Evaluating the use of sub-gigahertz wireless technologies to improve message delivery in opportunistic networks

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***Abstract*—The message delivery ratio of mobile opportunistic networks strongly depends on the transmission time, which is closely related either to the mobility of users and to the communication properties of the mobile devices. A larger radio transmission range allows longer contact durations, improving the message dissemination. Furthermore, user mobility is a crucial factor to be considered, especially when the mobile nodes are vehicles, because of their limited freedom of movement and the high relative speed.**

In this paper, we evaluate the use of a sub-gigahertz wireless technology, namely LoRa (Long Range), to establish links between the mobile users in an opportunistic network in order to augment the number of contacts and their duration. We evaluate the performance of LoRa, comparing it with WiFi, using the Epidemic protocol for message diffusion with realistic vehicular traces. Through simulations, we compare the message delivery probability and the network overhead. These experiments were carried out using the ONE simulator with minor modifications to model the typical behaviour of mobile users. The results show that, in opportunistic networks, increasing the range even while reducing the available bandwidth increases the message delivery ratio.

I. INTRODUCTION

Mobile Ad-Hoc Networks (MANETs) [1], [2] and Vehicular Ad-hoc Networks (VANETs) [3]–[5] are both self-forming and self-healing types of networks that provide peer-level communication links between mobile nodes without the support of fixed infrastructure. However, due to many factors but especially to user's mobility, these links may not last enough time to guarantee the message diffusion. Delay Tolerant Networks (DTNs) [6] were proposed as an alternative to disseminate and share information between mobile users. These wireless networks are being used in heterogeneous networks that lack network connectivity during longer periods than in MANETS, i.e., in the order of minutes or hours. Some authors [7] proposed their utilisation in catastrophe zones or in rural areas.

Similar to the relation between MANETs and VANETs, from the DTN model communication are derived the Vehicular Delay Tolerant Networks (VDTNs) [8] as a novel strategy to provide data transmission in vehicular scenarios. One type of networks inside the VDTN model are the Vehicular Opportunistic Networks. Opportunistic networks can also be considered as Partially Connected Networks [9], due to their ephemeral contact duration. Other authors, such the ones in [10], [11], define them as a subclass of DTNs. The reference communication model is typically based on the Epidemic protocol [9]. This protocol is widely used as a reference technique and its operations are based on the store, carry, and forward approach combined with the flooding of messages.

In this kind of disruptive wireless networks, where the communication between mobile devices is ephemeral, and the links are typically asymmetric and unstable, sending and receiving information depends on mobility and on the opportunity of contacting other devices, as long they are willing to collaborate. The duration of the contact between the nodes is a key factor in the dissemination of messages; if the contact time is too short, there will not be enough time for nodes to interchange all pending messages.

In this work we evaluate, through simulations, the performance of the Epidemic protocol in a vehicular opportunistic network when employing two different data transmission technologies: WiFi (more exactly WiFi-Direct) and the novel LoRa (Long Range) [12]. The latter provides greater communication range by working at sub-gigahertz frequencies, thus generating more contacts with greater duration, but provides a reduced bandwidth when compared to the former.

We use the ONE (Opportunistic Network Environment) simulator [13] with real GPS vehicular traces acquired from [14] while the frequency and size of messages are based on social networking applications [15]. The ONE simulator was designed and built to specifically evaluate DTN protocols and applications, and it is focused on the network layer without considering the particularities of lower layers such as physical and Media Access Control (MAC).

We evaluate the impact of both technologies in terms of ratio message delivery, latency, and buffer consumption, and the contact duration time for different buffer sizes and message TTLs (Time To Live).

The outline of the paper is as follows: an overview of related works about opportunistic vehicular networks and message diffusion is presented in Section II, a LoRa test bed platform is presented in Section III, and the experiments evaluation is presented in Section IV. Finally, Section V contains some conclusions and future work.

II. Related Work

Other authors already evaluated message dissemination using vehicular opportunistic networks in urban scenarios. In [16], the authors characterise a total of three vehicular traces in China, 2 from Shanghai (bus and taxis), and one from Shenzhen. In [8], [17], [18] the authors offer a wide application of vehicular networks, where and how to employ certain communication approaches. Also they establish the differences between MANETs, VANETs and VDTNs, considering that the high mobility of vehicles leads to short contact durations limiting the amount of data transferred. They explore the routing protocols and some mechanisms to improve the collaboration and data transmission in VANETs and VDTNs.

In the same context using another trace set of 4000 taxis, the author of [19] validated the collected data, and created their own mobility model called Shanghai Urban Vehicular Network (SUVnet). In [20]–[22] the authors examine the performance of protocols in opportunistic networks considering GPS information of large cities, like Rome, Berlin, Beijing, among others. In [23], [24] the authors propose improvements to diffusion protocols using analytical models tested by simulations. In the context of VANETs, the authors of [25] extend the Internet connection between cars using embed devices such as Raspberry Pi.

In [26] is proposed POR, a new Opportunistic Routing (OR) protocol for high-speed, multi-rate wireless mesh networks that runs on commodity WiFi interface supporting TCP. Its performance is analysed with a test bed with 16 fixed nodes in a mesh distribution, showing improvements to data transfer. A similar idea [27] is used to face the problem of vehicle high speed proposing a two-way routing protocol extending the access point connectivity through opportunistic routing. Also they demonstrate how to exploit the navigation system to predict mobility and route messages.

The above listed works propose performance improvements for the Epidemic dissemination of messages, taking into account different aspects of vehicular networks. Most of these proposals have been tested through simulations and test beds, however none of them considered the use sub-gigahertz wireless technologies with longer range to improve the message diffusion.

III. Long Range Data Transmission

In this section we describe some details of a possible data transmission system based on LoRa by depicting an architecture aimed to provide an opportunistic communication module for vehicular nodes.

A. LoRa Technology Features

LowPower, Wide-Area Networks (LPWAN) [28] are a feasible solution to link and support the thousands of devices headed for the Internet of Things (IoT) [29] [30]. Among the LPWAN technologies is LoRa, designed to optimize key aspects such as: battery lifetime, capacity, communication range, interference robustness and cost. LoRa is employed in multiple application domains, such as metering, security, and machine-to-machine (M2M). LoRa can reach a range of more than 15 kilometres in a suburban environment and more than 2 km in a dense urban zone. Its bandwidth goes from 250 bps to 50 Kbps depending on geographical conditions.

LoRa significantly increases the communication range thanks to the chirp spread spectrum modulation. Chirp communication systems have been used in military activities for several years thanks to the long communication distances that can be achieved and robustness to interference thanks to the modulation which uses the entire channel bandwidth to broadcast a signal.

LoRa is one of the best alternatives in real scenarios requiring a long distance transmission of moderated bandwidth while keeping power consumption low. In this work, we are interested in long range communications in vehicular networks. Low power is a bonus but is not a strong requirement in this application because any vehicle could provide more than enough energy.

B. Message Diffusion Design

In this subsection we present a possible design for an opportunistic message transmission device for vehicular networks using LoRa. Figure 1 shows the components and their interactions to implement an opportunistic communication system. Figure 1a depicts the hardware elements: 1) a Raspberry Pi device with a WiFi dongle, 2) One connection bridge or shield, and 3) a LoRa interface connected to the Raspberry Pi via the connection bridge. These components together will allow general WiFi devices (e.g., smartphones) to communicate through the LoRa interfaces using the Raspberry Pi as a bridge. It is important to note the frequency restrictions depending on each country, e.g. in Europe LoRa is authorised to use the bands of 433MHz and 868MHz.

On the top part of figure 1b, we illustrate the interaction between devices that are embedded on the vehicles. On the bottom part of this figure we also show an example of the epidemic diffusion scheme, where a vehicle $V1$ transmits the message $M1$ to $V2$, after some time $V2$ sends the message to $V3$ when both vehicles are in communication range, and the process continues until the message arrives to its destination.

IV. Performance Evaluation

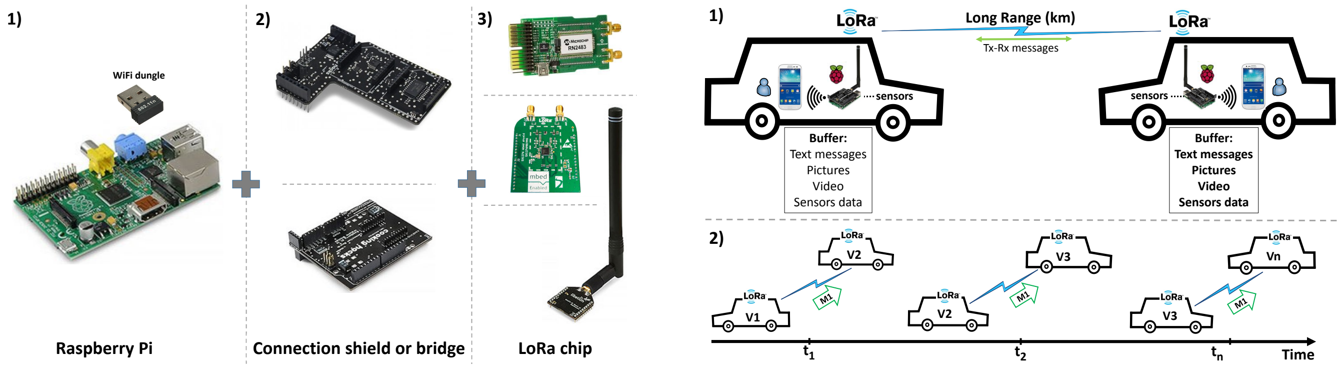
In order to evaluate the feasibility of our proposal we employed the ONE simulator [13] using a real vehicular movement trace and generating a network load based on typical multimedia mobile messaging applications.

A. Simulation Set-up

The vehicular trace (about 21 million of records) comes from a network formed by 316 taxi cabs in the vicinity of Rome during a whole month [14]. This GPS dataset was converted to Cartesian coordinates using a traverse Mercator projection [31] centred near the Coliseum covering an area of $100km \times 100km$. Figure 2 shows how the vehicular traces are distributed around the metropolitan area. Figure 2b is a zoomed view of the previous one, showing how the main urban area is almost fully covered by the traces.

The workload considered tried to mimic the typical dataflow for a multimedia messaging application where shorter messages are far more common than larger ones. Three message sizes and frequencies were considered: (1) a short text message ($1kB$) every hour, (2) a photo ($1MB$) every 18 hours, and (3) a video or high-resolution picture ($10MB$) every 96 hours. These frequencies were based on [15], while sizes are approximations of the content produced by current mobile phone hardware.

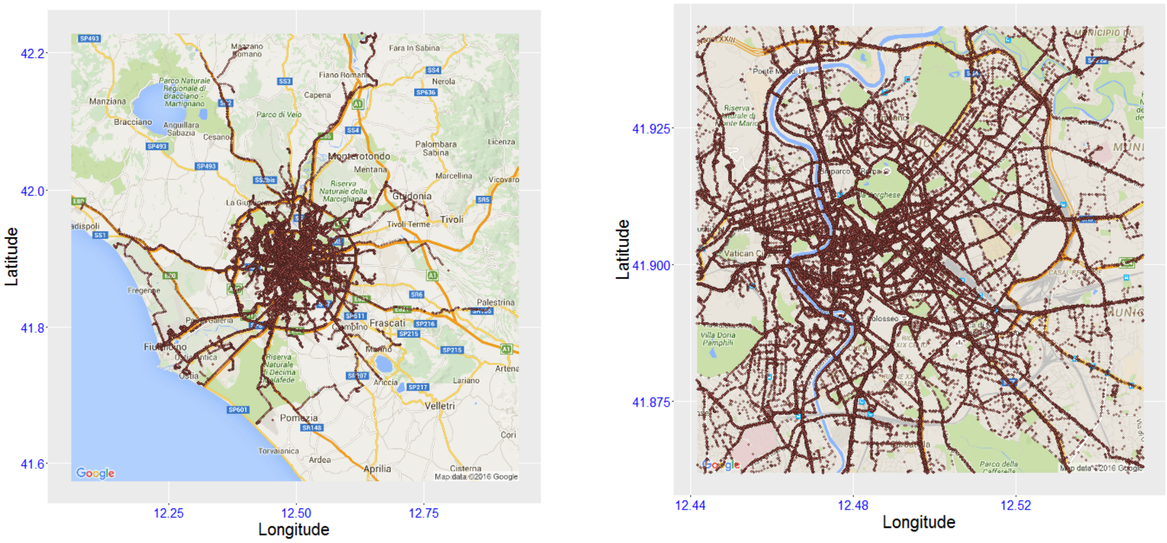
The experiments were performed using the ONE simulator. The ONE simulator was designed and built specifically to assess protocols for message dissemination in DTN Networks, namely: Epidemic, Spray and Wait, Prophet, First Contact, Direct Delivery, and Maxprop. ONE can use real traces or synthetic mobility models like Random Walk, Random Way Point, Grid, and Linear. These mobility models can be combined to model complex behaviours with different patterns as the day progresses (like Office and Work Day). For our experiments we modified the ONE simulator. Concretely, the ONE message generator (the *MessageEventGenerator* class), that injects a new message using a random interval time. This random time is uniformly distributed from a range configured in the simulation parameters. In order to obtain a more realistic model, we implemented an independent Poisson process for



(a) Network components

(b) Diffusion among mobile nodes

Fig. 1: Vehicular opportunistic network components and diffusion scheme.



(a) Metropolitan area of Rome (Zoom 10)

(b) Rome city center (Zoom 13)

Fig. 2: Vehicular GPS trace sample (Rome taxis-cab).

TABLE I: Simulation parameters varied to evaluate message diffusion.

Parameter	Values
Buffer Size	$50MB$, $100MB$, $200MB$, $1GB$
Routing	Epidemic
Mobile nodes	316
Time to Live	6 *hours*, 12 *hours*
Bandwidth	$2Mb/s$ (WiFi-Direct), $50Kb/s$ (LoRa)
Tx-Range	$50m$ (WiFi-Direct), $2500m$ (LoRa)

each user and message type, using an exponential distributed random generator. Although the ONE simulator produces a large variety of reports about the simulation process, there was no mechanism to obtain the buffer occupancy. We added a new report class that outputs the average and maximum buffer occupancy of all nodes for each step of the simulation. It also computes the maximum of the average buffer occupancy during the whole simulation.

B. Diffusion Evaluation

In order to compare the diffusion performance with both wireless technologies we run a battery of simulations varying the communication range and transmission bandwidth. WiFi-Direct is simulated with a range of $50m$ and a bandwidth of $2.1Mb/s$ while LoRa parameters are $2500m$ and $50Kb/s$ respectively (values based on the LoRa class B specifications).

Beside transmission range and speed, we also varied several key parameters such as buffer size and message TTL. The effect of these parameters have been analysed in our previous research [32]. In order to keep the number of simulations under reasonable limits, we only test the buffer management policy that has shown the best performance: prioritise small messages for transmission and large message for dropping when the buffer is full. Table I summarises the main parameters and their different values used in the performed experiments.

Figure 3 shows the number of contacts generated during the simulation among the taxis for both transmission technologies. As expected the large range of LoRa greatly increases contacts (up to 10 times). Furthermore, the average contact time increases from about two minutes with WiFi to 34 using LoRa, and the average inter-contact time (defined as the inter-any-contact time in [33]) with LoRa is about 7 times shorter.

Figure 4a shows the average delivery success ratio (i.e. delivery probability) for both technologies varying buffer size and TTL. This ratio in computed as the quotient between the number of messages that reach their destination and the number of messages generated in the simulation. This plot shows clearly the huge advantage (up to 50%) of LoRa over WiFi thanks to the larger number of contacts. We can also see that a larger TTL improves the epidemic diffusion for both technologies, but in the LoRa case, this improvement is not as significant as in WiFi. Furthermore, the influence of buffer size is negligible for this workload.

Figure 4b plots the average latency for all messages varying TTL and buffer size for both technologies. As in the previous figure the advantage of LoRa is clear (up to 40%) while the impact of the TTL is not as important as for WiFi and buffer size is also not relevant.

Latency shows an inverse relation to delivery probability, typical of the epidemic diffusion process. Allowing messages to stay longer increases their probability to be delivered in a future contact but this delivery will also have an increased latency. That is, more messages reach the destination, but with greater latency. These experiments show a clear trade-off between delivery probability and latency. Allowing a large TTL improves greatly the delivery probability but also increases the latency.

The main drawback of the epidemic diffusion process is the large overhead both in buffer occupation and bytes transmitted. Figures 5a and 5b show both results for the simulations performed. We can see that a buffer of 200MB is large enough to keep all messages generated and it seems that a small buffer could get almost full. However this does not affect message delivery in a significant way, as shown in Figure 4a. The amount of bytes forwarded with LoRa is similar for the different buffer size and TTL parameters. However, with WiFi this amount is larger for small buffer sizes, this is a side effect of the epidemic process. When two nodes establish a

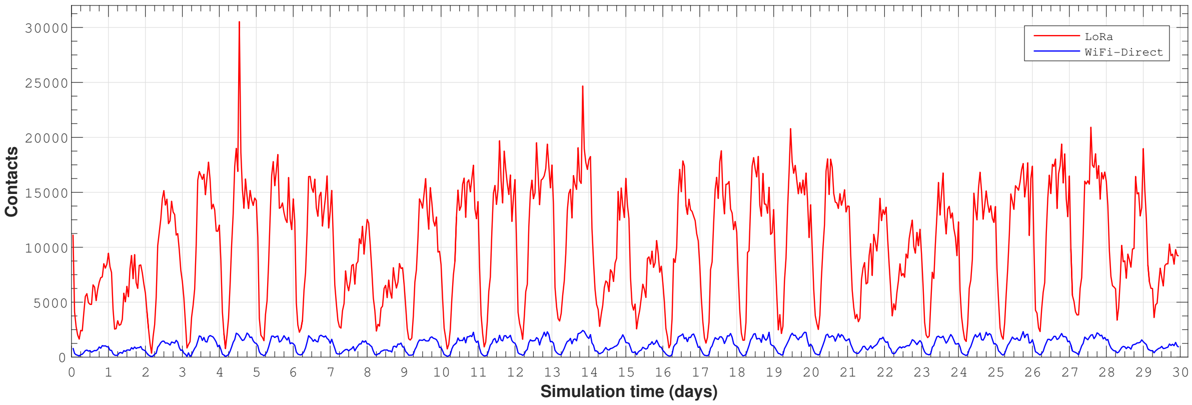
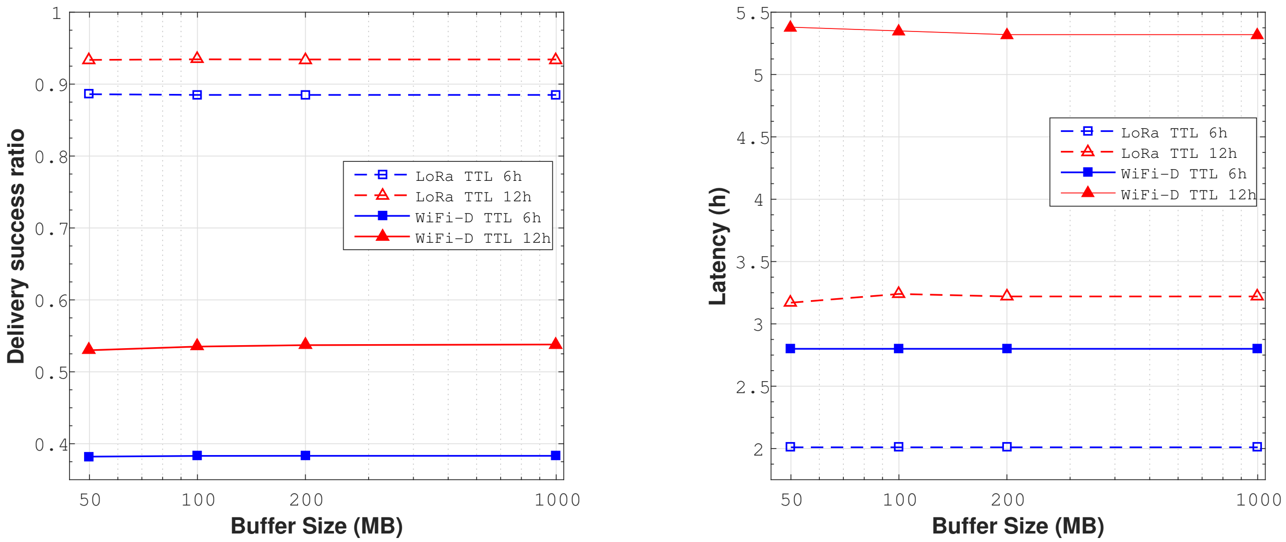


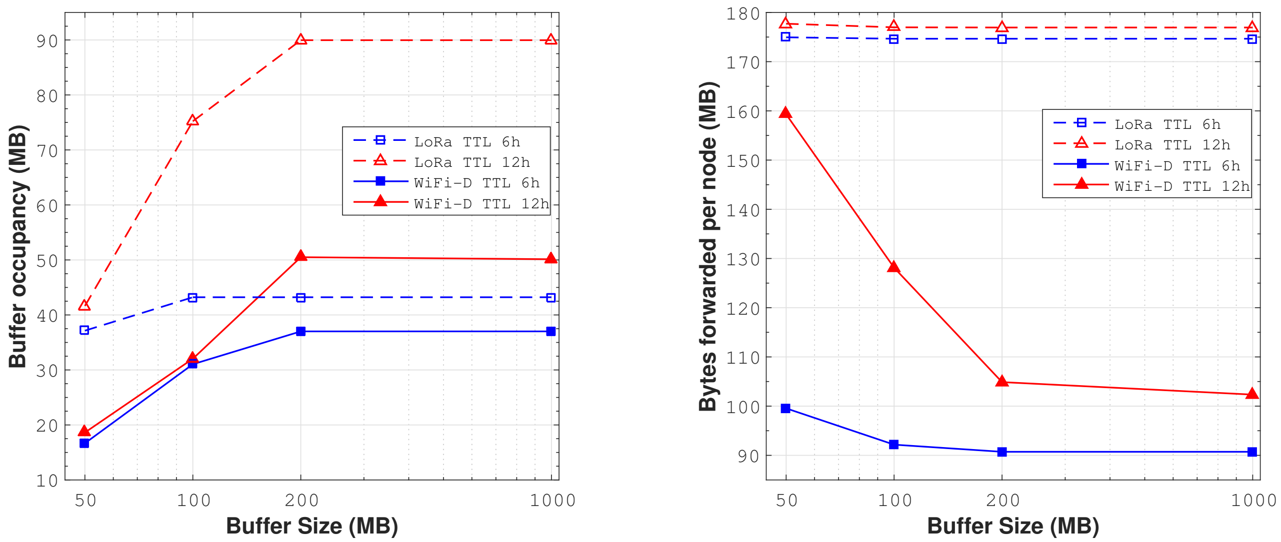
Fig. 3: Number of contacts per hour generated by the simulation for each transmission technology.



(a) Delivery probability.

(b) Latency time (hours).

Fig. 4: Average delivery success ratio and latency.



(a) Maximum of the average buffer occupancy from each node.

(b) Average bytes daily forwarded per node.

Fig. 5: Overhead results: Buffer occupancy and forwarded bytes

contact and one of them has a full buffer, messages are sent and discarded in a loop until the contact breaks, increasing artificially the amount of bytes forwarded. This effect is not as important with LoRa because of the very low bandwidth.

V. CONCLUSIONS AND FUTURE WORK

In this paper we evaluated the impact of a sub-gigahertz wireless technologies, in our case the novel Long Range (LoRa) technology, in a opportunistic network using the Epidemic protocol. The presented simulations were based on a real world movement trace from taxis of Rome and a workload from typical multimedia message applications. Two different scenarios were compared: one with short range / high bandwidth (WiFi) and another with long range / low bandwidth (LoRa).

In the studied scenario, LoRa improves significantly the message delivery ratio over WiFi in the range of about 40% to 50% for TTLs of 12 and 6 hours respectively. This is because a wider communication range allows not only more contacts but also those contacts will have greater durations. As we can see, in opportunistic networks, the delivery ratio is limited by the number of contacts so the communication range becomes the most important factor after message TTL or buffer size, leaving the available bandwidth as a no-crucial factor.

The next step in our research will be to perform experiments with a real prototype implementation using embedded devices with LoRa data transmission to validate our simulation setup.

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