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Optimizing mobility in LoRaWAN: A Resource Reservation approach

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***Abstract*—The evolution of vehicular networks continues with the advent of LPWAN (Low Power Wide Area Network). Thus, several studies currently concern the integration of LPWANs with ITS (Intelligent Transportation Systems). Among these LPWANs, LoRa with LoRaWAN, with its coverage capabilities, support of mobility, and implementation cost, is in the spotlight. However, the latter presents performance problems in highly mobile environments. Therefore, optimizing mobility in LoRaWAN is imperative for its integration into ITS. This requires performance improvements such as loss containment in very dense environments. In this paper, a resource reservation approach is proposed. It is based on device trajectory prediction and traffic differentiation in a dense multi-operator environment. This mechanism aims at reserving resources before the arrival of the device on the predicted antenna, thus reducing the rejections at the join phase while favoring " its subscribers ".**

***Index Terms*—LoRaWAN, LoRa, resource reservation, service class, vehicular.**

I. Introduction

Studies on vehicular communications have been going on for many years, with several solutions and standards proposed in the literature. Nevertheless, it is a field that remains in tune with the constant evolution of the automobile thanks to the integration of IoT and ' smart ' concepts by adopting different types of communication between vehicles, between vehicles and their infrastructure, or passers-by. These communications allow different categories of services like security, management, or comfort purposes [1]. Faced with the short range of Dedicated Short Range Communications (DSRC) and the cost of 5G technologies, the integration of Low Power Wide Area (LPWA) technologies, LoRa, in particular, seems to be a way to combine long-range and low-cost [2].

LoRa is a low-power, long-range communication technology. It uses ISM (industrial, scientific, and medical) bands that do not require any license. LoRaWAN defines the communication protocol and network architecture, while the LoRa physical layer enables the long-range communication link [3]. The LoRaWAN architecture is mainly composed of 4 parts: the end devices (ED) are generally composed of actuators and sensors that collect physical measurements and send the information to a gateway (GW), which decodes and re-transmits them to a network server (NS). The NS is the brain of the network and has a global view of the network. It can store data analytic applications, or send data to the designated application server [4]. Moreover, LoRaWAN supports handover. So when an ED arrives in a network, a join-request message is sent to the NS. The NS then contacts the home NS in case of roaming to access the join server (JS) and check if this ED can use this service. This is the join procedure [5].

LoRaWAN uses Adaptive Data Rate (ADR) to manage the devices by proposing a set of values for the transmission parameters. These parameters (Spreading Factor, Transmission Power, Bandwidth, and Coding Rate) depend on the number and position of the device about the gateway are proposed while taking into account the current situation of the network to avoid collision [6]. However, this mechanism encounters problems when the application integrates mobile objects. The network may experience local overload. But, if the vehicular network can be predicted, the resource can be booked in advance. The question of optimizing LoRaWAN in VANET (Vehicular Adhoc Networks) and simply in case of mobility arises. As a result, slicing and prefetching solutions are proposed in the literature to optimize the Quality of Service (QoS).

In this paper, we inspire from [7], where the vehicular prediction was used to ' prefetch ' DNS information. In this study, we use vehicular prediction to book in advance LoRaWAN resources. The idea is to accept newly arrived devices at an NS only when there is sufficient resource to serve the devices with adequate QoS. If too many devices are accepted, even if the probability that they transmit at the same time is low, congestion may occur. We consider two different classes of service: a priority one and a non-priority one. For example, the priority ones could originate from the operator's customers, while the non-priority ones can be from incoming other operator's customers.

The advantage of Lora is that it's free of charge and integrates real handover mechanisms, making it 'suitable' for the development of non-critical vehicular applications. Beyond Lora, what's interesting is the possibility of using trajectory prediction to manage network resources. The study considers a scenario where a neural network-based vehicular mobility prediction is used to reserve the resource in advance. The remainder is organized as follows: the second part covers related work, then part III describes our approach. The fourth section presents the results obtained and the limitations. Finally, section V concludes this paper with the conclusion and some perspectives.

II. Related works

Several papers propose optimizations in LoRa resource allocation. These solutions often involve setting options such as Spreading Factor (SF) and Transmission Power (TP) [8]

[9] [10] to ensure good performance. With the arrival of 5G, which promotes the association of several networks, and new technologies such as SDN (Software Defined Network), approaches taking into account the Quality of Services (QoS) are increasingly seen with slicing of the network into virtual sub-networks, each grouping EDs with similar QoS needs [11] [12]. These models are often based on mathematical models [12] or machine learning to do clustering [13] [14] to place devices in the right slices and are accompanied by methods of resource reservation by the slice. Still in QoS category, Lima et al. propose APRA an optimization of LoRaWAN resource allocation by juggling the different communication parameters (SF, TP, and bandwidth (BW)) [15]. Also, a PDR (Packet Delivery Ratio)–based QoS differentiation is proposed in [16] in a dense IoT environment. In [17], a new SF allocation model in LoRaWAN is based on load-balancing where each ED is initialized with an SF according to the RSSI and the SNR. However, most of these solutions are not designed for mobile devices due to ADR constraints.

To overcome this problem, BADR (Blind ADR), recommended by Semtech for mobile devices, uses a set of three SF values with SF12, SF10, and SF7 instead of a single DR as for ADR[18]. It presents satisfactory results in pet tracking compared to ADR. However, it does not consider the true mobility of the device since it will blindingly and alternately assign the 3 SFs regardless of the device's position with the GW. Some others solutions propose mobility handling [19] [20] [10] [21]. In [19], the authors provide an ADR enhancement for mobile devices following predefined mobility patterns (e.g. household robot, store camera, production line robot). They also rely on Received Signal Strength Indication (RSSI) measurements to determine the optimal transmission parameters. However, this approach has limitations for devices with unknown or undefined trajectories. Hence, its optimized version [21] is based on a Variable Order Hidden Markow Model (VHMM) to predict the node trajectory. Robbe et al. propose a mobility handling mechanism [20] that supports QoS. It relies on signal-to-noise Noise Ratio (SNR) measurements to identify different cases: exit, entry into a cell, on the PER desired by the ED and adjusts the SF and transmission power to obtain a reliable application while reducing energy consumption. This solution requires a modification at the ED level to introduce the desired PER. The signal reception power is measured in [10] to choose the initial SF considering the traffic differences (packet length) in the first step before choosing the right SF. This choice is based on the distance between the positions at the initial and current time. This distance is then compared to a constant α fixed at 10m (choice based on the constancy of RSSI up to 40m) to decide whether to change or keep the same SF. However, the solution requires calculations at the ED and GW levels. Moreover, it is only suitable for devices with low mobility. An evaluation of the impact of mobility with the use of LoRaWAN is proposed in [22]. The study compares two mobility models, the Random ways-point and the Gauss-Markov model, with the stationary model through simulations on FloRa with different scenarios. The PDR (Packet Delivery Ratio), the number of collisions, and the energy consumption are compared in various cases. HADR (Hybrid ADR) is proposed in [23] to meet the needs of applications alternating mobile and stationary conditions in response to ADR and BADR. It features a two-step mechanism starting with the computation of the distance between the current and previous positions of the device to evaluate its mobility. In the case of mobility, an optimized version of BADR is executed at the ED level using all the SFs. And in the opposite case, a modified version of ADR is run on the NS side. The performances are compared to ADR and BADR. [24] proposes a model based on the support vector machine (SVM) to determine the degree of mobility of a node because this would allow one to choose the adapted ADR algorithm without needing to know the trajectory of the node. They rely on the data present at the NS level, especially the RSSI and the SNR, as training data for ED classification in three classes: fixed, mobile, or deep indoor.

However, the speed and the rapid change of positions, with the density, are key factors influencing the quality of the received signal. The application of LoRa in the vehicular environment is relatively new, though more and more solutions are being developed. [2] propose experimentation of LoRa in a suburban setting to evaluate RSSI and coverage for two scenarios V2I and V2V, and two values of SF (7 and 12). Haque et al. propose in [25], an evaluation of the use of LoRa in V2I and V2V communications. In these exchanges, the ED relies on the RSSI measurements from the GWs in the V2I framework to choose the most optimal. Moreover, the V2V messages are made directly without passing by a GW. They also demonstrate the impact of the Kalman filter in stabilizing the received RSSI. Nevertheless, the GWs are relatively close (380 m), and the energy consumption is somewhat high compared to classical LoRa solutions (about 266 h max). In the same context, a study of LoRaWAN in the vehicular environment is proposed in [26] with a comparison of a simulation on NS3 and real experimentation. The impact of mobility with different speeds is evaluated with metrics such as RSSI, PDR, and PIR(Packet Inter-Reception) time. The results show consistent values between the simulation and the real experimentation. However, the authors still note the need to use a robust model. Similarly, Torres et al. consider a simulation and an experimental study of V2V and V2I communications in LoRa to evaluate the reception power, the received signal rate, and the Doppler effect in the suburban context [27].

Thus, as we can observe, most of the LoRaWAN optimizations in mobile do not consider very dynamic environments such as VANETS. Moreover, the topics related to LoRaWAN in vehicular mainly concern application or experimental studies to see the compatibility of LoRa with VANETs. Thus, the optimization of LoRaWAN in VANETs remains a relatively unexplored topic. In this paper, we try to go in this direction and see the effect of resource reservation in LoRaWAN.

III. Proposed approach

Our paper uses the traces of the city of Rome [28] and the mobility predictor in [29], where the same dataset was used and validated. For each input, four positions are predicted corresponding to the positions at t+1, t+2, t+3, and t+4 with t the current time. The antennas are placed virtually on the map (520 antennas) about 7 km apart. Each antenna hosts an NS. The antennas are pseudo-randomly divided into 5 operators (Normal law). The following figure represents the positions of the antennas and their distribution according to the operators. Each color designates an operator.

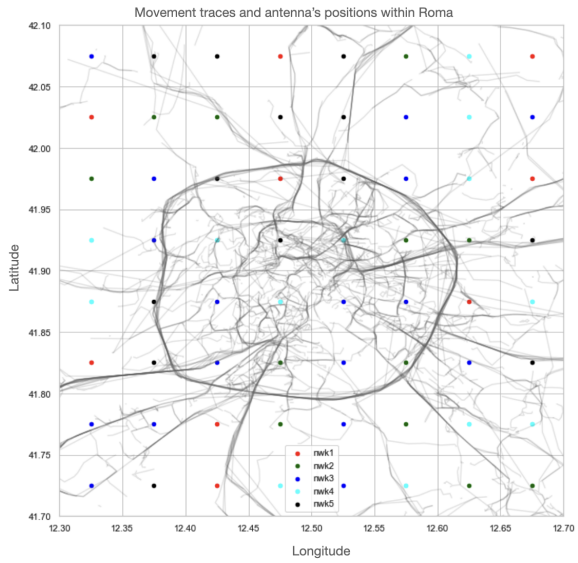


Fig. 1. Antennas distribution per operator within Roma

Our approach consists of two mechanisms: service differentiation and reservation.

A. Service differentiation

To implement service differentiation, we divide the traffic into two categories: priority and non-priority traffic. Traffic is prioritized if the operator to which the device subscribes is the same as the operator of the current antenna. It is non-priority traffic in case the subscription operator of the device is different from the home operator of the antenna the device is on. Only a device in priority traffic can make a resource reservation. Therefore, the resource reservation is exclusive to the device in priority traffic. This should favor the customers of the current operator at the expense of other roaming customers. We assumed each device starts from its home network (home NS and home operator). And from the first position, the home_operator is deduced for each device. Then, for the following positions, the home_operator of the current antenna is searched and compared to the home_operator of the vehicle to know the type of traffic (priority, non-priority).

B. Reservation

Resource reservation is only possible for priority traffic. This means that depending on the capacity of the GW/NS, the resource will be conserved for eventual priority traffic. Therefore, a non-priority device can only access a resource if there is remaining capacity outside the reservation. Thus:

- The standard join procedure is performed: the connection is allocated as best as possible, regardless of its class and according to the available capacity;
- Next, based on the results of the mobility prediction algorithm, reservations are made when possible on the predicted antennas (the base stations next to the one where the join is done) given a move and thus a next join. This is the reservation procedure.

These two mechanisms are illustrated in figure 2.

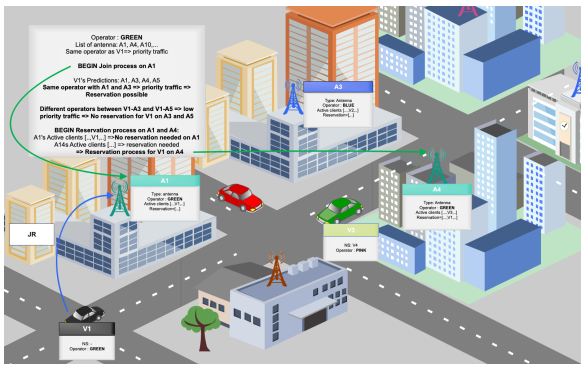


Fig. 2. LoRaWAN multi-operator resource reservation mechanism

We have studied two reservation mechanisms: nominative and non-nominative reservations.

1) Nominative reservation: This is the classic case. Every reservation is recorded with the car_id of the reserving party and the expiration date. In this way, a priority device with no reservation on the antenna is treated the same as non-priority traffic.

2) Non-nominative reservation: In this case, the reservations are only registered with their expiration date. Any device in priority traffic conditions can use a reserved resource without any prior reservation. So when a device arrives, we check if there is any reservation. If there are, we allocate the resources. Otherwise, we check if a resource is available (non-priority treatment).

We considered 4 parameters that could impact the scenarios:

- the reservation threshold: determines the maximum percentage of gateway capacity that can be reserved. A number too large is likely to cause many rejections for non-priority traffic, and hence for total traffic, due to unused reservations. And if the number is too small, there may be no service differentiation.
- the gateway capacity: corresponds to the amount of available resources and is calculated in terms of several devices, for simplicity's sake.
- the join interval: corresponds to the time a connection remains active between a device and an NS.
- reservation duration: determines how long a reservation is kept. This parameter may depend on the closeness

of antennas and traffic load, in turn, influenced by road conditions (traffic jams, rush hour), etc.

We are interested in the number of rejected joins called rejections because the notion of reservation, as defined here, intervenes during the join procedure that involves only two states: acceptance or rejection. Thus, evaluating the number of rejections seems to be the most appropriate criterion for measuring QoS. Fewer rejections mean more customers served from a global point of view. For a customer, this means a lower probability of being disconnected and unable to access the requested resource. This is one way of guaranteeing a certain quality of service. Other parameters like SNR and RSSI can be evaluated in the QoS but are managed at another level with other mechanisms, such as ADR. Thus, we evaluate the total and per-traffic type numbers of rejections for each reservation mechanism.

IV. Results and Limitation

A. Results

The total number of rejections per priority type is collected. The average rejection percentage is also calculated. For more visibility, values are left between 0 and 1. The closest antenna to the vehicle is chosen for prototype purposes.

1) Reservation threshold variation: Figure 3 describes the total, priority, and non-priority rejection ratios for the named and non-named reservation mechanisms, with a GW capacity of 400, a join time of 17 minutes, and a reservation time of 4 minutes. It corresponds to the average time it can take a vehicle to go from one antenna to another given that the longest distance between two antennas is about 7 km. The threshold 0.0 means a reservation of 0% of the total capacity, meaning no reservation. This is the reference point.

There are more rejections on priority traffic than non-priority traffic up to 10%. Then, it starts to have fewer rejections for priority traffic and the opposite for non-priority traffic. This can be explained by the fact that less than 10% of the traffic is booked and therefore treated as a priority, so more than 90% of the traffic is treated as non-priority. The rejections are higher due to unused reservations. As the reservation is nominative, only the device that made a reservation can use it. This leads to a total rejection rate higher than the reference, particularly when the threshold increases. The non-nominative version allows the minimization of these unused reservations and thus reduces the prediction errors. Since a device in priority can benefit from a reservation without having made one. At the 5% threshold, we see a clear difference between priority and non-priority traffic. This difference increases as the threshold increases. However, for very high reservation thresholds, this type of booking will generate more losses and converge as the nominative version.

The threshold at which the two mechanisms converge or start to generate more rejections depends on the number of requests, the capacity of the gateways, the join time, and the duration of the reservations. This leads us to study the variation of some of these parameters.

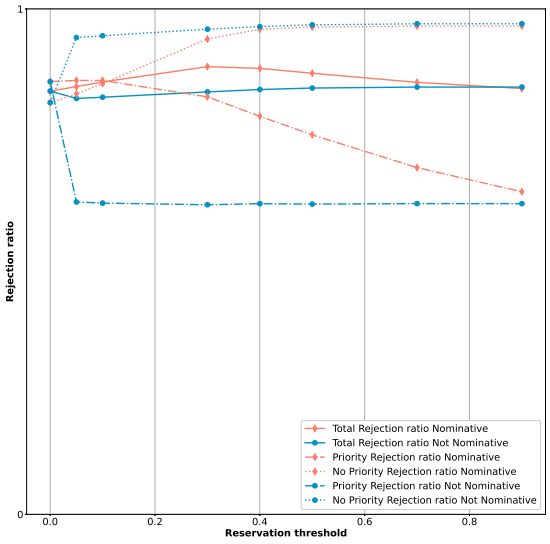


Fig. 3. Total, Priority, and Non-Priority rejection ratios for the named and non-named reservation mechanisms per thresholds, capacity=400, interval join=17$minutes$, reservation duration=4$minutes$

According to [30], a gateway can support up to 1000 nodes. To evaluate the impact of the different parameters (capacity, join interval, and reservation duration), we tested with a few antenna capacities: $200, 400, 600, 800$, and 1000. We set the threshold at 40% and vary one of these three parameters for each test.

2) Capacity variation: In the first step, the join and reservation times are set to 17 and 4 minutes, respectively. Then, we increase the capacity between 200 and $1,000$ devices per GW. Figure 4 depicts the total, priority, and non-priority rejection ratios for the nominative and non-nominative mechanisms depending on capacity. With an equivalent traffic volume, increasing the gateway capacity naturally reduces the number of rejections. This is particularly true for non-nominative reservations, whose priority refusal curve shows a pronounced downward trend. The more capacity the gateway has, the fewer unused reservations there are. As a result, we note more resources for non-priority traffic, particularly in the non-nominative mode and for both in the nominative case.

3) Join variation: To evaluate the impact of the join duration, we set the threshold at 40%, the capacity at 400, and the reservation time at 4 minutes. We test different values for join duration. Figure 5 represents the total, priority, and non-priority rejections for nominative and non-nominative mechanisms as a function of the joint duration. The join interval defines how long the resource is used before it is released. The bigger this interval is, the fewer resources there are for new arrivals. As a result, there are more losses. Moreover, each device has 10 positions in the used data set, so we have no information about what the device does after. A shorter

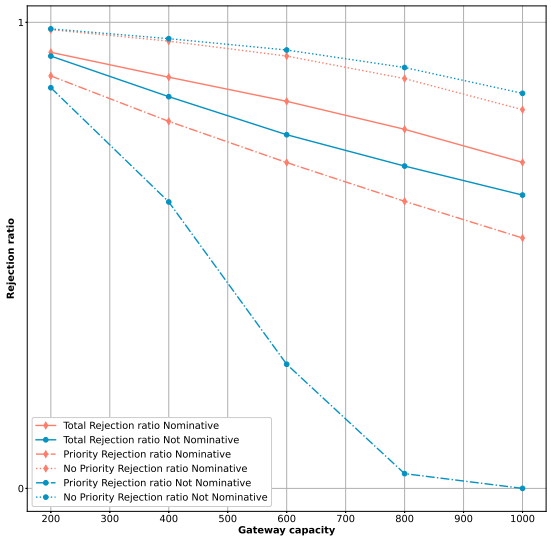


Fig. 4. Total, Priority, and Non-Priority rejection ratios for the named and non-named reservation mechanisms as a function of capacity,threshold=40%, interval join=17$minutes$, reservation duration=4$minutes$

junction interval allows a quick release of the resources at the last positions.

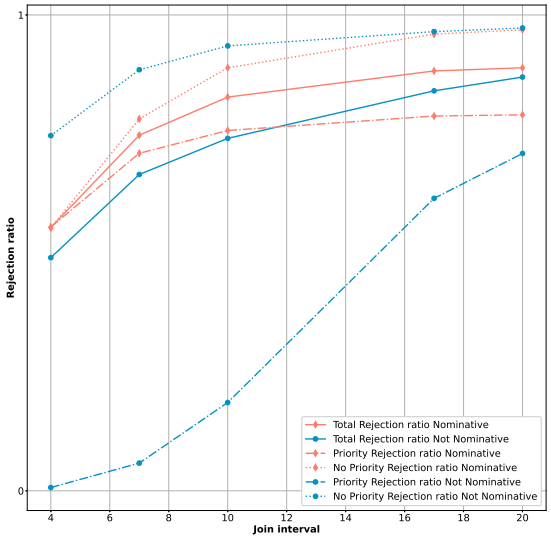


Fig. 5. Total, Priority, and Non-Priority rejection ratios for the named and non-named reservation mechanisms per thresholds, capacity=400, interval join=17$minutes$, reservation duration=4$minutes$

4) Reservation variation: For this section, the reservation threshold was set at 40%, the join time at 17 minutes, and the capacity at 400. Figure 6 represents the total, priority, and non-priority rejections for nominative and non-nominative mechanisms by reservation duration. The named reservation curves depict an inversion of the trends starting at a specific threshold, while reservation duration has little impact on the non-nominal mechanism. The reason may be that most reservations, if not used by devices that reserved them, may be used, sooner or later, by another device in a priority traffic situation. However, there is a slight difference for the nominative type. A device can make up to 4 reservations. These reservations are nominative and can only be used by the device that made them. A shorter reservation time reduces the number of unusable resources and increases the chance of having more devices covered.

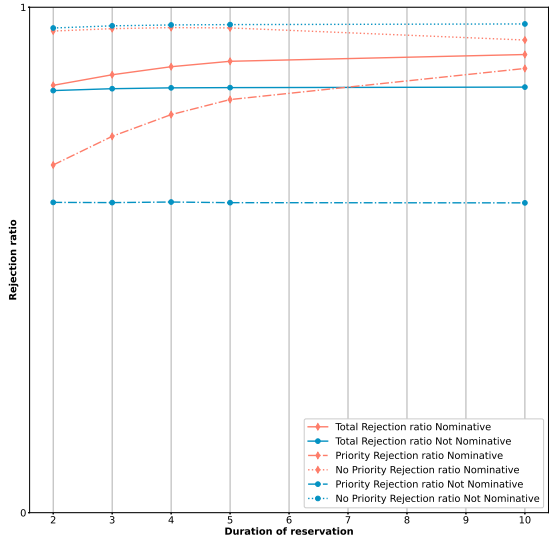


Fig. 6. Total, Priority and Non-Priority rejection ratios for the named and non-named reservation mechanisms per reservation duration, capacity=400, interval join=17$minutes$, threshold=40%

B. Limitations

The limitations concern firstly how the resource is reserved. In nominative reservations, the reserved resource can only be used by the device that made the reservation. As it can book up to 4 antennas, this means fewer resources for non-priority and priority traffic. In this case, reducing the duration of the reservations can be a solution. The Non-nominative mechanism avoids this issue, as reservations can be used by any device in a priority traffic situation. However, since the reservation is not nominative, a device in priority traffic without prior reservation on an antenna can benefit from the reservation made by another device if it arrives before. In addition, the reserved resource is deducted from the maximum capacity and cannot be used by non-priority traffic even if it gets to the antenna first. Lastly, we also assume that the

device communicates with only one antenna at a time and that each antenna hosts an NS, whereas, in practical situations, a message can be received by several antennas at the same time. The case studied here can be regarded as a worst-case scenario.

V. Conclusion

This paper presents a resource reservation mechanism in a vehicular environment for LoRaWAN-based IoT devices. Several simulations are conducted with different parameters to evaluate the evolution of the number of rejections. Two methods were compared. The Non-Nominative mechanism is the most optimal, with fewer rejections while offering service differentiation between subscribers and others. It is also the most computationally efficient method. The Nominative mode is more stable. It provides a more limited service differentiation than the Non-Nominative but with more rejections when there is congestion. Traffic differentiation is useful in QoS management to privilege primary subscribers in roaming states. Still, it can be applied to other directions, for instance, the needs in QoS differentiation between various application flows.

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