g.[5],[6],[13],[15]). DieselNet [14] is a vehicular-based disruption tolerant network where connections between nodes are short-lived and occasional. A common approach used to address delays and disruptions is via the use of a store-and-forward mechanism similar to electronic mail [10]. This makes communication possible, even when an instantaneous end-to-end path does not exist.

Several routing schemes have been proposed for DTNs. They can be categorized into three categories: (i) using message ferries or data mules to connect partitioned nodes [15],[20], (ii) using history-based information to estimate delivery probability of peers and pass the message to the peer that can best deliver the message [22], [26], and (iii) using 2-hop relay forwarding schemes where a source can send multiple copies to different relay nodes and have the relay nodes deliver to the destination when they encounter the destination [19],[21].

In our earlier work [25], we have evaluated the performance of a multihop routing scheme with custody transfer feature in a single domain DTN. We also have explored using message ferrying and high-power backhaul links for interdomain message delivery. Our work revealed that in a single domain environment, even with the custody transfer feature, the delivery ratio drops when the nodes are sparsely connected. So, in this paper, we propose a node-density based adaptive routing (NDBAR) scheme that provides better performance than previous approaches.

This paper is organized as follows: In Section II, we summarized related work. In Section III, we describe our node-density based adaptive routing scheme. In Section IV, we describe our simulation models. We also present and discuss our simulation results. We conclude in Section V.

II. RELATED WORK

Three categories of forwarding schemes have been proposed for DTNs. In the first category [20], the authors propose to use message ferries or data mules to gather data from stationary sources and deliver them to their destinations. However, nodes that move can be message carriers themselves without having to resort to special message ferries. In the second category [22],[26], the authors propose using history-based routing where each node maintains a utility value for every other node in the network, based on a timer indicating the time elapsed since the two nodes last encountered each other. These utility values which carry indirect information about relative node locations, get diffused through nodes' mobility. Nodes forward message copies only to those nodes with a higher utility for the message's destination. For example in [22], the authors propose a probabilistic metric called delivery predictability at every node for each known destination. This metric indicates how likely it is that a node will be able to deliver a message to each destination. The delivery predictability ages with time and also has a transitive property i.e. a node A that encounters node B which encounters node C allows node A to update its delivery predictability to node C based on its (A's) delivery predictability to node B and node B's delivery predictability to node C. In [22], a node will forward a message to another node it encounters if that node has a higher delivery predictability to the destination than itself. Such a scheme was shown to produce better performance than epidemic routing [24].

In the third category [19], [23], the authors propose using a 2-hop relay forwarding scheme where the source sends multiple copies (e.g. different erasure coding blocks) to different relaying nodes and the relaying nodes will deliver the copies they have to the destination node when they encounter the destination node. Again, such strategy will achieve small transmission overhead but may not enjoy high delivery ratio for messages with short deadlines. In this paper, we simulate scenarios similar to those reported in [22], [19] so that we can compare the transmission overhead and the delivery ratios of these different schemes with the schemes we design.

III. NDBAR SCHEME

In [25], we have evaluated the performance of multihop routing protocol in a DTN scenario where 40 nodes were distributed over a geographical area of 1000x1000 to 4000x4000 m^2 (assuming a transmission range of 250 m^2). A DSR-like multihop routing protocol [7] is enhanced with custody transfer feature [18]. Our simulation results indicate that when the node density drops below 4.4×10^{-6} (equivalent to finding only one neighbor within the transmission range), the delivery drops significantly despite the custody transfer feature. Table 1 shows the simulation results for the scenarios with 40 nodes distributed over 3000x3000 m^2 and 4000x4000 m^2. We see that the achievable delivery ratio is only 54.3% and 18.3% respectively even with the custody transfer feature turned on. Thus, to improve on the delivery ratio, we design the node-density based adaptive routing (NDBAR) scheme where nodes can turn into message ferries when they detect that the node density around them drops below a certain threshold.

Table 1: Performance of the multihop approach with custody transfer

Simulation Area	Delivery Ratio	Avg Dly	95% Pkt Dly	Overhead	Hop count
3000x3000	54.6%	1829	3500	2.1	1.1
4000x4000	18.3%	932	1500	0.8	1

In NDBAR scheme, we assume that each node periodically (e.g. every 20 seconds) broadcasts a neighbor discovery message to estimate n_d, the number of neighbors it has. When n_d drops below a certain threshold K, then that node will set a flag so that it will relay any future route-request message that it receives using high-power transmission. Any node that receives a high-power route request will take note of this fact, and will issue a high-power route reply when it hears from downstream nodes later. The high-power route reply message contains information about the location and speed of the node that replies. The previous-hop node that receives this reply will keep a record of this information so that if this route is chosen for packet delivery, the previous hop node will travel towards the next-hop node so that the data relay can be conducted using regular power transmission.

In Figure 1 below, we illustrate how NDBAR scheme works via an example. The source node, S, broadcasts a route request at regular power. Nodes n_7, n_4, and n_8 hear this route request and will re-broadcast the route request using regular power. Node n_4's rebroadcast is heard by nodes n_9, n_3, and n_8. Similarly, node n_9‘s rebroadcast is heard by nodes n_{11} and n_1 . Node n_{10} realizes that its observed number of neighbors is 1 (assume K is set to 1.5). Thus, upon hearing the route request from node n_1, n_{10} issues a high-power route request which reaches node n_2 . Node n_2 takes note that it receives a high-power route request from node n_{10} and rebroadcasts using regular power since the number of neighbors it observes exceeded K. This goes on until the route request reaches node D which is the destination. When n_2 receives a regular-power route reply from n_5 , it issues a high-power route reply to node n_{10} after attaching information regarding its (n_2) location and velocity. Node n_{10} relays this route reply back to S via node n_1 using regular-power route reply after recording n_2‘s location and velocity information. Since we assume that the data transmission rate is higher than the route request rate, we design the NDBAR scheme such that the node with low connectivity delivers the data packets via message ferrying. Thus, if this route is chosen, then when node n_{10} receives data packets from node n_1 , it will travel towards node n_2 until it (n_{10}) is close enough to deliver the data packets via regular power transmission to node n_2. Note that n_{10} can decide when it wants to move (e.g. after receiving several packets) towards n_2 depending on the speed of n_2 and the message rate that n_{10} receives from n_1.

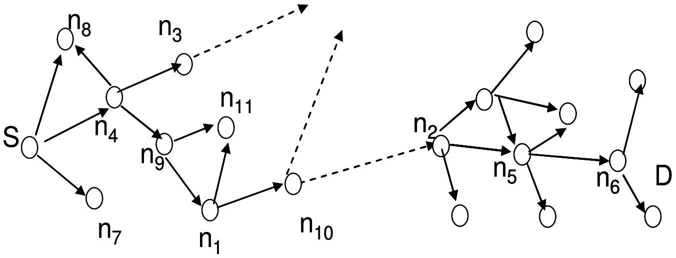

Figure 1. NDBAR scheme

IV. PERFORMANCE EVALUATION

We implemented the NDBAR scheme using NS-2 network simulation package [8] and the simulation results are presented in this section. We also include the custody transfer feature described in [18],[25]. The transmission range is set at 250m and each node is assumed to have 200 buffers. There are 10 flows and unless otherwise indicated, each flow has a packet rate of 1 every 4 seconds. The packet size is 512 bytes. The high power transmission is assumed to extend the transmission range to 500 m. The performance metrics we use are:

- Packet delivery ratio (PDR) which is the number of packets that are correctly delivered to the destination over the number of unique data packets sent by the source.
- End-to-end delivery latency which is the time it takes to delivery a data packet. We consider both the average and the 95 percentile values.
- Hop count which is the average number of hops it takes for a data packet to arrive at the destination.
- Transmission overhead [19] which is defined as the number of transmitted bytes over the number of generated bytes. The transmission bytes include the routing overhead messages and custody transfer request and acknowledgment messages. Custody transfer and acknowledgment messages are assumed to be 35 bytes each.

We conducted several sets of experiments. For mobility, we either use the random waypoint model (RWP) [7] or the ZebraNet mobility model [19]. For the random waypoint model, each node moves towards a randomly picked destination at a constant speed. Once the destination is reached, another destination will be randomly chosen and the node will start moving towards the new destination after a certain pause time. This behavior is repeated for the whole duration of the simulation. In our simulation, the node’s speed is chosen uniformly between zero and 5 m/s. For ZebraNet movement, we scale the node positions to fit into the geographical area used in our scenarios. We also scale the sampling time to be 8 seconds rather than 8 minutes. All the reported delay values in this paper are in seconds.

A. *Simulation Results*

1) *Impact of Node Density*

In our first set of experiments, we have 40 nodes distributed randomly over (a) 3000x3000 m^2, (b) 4000x4000 m^2, and (c) 5000x5000 m^2. Table 2 tabulates the results. It shows that NDBAR can significantly improve the delivery ratio but it comes at the expense of transmission overhead. To improve the delivery ratio from 54.6% (refers to Table 1) to 96.2% (refers to Table 2) for the 3000x3000m^2 scenario, one has to pay a transmission overhead of 17.5. It is almost impossible to deliver packets for case (c) using only multihop routing with custody transfer feature turned on but the NDBAR scheme can achieve a delivery ratio of 81.5% using a transmission overhead of 3.1.

Table 2: Performance of NDBAR scheme (RWP)

Simulation Area	Delivery Ratio	Delay	Hop count	Overhead
3000x3000	96.2%	818 sec	7.2	17.5
4000x4000	95.5%	1688 sec	5.3	12.4
5000x5000	81.5%	3455sec	2.8	3.10

To reduce the transmission overhead, we consider a variant of NDBAR (referred to as NDBAR-II). Each node is assumed to exchange information of its 1-hop and 2-hop neighbors with its immediate neighbors. A source node sends the data packet directly to a node that can reach the destination without going through the route request procedure. Otherwise, it broadcasts a data packet setting a neighbor relay expiry timer, w (set to 2000s). If a packet can be delivered to its destination via neighbor relaying before *w* expires, then a route request will not be issued. During the neighbor relaying period, a node will send the data packet to a neighbor with the highest contact probability to the destination. Otherwise, a route request will be issued by the node which receives the data packet. If the message or route request is received by a node that does not have enough neighbors, then the node is allowed to issue a high power route request message. Each node maintains its contact probabilities with its 1 hop and 2 hop neighbors. Let us denote node *i*'s contact probability with node *j* as P_j^i. P_j^i is updated as follows: node *i* periodically broadcasts a neighbor discovery message; if node *i* hears a response back from node *j*, then P_j^i is set to 1; otherwise the existing P_j^i value decays by a factor α (set to 0.8 in our experiments) periodically. We refer to this variant as the NDBAR-II scheme. We illustrate NDBAR-II in Figure 2. The source node S attempts to deliver the packet to destination D initially via 2-hop relaying until the packet reaches node n_3 where the number of neighbors drops below the threshold so a high power route request is issued.

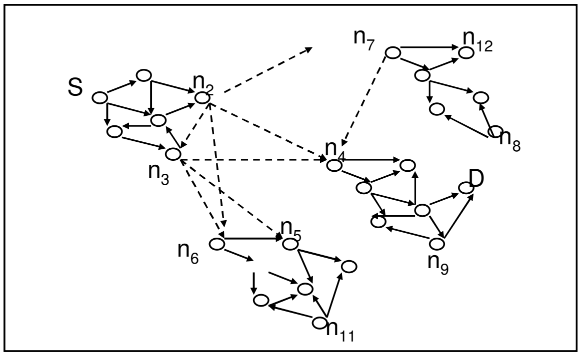

Figure 2: Enhanced NDBAR scheme (NDBAR-II)

The simulation results for the NDBAR-II scheme is shown in Table 3. Our results show that the NDBAR-II scheme can achieve relatively high delivery ratio (over 95% in 3000x3000 m^2 scenario) but with much reduced transmission overhead (decreases from 17.5 to 7.4). This comes at the cost of increasing the 95% message delivery latency. The transmission overhead will reduce further if higher packet generation rate is used.

Simulation Area	Delivery Ratio	Avg Dly	95% Pkt dly	Hop Count	Overhead
1000x1000	99.0%	203	700	2.4	5.3
2000x2000	96.4%	1470	4000	2.3	4.3
3000x3000	93.9%	2465	4327	5.4	7.4
4000x4000	92.4%	2654	5123	4.3	7.2

Table 3: Network performance (RWP) using NDBAR-II scheme.

2) Comparison with 2-hop erasure-coding and multihop schemes

In this section, we compare the routing performance of 2-hop erasure-coding relaying scheme [19], [25], the multihop routing scheme with custody transfer [18], and the NDBAR-II scheme. We simulated the scenarios tabulated in Table 4.

Parameter	Value
Simulation area	1000x1000, 1500x1500, 2000x2000, 3000x3000, 4000x4000
Simulation time	5000 seconds
Traffic pattern	10 pairs of CBR 512 byte/pkt
Mobility model	RWP with maximum speed equal to 5m/s, Zebranet Mobility Pattern

Table 4: Simulation Parameters

Tables 5, 6 & 7 tabulate the results for the 2-hop erasure-coding relay approach, the multihop approach and the NDBAR approach respectively with movements based on the random waypoint mobility model. Tables 8,9 & 10 tabulate the results for the three schemes using Zebranet mobility model [19].

Our results reveal that the 2-hop approach provides relatively good performance if ZebraNet mobility model is used until the node density drops below $4.4x10^{-6}$ (3000x3000m^2 scenario) when the delivery ratio becomes 76.2%. However, the 2-hop approach achieves very poor performance when the random waypoint model is used as the mobility model achieving only 78.4% in the 1500x1500 m^2 scenario and only 41.9% in the 3000x3000 m^2 scenario. The delivery ratio with multihop approach is very good until the node density drops below $4.4x10^{-6}$. The results clearly show that the NDBAR-II scheme achieves the best delivery ratio even in very spare networks and with reasonable transmission overhead. It also shows that NDBAR-II scheme is flexible enough to handle different mobility models.

Simulation Area	Delivery Ratio	Avg Dly	95% Pkt Dly	Overhead	Hop Count
1000x1000	95.3%	381	950	9.84	2
1500x1500	78.4%	1724	2250	7.73	2
2000x2000	41.9%	1222	3300	6.23	2
3000x3000	15.4%	1224	4196	4.53	2

Table 5: Delivery Performance using 2-hop approach (RWP)

Simulation Area	Delivery Ratio	Avg Dly	95% Pkt Dly	Overhead	Hop Count
1000x1000	100%	1.59	2.4	10.5	3.9
1500x1500	99.99%	43.4	2.7	13.2	5.7
2000x2000	99.99%	259.4	1600	10.4	5.3
3000x3000	54.6%	1829	3500	2.1	1.1

Table 6: Delivery Performance using multihop approach (RWP)

Simulation Area	Delivery Ratio	Avg Dly	95% Pkt dly	Overhead	Hop Count
1000x1000	99.0%	203	700	5.3	5.3 2.4
2000x2000	96.4%	1470	4000	4.3	4.3 2.3
3000x3000	93.9%	2465	4327	7.4	7.4 5.4
4000x4000	92.4%	2654	5123	7.2	7.2 4.3

Table 7: Delivery Performance using NDBAR-II (RWP)

Simulation Area	Delivery Ratio	Avg Dly	95% Pkt Dly	Overhead	Hop Count
1000x1000	96.8%	710	420	7.0	2.0
1500x1500	96.5%	366	950	8.0	2.0
2000x2000	99.0%	128	1500	10.3	2.0
3000x3000	76.2%	1678	4312	5.1	2.0

Table 8: Delivery Performance using 2-hop approach (ZebraNet)

Simulation Area	Delivery Ratio	Avg Dly	95% Pkt Dly	Overhead	Hop Count
1000x1000	99.99%	0.71	3	9.3	2.1
1500x1500	99.99%	29	130	14.4	4.1
2000x2000	99.99%	203	700	14.8	3.5
3000x3000	89.4%	1146	3985	2.47	1.1

Table 9: Delivery Performance using multihop approach (ZebraNet)

Simulation Area	Delivery Ratio	Avg Delay	95% Pkt Delay	Overhead	Hop Count
1000x1000	98.7%	86.9	488	5.96	2.9
2000x2000	98.0%	746	3000	4.64	2.6
3000x3000	93.2%	1242	3899	8.6	2.4
4000x4000	90.4%	2018	4565	7.7	2.8

Table 10: Delivery Performance using NDBAR-II (ZebraNet)

3) *Impact of Traffic Model*

We next evaluate the impact of traffic model on delivery performance using NDBAR-II scheme and random waypoint mobility model. In earlier sections, we use CBR traffic model for all the flows. In this section, we use a bidirectional traffic model described in [16],[17]. The source sends a message to the destination. Upon receiving the message, the destination will respond with another message. Random waypoint mobility model is used in this set of experiments. We evaluate the end-to-end delay of the bidirectional message flows.

Table 11 tabulates our simulation results. Compared to Table 7, the 95% bidirectional message delay is only about 10% higher than the 95% unidirectional message delay when the node density is above $4.4x10^{-6}$ but it almost doubles when the node density decreases to $4.4x10^{-6}$ and it triples when the node density drops to $2.5x10^{-6}$. The delivery ratio has dropped to 85.3% with bidirectional flows when the node density is $2.5x10^{-6}$ but it is still relatively high. The transmission overhead improves since the messages in the reverse direction do not have to incur extra route discovery overhead.

Simulation Area	Bidirectional-Delivery Ratio	Avg Delay	95% Pkt Delay	Overhead	Hop Count
1000x1000	99.0%	260	734	3.3	4.8
2000x2000	96.4%	533	4417	2.7	4.3
3000x3000	91.0%	4576	8643	9.1	9.6
4000x4000	85.3%	6414	15435	6.6	7.4

Table 11: Delivery Performance using NDBAR-II (RWP)

V. CONCLUSION

In this paper, we have designed a new routing scheme called the Node Density Based Adaptive Routing (NDBAR) scheme for DTN environment. Our scheme makes use of the neighbor density information each node observes to decide when a node will function as a message ferry to deliver data packets. Our preliminary simulation results indicate that both the 2-hop erasure-coding relay approach and the multihop with custody transfer approach fail to provide reasonable delivery ratio when the node density is lower than $4.4x10^{-6}$ (equivalent to 40 nodes over 3000x3000 m^2 with a regular transmission range of 250 m). The multihop with custody transfer approach provides better delivery ratio than the 2-hop erasure-coding approach but incurs higher transmission overhead. The NDBAR scheme that we design provides the best delivery ratio but this comes at the cost of additional transmission overhead. The enhanced NDBAR scheme (NDBAR-II) scheme that we designed is able to achieve comparable delivery ratio performance as the NDBAR scheme but with much reduced transmission overhead. Our simulation results indicate that the NDBAR-II scheme can achieve more than 90% delivery ratio using ZebraNet mobility model and 92% delivery ratio with a node density of 2.5×10^{-6} when the transmission range is 250 m. With bidirectional flows, our NDBAR-II scheme can still achieve 85.3% under the same network conditions. We intend to implement the NDBAR-II scheme and evaluate its performance in a reasonable size testbed.

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