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BUILDING A CENTRALISED SMART CITY SYSTEM FOR URBAN MOBILITY MANAGEMENT AND SOLVING PROBLEMS RELATED TO PARKING AREAS, PUBLIC TRANSPORT AND ECO-TRANSPORT - SMART PARKING SYSTEM NETWORK ARCHITECTURE AND OPTIMIZATION[28]

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Abstract: *The goal in the development of traffic management systems, and in particular the implementation of complete intelligent parking systems in an urban environment, is to reduce personnel costs and optimize the use of all available resources. Currently, finding a parking space is usually random, with the driver finding one on the street based on sheer luck or multiple attempts. The process sometimes takes a lot of time and effort and, in the worst case, to the impossibility of finding a parking space. An alternative is to identify a specific paid parking lot that has a sufficiently large capacity and/or use prepaid parking subscription services accordingly. However, this is not an optimal solution, as it is usually possible that the parking lot in question is far from the user's destination.*

On the other hand, intelligent parking systems, and specifically those based on the streets themselves along the sidewalks, are based on LoRa nodes. The number of these networks is increasing due to their operation in the unlicensed radio frequency bands and their easy and relatively cheap construction. The scalability of such networks suffers as the number of deployed devices increases. Performance drops due to increased contention and interference on unlicensed LoRa frequencies. This leads to an increased number of dropped messages and therefore to unreliable network communication.

Keywords: *Smart City, smart solutions, public transport, eco transport, LoRaWAN network, API and central database, smartphone app, Android, iOS, Validators, Centralised system, Web applications, Servers, efficiency, GPS*

INTRODUCTION

In the most general case in an urban environment, we can divide into 2 main types, dedicated parking spaces (Geng, Y., & Cassandras, C., 2011). The first type is the "Classic" parking lots, where we have a designated large area that is separated in some way from the rest of the city infrastructure, either by enclosures if it is of the open parking type, or if it is underground, above ground or ground, then it is part of some building or dedicated infrastructure. Access to this type of "Classic" parking

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lots at the Entrance/Exit is carried out on the principle of controlled access mode, and in the most general case it is a barrier controlled by accompanying hardware and management software (Pham, T., Tsai, M., Nguyen, D., Dow, C., & Deng, D., 2015).

Such type of parking lots can be both municipal and private property, and usually access to them is paid when they are intended for public use and in other cases they are intended for the own needs of a department or company, so that they are free for employees and access is limited only for a certain number of people.

The second type of parking is the designated parking spaces along the streets and boulevards themselves, where this is possible and allowed, of course, and in the general case they are municipal property (Zhao, X., Zhao, K., & Hai, F., 2014). Since they are entirely in open public areas, there is no way for them to be on a controlled access regime. Control over them is carried out by municipal employees who are responsible for certain parking areas and check the registration numbers of the cars to see if they have paid for their stay and in case of detected violations, they call the appropriate technical means for repatriation or violators are placed with restraining brackets. It is this second type of parking that is the subject of the Smart Parking system and the corresponding consideration of the network architecture of LoRa Nodes and LoRa Gateways, on which it is based. In the most general case when building such an intelligent integrated system, the idea briefly described is that each parking place is a LoRa Node, and one or several nearby parking areas of this type can be served by a LoRa Gateway (Concentrator).

EXPOSITION

In general, both types of parking exist in an urban environment, and in order to have a true universal integrated system, it must effectively manage all municipal parking areas, either type 1 or type 2, as this is provided for in its hardware and software architecture. First, we will look at the architecture of the "Classic" type of parking zones and how to effectively use the capacity we have in total from these zones. The architecture of the classic parking network (CPN) is shown in Fig. 1, where the dashed lines indicate a wireless connection and the solid lines indicate a wired connection. This type of network consists of routers that form the backbone of the CPN network to allow sensor networks to connect using wireless radio technologies to the centralized servers. Routers form a self-configuring and self-healing network, which is also called infrastructure connectivity.

We assumed that each parking lot is a node in the CPN. The network for deployment in a real environment is shown in Fig. 2, where each parking lot is marked. This network can be represented by a graph (Fig. 3), where:

P_1 is parking number 1; N_1 is the total number of parking spaces in P_1.

P_2 is parking number 2, N_2 is the total number of parking spaces in P_2.

P_n is parking number n, N_n is the total number of parking spaces in P_n.

The total capacity of the system is $N=N_1+N_2+N_3+\ldots+N_n$ (spaces). D is the actual distance between two nodes in the network. D_{ij} is the distance between nodes P_i and P_j. Fig. 4 shows the network, with the numerical representation of the relations between all parking spaces (the graph vertices).

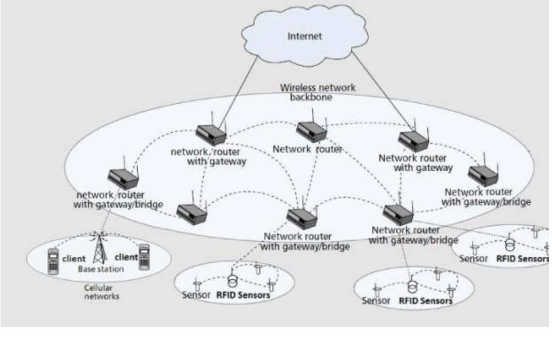

Fig. 1. The architecture of the parking network

Fig. 2. The network deployment in a real environment

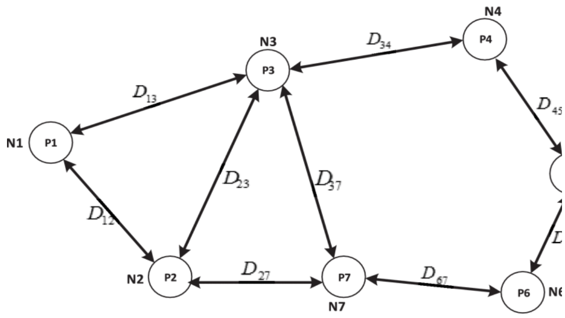

Fig. 3. The network represented as a graph

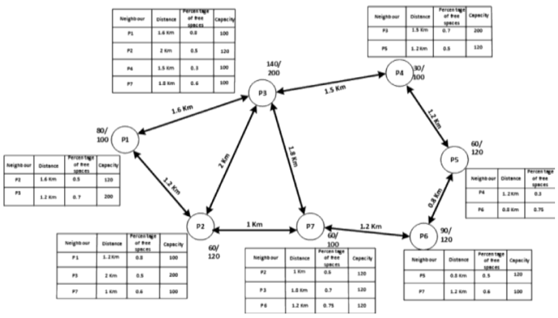

Fig. 4. The numerical values and the relations between the graph vertices

Each node has an adjacency table to maintain information about the current state of the network and a queue with a predetermined length. The neighbour table for each node contains information about the neighbouring nodes directly connected to it. On the other hand, queuing is used to control the number of vehicles forwarded to the node, which aims to prevent the number of vehicles from being overwhelmed beyond the capacity of the node. In this system, each node will broadcast a message to its neighbouring nodes after a new node joins or leaves it. This message includes information about all resources. The neighbour node that receives this message will update its neighbour tables (Pham, T., Tsai, M., Nguyen, D., Dow, C., & Deng, D., 2015).

As we have already discussed about the network architecture of the "Classic" type of parking lots, it is simply necessary to ensure a reliable network infrastructure connection, wired or wireless, this is a matter of the specific conditions and available possibilities in relation to the specific parking areas. Because with this type of parking, there is no need to have a sensor for each individual parking space, and the number of occupied/vacant spaces is determined by the software by counting at the Entrance and at the Exit, respectively entered/exited.

This is not the case with the second type of parking lots, which we have already mentioned, since we do not have fenced areas with controlled access. For this, here we already have an additional network layer, which for brevity we will call the sensor layer, and in fact it is the layer of the LoRa network (Fig. 5). The network architecture of the Smart Parking System, which is part of the Smart City integrated system for efficient management of urban mobility and specifically in terms of parking, public transport and eco-transport, largely follows the standard IoT network architecture (Fig. 6).

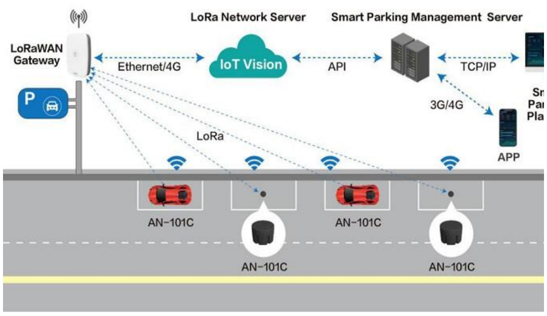

Fig. 5. The LoRaWAN-enabled devices from the sensor layer in the parking network

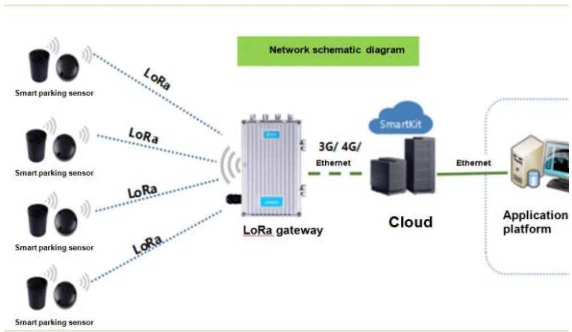

Fig. 6. The schematic diagram for the connectivity in the parking network

This would not surprise anyone, since the path of information from each particular parking place to the central server is in sequence as follows (Fig. 6):

Ultrasonic Sensor > LoRa Node > LoRa Gateway > Internet > Central Server

Following this path and starting from the specific parking space, the first element is the parking sensor, which in our case is an ultrasonic sensor and is not located in the asphalt, as with other similar systems, but is located in a parking peg on the sidewalk in close proximity to the parking space itself. This parking peg has the function of a marker of the parking space itself, and also has a printed QR code containing the UUID of the specific parking space, for identification and payment for the service used through the Smart Parking System mobile application. The parking peg also houses the LoRa Node and a battery power supply, sufficient to power the sensor and the LoRa Node for up to 5 years from its placement. The function of the LoRa Node is to read the information from the ultrasonic sensor, i.e., 2 states: THERE is or is NOT a parked car, periodically transmitting the current state to the LoRa Gateway or in other words to the hub according to its settings. The concentrator collects the information from all LoRa Nodes in a given parking area and, according to the set timing and the corresponding protocols, forwards them to the next network layer, either via the Internet via the 3G/4G network of a mobile operator, or the above-mentioned network infrastructure connection can be used. which was built for the first type of parking lots. This is a matter of technical decision relative to the specific situation and should be approached carefully and a judgment made for the most economically advantageous solution without affecting the quality of data transmission.

LoRa is a promising solution for smart city applications as it can provide long-distance connectivity with low power consumption. The number of LoRa-based networks is growing due to their operation in the unlicensed radio frequency bands and the ease of network deployment. However, the scalability of such networks suffers as the number of deployed devices increases. In particular, network performance is declining due to increased contention and interference in unlicensed LoRa radio frequencies. This leads to an increased number of dropped messages and therefore to unreliable network communication.

Low-power wide area networks (LPWANs) are a new class of communication networks aimed primarily at battery-powered and resource-constrained (IoT) devices. LoRaWAN is one such solution that relies on the LoRa (long range) physical layer to provide long-distance (in the order of kilometres) connectivity at low data rates and with low power consumption. Devices only need to sporadically send a small amount of data, which is adequately supported by LoRa data rates. Low power consumption ensures that IoT devices do not need replacement for at least 5 years.

Smart city applications, such as the Smart Parking System in our case, are characterized by a huge density of devices that must communicate with very low energy over long distances. However, the performance of LoRa networks decreases as the number of deployed devices increases, especially in urban areas where devices are typically located indoors. As these devices share access to unlicensed spectrum, radio frequency bands become congested with increased collisions, resulting in missed messages.

Network reliability is further degraded by the specifics of the urban environment, as well as by the limitations on the frequency of messages, and also by the competitive access of individual Nodes to the environment in LoRaWAN. Nevertheless, the performance of LoRa-based networks can be improved by appropriately configuring the radio parameters of each node, namely their spread factor (SF) and transmission power (TP). Briefly, we will focus on a method for dynamically adapting these parameters to improve reliability and energy consumption through a standardized Adaptive Data Rate (ADR) method. Unfortunately, this approach has several important limitations. In particular, ADR requires a long duration (hours to days) to reach ideal parameters for all nodes in a network. Such a long convergence time can lead to a significant amount of dropped messages, thus seriously reducing reliability. Therefore, it is essential that nodes already use the optimal parameters needed to ensure reliable transmissions during deployment.

A LoRa network involves low-cost, battery-powered end devices (or nodes) that communicate with hubs over the LoRa physical layer. Nodes send packets to hubs whenever there is data to communicate, i.e., they rely on an ALOHA-based MAC protocol. Such a protocol allows to keep the complexity of the nodes low (Bankov, D., Khorov, E., & Lyakhov, A., 2017). LoRa nodes are not connected to a specific hub - a message sent by a device is received by all gateways within its communication range. Gateways simply forward all received messages to a central network server where the core intelligence of the network resides. The network server manages the network and filters the duplicate packets received by the gateways. It also communicates with application servers that provide the actual business logic for processing data generated by each device (Rizzi, M., Ferrari, P., Flammini, A., & Sisinni, E, 2017).

In the optimal determination of the LoRa transmission parameters, the target network to be configured consists of one or more LoRa Gateways (denoted by set J) and LoRa nodes (denoted by set I). All nodes are stationary and d_{ij} denotes the distance between node i (i∈I) and gateway j (j∈J). Each node can use SF from a set of SF (S) and TP from a set of TP (P). The elements in S and P are discrete integers that depend on the region of operation. Nodes can be within the scope of one or more gateways; we assume that all nodes can reach at least one gateway with the highest TP. The path loss (in dB) between node i and gateway j is represented using the log distance path loss model.

$$PL_{ij} = \overline{PL}(d_0) + 10n\log\left(\frac{d_{ij}}{d_0}\right) + X_\sigma \backslash \text{tag1} \quad (1)$$

where $PL(d_0)$ is the average path loss over distance d_0, n is the path loss rate, and X_σ is a zero-mean Gaussian random variable with standard deviation σ. The gateway receives messages sent with the SF if the received power is above the receiver sensitivity (tol) for that particular SF.

The probability of collisions in SF follows from the ALOHA channel model, where nodes transmit data based on random access. Equation (2) represents the probability of collisions in a network with one gateway j and in a particular SF s

$$\mathbb{P}(s,j) = 1 - e^{-\frac{2^{s+1}}{s}\frac{L}{B}f_{js}\lambda} \backslash \text{tag2} \quad (2)$$

where λ represents the traffic per unit time, f_{js} is the fraction of nodes transmitting with SF s in the range of gateway j, B is the bandwidth (in Hz) and L is the packet length (in bits). The probability of collisions affects the delivery ratio in the network; i.e., if P(s,j) increases, fewer packets are successfully delivered and thus the delivery ratio of the network decreases.

To describe the problem, we aim to optimally assign SF and TP to all nodes, so that the network can reliably transfer messages with a high delivery ratio while maintaining low energy consumption. However, assigning SF and TP to nodes presents certain challenges and some unique trade-offs. To illustrate this, Fig. 7 presents a simplified scenario with four nodes (|I|=4), two gateways (|J|=2), two TPs (|P|=2) and four SFs (|S|= 4).

The dotted rings in Fig. 7 represent the range up to which SF can be used at a given power level p. A node can be configured with SF based on the region (A–D) in which it resides. Nodes should use higher SFs as the distance from the gateway increases. For example, in Fig. 7 Region A allows the use of any SF in {7,8,9,10}, region B allows {8,9,10}, etc. Furthermore, the region (and therefore the presence of SFs) depends on TP p. For example, in Fig. 7(a), Node 1 can use s∈{8,9,10} at the highest TP, while the same node can only use s∈{9,10} to reach Gateway 1 when configured with lower TP (Fig. 7(b)). Additionally, the node is not associated with a specific gateway. This means that transmissions from a node with certain SFs can be received by multiple gateways. For example, in Fig. 7(a), Node 2 can be configured with SF 9 or 10. In the first case (with SF 9), its transmissions are received only by Gateway 2, while both gateways can receive their transmissions with SF 10. By this way the effect of the node handing over multiple gateways must be considered. Finally, there are trade-offs in the assignment of SF and TP. Transmissions at high SF are performed at a low data rate, which implies that the time required to send a packet is higher. This increases power consumption because the radio remains in the transmit state (or high-power state) for a longer time. However, lower SFs can only be available at high TPs, which in turn increases power consumption. The goal is to optimize the association of SF and TP to each node in the LoRa network, so that both the probability of collisions and the energy consumption are as low as possible. Considering the dependence between SF and TP selection, as well as the large problem space with dense networks, the optimization problem for LoRa parameter assignment is divided into two stages. First, SF assignment is optimized based on all nodes using the highest TP. After the SFs are assigned, a second optimization problem determines the actual TP for each node, so as to minimize the total energy consumption of the network (Premsankar, G., Ghaddar, B., Slabicki, M., & Francesco, M., 2020).

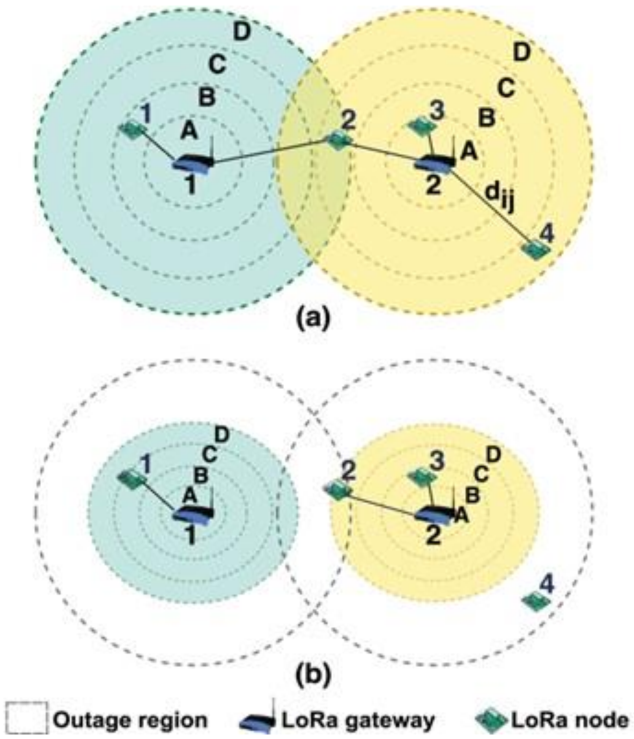

Fig. 7. The example network scenario used to describe the SF and TP assignment problem

CONCLUSION

The introduction into real operation of such a Smart Parking system is a serious investment for a municipality, and before such a step is taken, it is necessary to seriously weigh the financial benefits when introducing the intelligent parking system. It will undoubtedly improve efficiency and is proven to solve some of the known parking problems.

First of all, such a system will put an end to uncontrolled parking, with more and more blue and green zones for paid parking. Second, the collection of parking fees will be drastically increased. The sales of parking tickets will also be greatly enhanced, as will the effective collection of fines from offenders, as the system itself will quickly and accurately detect such cases and immediately inform the relevant officials. Thirdly, such a system will reduce the number of control officers in the Blue and Green zones, respectively the costs of wages and insurance, since 1 officer with a smart device and the corresponding software will be much more effective in detecting violators and imposing penalties, as and will be able to cover much larger areas than the Blue and Green Zones.

In addition to the financial aspect, the design of such a system must be approached very carefully, in the construction of the network architecture of the individual layers, respectively the main transport network layer (LAN/WAN) and the sensor layer (LoRaWAN), in order to achieve the best possible results at data transmission, with minimal packet loss and with the lowest possible energy consumption for the individual Nodes in the sensor layer. For this reason, already during the design, one should think about maximum optimization when deploying and configuring the individual LoRa Nodes and LoRa Gateways in the architecture of the sensor layer.

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