DTN Congestion Control Unplugged: A Comprehensive Performance Study

Aloizio P. Silva
Inst. Tec. de Aeronáutica
São José dos Campos, Brasil
aloizio@ita.br

Scott Burleigh
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California, USA
scott.c.burleigh@jpl.nasa.gov

Celso M. Hirata
Inst. Tec. de Aeronáutica
São José dos Campos, Brasil
hirata@ita.br

Katia Obraczka
UC Santa Cruz
Santa Cruz, California, USA
katia@soe.ucsc.edu

ABSTRACT

Unlike TCP/IP networks, in DTNs end-to-end paths between nodes cannot be guaranteed at all times. This means that DTN nodes may have to store messages for long periods of time before they can forward the messages towards their ultimate destinations. As a result, congestion control in DTNs is critical to achieve adequate performance, yet needs to be fundamentally different from congestion control in TCP/IP networks. This paper presents a comprehensive comparative performance study of DTN congestion control in a wide range of DTN scenarios. It complements our previous work [16] in which we study the performance of DTN congestion control in interplanetary network scenarios. As in [16], our results confirm that although congestion control helps alleviate DTN congestion, existing mechanisms fall short from achieving adequate message delivery ratio and latency. Our study also confirms that congestion control in DTN scenarios should be independent of the underlying routing protocol, should employ a combination of reactive and proactive control as well as local information instead of relying on global knowledge.

Categories and Subject Descriptors

C.2 [**Computer-Communication Networks**]: Network Architecture and Design; C.2.1 [**Network communications**]: Store and forward networks—*wireless communication*

General Terms

Performance, Experimentation

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Keywords

Delay and Disruption Tolerant Networks; Interplanetary Networks; Congestion Control; Network Performance

1. INTRODUCTION

Delay- or Disruption-Tolerant Networks (DTNs) were proposed in the late 1990's motivated by the vision of Interplanetary Internets (IPNs). The main goal of IPNs was to provide a more permanent data communication infrastructure in space to support space exploration missions. However, over the last decade, several earthbound applications in so-called "challenged" network environments have emerged. Example applications include environmental sensing, habitat monitoring, emergency response, disaster recovery, and bridging the digital divide, to name a few.

DTNs' main distinguishing feature is that continuous end-to-end routes cannot be guaranteed due to factors such as lapses in connectivity, arbitrarily long propagation delays, high and persistent channel error rates, etc. Under these conditions, participating nodes must store messages they are transmitting or forwarding in persistent storage until a "contact" opportunity arises, i.e., until the node has a suitable next-hop neighbor that can receive the message(s). Since contact opportunities may take an arbitrarily long time to occur, nodes, who often have limited storage capabilities, may have to store data for long periods of time and network congestion can quickly build up. Consequently, DTN congestion control is critical to ensure nodes are congestion-free and, when needed, can serve as relays for messages to be delivered end-to-end.

Since end-to-end paths between DTN nodes cannot be guaranteed at all times, congestion control in DTNs needs to be fundamentally different from congestion control in TCP/IP networks, and thus poses a variety of research challenges. The performance impact of DTN congestion control coupled with the challenges it raises have motivated a number of research efforts as documented in our DTN congestion control survey [6]. In our survey, we propose a taxonomy which maps the DTN congestion control design space based on congestion control's basic principles, including: how congestion is detected; whether open- or closed-loop control is employed; whether local- or global knowledge of the network is utilized; the types of contacts between nodes; and whether control is proactive or reactive. Using our taxonomy, we identified a subset of existing congestion control mechanisms that represent the current state-of-the-art of DTN congestion control. In our previous work [16], we studied the performance of these congestion control mechanisms in interplanetary DTN scenarios [4]. Our results showed that, even though congestion control helps alleviate network congestion, DTN congestion control's current state-of-the-art does not exhibit adequate performance in deep space communication scenarios. These results confirmed our expectations since existing congestion control mechanisms were not designed for IPN applications, but rather for earth-bound DTNs.

In this paper, we conduct a comprehensive comparative performance study of DTN congestion control in a wide range of terrestrial DTN scenarios. We consider various node mobility- ([15] [13] [1]) and routing regimes ([2] [3]). The remainder of the paper is organized as follows: in Section 2, we provide an overview of terrestrial DTN environments' main features as well as a brief description of the congestion control schemes we studied. Section 3 describes our experimental methodology while Section 4 presents the results of our comparative study. Section 5 concludes the paper with a discussion of the results and directions for future work.

2. BACKGROUND

2.1 DTN Scenarios

Section 1 listed a number of sample earthbound DTN applications, several of which target "extreme" environments. In these scenarios, DTNs are prone to arbitrarily long lived connectivity disruptions; however, unlike IPNs, they are not necessarily subject to delays in deep space caused by astronomical distances. Additionally, while in IPNs, contacts between nodes are typically deterministic and characterized by scheduled encounters [7] (e.g., based on the orbit of IPN nodes), in terrestrial DTNs, contacts can also be non-deterministic; they can be probabilistic, i.e, they occur following some probability distribution, or they can be completely random, also known as opportunistic. The main challenges affecting terrestrial DTNs can be summarized as follows:

1. **Intermittent connectivity** (e.g., due to node mobility which often results in opportunistic contacts);

2. **Long and variable delays** which are typically caused by connectivity disruptions;

3. **Variable error rates**; bit error rates (BERs) vary according to the type of environment (e.g., in a wireless sensor network the BER may be on the order of 10^{-1} to 10^{-3}, which is typically lower than BERs in deep space environments);

4. **Symmetric data rates**; data rates are frequently symmetric in terrestrial DTNs but may be asymmetric in some environments (e.g. underwater communication).

2.2 Selected DTN Congestion Control Mechanisms

For our comparative study, we picked a subset of DTN congestion control mechanisms from the schemes surveyed in [6] that we consider representative of the current DTN congestion control state-of-the-art. More specifically, each of the selected mechanisms addresses at least one of the DTN congestion control basic principles we used in the taxonomy proposed in [6] and we summarized in Section 1. The DTN congestion control schemes we study are: RRCC [18], AFNER [20], SR [14] and CCC [11]. Below, we briefly describe each of these mechanisms.

- **Retiring replicants congestion control (RRCC)** [18] allows each node to react independently to perceived congestion by specifying the number of message copies that it can relay. To determine the degree of replication, nodes observe the current level of local congestion as measured by the number of discarded messages. RRCC's worst case complexity is given by $O(n)$, where n is the number of exchanged messages during node encounters.

- **Average forwarding number based on epidemic routing (AFNER)** Using AFNER [20], a DTN node, whose buffer is full and needs to receive new messages, randomly drops messages based on the messages' *forwarding numbers*. More specifically, if a message's forwarding number is larger than the network's average forwarding number, then the message is dropped. A message's forwarding number is defined as the number of copies of the message, and the average forwarding number is the mean forwarding number over all messages currently in the network. AFNER's average forwarding number is not easy to compute in a real DTN since it requires global knowledge. Note that AFNER relies on epidemic routing. AFNER's worst case complexity is $O(n\ log(n)) + m)$, where n is the buffer size and m the total number of messages in the network.

- **Storage routing (SR)** migrates messages to alternate storage locations when congestion is detected [14]. SR avoids congestion by having nodes forward excess messages to neighbors that have available buffer space. When nodes that were at risk of congestion manage to reduce their buffer occupancy, any messages that were previously migrated are retrieved. SR operates as a local routing protocol diverting messages from their conventional routing path for later forwarding. Taking into account the node selection strategy, in the worst case, the cost of this mechanism is $O(n)+k$, where n is the buffer size and k is the number of alternate nodes.

- **Credit-based congestion control (CCC)** [11] tries to delete messages when congestion builds up at a node. Messages are dropped when deemed obsolete by their *time-dependent credit*. The mechanism works as follows: after a message has been generated from any DTN node, it carries a maximum amount of credit as its initial value. As time passes, one credit is decreased at every time unit. When two nodes encounter, they exchange messages and each node refunds the sent message's credit for the amount given by *penalty* at the sender side, and refills the received message's credit for the amount given by *reward* at the receiver. In the worst case, CCC's cost is $O(n)$, where n is the number of exchanged messages during node encounters.

3. EXPERIMENTAL METHODOLOGY

We conducted experiments using the ONE Simulator platform [10], which is a discrete event simulator specific for DTN environments.

3.1 Experimental Setup

We simulate an application scenario that emulates data transfer in a wireless communication network in order to study the performance of the four congestion control mechanisms described in Section 2.2. A scenario without congestion control is considered as baseline for our comparative study. Every pair of nodes that come into communication range of each other according to the simulated node movement can transfer data between them if they have data to send. Another interesting aspect of our study is to understand the dependence of the congestion control schemes on the underlying routing protocol [8]. To this end, we use three different routing protocols, namely Epidemic [19], ProPHET [12], and Spray and Wait [17].

The scenario we simulate includes 50 nodes that move according to a pre-defined mobility regime. As they move, nodes encounter one another "opportunistically". During these "opportunistic contacts", nodes can exchange messages. Figure 1 shows the output of the ONE simulator's graphic interface illustrating a snapshot of one of the DTN scenarios simulated. We assume that all nodes have the same transmission ranges. Table 1 lists the simulation parameters we used in our experiments and their values.

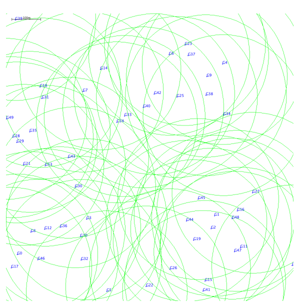


Figure 1: Snapshot of DTN scenario.

Three mobility models were used, namely Random Walk (RW), Random Way Point (RWP), and Shortest Path Map-Based Movement (SPMBM). In RW [5], a node randomly chooses a destination within the simulation area. It then moves from its current location to the new one with speed uniformly distributed within the interval given by *Group.speed*. When it arrives at its destination, it picks another one and repeats the steps above. The RWP mobility model [5] is a generalization of RW and works as follows: a mobile node picks a random destination within the simulated area; it then moves to that destination with constant speed chosen as a uniformly distributed random number in the interval *Group.speed*. When the node reaches its destination, it pauses for some time. In our simulations, the pause time is a uniformly distributed random number between $\{0, 120\}$ seconds. After that, the node picks another random destination and repeats the steps above. The SPMBM [9] model uses Dijkstra's shortest path algorithm to calculate the shortest path from the current location to a randomly selected destination. Similarly to RWP, when the node arrives at its destination, it also uses a uniformly random pause time between $\{0, 120\}$ seconds.

4. SIMULATION RESULTS

In this section, we present simulation results from our experiments. We use 95% confidence intervals, and, as our performance baseline, we use results obtained when no congestion control is employed. Each data point presented in the graphs below is computed as the average over 5 runs. We consider the following performance metrics: **Delivery ratio** defined as the ratio between the number of messages received at destination nodes and the number of messages generated; **End-to-End latency** defined as the average time to deliver messages to their destinations; and **Overhead** defined as the difference between the number of messages delivered and the number of messages relayed, divided by the number of messages delivered. Note that some graphs do not show the standard deviation because it is either zero or close to zero.

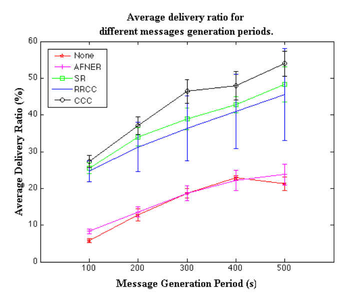
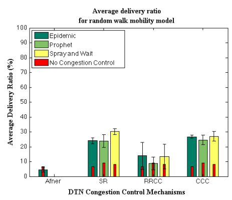


Figure 2: Message delivery ratio as a function of the message generation period (Epidemic routing, buffer size of 1000 Kbytes, transmit speed of 2.5 Mbps and RWP mobility model).

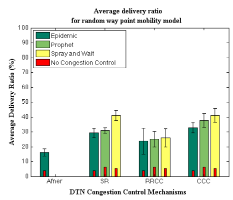
Figure 2 shows message delivery ratio as a function of the message generation period. As expected, for longer message generation periods, i.e., lower message generation frequencies, the delivery ratio increases. We observe that the CCC mechanism yields higher average delivery ratio than the other mechanisms (AFNER, RRCC, SR). We contend that the improvement in the delivery ratio is due to the hybrid (reactive and proactive) control approach adopted by CCC. In proactive mode, CCC prepares the network for upcoming congestion. In contrast, reactive control is retrospective, responding to the presence of salient or imperative congestion by engaging control only if needed via reactivation of previously stored information (messages' credit). CCC's good performance is due to the effective use of its credit-based strategy. Furthermore, its refilling and refunding technique benefits when large number of contact opportunities arise. Note that AFNER has the worst performance (the lowest average delivery ratio) even when compared to the baseline scenario (see Figure 2 *None* curve). This happens because AFNER requires information about all nodes in the network. However, obtaining global information in DTN environments is quite challenging and costly.

Parameters		
Name	Description	Value
Scenario.endTime	simulation time	43200 seconds
btInterface.transmitSpeed	bandwidth	2.5 Mbps
Group.router	routing protocol	[EpidemicRouter, ProphetRouter, SprayAndWaitRouter (10 msg copies)]
Group.movementModel	mobility model	[RandomWayPoint, RandomWalk, ShortestPathMapBasedMovement]
Group.bufferSize	node buffer size	500 Kbytes and 1000 Kbytes
Group.msgTTL	message time to live	43200 seconds
Group.nrofHosts	number of nodes in network	50
Group.speed	max and min speed that the nodes must move	$\{0.5, 1.5\}$ m/s
Movimentmodel.worldSize	area where simulation takes place	1 km × 1 km (RandomWayPoint, RandomWalk) and 6 km × 6 km (ShortestPathMapBasedMovement)
Events1.size	message size	$\{50, 100\}$ Kbytes
Events1.interval	i.e. one new message every 1 to 100 seconds	[1-100, 1-200, 1-300, 1-400, 1-500] seconds

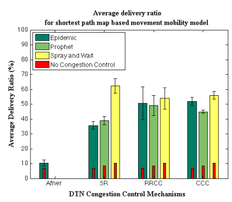
Table 1: Simulation parameters and their values



(a) Random Walk



(b) Random Way Point



(c) Shortest Path Map Based Movement

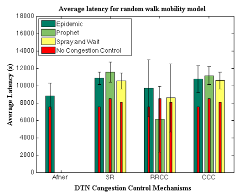
Figure 3: Average delivery ratio for each congestion control mechanism using different mobility models (transmit speed of 2.5 Mbps, buffer size of 500 Kbytes and message generation period of 300 s).

Node mobility is a critical factor influencing the performance of mobile networks. DTNs are no exception: the way nodes move determines their connectivity and thus impact their ability to relay messages. Figure 3 shows the average delivery ratio for different mobility models and routing protocols for each of the selected congestion control mechanisms. Under RW and RWP mobility, the delivery ratio is low, whereas under SPMBM, the average delivery ratio for different protocols is higher. We contend that SPMBM results in denser networks and thus more contact opportunities. Consequently, more messages can be forwarded, increasing the delivery ratio. However, the difference is minimal when we compare with RW and RWP. We argue that the delivery ratio becomes lower because the buffers in the intermediate nodes on the shortest path may already be at maximum capacity. As a result, messages are discarded and the delivery ratio decreases. Furthermore, AFNER performs worse than other mechanisms when compared to the baseline scenario. AFNER uses the network's average forwarding number to control congestion. Therefore, for networks that are sparser, there is a larger probability of disconnection. For this reason, more messages need to wait to be forwarded, resulting in buffers filling up. AFNER starts to discard messages based on an inaccurate network average forwarding number, which leads to its low delivery ratio. Unsurprisingly, this behavior confirms that the use of network global information to mitigate congestion in DTN is not a good design principle. Furthermore, as previously pointed out, AFNER does not consider the number of message copies, which is one of the reasons for buffer overflow. Additionally, its reactive congestion control approach is not adequate to DTN environments.

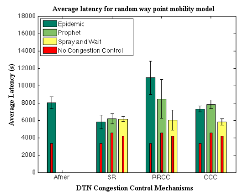
As depicted in Figure 3, for all mechanisms except AFNER (which was designed to operate over epidemic routing protocol), when different routing protocols are used the average delivery ratio values vary. Therefore, in view of the taxonomy presented in [6], RRCC, CCC and SR can be classified as routing-protocol-dependent (since they register different delivery ratio values for different routing protocols). It is noticeable that the CCC mechanism performs better with RW and RWP mobility models. When SPMBM model is used, CCC and RRCC exhibit similar behavior. We argue that their control strategies benefit from a denser network where there are more contact opportunities.

In Figure 3b, we investigate the performance of the selected mechanisms when the RWP mobility model is used. Large values of average delivery ratio can be observed for all congestion control mechanisms when compared with the baseline scenario. Looking at Figures 3a and 3b, we can immediately see that the mobility model has significant impact on the congestion control mechanisms. When RW and RWP are used, the mechanisms register a large delivery ratio for RWP. This is because in the RWP model the mobile nodes are more likely to cluster in the geographical center of the simulation. Therefore , there are more contact opportunities and thus more messages are forwarded. This increases the delivery ratio. At the same time, in the RWP model, node mobility and frequent but shorter contacts lead to higher buffer fill ratio, and thus more queuing. Overall, the gain in delivery ratio may or may not come with reduced delay.

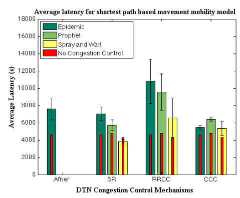
Despite of the high density of the network formed by the SPMBM mobility model, we observe large average message delivery latency values as shown in Figure 4c. This is for the reason that messages may be forced to take longer routes (leading to larger delays) because the well-connected nodes, which would enable shorter paths, may already have full buffers and thus cannot be chosen as next hops. Observe that mobile nodes choose random directions when using RW (Figure 4a) or RWP (Figure 4b). In these trials, messages may travel over longer paths before arriving at their destinations, increasing the overall message average latency. The average latency decreases for SPMBM. The SPMBM



(a) Random Walk

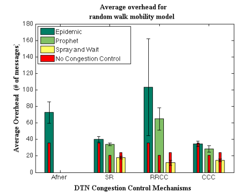


(b) Random Way Point

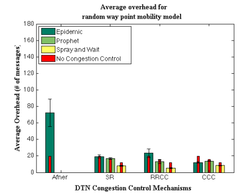


(c) Shortest Path Map Based Movement

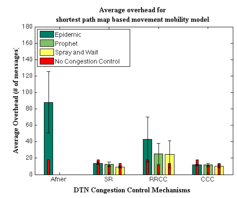
Figure 4: Average latency per congestion control mechanism for different mobility models (transmit speed of 2.5 Mbps, buffer size of 500 Kbytes and message generation period of 300 s).



(a) Random Walk



(b) Random Way Point



(c) Shortest Path Map Based Movement

Figure 5: Average overhead per congestion control mechanism for different mobility models (transmit speed of 2.5 Mbps, buffer size of 500 Kbytes and message generation period of 300 s).

model is an improved version of the RWP model, where nodes choose random destination decision points and move to those destinations following the map-based shortest path. Thus mobile nodes move less (due to the shortest path computation) when using SPMBM mobility model and, again, this model provides a denser network scenario in comparison to the RW and RWP, which are relatively sparse. As a result, in the SPMBM model the contacts are more frequent. Thus more messages are forwarded, reducing delivery delay and increasing delivery ratio. In all three mobility models, the combination of epidemic routing protocol and the AFNER mechanism results in relatively low average latency. AFNER's operation of dropping messages leads to reduced opportunity to forward older messages. The messages which have been discarded are those that have more copies in the network. As a result, newly arriving messages can be forwarded to their destination more rapidly, minimizing delivery latency. Again, though, AFNER uses the network's average forwarding number to decide which message to discard. This information can often be outdated because of intermittent connectivity, resulting in a low delivery ratio.

Figure 5 shows *overhead* incurred by each congestion control scheme under different routing regimes. It provides a measure of the average number of message transmissions required to deliver a message from the source to its destination. As such, the overhead graphic indicates the amount of network resources needed to deliver a message to its destination. We expect that before congestion occurs, additional replicas will increase the probability that messages get delivered. However, as the network gets congested that relationship changes as more replicas mean more congestion and thus lower message delivery probability. As we have seen, Epidemic Routing results in the transmission of many more message copies within the network, compared to the Prophet and Spray and Wait protocols. This is because, under Epidemic Routing, each node replicates a message every time it encounters another node that does not have a copy of the message. This drastically increases the number of times a message is relayed to intermediate nodes. We also observe that AFNER's overhead is higher than the overhead incurred by the other mechanisms. This behavior can be attributed to AFNER's use of Epidemic Routing as well as the fact that AFNER reactively discards messages based on the network's average forwarding number when congestion is detected. As a result, messages can be replicated and then until congestion has been mitigated. This increases the number of relayed messages in the network considerably while the number of delivered messages remains the same which increases the overhead. In other words, it increases the amount of network resources that are used to deliver one message to its destination. Note that for different mobility models the lower overhead values of the congestion control mechanisms yield higher delivery ratio values (see Figure 3).

5. CONCLUSION

This paper evaluated the performance of four DTN congestion control mechanisms which represent the state-of-the-art in DTN congestion control based on the survey we present in [6]. We examined three performance metrics, namely delivery ratio, latency, and overhead, and we also evaluated the congestion control schemes in terms of their routing protocol independence. As baseline, we use the same simulation scenarios without congestion control. This study complements our previous work [16], which studied DTN congestion control performance in deep space communication environments. This kind of quantitative study provides useful insight to help guide the design of effective and interoperable DTN congestion control mechanisms.

Our results confirm that, since messages may be buffered for long periods of time before being acknowledged, buffer overflow becomes highly common resulting in excessive latencies and message losses. This is aggravated by the fact that reactive congestion control schemes such as AFNER and SR are severely impacted by delayed control decisions.

We show that adopting a proactive or hybrid approach such as RRCC and CCC may significantly improve the network's performance; this appears to be an interesting strategy for DTN congestion control mechanisms.

According to our results, DTN routing protocols have a significant impact on congestion control mechanisms' performance (e.g. SR, RRCC and CCC). Patterns of mobility show similar impact. The relation between routing and mobility appears clear here. Therefore, the design of more intelligent, efficient and routing-protocol-independent congestion control mechanisms is of particular interest.

In summary, our results indicate that congestion control helps to increase message delivery ratio, even in highly congested network scenarios. Our study also indicates that good design principles for congestion control in DTN scenarios include: using a combination of reactive and proactive control as well as using local information instead of relying on global knowledge. Additionally, designing a congestion control mechanism that is routing protocol-independent helps with interoperability and applicability to a wide variety of DTN scenarios. Using the insights gained from our quantitative performance study of existing DTN congestion control, as future work, we will design a congestion control framework that can automatically adapt to the conditions of the operating environment.

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6. REFERENCES

[1] M. Ababou, R. Elkouch, M. Bellafkih, and N. Ababou. Impact of mobility model on supp-tran optimized DTN spray and wait routing protocol. *International Journal of Mobile Network Communications & Telematics (IJMNCT)*, 4(2), 2014.

[2] F. Alnajjar and T. Saadawi. Performance analysis of routing protocols in delay/disruption tolerant mobile ad hoc networks. In *Proceeding of 10th WSEAS inter. conference on electronics, hardware, wireless and optical communications*, pages 407 – 417, 2011.

[3] A. Aziz and S. Yamada. A handoff-based and limited flooding (HALF) routing protocol in delay tolerant network. *International Journal of Wireless & Mobile Networks (IJWMN)*, 4(2), 2012.

[4] S. Burleigh, A. Hooke, L. Torgerson, K. Fall, V. Cerf, B. Durst, K. Scott, and H. Weiss. An approach to interplanetary internet. *IEEE Communication Magazine*, July 2003.

[5] T. Camp, J. Boleng, and V. Davies. A survey of mobility models for ad hoc network research. *Wireless Communications and Mobile Computing*, 2(5):483–502, 2002.

[6] A. P. da Silva, S. Burleigh, C. M. Hirata, and K. Obraczka. A survey on congestion control for delay and disruption tolerant networks. *Ad Hoc Networks*, August 2014. Elsevier.

[7] G. J. Holton and S. G. Brush. *Physics, The Human Adventure: From Copernicus to Einstein and Beyond*. Rutgers University Press, 2001.

[8] S. Jain, K. Fall, and R. Patra. Routing in delay tolerant network. In *Proceedings of the Conference on Applications, Technologies, Architectures, and Protocols for Communications*, 2004.

[9] A. Keränen and J. Ott. Increasing reality for DTN protocol simulation. Technical report, Helsinki University of technology, Networking Laboratory, 2007.

[10] A. Keränen, J. Ott, and T. Karkkainen. The ONE simulator for DTN protocol evaluation. In *The 2nd Inter. Conference on Simulation Tools and Techniques*, 2009.

[11] L. Leela-amornsin and H. Esaki. Heuristic congestion control for massage deletion in delay tolerant network. In *Smart Spaces and Next Generation Wired/Wireless Networking*, August 2010. Third Conference on Smart Spaces and 10th International Conference.

[12] A. Lindgren, A. Doria, and et. al. Probabilistic routing in intermittently connected networks. *Computer Communication Review*, 7:19–20, 2003.

[13] S. Rashid, Q. Ayub, M. S. M. Zahid, and A. H. Abdullah. Impact of mobility on DLA (drop largest) optimized DTN epidemic routing protocol. *Inter. Journal of Computer Applications*, 18(5), 2011.

[14] M. Seligman, K. Fall, and P. Mundur. Alternative custodians for congestion in delay tolerant networks. In *Proceedings of the SIGCOMM CHANTS'06*, 2006.

[15] M. Shahzamal, M. F. Pervez, M. A. U. Zaman, and M. D. Hossain. Mobility models for delay tolerant network: A survey. *Inter. Journal of Wireless & Mobile Networks (IJWMN)*, 6(4), 2014.

[16] A. P. Silva, S. Burleigh, C. M. Hirata, and K. Obraczka. Congestion control in disruption-tolerant networks: a comparative study for interplanetary networking applications. In *Proceedings of the 2014 MobiCom CHANTS'14*, 2014.

[17] T. Spyropoulos, K. Psounis, and C. Raghavendra. Spray and wait: an efficient routing scheme for intermittently connected mobile networks. In *ACM SIGCOMM workshop on Delay-tolerant Networking*, page 259, 2005.

[18] N. Thompson, S. C. Nelson, M. Baknt, T. Abdelzaher, and R. Kravets. Retiring replicants: Congestion control for intermittently - connected networks. In *Proceedings of the IEEE INFOCOM'2010*, pages 1–9, March 2010.

[19] A. Vahdat and D. Becker. Epidemic routing for partially-connected ad hoc networks. Technical report, Duke University, 2000.

[20] L. Yun, C. Xinjian, L. Qilie, and Y. Xianohu. A novel congestion control strategy in delay tolerant networks. In *Second International Conference on Future Networks*, 2010.