A Trajectory-Based Approach to Improve Delivery in Drive-Thru Internet Scenarios

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***Abstract*—In this paper, we propose an architecture for hybrid drive-thru Internet scenarios which combine wired and wireless networks. This architecture handles user mobility inside vehicles in intermittently-connected wireless networks by extending the utilization of delay-tolerant networks to the wired infrastructure. A routing protocol that combines static with epidemic routing is proposed to avoid epidemic message forwarding in the wired infrastructure and, at the same, to maintain communications in the wireless network. We also propose a trajectory-based mechanism to further avoid message replication in the wired infrastructure. Experimental results show that the proposed mechanism can avoid message replication in the wired and wireless networks and still be transparent for users' applications even with access point changes.**

I. Introduction

To date, the preferable technology for Internet mobile access is cellular 3G/4G. Although it provides higher bandwidth, users can push cellular networks to their limits, leading operators to adopt data offloading strategies [1]. The utilization of opportunistic networks is also a promising alternative, since they can avoid data congestion in cellular networks [2].

Among the opportunistic networks, IEEE 802.11 is an affordable widespread technology. IEEE 802.11 networks can also be applied to vehicular settings where mobile users obtain Internet connectivity via drive-thru communications [3]. To this end, users inside vehicles connect to road side units (RSUs), which provide access via a gateway to the wired infrastructure. Although the benefits of vehicular networking are many-fold, its wide adoption is still challenging. The current network architecture is composed of many connectivity islands, delimited by the radio range of each RSU. Roaming through consecutive islands imposes short-living and intermittent connectivity, leading users to experience service interruptions or inability to establish end-to-end communications.

The deployment of routing protocols which do not rely on the connectivity assumption has been largely investigated in vehicular networks. Delay and disruption Tolerant Networks (DTNs) [4] use message switching with custody transfer to circumvent intermittent connectivity. Instead of simply forwarding received messages, intermediate nodes store and replicate these messages upon finding an opportunistic contact. In the most trivial approach, nodes epidemically replicate received messages to all nodes encountered until the destination is reached, or a timer expires. Although the epidemic approach is valid in scenarios where no information is available, it is inefficient from the viewpoint of message overhead [5], [6]. Smarter approaches exist, they usually use statistical [7] or geographical [8] strategies to choose which bundles to forward or dispose. In drive-thru communications, if mobile users cannot stay connected to a single RSU for time enough, the connectivity problem occurs given the high mobility of nodes. The DTN then must consider the hybrid infrastructure to provide mobile users with a reasonable service.

In this paper, we experiment with a hybrid architecture based on IEEE 802.11 and DTN. Our main contributions are: (i) a hybrid architecture to deal with mobile users in drive-thru scenarios, which includes an adapted version of a DTN routing protocol in the wired infrastructure; (ii) an adapted DTN routing protocol which combines the utilization of static and epidemic routing in the wired and wireless network, respectively; (iii) a trajectory-based mechanism to reduce network traffic in the wired and wireless infrastructure. Results show that we can provide transparent services for mobile users by also using DTN in the wired network.

This work is divided as follows. Section II presents our key contributions, while Section III provides implementation details. Section IV presents our testbed. The experiments and the obtained results are described in Section V. Finally, Section VI concludes this work and presents future directions.

II. Proposal

We propose a hybrid routing architecture to tackle user mobility by extending the DTN use to the wired infrastructure. Epidemic routing is used in the wireless part whereas static DTN routing with mobile user trajectory information is used in the wired part. The combination of static routing and trajectory information avoids bundle replication in the wired network and reduces control messages in the wireless part.

A. Architecture

Figure 1 shows the proposed architecture. Mobile users run Internet applications using IEEE 802.11 contacts to exchange data. The architecture has four entities: the mobile user inside a vehicle, the vehicle with embedded wireless equipment, the Road Side Unit (RSU), and the Central. Users and vehicles are in the wireless network, whereas the Central is in the wired part. The RSU is in charge of interconnecting the wireless network to the wired infrastructure.

We assume users run applications with a certain level of interactivity. In addition, users do not use customized versions of their applications, which render our architecture

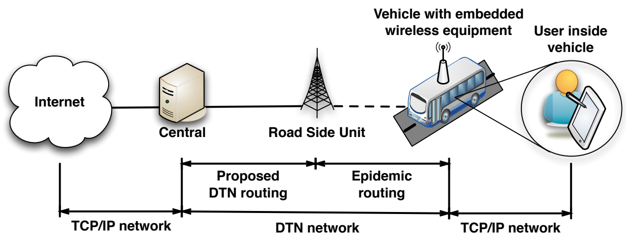


Fig. 1. The proposed architecture: the mobile user, the vehicle with embedded wireless equipment, the Road Side Unit (RSU), and the Central station.

backward compatibility. This is possible because the wireless equipment in vehicles plays the role of entry point to the DTN, encapsulating and decapsulating the data sent from and received by users, respectively. Using equipments capable of interconnecting TCP/IP networks with DTN ones is simpler than counting on the utilization of specific applications for intermittently-connected scenarios. In public transportation systems, such equipments can intermediate the communication of lots of users with the Internet without application changes. Another entity to intermediate communications between the DTN network and the Internet is needed. This is the job of the Central station which receives the bundles from all mobile users and sends them to the Internet. The same is true in the downstream direction, where the Central station receives responses and sends them to the mobile users.

By using the DTN, we can deal with mobility in drive-thru scenarios. The IP addressing problem and its strong correlation with topology can be circumvented by data forwarding based on DTN identifiers. In addition, we consider the Central station as the single interconnecting point with the Internet in the wired network. Finally, finding a mobile user means first locating the vehicle carrying her. Hence, for the DTN, source and destination nodes are the vehicles and not the user inside.

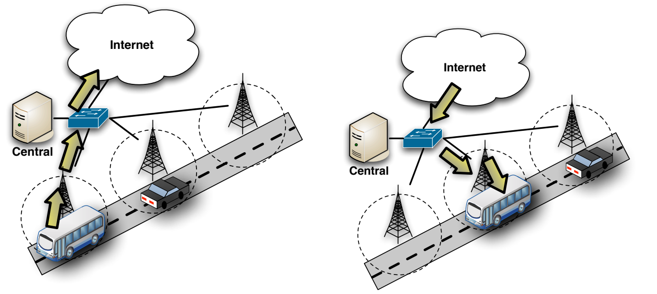
B. Hybrid routing

Epidemic routing is valid in scenarios where no information about vicinity is available. Nevertheless, since nodes are static in the wired part of the hybrid architecture, a static routing scheme is applied to connect the Central to the RSUs. In fact, DTN implementations provide such option, which is used to avoid bundle replication. With such possibility, we can adjust the routing settings of the DTN implementation according to the underlying network. The DTN identifier must be maintained in both networks (wireless and wired) to handle mobility.

The tradeoff of the hybrid configuration is the different routing schemes each RSU must deal with. In our architecture, each RSU must handle static and epidemic routing configurations in their wired and wireless interfaces, respectively. This raises implementation issues described in Section III.

C. Overhead reduction

Although the utilization of static routing can reduce bundle replication in the wired network, the position of the mobile node is still unknown. If not using epidemic routing, in the worst case, the Central station would have to send to all RSUs the upcoming message destined to the mobile node. Hence, estimating vehicles' position can further reduce the number of messages transmitted in the wired network because the Central would only forward received messages to specific RSUs.



(a) (b)

Fig. 2. Trajectory-based forwarding: (a) a mobile user sends a request to the network; (b) the response is forwarded to the RSU closest to the mobile user according to the prediction of the proposed trajectory-based forwarding.

In DTNs, nodes exchange buffer mappings before data exchange to avoid message duplication. As a side-effect of estimating the mobile nodes' position, the exchange of control messages in the wireless network also decreases because the Central station forwards all received messages to the RSU closest to the mobile user. Control messages then are reduced because the destination is probably found sooner. The tradeoff is the possibility of not finding the mobile user due to vehicles' unexpected movements. In this case, data losses can occur.

In our proposal, vehicles send positioning information to the Central station every time they connect to a RSU in a DTN bundle with specific purpose. Since we assume the complete trajectory of all vehicles is known in advance, after receiving the bundle, the Central can predict the future location of the vehicle. The complete trajectory can be predetermined or informed by cooperating users. Upon receiving position information, a database maintained by the Central is updated with the information regarding the future RSUs in the way. If the Central needs to send a message to a vehicle, it can lookup its database to be aware of the next RSU the vehicle will connect. Thus, it is possible to reduce the number of RSUs in charge of forwarding bundles. To improve reliability, the Central sends the bundle to the most probable RSU and to their neighbors. Then, even if the vehicle changes its trajectory, the mechanism can deliver the bundle.

Figure 2 illustrates the trajectory-based proposal for message replication reduction. A mobile user sends a request to the network (Figure 2(a)), whereas the response is forwarded by the Central to the RSU closest to the mobile user (Figure 2(b)).

III. Implementation Details

This section provides further details about the hybrid routing and the trajectory-based approach implementation.

A. Hybrid routing

In the hybrid routing, we have to configure two different routing schemes per RSU, static and epidemic. However, the

DTN implementation used, `IBR-DTN` [9], permits only one routing mode independent of the number of interfaces. In this case, we develop an alternative to circumvent such limitation. We configure the epidemic routing and we add firewall rules to the wired interface so it behaves as a static one.

Another implementation issue concerning the RSU acting as an interconnecting point, i.e., connecting the epidemic network to the static one, is the destination DTN identifier change. To force the RSU to behave as a bridge, additional information is added containing the final destination identifier inside the DTN bundle. Hence, if the Central station wants to communicate to a vehicle, it must add the identifier of this vehicle in the bundle and then sends it to the corresponding RSU. The RSU uses this identifier added to send the message to the correct vehicle.

B. Trajectory-based forwarding

The trajectory-based approach is implemented via a "localization application" which provides the Central station information about vehicles' position. Hence, the wireless equipment inside the vehicle connects to a wireless using a script which first searches known wireless network IDs (SSIDs), and then connects to the one with highest signal strength. For reliability purpose, we test the connectivity between the vehicle and the Central station using a sequence of `pings`, if the connection is not good enough, the script tries to connect to other RSU, restarting the whole procedure. After establishing the connection between vehicle and Central station, the vehicle creates a localization bundle and sends it to the Central. This procedure uses the `dtnsend` application available in `IBR-DTN` [9], which is the implementation used in this work. The bundle contains a file written in `XML`.

In the Central station, the localization application runs an infinite loop receiving bundles from the wireless users. The Central uses the `dtnrecv`, which is the application from `IBR-DTN` to receive files sent with `dtnsend`. The received bundle is analyzed and the position information is extracted. The application uses the bus ID to lookup its predetermined trajectory. Using the trajectory and the RSU ID, the application predicts the next RSU the vehicle will be nearby. The information obtained regarding the current and future positions is written into a file named according to the vehicle ID. These files are used as input of other applications to find the vehicle position. In this work, the static routing can be aware of a given vehicle position by reading its corresponding log file.

When the Central station sends a message to the vehicle, it sends to the last RSU the vehicle was seen as well as to the next one in the vehicle trajectory.

IV. Testbed Setup

Our testbed is composed of one desktop and six wireless routers. The desktop plays the role of Central station, whereas the wireless routers play the role of RSUs or wireless equipments inside vehicles. Routers playing the role of vehicle equipment also assume the role of mobile clients.

The desktop is an Intel Pentium D with 3.20 GHz processor and 4 GB of RAM. The operating system is a Debian Etch [10] and the DTN protocol implementation is the `IBR-DTN` [9]. The routing protocol is static, which requires the previous configuration of all RSUs. The RSUs are D-Link DIR-320 wireless routers with 32 MB of RAM and 4 MB of flash memory. These routers run the OpenWrt [11] operating system. The routing protocol is configured according to the interface card; wireless cards are in epidemic mode, whereas wired ones are in the adapted static mode. All RSUs provide a wireless LAN to be connected by vehicles. Additionally, RSUs store bundles in their buffer for awhile if the mobile destination is not in range. Hence, all routers have a USB flash drive due to onboard storage constraints. The wireless equipment inside the vehicles is also D-link DIR-320 wireless routers with the same Linux distribution of RSUs. Nevertheless, instead of acting as access points to the wireless network, routers inside vehicles act as clients of the wireless networks. Routers inside vehicles also have USB flash drives.

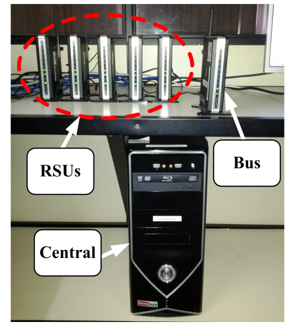


Fig. 3. Our testbed: 5 RSUs, a Central station, and a router playing the role of the equipment inside the vehicle and the mobile user.

The network scenario used is in Figure 3. There are five RSUs in the testbed, a Central station and a single router representing, at the same time, the equipment inside the vehicle and the mobile user. A script emulating the vehicle movement is used connecting and disconnecting to the RSUs as it would happen if the vehicle were really in motion.

V. Results

We evaluated the following metrics: vehicle localization time, number of message replications, message delivery rate, and traffic in the wireless network. To know the decrease in delivery rate imposed by our solution, we compared our proposal with the epidemic routing protocol which is the best in terms of delivery rate. Since our localization approach relies on predetermined trajectories, we conduct our tests considering the vehicle as a university bus. In addition, we assume that the bus stops are the most suitable place to locate a RSU. Hence, in preliminary evaluation, we measured the average time a bus remains connected to the same RSU. We consider the case where the bus does not stop and the case where it stops to pick up passengers. Both evaluations were conducted at UFRJ (*Universidade Federal do Rio de Janeiro*) to permit results as real as possible.

According to our measurements, the bus remains connected in average 65 s and 36 s if it stops or not, respectively. In our tests, the radio coverage achieves approximately 200 m. In addition, the time the bus remains disconnected between consecutive RSUs is 90 s. This is computed considering the distance between consecutive bus stops and the maximum allowed speed in our campus, which are 1 km and 40 km/h, respectively. We compare our proposal with epidemic routing running in all network nodes.

A. Vehicle localization time

The proposed hybrid routing requires localization messages from the bus to the Central station. Thus, communications between these two entities must be conducted in a time frame lower then the minimum time connected to a RSU. If this is assured and the bus trajectory follows the one expected, the localization system is supposed to correctly track the bus.

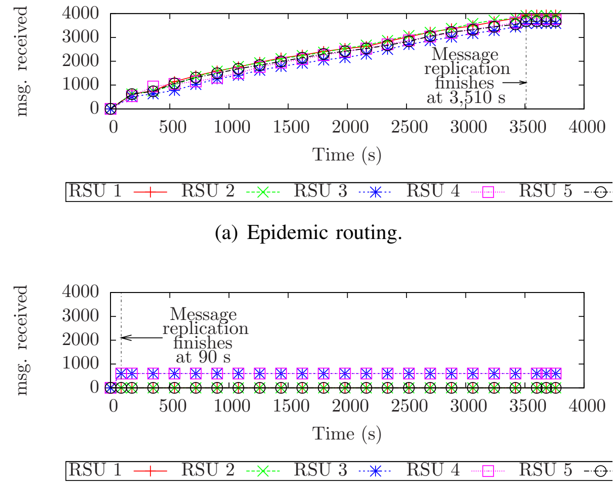
In this test, we measured the time needed by the whole procedure since the association to a wireless network until the correctly reception of the corresponding information by the Central station. To this end, we have created two scripts, one to be executed in the Central station and another to be executed in the bus router. The bus script is responsible of connecting it to the RSU, writing the time the script started at a log file, and sending the localization message to the Central station. The Central station waits for a localization message and upon receiving one, it writes the arrival time also in a log file. The clocks of the bus router and of the Central station are synchronized via the same NTP server. Although we use clock synchronization to predict vehicles' position, small time shifts are tolerable since the time scale can be in the order of seconds or even minutes.

The same test was performed ten times and the results reveal that the average time needed for this procedure is 15.6 s, with standard deviation of 3.98 s. We observe that the time needed to a localization message to reach the Central station is less than the worst case scenario, when the bus only stays connected for 36 s to the RSU. Thus, in our tests, we can assure that the localization message is delivered and, consequently, the mobile nodes can be tracked. It is also worth mentioning that most of the localization time is spent by the DTN daemon in vicinity discovery.

B. Message replication

In the message replication test, the router acting as a bus emulates the movement throughout the different RSUs. The period that the bus remains connected to a RSU is 65 s, which is the time required for a bus to pick up passengers, and the time the bus is not connected to any RSU is 90 s. In the test, the bus starts its movement in RSU 1 and goes through all RSUs in ascending order of IDs. The Central station sends a different message every 0.1 s for the bus during 1 minute. As the time the bus remains connected to the same RSU is greater than the time the Central station sends messages, during the entire test, the bus is still connected to the same RSU.

Table I expresses the percentage of messages received by each RSU, considering the messages sent by the Central station plus control messages. Because messages are replicated, the total amount received by a RSU can surpass 100%. From Table I, we observe that the proposed architecture reduces in more than fifteen times the number of message replicas in the wired network, if compared with the epidemic routing protocol. In addition, as the proposed message forwarding uses the trajectory-based approach, messages are only forwarded to the last RSU the bus was connected to and to the next one in its trajectory. We can infer that the bus was connected to the network provided by RSU 3. The percentage above 100% occurs because localization messages are also sent by the proposed forwarding approach.



(a) Epidemic routing.

(b) Proposed routing.

Fig. 4. Message replication in the wired network.

In the epidemic routing, message replications are received by all RSUs. The high number of replicas occurs because each RSU, upon receiving a message, replicates it to every other RSUs. Hence, the advantage of using the proposed routing is proportional to the number of RSUs. Whereas the number of message replicas is constant in our approach, it increases with the number of RSUs using epidemic routing.

TABLE I
MESSAGE REPLICATION IN RSUS.

RSU ID	Proposed routing	Epidemic routing
1	0%	657.3%
2	0%	652.3%
3	100.2%	598.5%
4	100%	629.7%
5	0%	612.7%
Total	200.2%	3150.5%

In our test, messages are sent by the Central in 1 minute. Nevertheless, the routing approach reacts differently, spending additional time to finish message replication to all RSUs. In the proposed approach, the routing procedure takes 90 s to send the messages to the RSUs selected according to the trajectory-based approach proposed (Figure 4(b)). In opposition, the epidemic routing takes 58 min. and 12 s to send messages and replications to every other RSU (Figure 4(a)). In both cases, the plateau is achieved when the message replication finishes. This shows the negative impact of epidemic routing in wired networks, which is avoided in our architecture.

C. Message delivery

In the message delivery test, the bus roams along the five RSUs, stopping to pick up passengers on each one. The test is handled during 24 h and the Central station sends 500 messages during the experiment. This test evaluates the communication in the point of view of the router in the bus.

Table II shows the results for the number of messages lost, the percentage of messages delivered to the bus router, the average number of message replications received by the bus router, and the maximum number of message replications received by the bus router. Analyzing the results, we observe a tradeoff of the trajectory-based approach. The average number of message replications delivered to the bus and the number of messages lost are greater than in the epidemic routing. Nevertheless, the number of message replications is a function of the number of RSUs used during the localization procedure. Although we use only current and next RSU in the bus trajectory, this could be set to only the following RSU or even to all RSUs in same area. This depends on the level of reliability we want versus the number of message replications.

TABLE II
MESSAGE DELIVERY STATISTICS.

Statistics	Epidemic	Proposal
Number of messages lost	0.00	3.00
Message delivery rate	100.00%	99.60%
Avg. number of replicas received	1.36	1.79
Max. number of replicas received	2.00	2.00

D. Wireless traffic analysis

In the analysis of traffic on the wireless network, the amount of data transferred between the bus and all RSUs connected on its trajectory was measured. The Central sent 160 messages equally distributed over 2 h. Such messages were received in 55 contact opportunities with the RSUs, where the first and the last 6 opportunities were only used to estimate the control traffic. We also examined the message delivery rate. We would like to identify the causes of a possible reduction in the delivery rate, be it due to network load or the effect of the localization approach.

The bus has the same movement pattern of the previous experiment, i.e. 65 s of connection with the RSUs and 90 s of disconnection between RSUs. This test was performed for four different configurations: the epidemic and three different hybrid configurations. The difference between the hybrid configurations is the number of RSUs serving as intermediate node between the Central and the mobile destination. We tested the settings in which the Central sends messages to only the last RSU where the bus was found (Hybrid Configuration 1RSU); to the next and last RSU in the bus trajectory (Hybrid Configuration 2RSU); and to the last and the next two RSUs in the bus trajectory (Hybrid Configuration 3RSU). It is expected that increasing the number of RSUs results in a higher traffic in the wireless network and in a higher delivery rate.

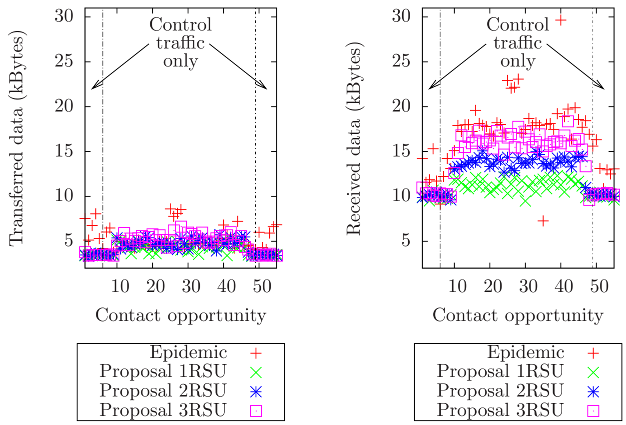
Table III shows, for each scenario, the delivery rate and the number of messages lost, disregarded the replicas. The average message replication and the maximum number of received replicas are also presented. The delivery rate is lower compared with the previous results (Table II) because the we now consider a mobile scenario with more load.

Table III shows that the delivery rate of Hybrid Configuration 1RSU was 31.25%, which is low since messages are only delivered to RSUs in which buses are connected. This means that only messages generated by the Central in the time interval between the localization bundle reception and the bus departure from its stop could be received. It is observed that the delivery rate of the Hybrid Configuration 3RSU and of the epidemic configuration are similar, demonstrating that the proposed configuration is able to increase the delivery rate by increasing the number of intermediate RSUs. Furthermore, we can note that it is possible to obtain a delivery rate near to the epidemic configuration with three RSUs. It is also worth mentioning that the number of copies received by the bus reflects the number of messages generated in the Central in the epidemic scenario; and the number of messages generated in the RSUs in the hybrid case.

TABLE III
MESSAGES DELIVERY STATISTICS.

Configuration	Delivery rate	# of msg. lost	Avg. msg. replication	Max. # of replicas
Epidemic	80.63%	31	1	1
Hybrid 1RSU	31.25%	110	1	1
Hybrid 2RSU	59.38%	65	1.48	2
Hybrid 3RSU	80.00%	32	1.88	3

Figure 5 shows the amount of data transmitted and received by the bus in the contact opportunities with the RSUs. The results show that the number of intermediate RSUs has direct influence in the wireless network traffic. Comparing the epidemic configuration with the hybrid configurations, it is noted that the epidemic configuration has on average more traffic than any of the hybrid configurations. This effect is most evident in the data received by the bus, since the data transmitted by the bus to the RSUs are only for control, in the realized experiment. It is important to note that the Hybrid Configuration 3RSU presents results of delivery rate close to those of epidemic, and even with more message replication, the Hybrid Configuration 3RSU inserts a smaller amount of data in the wireless network. This is a consequence of the localization application, which reduces the amount of data on the wired network, and also decreases the control load in the wireless network. This control load is used by the DTN network before



(a) Transmitted data. (b) Received data.

Fig. 5. Transmitted and received data through bus wireless interface.

message exchange to avoid replicas.

Table IV shows the average with standard deviation of the transferred load (data plus control). The averages of the data transmitted and received by the bus along the contact opportunities are shown, besides the total data transferred. Again, it is apparent that the configuration that inserts the largest amount of data in the wireless network is the epidemic, followed by the Hybrid Configuration 3RSU. It is worth mentioning that the traffic becomes more stable by reducing the number of intermediate RSUs.

TABLE IV
LOAD (KB) IN THE WIRELESS NETWORK.

Configuration	Transmitted	Received	Total
Epidemic	5.27±1.35	16.83±3.71	22.10±4.41
Hybrid 1RSU	4.11±0.61	10.91±0.83	15.03±1.40
Hybrid 2RSU	4.41±0.75	12.65±1.81	17.05±2.51
Hybrid 3RSU	4.71±0.95	14.23±2.85	18.94±3.76

An additional result can be seen in Figure 5 during periods of system stabilization – first and last six contact opportunities. During these periods, all traffic on the wireless network is due to control. In the epidemic scenario, where all RSUs and Central become indirect neighbors of the bus, the control traffic results from the regular exchange of neighborhood information. However, in hybrid configurations, it results from the regular exchange of neighborhood information and also from the localization bundle being sent. Since only the Central is an indirect neighbor of the bus in the hybrid case, there is a reduction of neighborhood information. We can note in those periods that a greater overhead is inserted by the epidemic scenario, which confirms previous results. While all hybrid scenarios have control rate between 12 and 15 kB, the epidemic scenario has rates varying from 12 to 24 kB.

We conclude that the proposed scenario can decrease traffic control in the wireless network and still achieve delivery rates similar to the epidemic configuration. Both the delivery rate as well as the data payload depend on the selected settings, such as the number of intermediate RSUs. The performance of this proposal would be more apparent in larger scenarios, where the number of RSUs is greater than five.

VI. CONCLUSIONS

In this paper, we proposed an architecture for hybrid scenarios which handles users' mobility inside vehicles in intermittently-connected wireless networks by extending the utilization of delay-tolerant networks to the wired infrastructure. In addition, a routing protocol combining the utilization of static and epidemic routing was proposed, along with a trajectory-based mechanism to avoid message replication in the wired network and also to reduce the control traffic in the wireless network. Experimental results showed that the proposed mechanism reduces message replication in the wired network and still provides seamless mobility for wireless users. The static routing plus the trajectory-based approach reduce in fifteen times the number of message replicas in the wired network. Furthermore, the proposal was capable of reducing the control traffic of the wireless network, while still being able to maintain the same delivery rate as the epidemic configuration. As future work, we plan to propose a mechanism to dynamically change the expected route of vehicles so as to predict route changes or even RSUs malfunctioning.

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