A Predicted-contact Routing Scheme for Brazilian Rural Networks

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Abstract. *Provide low-cost Internet access in rural areas of developing countries is a real challenge. Conventional communications are expensive and an alternative approach is to use vehicles to carry data to and from rural areas and Internet gateways located in an urban center, using a delay tolerant network architecture. The main challenge in these networks is the routing scheme, because the routes need to be determined without establishing an end-to-end path. This work considers a real scenario of the northeast of Brazil, employing scholar buses to carry data. We propose a routing algorithm, capable of considering the uncertainty of the bus timetable. The simulation results show that the predicted-contact routing scheme presents a high message delivery rate, a low medium delivery delay, and a low buffer occupation.*
Keywords*: rural networks, developing regions, DTN, routing, and Internet.*

1. Introduction

Underdeveloped countries concentrate communication infrastructure in the crowed urban areas whereas rural areas remain underserved. Therefore, providing digital inclusion to the inhabitants of poor communities in rural areas is a great challenge because the conventional solutions to provide Internet access are economically prohibitive [1, 2]. The Brazilian government is making an effort to bring Internet access to underserved communities in its program of digital inclusion. Many Brazilian rural districts already have kiosks with computers, but without Internet access. Research projects are focusing on asynchronous modes of communication using buses and cars equipped with a wireless access point and a storage device to carry data to and from rural Internet kiosks and Internet gateways in urban centers [3, 4]. These data carrying routers are called data *Mobile Ubiquitous LAN Extensions* (MULEs). Figure 1 shows a bus (MULE) that download data from a rural kiosk source, buffer it, and deliver the data when it reaches destination. A variety of non-real-time services can be provided from rural kiosks to inhabitants of rural areas such as: email with large attachments, file transfers, distance learning, e-Government, etc. Therefore, networks using data mules are a low cost option to deploy Internet access on sparsely populated rural areas in Brazil.

A rural data-MULE network differs significantly from conventional Internet scenario. First, the topology of the rural network varies with time because links are established and disconnected due to MULEs motion. Second, a connected path from the origin to the destination is rare whereas disconnected links are common. Finally, the end-to-end delay is long due to the absence, at any instant of time, of a path between the source and the destination. The uniqueness of this environment led to a new set of networking challenges. Conventional Internet protocols [5] are not suitable mainly because an end-to-end path does not exist or there is a large delay between sending the data and its corresponding acknowledgement. This kind of networks are classified as Delay-Tolerant Networks and an appropriate architecture was proposed in [6]. This architecture uses store-and-forward message switching to overcome intermittent connectivity. Using store-and-forward message switching, the message is completely received and stored before it is sent to another node, which may or may not be the final destination. The nodes have to store the messages during some time because the links are not always available, thus requiring a persistent storage such as a hard disk or flash memory. The DTN architecture implements store-and-forward message switching by overlaying a new protocol layer called *bundle layer* on top of heterogeneous region-specific lower layers and below the application layers.

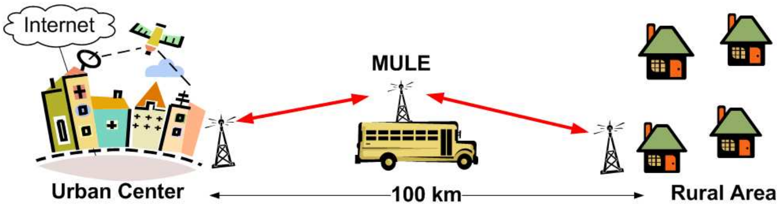


Figure 1. An example of rural network.

Routing is one of the key components in the DTN architecture. DTN routing proposals are classified as deterministic or stochastic [7]. The deterministic case assumes that the future topology of the network is always known. Thus, the routes can be calculated in advance. In the stochastic case the network behavior is random and not known, making difficult the routing calculation. Nodes have to communicate during opportunistic contacts, in which a sender and a receiver make contact at an unscheduled time.

We propose a routing scheme for data-mule based delay tolerant networks. We analyze the performance of the proposed routing scheme for a specific real-case scenario in northeast of Brazil. The MULEs are scholar buses that carry students to and from the communities to the urban center. In our scheme we take into account the uncertainty of the predicted contacts due to delays in the buses scheduling. The results show high message delivery rate, low medium delivery delay, and low resource requirements.

This article is organized as follows. Section 2 presents the related works. Section 3 introduces the proposed routing scheme. Section 4 describes the performance evaluation scenario. The simulation results are shown in Section 5. Finally, Section 6 concludes this work.

2. Related Work

Jain *et al* [8] analyze the impact of the amount of knowledge available in DTN deterministic routing. The knowledge about the network is classified in four *knowledge oracles*. An oracle is an abstraction which means "the information available for every node about a subject". The first oracle is the *Contacts Summary Oracle*, which provides the average waiting time until the next contact between any two nodes. The *Contacts Oracle* gives information about contacts between two nodes at any point in time. The *Queuing Oracle* informs instantaneous buffer occupancies at any node and any time. This information can be used, for example, to route around congested nodes. The last oracle is the *Traffic Demand Oracle*. This oracle contains information about the present and the future traffic demand. The authors evaluated the proposal in a scenario of a rural village. The knowledge about all the oracles improves routing algorithms performance. In spite of being hard to obtain all information provided by the oracles at real time, the main contributions of this proposal are the knowledge classification and the impact of each oracle on the routing algorithms performance.

Epidemic routing [9] is the widely used approach for stochastic DTNs. In this algorithm, the messages are replicated to every node, when a contact occurs, until all nodes have a copy of every message. When a node contacts another, they exchange messages to synchronize their buffer contents. Epidemic routing can thus achieve high delivery rates and minimum delay if there are no resource constraints, such as node storage and energy capacity. Unfortunately, this proposal demands a high number of message replications and a huge buffer space. Besides, epidemic routing is not scalable when the network load is high. Improved flooding schemes proposed by Harras *et al* can be used to reduce the replication cost caused by epidemic routing [10]. Wang *et al.* proposed an algorithm in which the source transmits the message to a node only if the next hop of the node is the destination [11].

Message Ferrying is a different approach in which the mules, called *message ferries*, have a non-random proactive movement to collect and deliver data. This mechanism has two variations depending on who initiates the non-random proactive movement of the ferries. In the first variation, nodes know the ferry trajectory and move close periodically to contact the ferry. In the second variation, ferries move proactively to contact nodes. Therefore, when nodes want to send packets, they contact the mules using a long-range radio. After the reception of the control packet, the mule adjusts its trajectory to meet the node [12]. Zhao *et al.* also suggested the use of multiple ferries to minimize the average message delay [13]

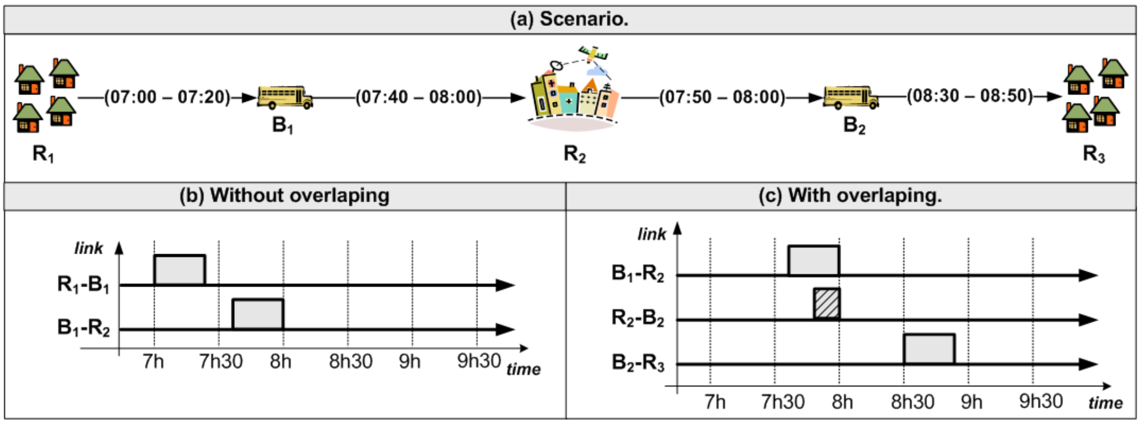
Ferreira [14] proposed a routing algorithm based on the evolving graphs model, which considers links that are only active during a certain period of time. Thus, the evolving graph is represented by a set of nodes and links, like a conventional graph, but the links are labeled with indexes corresponding to the time intervals where the link is active. In the graph, a route from a source node to a destination node is a set of links that connects the source to the destination. As in the evolving graph, links only exist during a certain period of time, a similar concept to route, called *journeys*, is defined. A journey consists of a time-ordered set of links, connecting a source node to a destination node, where the next link can never be a link that has only existed in the past. By considering this restriction, a message will never be transmitted over a link that only existed during the past.

The proposed routing algorithm is based on the evolving graphs model. We introduce an uncertainty degree in the links due to the bus scheduling. We consider that the exact arrival time of buses is unknown.

3. The Proposed Routing Scheme

The proposed routing algorithm is based on the evolving graphs model. The deterministic evolving graph assumes that the link is active during the entire interval specified for each link. Furthermore, the contact can be accomplished at any time during this interval. Therefore, the routing algorithm must only to take into account if the initial time of the next link is greater than the initial time of the actual link. When considering scholar buses as MULEs we introduce an uncertainty due to the bus scheduling. Thus, our routing algorithm has to take into account that exact arrival time of buses is unknown and, as a consequence, deterministic routing protocols do not apply in this scenario. The next forwarding links must be predicted with a certain probability. Nodes, however, can use the knowledge of the expected arrival time specified in the timetable to increase routing protocol performance. Therefore, our proposal is to use the bus contact predictability to select routes more efficiently. The proposed protocol has a high delivery rate and uses a low number of message copies, which reduce the overall buffer occupation.

Figure 2(a) shows a rural DTN scenario with predicted contacts. The intervals represent the expected departure/arrival time considering occasional delays. For example, bus B_1 leaves area R_1 between 07:00 and 07:20 and arrives at area R_2 between 07:40 and 08:00. If a user from area R_1 sends a message to area R_2, the message can be delivered using message switching and persistent storage even without an end-to-end path, through R_1-B_1-R_2 route. The message, however, must be generated before the bus B_1 leaves. If a user from area R_1 wants to send a message to another user of area R_3, the route R_1-B_1-R_2-B_2-R_3 must be applied. If the user sends the message before B_1 departure, the message will always arrive at region R_2. Nevertheless, if the message arrives after 07:50 at R_2, it may not reach area R_3, because the bus B_2 may leave before the message arrives at R_2. Figure 2(c) shows that there are time intersections between the link intervals, which means that the message may not be successful delivered.


(a) Scenario.

(b) Without overlaping

(c) With overlaping.

Figure 2. Rural DTN scenario with predicted contacts.

Our proposal is based on evolving graphs, as shown in Figure 3, in which the time interval corresponds to a period of time where a predicted contact will happen. The contact probability in the interval is modeled by a continuous uniform distribution. Therefore, the journey concept is different from evolving graph model, because the contact failure probability in overlapping intervals must be taken into account. Thus, the journey is defined by $j = (\tau, \omega)$, where

- $\tau = (n_1, n_2, n_3, \cdots, n_{N-1}, n_N)$ is the sequence of N ($N > 1$) nodes that composes the journey from the source node n_1 and the destination node, n_N;
- $\omega = ((t_{i_{l_1}}, t_{f_{l_1}}), (t_{i_{l_2}}, t_{f_{l_2}}), ..., (t_{i_{l_{N-2}}}, t_{f_{l_{N-2}}}), (t_{i_{l_{N-1}}}, t_{f_{l_{N-1}}}))$ is the sequence of time intervals of the $N-1$ links (l) used on the journey, where $(t_{i_{l_p}}, t_{f_{l_{p+1}}})$ represents the time interval ($initial\ time$, $final\ time$) in which there will be a contact between nodes n_p and $n_{(p+1)}$ that are part of the journey, considering $t_{i_{l_p}} < t_{f_{l_p}}$ and $1 \leq\ p \leq (N-1)$.

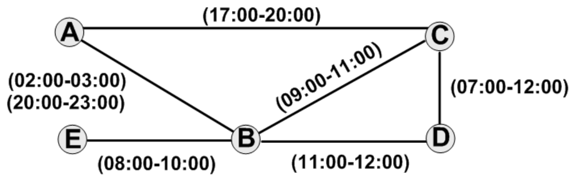


Figure 3. Example of connectivity graph.

Our evolving graph model allows every node to determine all the possible journeys that exist at anytime. Therefore, a routing algorithm can select the best appropriate journey for a specified end-to-end performance parameter. A journey is only considered to be valid if the final time of each interval is greater than or equal to the initial time of every previous interval, for the intervals after the first interval. If N is the number of nodes that composes the journey, a journey is valid if

$$\forall l_p \in j(\tau,\omega), \cup_{p=2}^{N-1}\left(\cup_{p'=1}^{p-1} t_{i_{l_{(p-p')}}} \leq t_{f_{l_p}}\right), for N > 2. \tag{1}$$

Every node computes its journey table. In order to make sure the latest information is used on the routing decisions, the journeys are always recomputed when an interval is modified. The journey table of a node in the region R_1, represented in Figure 2, is on Table 1. Every journey is represented by the destination node, the forwarding nodes that participate in the routing (τ), the number of hops, and the intervals for each hop (ω). The last field of the table is the success probability. This probability is independently computed for every journey and represents the probability of a journey to be successful when there are overlapping intervals. Therefore, the metric used by our routing algorithm is the success probability. Based on this probability and on the time that the message is generated, the source node is able to select the best journey to send the message.

The computation of the successful delivery probability, $P_s(j)$, of a journey, j, represents the probability of journey j to be successfully accomplished, taking into account all the failure possibilities generated by overlapping intervals. In other words, $P_s(j)$ gives the probability of a message $M(o,d)$, generated by a origin node o, to be delivered to the destination node d, using the journey j. For one hop journeys, the probability of success is always equal to one $(P_s(j) = 1)$, because there is just one interval, and no comparison to previous intervals is needed. On the other hand, for more than one hop journeys it is necessary to compare each $N-1$ interval of the journey j with the previous intervals. For example, for a two-hop journey $(N = 3)$, where E_{l_p} is the contact moment between the nodes n_p and $n_{(p+1)}$ of journey j, the success probability is represented by $P_s(j) = P(E_{l_1} \leq E_{l_2})$. To compute this probability, the conditional function distribution is used, resulting in $F_{E_{l_1}|E_{l_2}}(t|t) = P(E_{l_1} \leq t|E_{l_2} = t)$. Due to the independence of events E_{l_1} and E_{l_2}, the success probability is expressed by

$$P_s(j) = \int_0^\infty F_{l_1}(t) f_{l_2}(t)dt. \tag{2}$$

Equation 2 can be generalized for journeys with more than two hops. Thus, $P_s(j)$ is given by

$$P_s(j) = \int_0^\infty ... \int_0^\infty \left(\int_0^\infty \left(\int_0^\infty F_{l_1}(t) f_{l_2}(t)dt\right) f_{l_3}(x)dx\right) f_{l_4}(y)dy \cdots f_{l_k}(z)dz \tag{3}$$

for every journey j, with $N > 2$ hops. Since the contact is modeled by a continuous uniform distribution, the integrals intervals can be adjusted, and $P_s(j)$ is given by

$$P_s(j) =$$

$$= \int_{\max(t_{i_{l_{N-2}}}, t_{i_{l_{N-1}}})}^{t_{f_{l_{N-1}}}} \cdots \int_{\max(t_{i_{l_2}}, t_{i_{l_3}})}^{t_{f_{l_3}}} \left(\int_{\max(t_{i_{l_1}}, t_{i_{l_2}})}^{t_{f_{l_2}}} F_{l_1}(t) f_{l_2}(t) dt \right) f_{l_3}(x) dx \cdots f_{l_{N-1}}(z) dz. \tag{4}$$

4. Performance Evaluation Scenario

Our proposition is designed to provide some services, like electronic mail and the World Wide Web to rural areas in Brazil. Therefore, in our analysis, we used a real scenario based on a rural city, called Itapipoca, situated in the northeast of Brazil. The map of city is shown on Figure 4. The area denoted by `1` is the urban center of the city which has communications infrastructure to offer Internet access. It is thus the area which receives data collected with the mules in the rural region. The other areas denoted by `2`, `3`, and `4` are districts, and the other circles represented by `4` to `27` are small communities. These places compose the rural area, which are kilometers far away from Itapipoca and have no network infrastructure. Scholar buses transport children from the nearest school. These buses, in our proposition, also work as the data mules, storing and delivering all data collected in the rural area. The bus timetable departure is shown on Table 2 and the bus arrival is shown on Table 3, where S represents the source area and D the destination area. Every bus just departs from one source area, arrive at the destination and later return to the source area.

The daily journeys connect the small communities to the nearest district and the districts to the urban center. As the classes are offered in the morning, afternoon and night, buses repeat their journeys three times per day. To run simulations, we used the following data provided by the Itapipoca city government: the distance among the 27 places in the map, the descriptions of each journey, and the expected departure and arrival time in each place. The maximum number of contacts over time is shown in Figure 6(c) and 6(d).

5. Simulation Results

The simulator was implemented in Matlab 7.0. The simulator receives as parameters all the periods in which the network connections are expected to happen. The scenario models the city of Itapipoca, described in Section 4. We considered that there is no connection among buses or among different areas. Therefore, the simulator input is the interval in which the contact of a bus with a region is expected to happen. This data is used by each network node to calculate the probability of success of each possible journey, according to Equation 4. As the journeys are repeated every day, there is no need to frequently recalculate the journey table of each area. Nodes update their tables only when a bus journey is inserted, altered or canceled. In our simulation, nodes calculate the table only once.

We implemented four routing algorithms:

- Direct Contact - the source area only sends the message to the mule if the next contact of the mule is the destination [11];

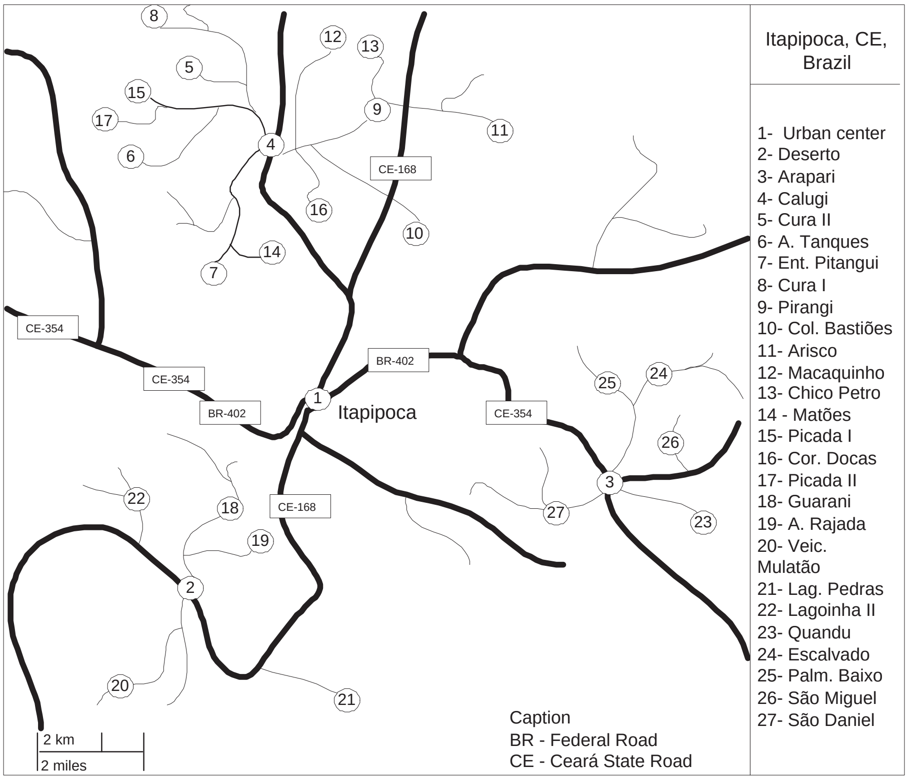
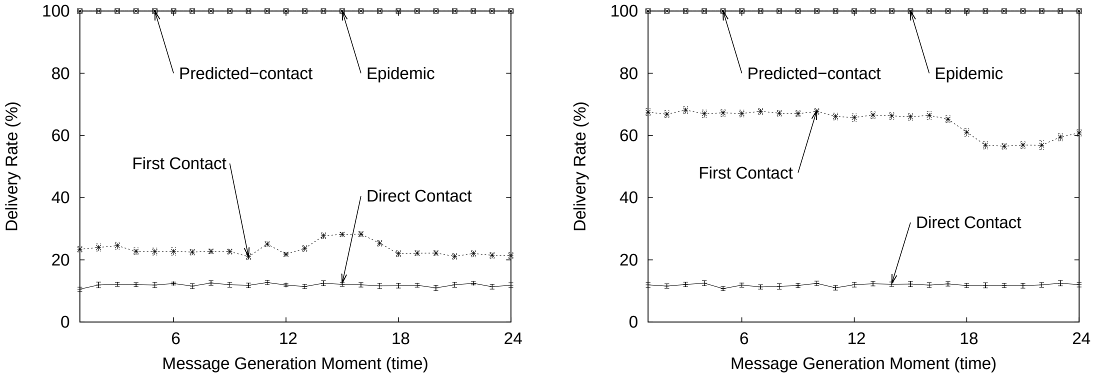


Figure 4. Rural area of Itapipoca, neighboring communities, and scholar bus itineraries.

- First Contact - the source area sends the message to the first mule that makes contact. Next, the mule sends this message to the first region it contacts, and so on [8];
- Epidemic, which the message is replicated to all mules and all areas [9];
- The proposed routing algorithm called Predicted-contact Routing.

The simulation time is five days. In each simulation round, we run the four routing algorithms, and the message rate is 100 messages per hour, during the first day. The message sending time in each hour is chosen randomly. Two scenarios are evaluated. In the first scenario, the source of the message is randomly chosen and the destination is always the urban center, which is Itapipoca. In the second scenario, the source is always the urban center and the destination is randomly chosen among the other regions. The results are observed five days after the day chosen to send the messages. We considered all messages that were not received up to the fifth day as undelivered. The results show a confidence interval of 95%.

Figure 5(a) and 5(b) show the delivery rate related to the message sending time for both scenarios. The algorithm direct contact has the worst delivery rate because routes with more than one hop are usual in this real rural DTN scenario. The delivery rate for the first contact algorithm improves when the urban center is the destination of the messages, as shown in Figure 5(b). When a node in a small community sends a message towards the urban center, the message is always delivered to the nearest district, because small communities' buses always go to the districts. Thus, for the first contact algorithm to deliver the message, the first bus that leaves the district must go to the urban center. Otherwise, the message will be delivered to other small community and has to be sent back to the district in a later time, thus increasing the delay and also decreasing the successful message probability up to five days. If the urban center generates the message, the delivery rate is even worse, when compared with the reverse direction, because the first bus that leaves the urban center may not go to the right district. Besides, if the bus goes to the appropriate district, the first bus that leaves this district may not go to the destination of the message. Epidemic and predicted-contact routing algorithms have the best delivery rates. In epidemic algorithm, nodes forward many copies of the same message in the network, increasing message delivery probability. In the predicted-contact routing mechanism, the performance is achieved by the calculation of the routes with best success probability. The major advantage of our proposal is the storage requirements. The delivery rate of predicted-contact routing with only one copy of each message is the same of epidemic algorithm, which repeat each message to all contacted nodes.



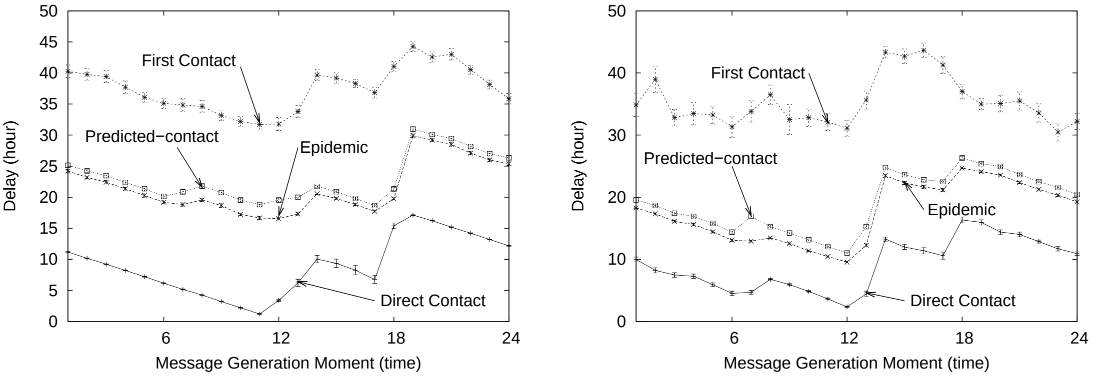
(a) Urban center as destination.

(b) Urban center as source.

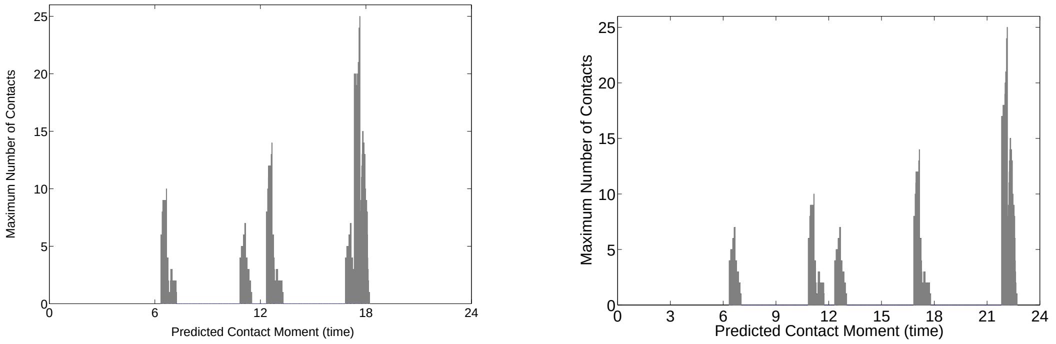
Figure 5. Percentage of delivered messages up to the fifth day.

Figures 6(a) and 6(b) show the message delivery delay of each routing protocol. We considered in this analysis only the messages that are delivered up to five days. Figures 6(c) and 6(d) shows that the buses are concentrated during some moments at the morning, afternoon and night. If the message is generated right before the beginning of the moment the buses leave, it will have the minimum delay. If the message is generated during the moments the bus are concentrated, it may or may not be delivered, because the bus that could deliver the message might have already left, thus increasing the average delay. If the message is generated right after the moment the last bus leaves, it will have the maximum delay, because it will have to wait for the next bus. As the moment the message is generated approaches the moment of the next buses the delay reduces, because the message will have to wait less time for the next bus.

Direct contact presents the lowest medium delay, because the messages are only delivered by mules that directly contact the destination area and thus have a low delay. Even though the direct contact algorithm presents the lowest medium delay for the delivered messages, it successfully delivers only 10% of the messages. The first contact algorithm can be considered the worst algorithm, because it presents the highest medium delay and less than 30% of the messages are successfully delivered. Both the epidemic algorithm and the proposed algorithms successfully deliver 100 of the messages. The epidemic algorithm has the lowest delay because it uses all the possible routes to send the messages. The proposed algorithm presents similar medium delay when compared to the epidemic.



(a) Urban center as destination.
(b) Urban center as source.

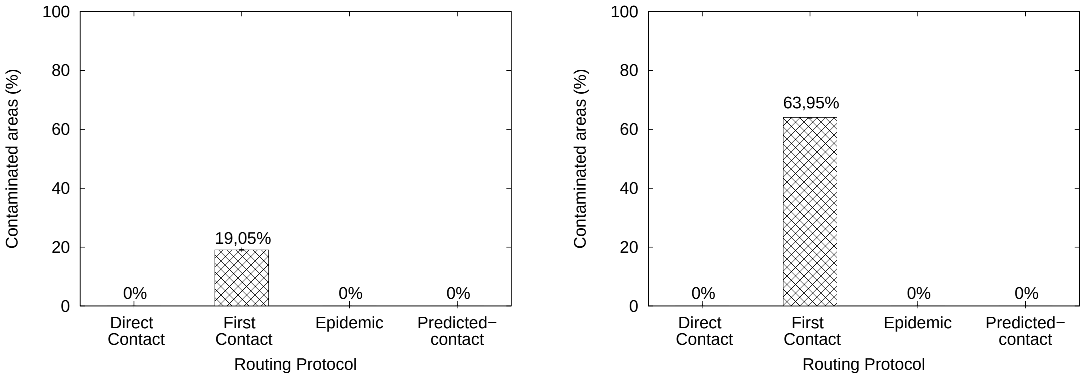


(c) Urban center as destination.
(d) Urban center as source.

Figure 6. Delivered message delay.

The preceding results show that both the proposed and epidemic algorithms delivers 100% of messages and have similar delivery delays. Nevertheless, we also have to consider, for overall performance of the network, the total number of messages sent and stored by the intermediated nodes. Thus, an area is classified as contaminated if it is an intermediate hop of any message that is routing to the destination. Figures 7(a) and 7(b) show the percentage of contaminated areas by undelivered messages. We can observe that the first contact algorithm, if the first contact is not in the correct direction to the destination, the message will travel and be replicated to nodes in wrong areas.

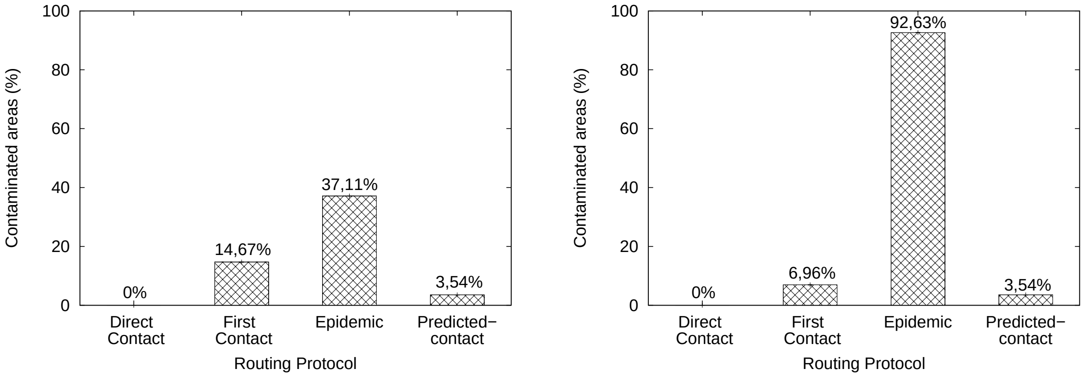
The percentage of areas contaminated by each delivered message is shown in Figures 8(a) and 8(b). Obviously, there are no contaminated areas, when the direct contact algorithm is used. For the first contact algorithm, a message only has a high successful delivery probability if the first mule destination is in the correct direction to the destination node, otherwise useless messages contaminate nodes. The epidemic algorithm has the worst result, because the messages are replicated at every contact. Besides, more messages are replicate when the source is the urban center because the star topology that splits messages in all directions to all districts and all small communities. When a district sends a message to the urban center, this message does not contaminate other districts. On the other hand, the proposed routing algorithm only replicates messages to the necessary forwarding nodes in order to attain the destination node. Therefore, our proposal presents the best performance results with 100% of successful delivery rate, low medium delivery delay, and a minimum number of replicate messages that represents the lowest capacity requirement for the MULEs.



(a) Urban center as destination.

(b) Urban center as source.

Figure 7. Percentage of contaminated areas by undelivered messages.



(a) Urban center as destination.

(b) Urban center as source.

Figure 8. Percentage of contaminated areas by delivered messages.

6. Conclusions

Rural networks are important to promote affordable technology to underserved communication areas. The delay tolerant network architecture seems to be a low cost solution to provide Internet access and, as a consequence, digital inclusion to poor rural communities. In this paper we present a MULE-based rural network where the MULES are scholar buses. A real scenario of the northeast of Brazil is considered in the performance evaluations. We proposed a new routing scheme that takes into account the real timetable of the buses and its possible delays. A predicted-contact based algorithm is developed to select the best successful-delivery-rate route.

Four routing algorithms were implemented and compared: direct contact, first contact, epidemic, and our proposal, called predicted-contact. The simulation results show that the direct contact and the first contact algorithms do not fit well for the considered scenario. The direct contact algorithm does not work well because more than one hop is required to attain the destinations, due to the MULEs itineraries. The first contact is inefficient because the first MULE can take the wrong direction to attain the destination. On the other hand, both the proposed and epidemic algorithms successfully deliver all messages and present similar delivery delays. The great drawback of the epidemic algorithm is the required storage capacity and worthless message replications, due to the flooding approach. The proposed algorithm has a high efficiency, because only one copy of the message is used to deliver the message and, as consequence, low cost equipments can be used. Our proposal seems to be an efficient and low cost alternative of rural network to provide digital inclusion in Brazil.

References

[1] E. Brewer, M. Demmer, B. Du, M. Ho, M. Kam, S. Nedevschi, J. Pal, R. Patra, S. Surana, and K. Fall, "The Case for Technology in Developing Regions," in *Computer*, vol. 38. IEEE Computer Society, June 2005, pp. 25–38, DOI:10.1109/MC.2005.204.

[2] A. S. Pentland, R. Fletcher, and A. Hasson, "Daknet: Rethinking connectivity in developing nations," in *Computer*, vol. 37, no. 1. IEEE Computer Society, January 2004, pp. 78–83, DOI:10.1109/MC.2004.1260729.

[3] TIER, "Technology and Infrastructure for Emerging Regions," http://tier.cs.berkeley.edu, February 2007.

[4] KioskNet, "The KioskNet Project," http://blizzard.cs.uwaterloo.ca/tetherless/index.php/KioskNet, February 2008.

[5] K. Fall, "A Delay-Tolerant Network Architecture for Challenged Internets," in *SIGCOMM*. ACM, February 2003, pp. 27–34, DOI:10.1145/863955.863960.

[6] V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, K. Fall, and H. Weiss, "Delay-Tolerant Networking Architecture - RFC4838," April 2007.

[7] Z. Zhang, "Routing in Intermittently Connected Mobile Ad Hoc Networks and Delay Tolerant Networks: Overview and Challenges," *IEEE Communications Surveys & Tutorials*, vol. 8, no. 1, pp. 24–37, October 2006, DOI:10.1109/COMST.2006.323440.

[8] S. Jain, K. Fall, and R. Patra, "Routing in a Delay Tolerant Network," in *ACM SIGCOMM*, vol. 34. ACM Press, 2004, pp. 145–158, DOI:10.1145/1030194.1015484.

[9] A. Vahdat and D. Becker, "Epidemic Routing for Partially-Connected Ad Hoc Networks," Duke University, Tech. Rep., April 2000.

[10] K. A. Harras, K. C. Almeroth, and E. M. Belding-Royer, "Delay Tolerant Mobile Networks (DTMNs): Controlled Flooding Schemes in Sparse Mobile Networks," *International Conferences on Networking (IFIP)*, May 2005.

[11] Y. Wang, S. Jain, M. Martonosi, and K. Fall, "Erasure-coding based routing for opportunistic networks," in *WDTN '05: Proceeding of the 2005 ACM SIGCOMM workshop on Delay-tolerant networking*. ACM, August 2005, pp. 229–236, DOI:10.1145/1080139.1080140.

[12] W. Zhao, M. Ammar, and E. Zegura, "A message ferrying approach for data delivery in sparse mobile ad hoc networks," in *MobiHoc '04*. ACM, May 2004, pp. 187–198, DOI:10.1145/989459.989483.

[13] ——, "Controlling the mobility of multiple data transport ferries in a delay-tolerant network," in *INFOCOM'05*. IEEE, March 2005, pp. 1407–1418, DOI:10.1109/INFCOM.2005.1498365.

[14] A. Ferreira, "Building a Reference Combinatorial Model for MANETs," *IEEE Network*, vol. 18, no. 5, pp. 24–29, September–October 2004, DOI:10.1109/MNET.2004.1337732.

Table 1. The journeys table.

Destination	τ	Hops	ω	Prob. Success
R2	R1-B1-R2	2	(07:00-07:20),(07:40-08:00)	1
R3	R1-B1-R2-B2-R3	4	(07:00-07:20),(07:40-08:00),(07:50-08:00),(08:30-08:50)	0.75

Table 2. Bus departure time table.

Period of a day	S-D	D-S
Morning	06:20-06:40	10:40-11:10
Afternoon	12:20-12:40	16:40-17:10
Night	17:20-17:40	21:50-22:10

Table 3. Bus arrival time table.

Src	Dst	Morning(S-D)	Morning(D-S)	Afternoon(S-D)	Afternoon(D-S)	Night(S-D)	Night(D-S)
1	2	06:32 - 06:52	11:02 - 11:22	12:32 - 12:52	17:02 - 17:22	-	-
7	4	06:54 - 07:14	11:24 - 11:44	12:54 - 13:14	17:24-17:44	-	-
8	4	-	-	12:58 - 13:18	17:28 - 17:48	-	-
26	3	06:25 - 06:45	10:55 - 11:15	12:25 - 12:35	16:55 - 17:15	-	-
27	3	06:25 - 06:45	10:55 - 11:15	12:25 - 12:35	16:55 - 17:15	-	-
15	4	06:53 - 07:13	11:23 - 11:43	-	-	-	-
2	18	06:41 - 07:01	11:11 - 11:31	12:41 - 13:01	17:11 - 17:31	-	-
23	3	06:27 - 06:47	10:57 - 11:17	12:27 - 12:47	16:57 - 17:17	-	-
19	2	06:39 - 06:59	11:09 - 11:29	12:39 - 12:59	17:09 - 17:29	-	-
3	27	06:25 - 06:45	10:55 - 11:15	12:25 - 12:35	16:55 - 17:15	-	-
1	4	06:37 - 06:57	11:07 - 11:27	12:37 - 12:57	17:07 - 17:27	-	-
24	3	-	-	-	-	17:39 - 17:59	22:09 - 22:29
21	2	-	-	12:37 - 12:57	17:07 - 17:27	17:37 - 17:57	22:07 - 22:27
22	2	-	-	-	-	17:37 - 17:57	22:07 - 22:27
20	2	-	-	-	-	17:45 - 18:05	22:15 - 22:35
16	4	-	-	-	-	17:43 - 18:03	22:13 - 22:33
9	11	-	-	-	-	17:47 - 18:07	22:17 - 22:37
17	4	-	-	-	-	17:45 - 18:05	22:15 - 22:35
5	4	-	-	-	-	17:46 - 18:06	22:16 - 22:36
10	4	-	-	-	-	17:46 - 18:06	22:16 - 22:36
23	3	-	-	-	-	17:34 - 17:54	22:04 - 22:24
26	3	-	-	-	-	17:25 - 17:45	21:55 - 22:15
3	1	-	-	12:28 - 12:48	16:58 - 17:18	-	-
12	4	-	-	-	-	17:53 - 18:13	22:23 - 22:43
13	9	-	-	-	-	17:37 - 17:57	22:07 - 22:27
9	4	-	-	-	-	17:32 - 17:52	22:02 - 22:22
25	3	-	-	-	-	17:31 - 17:51	22:01 - 22:21
14	4	-	-	-	-	17:48 - 18:08	22:18 - 22:38
6	4	-	-	-	-	17:49 - 18:09	22:19 - 22:39

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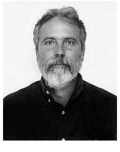

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