

Multicast Routing Protocol for Vehicular Delay-Tolerant Networks

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Abstract— Disruptions, high dynamism and no end-to-end communication are some of the Vehicular Delay-Tolerant Networks (VDTNs) main characteristics. This paper describes the implementation of a new VDTN multicast routing protocol which makes use of knowledge about previous encounters to estimate congestion and density and better spread data bundles and limit the number of copies to reduce overhead.

After a brief introduction to Delay-Tolerant Networks, VDTNs, and protocols, the new multicast routing protocol, named NewVDTN, is described. It will be compared against Epidemic Multicast. The protocols were implemented and tested on The Opportunistic Network Environment simulator, concluding that NewVDTN shows a similar or better delivery ratio and delay with an enormous reduction of overhead, as compared with Epidemic Multicast.

Index Terms— Vehicular Delay-Tolerant Network, Multicast, Routing Protocol, NewVDTN, Scheduling and Dropping Policies.

I. INTRODUCTION

Nowadays, most communication networks assume end-to-end connectivity. On the other hand, there are networks with substantial delays on data transmission. The lack of path from the sources to the final data destinations is the main cause of these long delays experienced by this kind of networks. In the open literature these networks are known as Intermittently Connected Networks (ICNs), which include spatial networks, wireless sensor networks and mobile ad-hoc networks. These networks may be characterized by sparse and intermittent connectivity, long and variable delay, high latency, high error rates, highly asymmetric data rate, and even no end-to-end connectivity. A new paradigm known as Delay-Tolerant Networking (DTNs) was proposed to address these issues.

A new layer called Bundle Layer transforms the application data units into Protocol Data Units (PDUs) called bundles, which are forwarded by DTN nodes according to the Bundle Protocol [1]. It is intended to “bundle” together all the information required for a transaction, minimizing the Round-trip exchanges, which is useful when the round-trip times (RTTs) can be very large, like in DTNs [3].

VDTNs are DTNs that include vehicles and stationary nodes, which can act like relay nodes (traffic lights, gas stations, vertical traffic signals, and others). Vehicle movement may be exploited to carry data from a place to another.

Routing packets is a big challenge. Due to the movement of vehicles, these networks are very dynamic. The contact

possibilities, frequency and time are inconstant, depending on the vehicle density. In rural areas, vehicle density is very low, which makes node contact unusual. In addition, the contact time for data transmissions is short. On the other hand, in a city scenario, there is a high vehicle density, resulting in a much superior node contact frequency which allows better success possibilities and efficiency on data messages delivery.

Therefore, the used method for data packets transfer is the store-carry-and-forward approach, which consists on storing bundles in node buffers, carrying them until the detection of a destination node or a node whose movement suggests a future encounter with a destination node and, at last, forwarding, which is the delivery of the bundle.

Besides the routing challenge, VDTNs have several undefined aspects: storage capacity, transmission range, buffer management and others. Applications such as traffic condition notifications, gathering information about road pavement conditions or battle field information dissemination between soldiers can be implemented by these networks. There are numerous important applications that can be based on VDTNs. Applications that can be useful for users’ support or even vital for their survival.

These kinds of applications require a certain strategy type in order to deliver data messages, most of the times to groups of users. Multicast Routing is a method that allows the data transmission to a specific group of users. Most existing communication protocols do not support multicast groups where the changes of group members are frequent, so it is necessary to find an efficient solution to solve the problematic of multicast groups, and so, support the VDTNs high dynamism.

The next section presents some of the existing multicast and unicast routing models for DTNs, as well as a brief description of these types of networks. The third section explains in detail the new multicast routing protocol proposed, called NewVDTN, and the protocol implementation made in the ONE simulator. Features like dynamic message copy limitations, carefully selection of vehicles where to forward bundles, as well as methods to estimate network density and congestion have a positive impact regarding the new protocol’s performance. A time to live (TTL) assignment which considers the created message priority, as well as the scenario type (sparse or dense), together with the implemented dropping and scheduling policies, ensures a correct order of the individual

delivery rates for each message priority. These aspects are verified on section four, where the simulation results are analyzed and discussed.

II. STATE OF THE ART

A. Vehicular Delay-Tolerant Networks - VDTNs

The VDTN concept accepts sparse networks with low contact frequency and high dynamism through the store-carry-and-forward paradigm [3].

Some of VANETs and VDTNs characteristics are the fact that sometimes it is possible to predict the vehicle movement since it is constrained to roads and some vehicles have well defined routes. Also, because of vehicles constant movement, the network topology frequently presents changes in short periods of time. All vehicles can be considered as potential nodes with a wireless car-to-car network mechanism with a maximum hop range of 1000m (WAVE (Wireless Access for the Vehicular Environment) systems, IEEE 802.11p), limiting the communication range between the network vehicles.

Among the network nodes, we have two new node types, MULE (Mobile Ubiquitous LAN Extensions) nodes and stationary relay nodes. These nodes intend to increase the network communication opportunities. MULEs are mobile nodes that pick up data in one place and deliver it in another, functioning as simple transportation. On the other hand, relay nodes are stationary nodes with store-and-forward capabilities located on road intersections. Both node types will increase bundle delivery ratio as well as decrease the delay.

B. Unicast Routing

The Bundle protocol does not define any method to establish routes to transmit the messages inside the network, so, it is necessary to adopt a routing mechanism to lead the bundles hop-by-hop according to the store-carry-and-forward approach used in VDTNs. We can distinguish two categories of unicast routing methods, the knowledge-based routing and the probabilistic-based routing [5]. As we know, VDTNs are very dynamic networks, and so, the knowledge-based routing is difficult to implement as it requires a certain type of previous knowledge about the network, like network connectivity patterns, source and destination nodes' geographical locations or even node movements schedules. With this kind of knowledge, the routing decisions can be made using Dijkstra's algorithms or similar. Therefore, some of probabilistic-based routing approaches will be described next. These methods do not need any previous knowledge about the network. The routing is based on local information. An estimation of the probability that the contacted node has to deliver the messages to the destination is made. This estimation method is what differs among the several routing approaches [1].

- **Epidemic** – Replicates the messages to all contacted nodes that do not have them yet. Comparing to other solutions it wastes too much storage space and bandwidth. It is one of the simplest cases to perform multicast routing.
- **Spray-and-Wait** – The source generates 'n' copies of a

message. On 'normal' mode, the source transfers a single copy to the first 'n-1' distinct contacted nodes; the 'binary' mode consists on the forwarding of 'n/2' message copies to each distinct contacted node until there is only one copy left on the node, which will only be forwarded to a final destination.

- **PROPHET** – Transfers a message only if it estimates that the contacted node has higher chances to deliver the message to the final destination. The estimation is made based on past encounters.

Other more complex approaches that deal with sparse and disruptive networks are the protocols VADD (Vehicle-Assisted Data Delivery), SADV (an extension of VADD), D-MinCost, D-Greedy and PROMPT. A survey about these methods can be found in [4].

Another important solution is Geographic-based routing that makes the decisions based on nodes' location. Each vehicle has knowledge about its location using a localization system like GPS (Global Positioning System). These locations, just like the destination node location, are obtained by periodic beacon messages exchanged between nodes. Then, the routing decisions are made according to the greedy method: the closest node to the destination is selected as next hop [4][8].

C. Multicast Routing

Due to the short data transfer delay on the Internet or on MANETs, it is assumed that multicast members do not or rarely change during transfer situations. As so, the multicast data packets receptors are well defined. On the other hand, DTNs experience long connection delays and disruptions, resulting in frequent changes on multicast group members.

Therefore, it is necessary to define new multicast models as a solution to this kind of problems. Some of the existing multicast routing solutions for DTNs are [2]:

- **Unicast-based routing (UBR)** – The source sends an independent bundle copy to each receptor that wants to receive that message. The source must have knowledge about all group members.
- **Broadcast-based routing (BBR)** – Also called epidemic routing. The network is flooded by messages until they eventually get to their receptors. This method does not need any knowledge about the group members.
- **Tree-based routing (TBR)** – Defines a graph (tree) of the DTN in which the root is the source node. This model has two versions: the Static-Tree-based routing (STBR) which maintains the same initial tree during the entire multicast session; and the Dynamic-Tree-based routing (DTBR) where each bundle has a tree associated. Due to the DTN's connection variations each tree may change on each route hop. This method adapts on a certain way to the network dynamics but it will create an overhead regarding each tree update.
- **Group-based routing (GBR)** – Uses a forwarding group concept. A forwarding tree to reach all receivers and a forwarding group with nodes in the forwarding tree, including the receivers, are settled. Messages are flooded

to the forwarding group to increase the delivery ratios, and then forwarded along the tree to the destinations.

D. The ONE Simulator

The Opportunistic Network Environment (The ONE) [6][7] JAVA based simulator was used for the routing protocols implementation and tests. This simulator uses the Helsinki city map and allows node movement modeling, inter-node contact using several interfaces, routing, message processing and application interaction. The simulation scenarios consist of several nodes with different defined capabilities. Each node has a set of basic capabilities: radio interface, persistent storage, movement pattern, power consumption, message routing, and application interactions. Complex capabilities as the movement or routing are configurable by specific modules, which implement particular behaviors for these capabilities. On each node, the modules have access to simulation parameters and state, like the position, movement and current neighbors. These factors make the geographic routing implementation possible. The node connectivity is based on localization, communication range and bit-rate. The results collecting and processing is made through visualization, reports and post-processing tools.

Three synthetic movement models are available: random movement; map-constrained random movement and; human behavior based movement.

Routing is implemented by the routing modules that decide which messages will be forward according to the existing contacts. A framework is included for defining the algorithms and rules used for routing. The simulator comes with 6 well known DTN routing protocols: Direct Delivery; First Contact; Spray-and-Wait; PRoPHET; MaxProp and Epidemic [6], but only supports unicast.

III. THE NEW MULTICAST ROUTING PROTOCOL

A. NewVDTN Multicast Routing Protocol

The implemented multicast routing protocol, named NewVDTN, is based on Geographic-based routing and has features and methodologies based on the PRoPHET and Spray-and-Wait protocols.

There are two main kinds of scenarios based on vehicle density: dense scenarios, characteristic of cities where the vehicle density is high; and sparse scenarios, as in rural areas where vehicle density is low. Due to the low density of sparse scenarios, the objective is to forward messages to as many vehicles as possible, in order to get better deliver possibilities to final destinations. For, dense scenarios, a careful selection of MULE nodes is made, considering aspects such as their movement directions and the network general storage level estimation, to reduce congestion. The messages' priority is also considered in both scenarios.

Table 1 shows some multicast groups in a real life scenario.

Associated with each bundle are: a destination address that can be a multicast group, distance range, TTL, priority (High, Normal or Low), maximum number of hops and maximum number of MULE nodes. TTL is defined regarding the

information type and is adapted to the messages' priority when a dense scenario is detected. In dense scenarios, according to high, normal or low priority, the assigned TTL will be twice, the same or half of the default TTL. When a node wants to receive information of some multicast group, the group registration is made by the Application layer that informs the Bundle layer in which groups the applications are interested. The messages' maximum range is computed according to the information type. Information about a certain scenario zone does not need to be propagated outside that zone. This range limitation can be controlled using vehicles' GPS system, bundles' TTL and maximum number of hops. By using the GPS, the messages sources' locations are saved in the created bundles. When a bundle TTL expires or the maximum range is passed, the bundle is dropped. When the maximum number of hops is reached, the message is no longer forwarded to a node that is not a final destination. The maximum number of message copies will limit the number of MULEs used for message routing. The higher the bundle priority, the higher the number of used MULEs. This parameter varies according to the network vehicle density.

Table 1 – Examples of multicast groups and characteristics.

Information type	Multi cast group	Range	Hop limit	TTL	Priority	max MULEs
Gas prices	A	2000m	8	24h	Normal	16
Traffic changes	B	2000m	10	30 min	High	20
Car crashes	C	2500m	10	20 min	High	20
Restaurants	D	2000m	5	24h	Low	5

Each network node maintains some information that helps message routing. The network node density is estimated by each node using an Exponentially Weighted Moving Average (EWMA) that assigns an importance/weight to each network node. The following formula is used to compute an average estimate of the contacted vehicles per period of time.

$$Sc_1 = 0$$

$$For t > 1, \quad Sc_t = \alpha \times Y_{t-1} + (1 - \alpha) \times Sc_{t-1} \quad (1)$$

Each 60 seconds, the node updates the estimate. 'Y' represents the number of contacted nodes verified within that period of time. 'Sc' is the importance/weight of the node and indicates the contacted vehicle density along the nodes' path. The coefficient 'α' is a constant value between 0 and 1, representing the degree of weighting decrease. The higher the value, the faster the older observations are depreciated. Nodes with largest estimation (importance/weight) are the ones with more contacted nodes per period of time and therefore, have better possibilities of contact with final destination nodes. During contacts, the list of contacts is sorted according to each contact importance. Thus, preference of message transmission is given to the nodes with better estimations and therefore, better possibilities of encounters.

The network general storage level is estimated in a similar way. Instead of the number of contacted nodes, the formula is updated regarding the occupied buffer space on each contacted node represented by 'Y' in this case. Each time a node is contacted, the estimate 'Sbuff' is updated with the occupied buffer space of the contacted node. This estimate about the network level of occupied buffer space is important to decide which bundles are forwarded and consequently, to the routing.

In order to make a careful choice of MULE nodes, the direction of movement is calculated based on the following formula:

$$Dir = atan2(lon_2 - lon_1, lat_2 - lat_1) \quad (2)$$

Where $atan2(x,y)$ is the arctangent of 'y/x' with the capacity of deciding (based on 'x' and 'y' signals) to which quadrant the angle belongs. lon_1 and lat_1 are the longitude and latitude of the older node coordinates and lon_2 and lat_2 correspond to the current coordinates.

Three buffer types are used for messages storing: The first for incoming messages; the second for messages that the node received as a final destination; and the third for messages carried by the node.

Each time nodes establish contact there is an information exchange, as follows:

1. Both nodes exchange information about the multicast groups of the carried messages, movement direction and buffer occupation.
2. Each node informs the other about the registered multicast groups. It is possible that a node is not interested in any multicast group bundles carried by the other node.
3. The message bundles are forwarded between nodes. If any information was requested and the contacted node has enough buffer space to receive bundles, the movement direction is checked to see if the node is a good MULE option. If so, the bundles are sent ordered according to several factors and the node is considered a MULE.

The message transfer can be made according to several approaches and sorting methods. The scheduling and dropping methods are of great importance to the routing protocol performance. There are two cases of message transfer:

- I. A node carries bundles for the contacted node multicast groups.
 - All the bundles in which the destination multicast address corresponds to any multicast group address of the contacted node are forwarded.
- II. A contacted node has enough buffer space to store more bundles or if it makes it available by dropping some messages, it can be chosen as a MULE according to the following evaluation:
 - Estimated vehicle density – For both sparse and dense scenarios, messages are forwarded to other contacts according to a list of contacted nodes sorted by the estimated vehicle density of those nodes.
 - Movement direction – For dense scenarios, the direction of the contacted node movement must be different from the node that carries the bundles in at least 45°, to better

spread bundles in different directions with reduced overhead. For sparse scenarios this aspect is not verified because the intention is to forward messages to the largest number of nodes possible.

- General level of occupied buffer storage – A high level means a large number of messages inside the network, so only messages with high priority are sent. Therefore the network is not overloaded with messages of lower importance. If the level is low, the lower priority messages are also transmitted. This estimate is evaluated according to certain thresholds and is only used in the scheduling policy for dense scenarios.
- After the previous factors evaluation, scheduling is made according to one of several approaches:
 - Random: Used on Epidemic Multicast. The messages are sent in random order.
 - Absolute Priority: Messages are transferred according to their priority. First high priority, then normal and low priorities.
 - TTL: Bundles with higher TTL are transferred first because they have higher probabilities of still getting to their final destinations.
 - Weighted Fair Queuing (WFQ): Transmissions are made according to proportions assigned to each priority class (method detailed in section C)
 - Absolute priority and TTL combination.

The number of MULE nodes is conditioned by the number of message copies created inside the network. This method is similar to the one used on the Spray-and-Wait protocol. The number of message copies is determined according to the message priority and the estimated vehicle density on the source node. Sparse scenarios will have more MULEs than dense scenarios. The following formulas are used:

$$P = 0.4, \text{ for low priority}$$

$$P = 0.6, \text{ for normal priority}$$

$$P = 0.8, \text{ for high priority}$$

$$mules_t = round\left(\frac{P}{Sc_t} \times \beta\right), \text{ if } Sc_t < 1 \text{ then } mules_t = 16 \quad (3)$$

'Sc' is the estimated vehicle density at source node. If this density is less than one, a fixed value of 16 MULEs is adopted for all scenarios. The number of MULEs is computed according to the priority, 'P', of the message to be created. Parameter 'β' is an adaptive variable that will vary according to the scenario type. It will be 100 for dense scenarios and 50 for sparse. In order to reduce bundle routing delay, it is better to use a larger number of MULE nodes in sparse scenarios, where vehicle density is low. In dense scenarios, there is no need to use such a high number of MULEs because the probabilities of vehicle encounters are higher.

All the tests and implementation were made in The ONE simulator. In order to compare the new multicast routing protocol, NewVDTN, an Epidemic Multicast routing protocol, named EpidemicMC, was implemented with the addition of maximum distance range control and the message priority and TTL, as for the NewVDTN protocol. Therefore, EpidemicMC

differs in a certain way from the usual Epidemic routing protocol. Several dropping and scheduling policies were also tested in order to achieve better performance.

B. Dropping Policies

When the buffer gets full, messages have to be removed in order to receive more messages. Therefore, the dropping policy used is an important aspect for routing improvement and better delivery ratios. The tested dropping policies on both routing protocols were the following:

- **First In First Out (FIFO):** The message dropping is made according to the oldest received message. The messages priorities are not considered.
- **Lower TTL:** The messages with lower TTL are dropped first. Preference is given to newer messages with better chances to get to their destinations.
- **Lower Priority and TTL:** The dropping is made according to the lower priority and TTL. There is a message sorting in the buffer to drop first the messages with lower TTL within the messages with lower priority.

C. Scheduling Policies

The scheduling policy will determine the order in which the messages are transferred. Therefore it is also an important aspect to protocol performance. Preference is given to messages with higher priority, and so the order in which the transmissions occur will in a certain way define that preference or importance for the messages with higher priority inside the network.

In the EpidemicMC protocol, the predefined Random scheduling policy of the ONE simulator is always used.

The NewVDTN protocol always makes, before the transmissions, a sorting of the contacted nodes list by vehicle density estimation, 'Sc'.

In dense scenarios, the messages are sent according to the contacted node buffer occupancy estimation, 'Sbuff'. If the occupancy is larger than 80%, it means that the network message flow is high and so only the messages with higher priority are transmitted. If the occupancy is between 60% and 80%, first the higher priority messages are sent and then the medium priority ones. Finally, if the occupancy is below 60%, all messages are sent, according to priority order.

In sparse scenarios, the intention is to send the largest number of messages to as many nodes as possible, using the better method possible. The buffer occupancy is not considered and messages are transmitted with a certain order defined according to the following scheduling methods:

- **Absolute Priority:** The message buffer is sorted by message priority.
- **Higher Priority and TTL:** The message buffer is sorted first by TTL and then by priority, thus the first sent messages are the ones with larger TTL and priority.
- **Weighted Fair Queuing (WFQ):** Messages are sorted according to a certain value assigned to each message by the following formula:

$$value = seq + priority \times bytes \quad (4)$$

'priority' is the message priority that can be 3, 2 or 1 according to high, normal and low priorities. 'bytes' is the message size and 'seq' is the receiving order of the message according to a certain priority class. If a message of a certain priority class is the first message found in the buffer, 'seq' is 0; for other messages, that parameter will be the value of 'value' assigned to the previous message of that priority.

The WFQ method is only used in sparse scenarios. Given the high vehicle density in dense scenarios, the general buffer occupancy of the contacted nodes is considered, and the messages are transmitted according to the higher priority and TTL. This method will give a certain preference to higher priority messages during network transmissions.

IV. RESULTS

A. Test Scenarios

Two scenario types will be used: a **sparse network with 24 nodes** (4 relays 'R', 16 cars 'V' and 4 buses 'B') and a **dense network with 80 nodes** (4 relay 'R', 60 cars 'V' and 16 buses 'B'). The idea is to test the protocols' performance in cases that are similar to a rural area where usually the vehicle density is low and a city where the traffic is dense.

All the network nodes have a GPS system installed and a WAVE IEEE 802.11p system (5.9GHz frequency band). Considering the signal attenuation, the WAVE system range is configured as 250m and the bitrate is 9Mbps. Naturally, this is a simplified model for the simulations. The Helsinki map dimensions are 4.5km of width and 3.4km of height. The different network nodes have the following configurations:

- **Cars:** - Map Based Movement as movement model.
 - Waiting time of 0 to 120 seconds after arriving to the destination.
 - Speed of 10 to 50 km/h.
- **Buses:** - Map Based Movement as movement model.
 - Waiting time of 10 to 30 seconds after arriving to the destination.
 - Speed of 10 to 40 km/h.
- **Relay:** - Static.

The buffer size will be adjusted during the tests. The size of the information carried by the bundles will vary according to the information type.

In Figure 1, the route (red) assigned to node 'V9' (blue point) can be seen as well as the several node contacts (black lines) between nodes. The figure represents the 24 node scenario where the relay nodes are located on the following map locations, presented in the map as orange points:

R20 – (1392 , 631)	R21 – (1220 , 1566)
R22 – (2488 , 1058)	R23 – (2279 , 1862)

The measured parameters during the simulations were the bundle delivery ratio, average latency, average number of hops and the generated overhead. The performance of both protocols was tested varying the number of network mobile nodes. The performance was tested using different message sizes and

several dropping and scheduling policies. On the following scenarios, a comparison will be made between the NewVDTN and EpidemicMC multicast routing protocols.

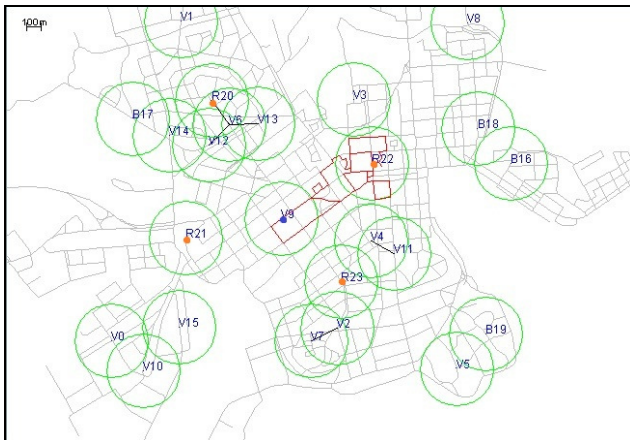


Figure 1 - Sparse scenario of 24 nodes

B. 24 Nodes Scenario

The 24 nodes scenario uses a 15000 seconds simulation with vehicles registered in the multicast groups and relay nodes not. A high message generation rate is used and the maximum number of hops and messages maximum distance range were implemented. Four sources were configured to generate new messages with sizes between 5 and 1000KB, at every 2-5 seconds, between time 1000 and 3000 seconds.

- Maximum number of hops defined as 10 for high, 8 for medium and 5 for low priority messages.
- Messages maximum distance range from source of 2000m or 2500m according to the multicast group.
- NewVDTN uses a predefined maximum number of MULEs of 16.
- Vehicles randomly registered in multicast groups remaining the same for each of the 10 simulations.
- Vehicles with 8MB of buffer size. Relay nodes with 50MB.
- NewVDTN uses $\alpha=0.6$ for the vehicle density and general buffer occupancy estimations.
- NewVDTNs dropping policy according to lower priority and TTL and WFQ scheduling.
- EpidemicMCs dropping policy according to lower priority and TTL. Random message scheduling.
- On both protocols, 10 simulations were averaged. The movement model used 10 movement seeds to generate the vehicles routes. A 95% confidence interval was computed for the mean values.

The average latency values presented by both protocols are very similar (Figure 2). NewVDTN uses less message copies than EpidemicMC, as less MULEs are used for message carrying. However it ensures similar or even better latency results. This means that the excessive EpidemicMC message overload becomes unnecessary when NewVDTN has similar performance.

Figure 3 shows that the NewVDTN protocol uses less hops for delivering messages than EpidemicMC, as expected. Due to

the epidemic nature of EpidemicMC, the messages exchange between nodes is higher and there is no control regarding to the number of copies. On the other hand, NewVDTN limits the number of messages copies and hops, so it is natural that the average number of hops is less than for EpidemicMC.

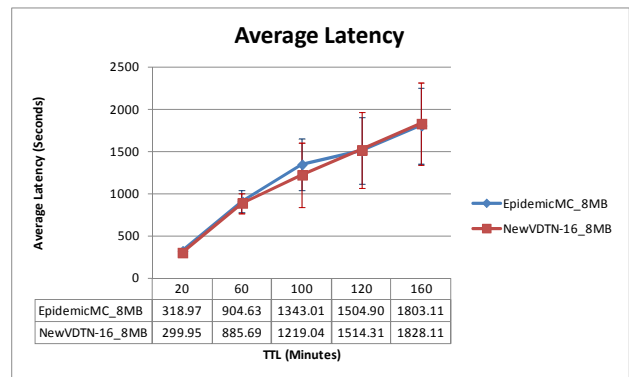


Figure 2 – Average latency of delivered messages.

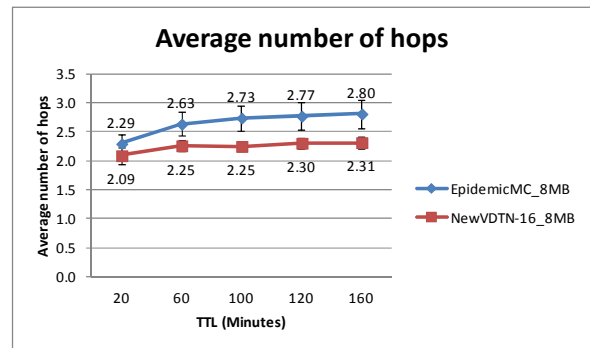


Figure 3 - Average number of hops used to deliver the messages.

The overhead (Figure 4) as in all tested scenarios is much higher for the EpidemicMC that disseminates a very high number of messages copies inside the network. The same message generation period for all sources forces higher message traffic and a larger number of transmissions. NewVDTN controls these transmissions by the message copies' limitation and so the overhead is extremely low as compared with EpidemicMC. This is one of the aspects that makes the new routing protocol better than EpidemicMC. As we can see, the NewVDTN overhead values decrease with the TTL increase. This may be connected with the fact that messages with lower TTL are removed more frequently and so it allows a larger number of message exchanges between nodes, increasing the overhead.

Using the WFQ scheduling method together with the implemented features, a better delivery ratio for the new routing protocol was achieved. This scheduling policy allows a better traffic division regarding the message priority classes (Figure 5, 6). The increase of the delivery ratio with the messages TTL is normal, because with higher TTL, messages have more time to find final destinations. The low delivery ratios of both protocols results from the high message generation rates which increases the network message traffic and in some occasions makes the source nodes drop a high number of messages to be able to keep creating new ones.

The dropping of messages with less priority and TTL makes possible a correct order of priority classes' delivery ratios. As shown in Figure 5, the EpidemicMC values are not so good as the ones for NewVDTN, in Figure 6. This is caused by the random delivery of messages and the high message overload created by the epidemic nature of the protocol.

Figure 6 shows the better delivery values of the NewVDTN resulting from the fair message buffer organization made by the WFQ scheduling policy for the transmissions. The dropping policy is the same as for EpidemicMC, so the graphs' characteristics are identical. The high confidence interval achieved shows that in this scenario with few nodes and using different movement seeds there is a high uncertainty of encounters, and so of final destination message deliveries.

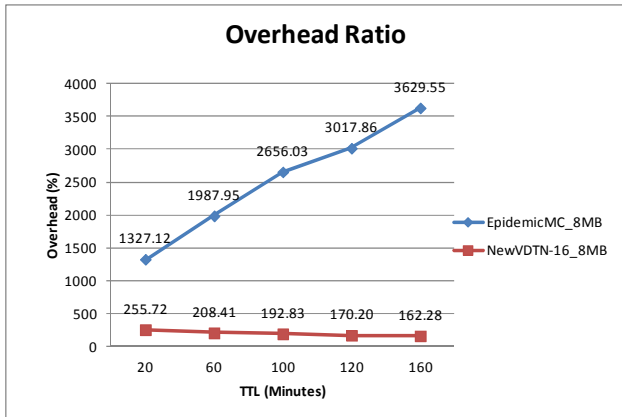


Figure 4 - Generated overhead by both protocols inside the network.

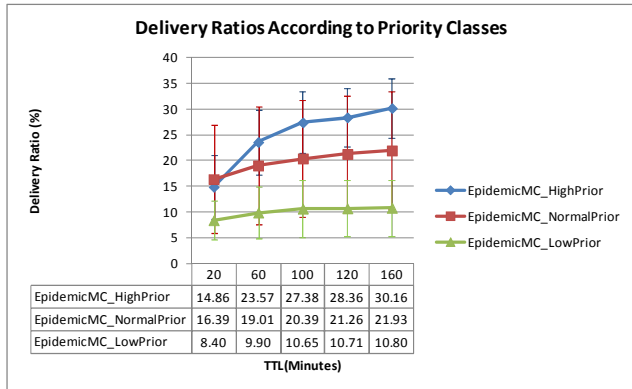


Figure 5 - Priority classes' delivery ratios for EpidemicMC.

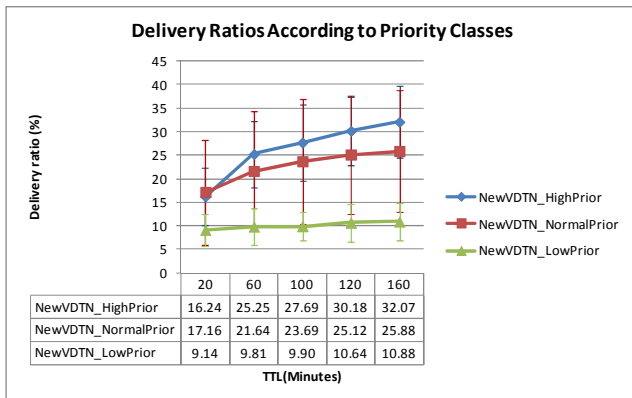


Figure 6 - Priority classes' delivery ratios for NewVDTN.

C. 80 Nodes Scenario

The 80 nodes scenario's configurations are the same as for the previous scenario with the following modifications:

- Simulation time of 8 hours (28800 seconds).
- NewVDTN implements a dropping policy according to lower priority and TTL. The messages transmissions are made according to priority and the general buffer occupancy estimation, 'Sbuff', as explained previously.
- EpidemicMC with a dropping policy according to lower priority and TTL and message scheduling with a random order.

There is a larger difference between both protocol values and the difference between the several priority classes delivery ratios becomes more evident as compared with the previous 24 nodes scenario.

Comparing to the average latency of the 24 nodes scenario, now lower latencies were achieved in this dense scenario, as expected (Figure 7). More nodes allow more encounters, and so it is more likely to make contact with final destination nodes. EpidemicMC has better latency results because of its epidemic nature which, with the increased number of nodes that can carry bundles, will deliver the messages faster, lowering the average latency. The EpidemicMC protocol generates a high message overload creating a high number of message drops. On the other hand, NewVDTN does not force such a high message overload, allowing messages to stay longer on the buffers until eventually they get to their final destinations. Consequently, the average latency time increases.

With the increased number of nodes, the average number of hops used to deliver messages (Figure 8) increases too, as expected. The limitations implemented on the NewVDTN protocol result on a lower increase of the number of hops as compared with EpidemicMC that has no limitations like maximum number of hops or maximum number of MULEs.

The delivery ratio for the NewVDTN protocol shows better results (Figure 9). There is a natural increase of values as compared with the sparse scenario. With more vehicles in the network, chances of encounters with final destination nodes increase and more messages are delivered too. The NewVDTN implemented limitations allow an increase of the delivery ratio with the messages' TTL and better performance than EpidemicMC.

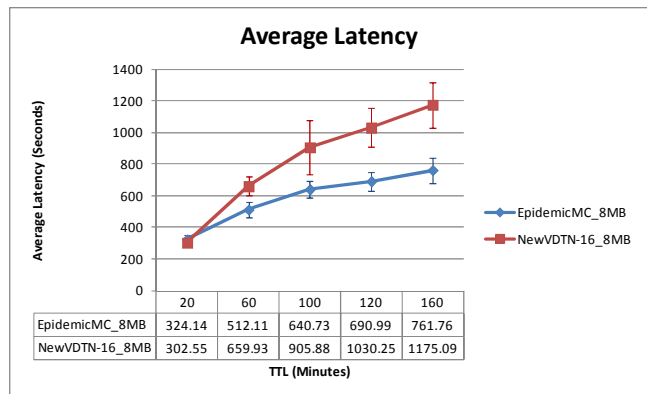


Figure 7 - Average latency of both protocols.

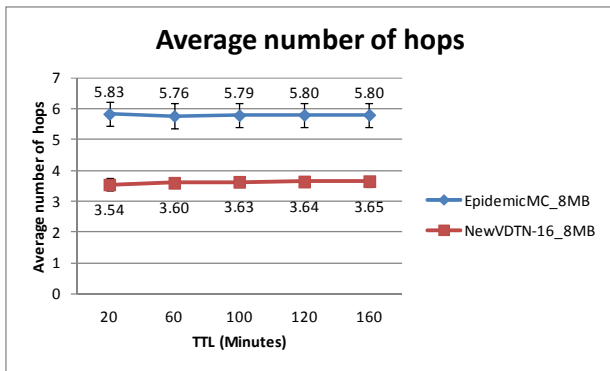


Figure 8 - Average number of hops used to deliver multicast messages.

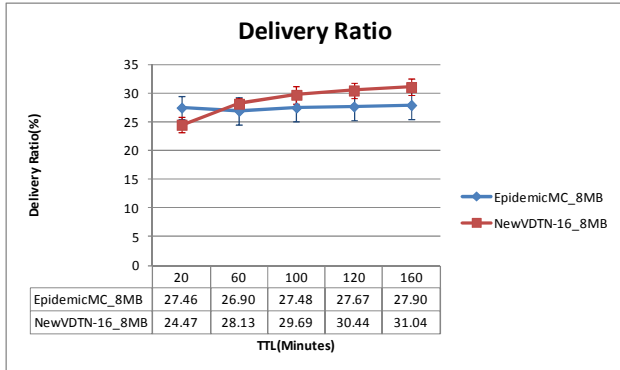


Figure 9 - Delivery ratios of both routing protocols.

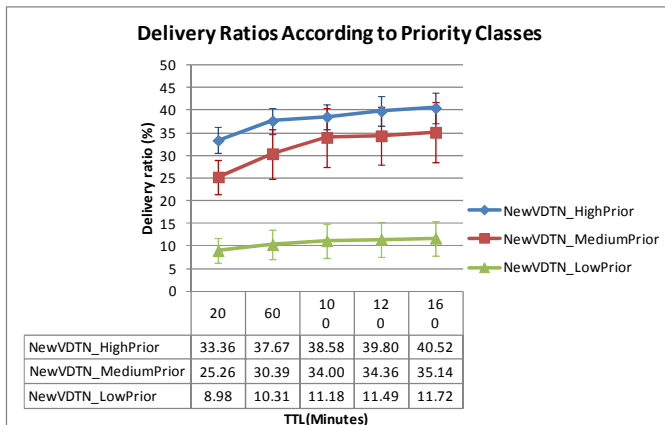


Figure 10 - Priority classes' delivery ratios for NewVDTN.

The objective of getting a correct order of delivery ratios according to priority classes was also achieved in this scenario (Figure 10). The TTL assignment according to the message priority and the dropping policy used by both protocols makes the delivery ratios to be correctly ordered.

V. CONCLUSION

A new multicast routing protocol which implements a number of message copies limitation similar to Spray-and-Wait but with a more intelligent network message spreading was proposed.

A differentiation between dense and sparse scenarios is made according to an estimation of the number of nodes met. If a dense scenario is detected, the sources assign a TTL to the created message according to the message priority. Messages

are scheduled according to priority and general buffer occupancy estimation. In sparse scenarios, better results were achieved with a WFQ scheduling policy which sorts the message buffer fairly.

With NewVDTN, a dynamic assignment of the maximum number of MULE nodes and a careful choice of MULE nodes is made. The list of contacted nodes is always sorted according to their vehicle density estimation, thus it is possible to forward messages first to the contacts with more contact probabilities. Another implemented feature was the choice of MULE vehicles according to their movement direction which has to be at least 45° different from the movement direction of the node that carries the bundles, which contributes to better spread the bundles.

These mechanisms contribute to an enormous overhead reduction, a better network congestion control, resulting in better delivery ratios. Only the average latency for dense scenarios was better when using EpidemicMC, as NewVDTN was designed for sparse scenarios.

As future work, other node movement models and larger scenarios may be used for a better representation of real situations. Well defined vehicle routes assigned to people who have to drive to work and return home, as well as taxis random movements can be used in further tests.

Features like message TTL, maximum range or maximum number of hops can be changed to more dynamic mechanisms. Other dropping and scheduling policies can be also tested.

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