Scheduling and Drop Policies for Traffic Differentiation on Vehicular Delay-Tolerant Networks

Vasco N. G. J. Soares[1,2,3], Farid Farahmand[4], and Joel J. P. C. Rodrigues[1,2]
[1]Instituto de Telecomunicações, NetGNA Group, Covilhã, Portugal
[2]Department of Informatics, University of Beira Interior, Covilhã, Portugal
[3]Superior School of Technology, Polytechnic Institute of Castelo Branco, Castelo Branco, Portugal
[4]Department of Engineering Science, Sonoma State University, CA, USA
vasco.g.soares@ieee.org; farid.farahmand@sonoma.edu; joeljr@ieee.org

***Abstract* - Vehicular Delay-Tolerant Networks (VDTNs) are a promising technology for vehicular communications, creating application scenarios that enable non-real time services with diverse performance requirements. Because of scarce network resources (e.g. bandwidth and storage capacity) and node's short contact durations, the underlying VDTN network infrastructure must be capable of prioritizing traffic. This paper investigates several scheduling and drop policies, which can be used to implement traffic differentiation. Priority Greedy, Round Robin, and Time Threshold scheduling polices are proposed. In terms of drop policy, the message with the lowest priority and the lowest remaining time-to-live is discarded first. We evaluate their efficiency and tradeoffs, through simulation. The results presented in this paper can be used as a starting point for further studies in this research field, and give helpful guidelines for future VDTN protocol design.**

1. INTRODUCTION

Vehicular Delay-Tolerant Networking (VDTN) is a Delay-Tolerant Network (DTN) [1] based architecture concept for transit networks, where the movement of vehicles and their message relaying service is used to enable network connectivity under unreliable conditions. VDTNs are characterized by high node mobility. In conjunction with energy constraints, finite bandwidth, short radio transmission ranges or obstructed radio links, VDTNs result in intermittent connectivity and short contact duration times.

To cope with disconnection, the store-carry-and-forward paradigm is used. VDTN network nodes store messages on their buffers, while waiting for opportunities to forward messages to intermediate nodes or to the final destination. In order to improve message delivery probability, and minimize the message delivery delay, routing protocols may replicate messages along various network nodes.

Figure 1 shows an example of a VDTN in an urban scenario. *Mobile nodes* (e.g., vehicles) physically carry data (messages), exchanging data with one another. *Stationary relay nodes* are fixed devices located at road intersections, with store-and-forward capabilities. They allow *mobile nodes* passing by to pickup and deposit data on them, thus increasing the number of contact opportunities and improving the message delivery ratio [2-4].

VDTNs have several potential application scenarios, such as, traffic condition monitoring, collision avoidance, emergency message dissemination, free parking spots information, advertisements, and, for example, to gather data collected by vehicles like road pavement defects [5-7].

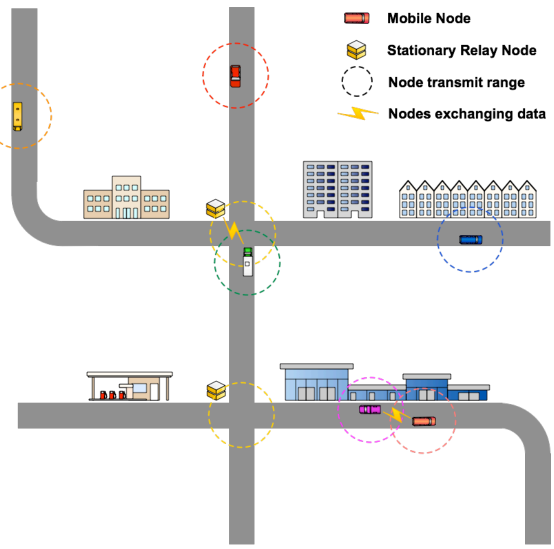

Figure 1 – Example of a vehicular delay-tolerant network in an urban scenario.

One can envision an urban scenario with opportunistic connectivity, where a VDTN can support several asynchronous applications simultaneously. Each application can generate traffic with different requirements in terms of message delivery probability and message average delay. For example, emergency alerts should be handled with more priority than advertisements data. Such a scenario motivates the need to introduce support for traffic priorities, and appropriate scheduling and drop mechanisms to support different classes of service (CoS). In this sense, the paper evaluates the impact of enforcing distinct scheduling and drop message prioritization policies on the Spray and Wait DTN routing protocol [8], applied to VDTN networks. Spray and Wait creates a number of copies N to be transmitted ("sprayed") per message (assuming 12, in this study). In its binary variant (considered in this work), any node *A* that has more than 1 message copies and encounters any other node *B* that doesn't have a copy, forwards to *B N/2* message copies and keeps the rest of the messages. A node with 1 copy left, only forwards it to the final destination.

The remainder of the paper is organized as follows. Section 2 identifies the problem and describes the proposed approach. Section 3 discusses the performance evaluation of scheduling and drop policies for traffic differentiation on VDTNs. Finally, Section 4 concludes the paper and presents further research directions.

2. SCHEDULING AND DROP POLICIES

To support different types of applications with distinct performance requirements it is needed to provide differentiated classes of service for VDTN traffic. Therefore, it is necessary to provide a way to specify the relative priority of messages exchanged in a VDTN. At the same time, it is also required to enforce scheduling and drop policies that implement traffic prioritization across all network nodes.

We consider a VDTN priority scheme based on the similar concept proposed for the DTN architecture [1]. Thus, we assume three priority classes of traffic: *bulk*, *normal* and *expedited*. *Bulk* messages have the lowest priority, and are sent on a least effort basis. *Normal* messages are sent prior to *bulk* messages. *Expedited* messages (bundles) have the higher priority and are sent prior to any messages from other priority classes. Network applications mark network messages based on their requirements.

Figure 2 shows a general diagram illustrating how VDTN traffic can be differentiated at a given network node. Using an indexing system, incoming messages are indexed based on their priority class. Preference is given to high priority classes, which means that in cases of buffer overflow, *bulk* messages (bundles) are discarded first. The buffer space occupied by these messages is saved for higher priority ones (*normal* and *expedited* messages).

Traffic differentiation scheduling policies can use the indexing system to determine outgoing message order. In this work we propose the following scheduling policies for VDTNs: Priority Greedy, Round Robin, and Time Threshold.

Priority Greedy (PG) scheduling policy strictly complies with the priority class sequence from high (*expedited*) to low (*bulk*). At a contact opportunity, higher priority class messages are always scheduled ahead of lower priority class messages. Hence, higher priority messages have the ability to monopolize the network resources (e.g. bandwidth and storage), and lower priority messages may be severely delayed. These messages may also be dropped in scenarios with limited network resources and short contact duration times.

In order to prevent starvation and assure that all priority classes have an equal opportunity to dispatch their messages, a Round Robin (RR) scheduling policy may be considered. This policy scans priority class indexes in a circular order, serving one message from each class that has a non-empty index.

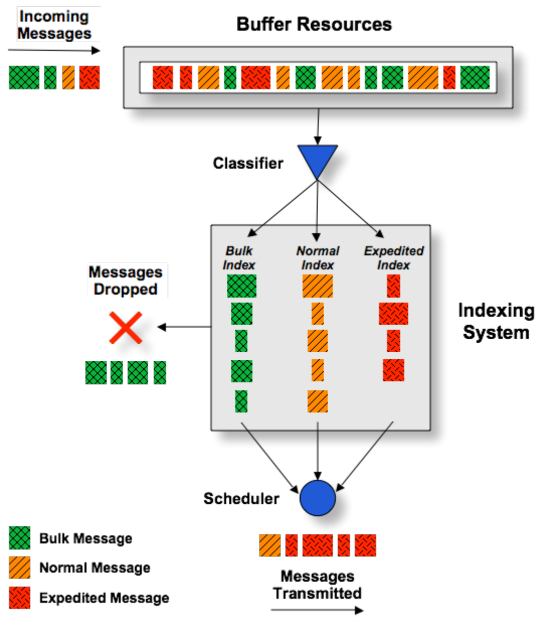

Figure 2 – Indexing System for traffic differentiation.

Time Threshold (TT) scheduling policy orders messages to be forwarded at a contact opportunity using a double criterion, the priority class of each message and their corresponding remaining time-to-live (TTL). This policy also gives preference to *expedited* messages. However, it takes into account the fact that messages with low remaining TTLs, have less time left to reach destination before expiring. Therefore, for instance, it can be preferable to schedule a *normal* message first with a large remaining TTL, instead of an *expedited* message who's TTL will expire soon. When ordering messages to be forwarded, this scheduling policy follows priority class sequence from high to low. But, at each priority class, it only selects messages whose remaining TTL is greater than a predefined threshold. The remaining messages will be scheduled to be sent afterwards.

In a previous work [9], we studied the effect of scheduling and dropping policies to reduce the messages delivery delay in a VDTN. We concluded that scheduling messages with longer remaining TTLs to be sent first, decreases the message average delay significantly and increases the overall message delivery probability. Based on those results, in this paper, for each of the above-mentioned scheduling policies, we evaluate the effect of sorting the priority class index entries based on messages' arrival time (to the node's buffer) or on messages' remaining lifetimes (TTL).

The indexing system (Figure 2) is also used to determine which messages should be dropped when buffer overflow occurs. The criterion is to discard the message with the lowest priority and the lowest remaining TTL first.

The main contribution of this paper is the performance evaluation and comparison of the above-described policies. They are enforced on the DTN routing protocol Spray and Wait, applied to a VDTN.

3. PERFORMANCE EVALUATION

This section evaluates the impact of the above-described scheduling and drop policies on the performance of a VDTN network with traffic priorities. For this purpose, a simulation study using the Opportunistic Network Environment (ONE) Simulator [10] has been executed. We created a set of extensions for the ONE simulator to support traffic priorities, and scheduling and drop policies for traffic differentiation. Next subsections present the simulation setup and results analysis.

3.1 Simulation Setup

In order to evaluate scenarios close to the reality, we use a real world map-based model of part of the Helsinki downtown area, with a dimension of 4500×3400 meters (Figure 3). We consider 40 vehicles (mobile nodes) moving across map roads, with random speeds between 30 and 50km/h. When a vehicle arrives at a destination, it randomly waits from 5 to 15 minutes, before departing to a new random map location. Each vehicle has a 100 Mbytes message buffer.

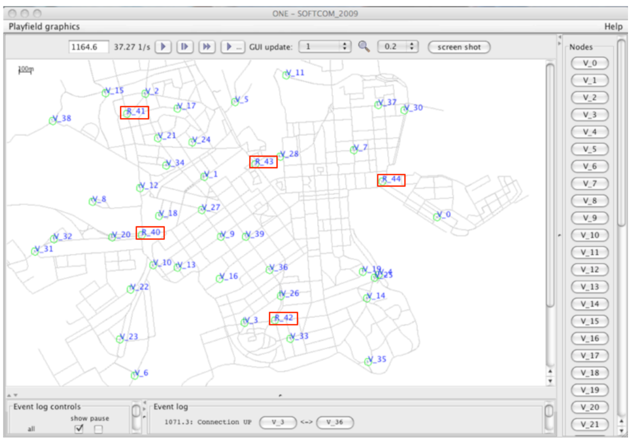

Figure 3 – ONE Simulator running the simulation scenario (vehicles (V) and relay nodes (R)).

Five stationary relay nodes are placed at the road intersections, shown in Figure 3. Each one has a 500 Mbytes message buffer size. Messages (bundles) have random source and destination vehicles, and a time-to-live (TTL) of 60 minutes. Their size is uniformly distributed in the range of [500 K, 1 M] (Bytes). Messages are deleted from buffers when their TTL expires or congestion occurs. When a message is successfully delivered to its final destination, it is discarded from the sender node's buffer.

We use three message event generators, one for each priority class of traffic. This allows us to create different scenarios where we change the volume of network traffic generated for each priority class. Table 1 summarizes the inter-message creation interval ranges (uniformly distributed) for each priority class of traffic, in the three scenarios studied in this work.

	Traffic Priority Class		
	Bulk	**Normal**	**Expedited**
Scenario 1	[15, 30]	[15, 30]	[15, 30]
Scenario 2	[15, 30]	[15, 30]	[30, 60]
Scenario 3	[30, 60]	[30, 60]	[15, 30]

Table 1 - Inter-message creation intervals (seconds).

We are interested to evaluate the message delivery probability (measured as the relation of the number of unique delivered messages to the number of messages sent). This performance metric is registered for each priority class of traffic, when the different scheduling and drop policies are enforced in each scenario.

We simulate the creation and messages exchange during a period of 12 hours (e.g., from 8:00 to 20:00). Network nodes connect to each other using IEEE 802.11b with a data rate of 6 Mbit/s and a transmission range of 30 meters, using omni-directional antennas. For each result, we run a batch with 30 simulations for each combination of parameters, using different random seeds, and report the mean values.

3.2 Results Analysis

We start results analysis with the case where network traffic is generated at the same rate for each priority class (Scenario 1). As expected, Figure 4 shows that Priority Greedy policy presents results with the greatest differences between the delivery ratios for each priority class. This behavior occurs because this policy schedules all the messages with high priority (*expedited* messages) to be forwarded first.

Round Robin scheduling policy, serves the priority classes equally. Therefore, one could expect to see approximately the same values of delivery probability for each of the priority classes. However, the drop policy discards lower priority messages first. Hence, network nodes will store, carry, forward and deliver more *normal* and *expedited* messages.

Regarding the Time Threshold policy, we consider two threshold values: 0.25 and 0.5. This means that when messages are ordered to be sent, this policy goes through each priority class and schedules the messages whose remaining TTL is greater than 25% or 50% of the message's initial TTL (60 minutes) first. For example, with threshold equal to 0.25, it means that it will schedule messages with remaining TTL greater than 15 minutes – corresponding to 25% of 60 minutes (initial message's TTL). As previously explained, the motivation for this policy comes from the fact that Priority Greedy can neglect all lower priority messages, preferring to transmit higher priority ones, even though their TTL can expire soon, and may not be enough for those messages to arrive at their destination.

Time Threshold approach also prefers to send *expedited* messages first, but gives an opportunity for *normal* and *bulk* messages to be propagated in the network. Therefore, we can observe that when Time Threshold 0.25 was enforced, *bulk* messages delivery ratio increased 2%, and for *normal* messages 3%, when compared to the ones observed in Priority Greedy. These differences increase when the time threshold is 0.5, to 5% and 6% respectively. However, the expedited messages delivery ratio decreased 3%.

Figure 4 also allows us to conclude about the importance of sorting the indexes of priority classes based on the messages' remaining TTL. We define this process as the creation time (CT). By doing that, messages with longer remaining TTLs (at each priority class) will be scheduled for being sent first. This increases their probability to be relayed more times between network nodes. Thus, it contributes to increase the delivery ratio across all priority classes, when compared to the case where priority class indexes are sorted based on the messages arrival time (RT) to the node's buffer. This process is identified by receive time (RT). As may be seen in this Figure 4, Priority Greedy increases the *expedited* messages delivery ratio in 5%, and 2% for *normal* messages.

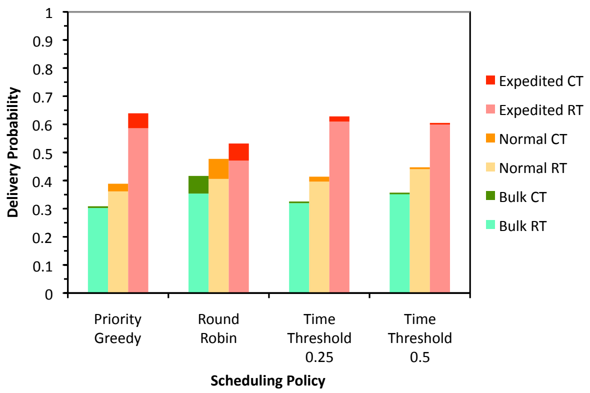

Figure 4 – Message delivery probability in Scenario 1.

In the second scenario (Scenario 2), the volume of traffic of *expedited* messages is decreased. This will cause less contention for network resources and network nodes will be able to store more *normal* and *bulk* messages on their buffers. Therefore, more messages are successfully delivered in all priority classes (shown in Figure 5).

Notice that all scheduling policies increase significantly the delivery ratio of *bulk* messages, especially in the case of *normal* messages (when compared to the first scenario – Figure 4). Like in the previous scenario, as may be observed in Figure 5, when Time Threshold is equal to 0.25, it increases the delivery ratio of *bulk* and *normal* messages (CT) in 3% and 4%, respectively, when compared to Priority Greedy. At the same time, it maintains approximately the same delivery probability for *expedited* messages.

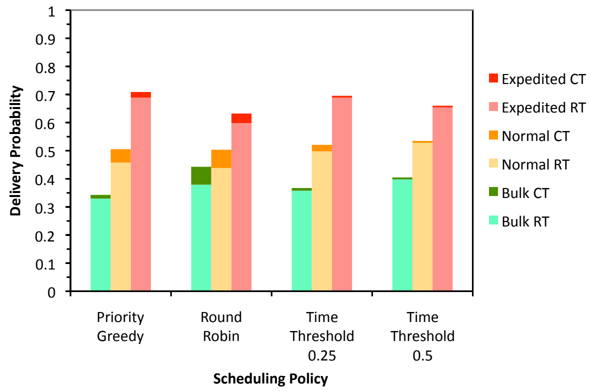

Figure 5 – Message delivery probability in Scenario 2.

In the third scenario, *expedited* messages are generated at the same rate as in the first scenario, while the traffic volume of *normal* and *bulk* messages is decreased. Interestingly, as may be seen in Figure 6, *expedited* messages delivery ratio increases across all scheduling policies, when compared to the first scenario. This effect is caused by the reduction of the network traffic load, which results in less contention for bandwidth and storage resources. Round Robin results confirm this observation. Similar to the previous scenarios, we observe that Time Threshold performs better with a threshold value equal to 0.25.

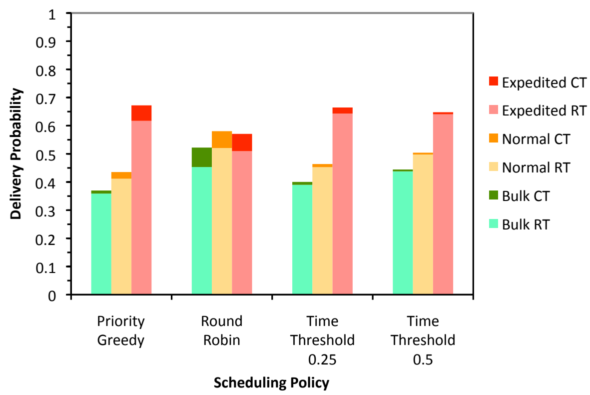

Figure 6 – Message delivery probability in Scenario 3.

Through all the three studied scenarios, it was observed that Time Threshold is the only scheduling policy that does not take significant advantage of sorting the indexes of the priority classes' messages based on the remaining messages' lifetimes. This is due to this algorithm that implicitly gives preference to messages with larger remaining TTLs.

4. CONCLUSIONS AND FUTURE WORK

In Vehicular Delay-Tolerant Networks, traffic prioritization can be used to achieve differentiation when network resources (e.g. bandwidth and buffer) are scarce, and contact durations between network nodes are short. This paper focused on performance evaluation of different scheduling and drop policies to implement traffic differentiation in VDTNs. Priority Greedy, Round Robin, and Time Threshold scheduling polices were proposed. In terms of drop policy, the message with the lowest priority and the lowest remaining TTL is discarded first. In order to compare the efficiency of these policies, an opportunistic network environment was considered, and three different simulated scenarios were studied. Each scenario had different traffic loads for each priority class.

This work intends to provide a starting point for further studies on other scheduling and drop priority-based policies. For instance, if the duration of a contact between two network nodes could be previously determined or predicted, a scheduling policy could assign different proportions on occupying link bandwidth for the priority classes. By this way, each priority class would be served and transmit a correspondent volume of data.

It would also be important to extend this study to scenarios with more constrained network resources, changing the frequency and duration of contact opportunities. The performance of scheduling mechanisms should also be analyzed under scenarios with vast geographical areas (rural connectivity) and low network nodes density.

Introducing VDTN "quality of service" routing capabilities and studying its effect over the traffic performance and the network utilization, is also one of our interests for future work.

ACKNOWLEDGMENTS

Part of this work has been supported by *Instituto de Telecomunicações*, Next Generation Networks and Applications Group (NetGNA), Portugal, in the framework of the Project VDTN@Lab, and by the Euro-NF Network of Excellence of the Seventh Framework Programme of EU.

REFERENCES

[1] V. Cerf, S. Burleigh, A. Hooke, L. Torgerson, R. Durst, K. Scott, K. Fall, and H. Weiss, "Delay-Tolerant Networking Architecture," RFC 4838, April 2007, [Online]. Available: ftp://ftp.rfc-editor.org/in-notes/rfc4838.txt.

[2] N. Banerjee, M. D. Corner, D. Towsley, and B. N. Levine, "Relays, Base Stations, and Meshes: Enhancing Mobile Networks with Infrastructure," in *14th ACM International Conference on Mobile Computing and Networking (ACM MobiCom)*, San Francisco, California, USA, September, 2008, pp. 81-91.

[3] V. N. G. J. Soares, F. Farahmand, and J. J. P. C. Rodrigues, "Improving Vehicular Delay-Tolerant Network Performance with Relay Nodes," in *5th Euro-NGI Conference on Next Generation Internet Networks (NGI 2009)*, Aveiro, Portugal, July 1-3, 2009.

[4] W. Zhao, Y. Chen, M. Ammar, M. Corner, B. Levine, and E. Zegura, "Capacity Enhancement using Throwboxes in DTNs," in *IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS) 2006*, 2006.

[5] R. Tatchikou, S. Biswas, and F. Dion, "Cooperative Vehicle Collision Avoidance using Inter-vehicle Packet Forwarding," in *IEEE Global Telecommunications Conference (IEEE GLOBECOM 2005)*, St. Louis, MO, USA, 28 Nov. - 2 Dec., 2005.

[6] O. Brickley, C. Shen, M. Klepal, A. Tabatabaei, and D. Pesch, "A Data Dissemination Strategy for Cooperative Vehicular Systems," in *Vehicular Technology Conf. 2007 (VTC2007)*, Dublin, 2007, pp. 2501-2505.

[7] L. Franck and F. Gil-Castineira, "Using Delay Tolerant Networks for Car2Car Communications," in *IEEE International Symposium on Industrial Electronics 2007 (ISIE 2007)*, Vigo, Spain, 4-7 June, 2007, pp. 2573-2578.

[8] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Spray and Wait: An Efficient Routing Scheme for Intermittently Connected Mobile Networks," in *ACM SIGCOMM 2005 - Workshop on Delay Tolerant Networking and Related Networks (WDTN-05)*, Philadelphia, PA, USA, August 22-26, 2005.

[9] V. N. G. J. Soares, J. J. P. C. Rodrigues, P. S. Ferreira, and A. Nogueira, "Improvement of Messages Delivery Time on Vehicular Delay-Tolerant Networks," in *The 38th International Conference on Parallel Processing (ICPP-2009) Workshops - The Second International Workshop on Next Generation of Wireless and Mobile Networks (NGWMN-09)*, Vienna, Austria, September 22-25, 2009.

[10] A. Keränen, J. Ott, and T. Kärkkäinen, "The ONE Simulator for DTN Protocol Evaluation," in *SIMUTools'09: 2nd International Conference on Simulation Tools and Techniques*, Rome, March 2-6, 2009.