IoT Enabled Optimized Architectures for GPS Anti-Theft Tracking Devices

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Abstract— In this paper we summarize in a split direction state of the art survey – marketwise and research-oriented and we present a twofold IoT enabled, anti-theft system architecture – one oriented towards bicycles, that do not have a battery or its own electrical system and one oriented towards electrical vehicles such as electrical bikes/scooters and cars. We corroborate the hardware architecture with a functional software architecture, that can be easily used on both solutions. In the end, we present the relevant results of a case study implementation of the architectures: the tracking map resulted from continuous monitoring of the GPS position and periodical transmissions by GPRS connection and the variations in SMS receiving times.

Keywords— IoT, anti-theft, tracking, autonomous system.

I. Introduction

Tracking your belongings, if it is a bike, a motorcycle, car, some merchandise or any other stuff ads more security to that entity and makes you feel less stressed knowing the exact location of your stuff. This project aims to give the possibility to people to use GPS tracking and on-time reporting of the position, without having to bother with the dimensions of the tracker.

As the number of bikes has increased, bike thefts has kept the same trend. For a car there are plenty of possibilities to delay the attack or to scare the attacker and modern cars have incorporated key less detection of the owner and GPS tracking. Bicycles on the other hand have little or almost none alarm system. On the market there are different alarm systems or tracking systems for bikes, but they are exposed and visible. These systems are encapsulated in a bike light or back-light, which is exposed and the thief can easily detach it and throw it away.

In this paper we summarize in a split direction state of the art survey – marketwise and research-oriented and we present a twofold IoT enabled, anti-theft system architecture – one oriented towards bicycles, that do not have a battery or its own electrical system and one oriented towards electrical vehicles such as electrical bikes/scooters and cars. We corroborate the hardware architecture with a functional software architecture, that can be easily used on both solutions. In the end, we present the relevant results of a case study implementation of the architectures: the tracking map resulted from continuous monitoring of the GPS position and periodical transmissions by GPRS connection and the variations in SMS receiving times.

II. Market study

The number of cyclists is rising continuously and mayors and administration of most and most countries take supportive measures to help the cyclists manage through the city. Netherlands is a country where the number of bicycles is higher than the number of cars and almost each citizen has a bicycle [1].

In the Netherlands 27% of all trips and 25% of trips to work are made by bike and bike theft is a big problem, with about one of five (20%) bicycles being stolen each year.

Denmark is recognized as one of the most bicycle friendly country in Europe. There are bicycle paths, and a lot of stations where people can rent bicycles to reach different points of the city. 37% of all citizens ride their bike on a daily basis.

Besides Netherlands and Denmark, other countries such as Germany, Sweden, Norway, Finland, Switzerland, Japan, Belgium, China and many others promote bikes and the adoption of bikes.

- In Germany 9% of all trips are made by bike.
- In Sweden 9% of all trips are made by bike.
- In Norway 4% of all trips are made by bike. In Norway, with a population of 4,943 million people and 3 million bicycles, 60.000 bicycles disappear each year, never to be seen by their owners again. Most bicycles are stolen from places owners assume are safe. An experienced thief can take even locked bikes in about 10-20 seconds. On the streets, the value of a stolen bicycle is approximately 5-10% of the bicycle's original retail value, with an inverse relationship between value and percentage worth on the street. About 10% of the stolen bicycles are exported to Russia and Eastern Europe.

- In Finland 9% of all trips are made by bike.
- In Switzerland 5% of all trips and 10% of trips to work are made by bike.
- In Belgium 8% of all trips are made by bike.
- China: 60 percent of local cyclists in Shanghai (most populous city in China) pedal to work every day. The city is home to 9,430,000 million bicycles and 19,213,200 people. Regarding the bike thefts, CBS [2] gives some references about the percent of victims compared to their age. Most of the bike theft victims are young people, 15 to 24 years old, followed closely by 25 to 34 year old bike owners, as seen in Fig. 1.

Maybe unexpected, but in the same study, CBS shows that the higher the degree of urbanization, the higher the number of victims, as seen in Fig. 2. With a higher degree of urbanization, the density of the population increases, and the numbers of bikes. Since, usually, in highly urbanized zones the average income is higher than in less urbanized zones, people afford having more expensive bicycles. The more valuable the bike, the higher the attraction for bike thieves, and hence, the higher of number of victims.

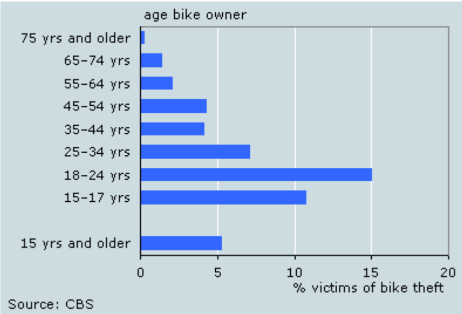

Fig. 1 Percent of bike theft victim's vs age of victims [2]

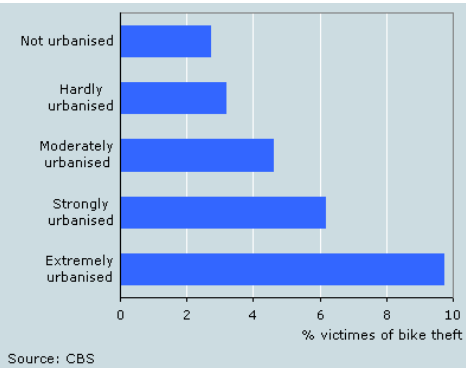

Fig. 2 Percent of bike theft victim's vs urbanization level [2]

III. State of the Art

Since the beginning of bike theft, people are looking round a clock for different solutions. The most used solutions are blocking systems that make bicycle stealing harder. Some bikers have even bought 15mm thick metal cables that are usually used for blocking motorcycles to block their bike. Unfortunately, not one of these solutions have eliminated or even reduced the problems of bike theft. Most of the classical blocking devices can be destroyed by thefts in tens of seconds.

Still, some new ideas and devices have appeared on the market that allow easier locking and unlocking for the bike and they claim that they are indestructible. In the following we will present some of the well-known locking devices.

A. Commercial solutions

BitLock (Fig. 3) is an intelligent bike locking system that can be controlled by a smartphone using Bluetooth. The product is advertised as being a reinforced lock, made out of heat-treated and cut-resistant steel that is resistant to bolt cutter and hacksaws. The lock is also mentioned to be waterproof and to have an extended temperature range of operation. It is available for 119$ for preorder, 15% off Retail. Besides the lock function, the device can also record the average speed, distance traveled and other such parameters [3].

Similar to *Bitlock*, *Skylock* (Fig. 4) is a smart locking system that has 3-axis accelerometer, LED indicators, capacitive touch interface, active motor control, shackle insertion detection, weather resistant, shockproof and ruggedized, steel shackle, steel internal housing, impact resistant rubber shell, Wireless, Bluetooth 4.2, Trace PCB antenna, Power & Battery, Built-in rechargeable LiFePo4, Thin Film Solar Panel, USB charging, Software Compatibility, Apple iOS 6.1 or greater, Android 4.0.3 or greater [3].

SpyBike is also a GPS tracking device, but a hidden one this time, therefore its name. It practically spies on the thief who ran away with your bike, confident that you lost track of him for good. *SpyBike* is hidden inside your bicycle steerer tube, and looks just like a normal head cap, in order to avoid suspicion. If the bike is stolen, you can use *SpyBike* to track the movements of your bike through GPS. *SpyBike* contains a motion sensor, which awakes when it detects prolonged movement. At this point, it will immediately send you an SMS informing you that the bike is on the move, and its whereabouts. The device will pause when the bike is no longer moving, and will resume its warnings and GPS tracking when the bike is on the move again.

SpyBike TopCap (Fig. 5) is a cylindrical device that can be put inside the frame so that no one would suspect a tracker. *Spybike Seatpost* (Fig. 6) it is a bicycle tracker that hides by masking itself as a seat post. Inside, like the first presented *Spybike*, contains a GPS tracker and a high-capacity battery for longer autonomy.

Lock8 (Fig. 7) is a bike lock which is triggered not by a physical key, but an average Smartphone. It also has an integrated GPS system which allows you to know the exact location of your bike, at any moment, and share your location with other friends which use the same tracking device. It is provided with a magnetic induction system, so the battery charges while you're cycling. It also features a quite powerful alarm, which goes up to 120dB. According to the producer specifications, the system is quite durable, since it provides a weather resistant, industrial strength Polycarbonate shell [3].

Helios (Fig. 8) is a quite similar tracking device, without the cable lock system though. The *Helios Bar* which will replace the original bike horns, contains a GPS device that allows the owner to track the location of his or her bike anywhere in the world. The bike owner has only to insert a SIM card in the device, and, in order to retrieve the bike location, all one has to do is to send the "bike" a SMS, and the device will respond with a SMS containing a GPS map with the actual location of the bike. The *Helios Bars* comes in different forms and sizes, in order to match the characteristics of different bike models [3].

Fig. 3 BitLock [3]

Fig. 4 SkyLock [3]

Fig. 5 SpyBike TopCap [3]

Fig. 6 SpyBike Seatpost [3]

Fig. 7 Lock 8 [3]

Fig. 8 Helios [3]

B. *Recent research word and projects*

Recent work of peer researchers shows that there is a high interest in the subject regarding vehicle and bike tracking. There are many approaches that address the previously mentioned issue.

- One approach is to develop a system that: *is autonomous, use GPRS/SMS/3G/4G/5G communication, use GPS system localization method*. In addition to these specifications, some solutions allow interaction with the vehicle (or with the smart bike/electric bike) through On-Board Diagnostics (OBD) interface or with a simple immobilization relay.

  Systems that rely on this topology and architecture are presented by the researchers in [4], [5], [6], [7]. Some of them are dedicated to bike theft protection, some of them are dedicated to car tracking (without interfacing with the car system) and some of them can interact with the car's electrical system and can detect the ignition contact and can activate an *ECU Kill Switch* or other immobilization systems.

- Another approach is to develop a complete infrastructure that allows localization using trilateration/triangulation methods. These systems use Bluetooth, LoRa or ZigBee technologies and are based on the reported RSSI of the on-board modules. The communication of the position of the vehicle or of the bike is made using the same low power modules that rely on the developed infrastructure.

  A motorcycle anti-theft system based on BLE 4.0 is proposed in [8]. The authors show that the experimental results prove that the proposed system can be used in real situations, for example in the Prachinburi province in Thailand. In [9] the authors present a different solution, based on ZigBee modules. The authors state that their concept provides the capability to determine the location of an electric bike using RSSI, providing anchors for trilateration using ZigBee modules.

- Other solutions rely on vision based and AI detection using images of the vehicles in traffic.

IV. Proposed Architecture

Based on the functional and structural architecture of both commercial and peer researchers' solutions identified in Section III we propose two structural architectures:

A. *IoT enbaled tracking system architecture dedicated to bike monitoring solutions*

We present in Fig. 9 our optimized architecture for a flexible IoT enabled device that allows remote monitoring with anti-theft capability. The system is powered by a main battery that can be detached from the bike and recharged by the user. Optional, for a higher reliability and redundancy, during the recharge of the main battery (or if the main battery is identified by the thief), the anti-theft solution is powered by a secondary rechargeable battery inaccessible without unmounting the device. The secondary battery is afterwards recharged from the main battery. This allows for a higher autonomy and a redundancy in powering the device. The module allows configuration through a Bluetooth connection. When the user is away, and the Bluetooth module does not detect the *legit users' phone*, the device can be triggered by movement of the bike (using an embedded accelerometer – e.g., ADXL345). When a trigger occurs, the GPS module is activated, and after the localization is possible, periodically, the location of the bike is sent by SMS to the user, or it is continuously uploaded on a webserver using GPRS connection. Simultaneously, a high-power alarm siren is turned on, to scare the thief away or to attract attention of the nearby people.

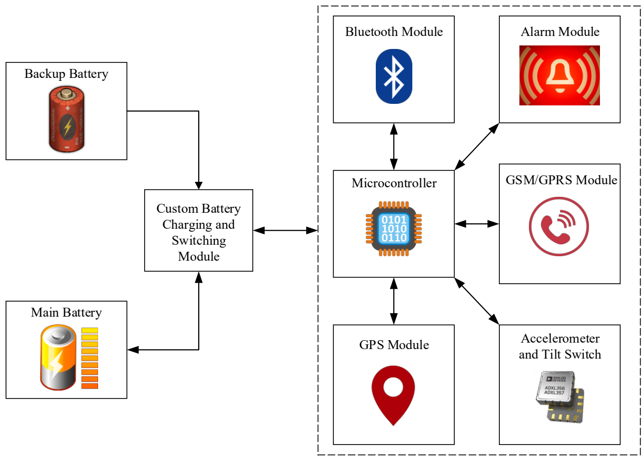

Fig. 9 Bike Monitoring System Architecture

B. *IoT enabled flexible vehicle anti-theft system architecture*

We present in Fig. 10 our optimized architecture dedicated to car/electric bike/electric scooter and other electric vehicles that allows extended functionalities such as OBD diagnostics, ignition/motor inhibit system (using a simple *Kill Switch immobilizer*).

Like the system presented in subsection A, the system has an internal redundant battery that allows it to operate, even if the main power source is not present (the tracker is disconnected from the vehicle's battery). Besides the accelerometer and tilt switch that detect physical interaction with the vehicle, all the positioning methods (GPS) and communication modules are present (GPRS/Bluetooth). In addition, the architecture allows the use of an OBD extension for remote monitoring (for car fleet solutions) of the vehicle parameters and a vehicle immobilizer method (*ignition remote controlled kill switch*). The functionality of each module can be configured through the Bluetooth connection.

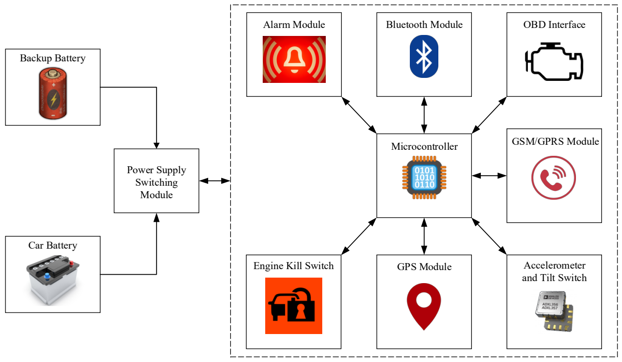

Fig. 10 Vehicle Monitoring System Architecture

C. *Software architecture*

For the hardware architectures previously presented, we now present a simplified functional diagram of the software and of the functionalities. In Fig. 11 we have represented the 4 main elements that constitute our system:

- The anti-theft **device** (that can be used on a bike or on a vehicle)
- The **Server**
- The **Web Client application**
- The mobile **terminal**

When the anti-theft is triggered, it immediately activates and it transmits by SMS data regarding the current position (determined initially from the GPRS module cell localization, and afterwards, using the GPS module) to the mobile terminal. The device also initiates a TCP connection (or UDP transmissions, based on the configuration) with the server and transmits all available data to the Server. The data is presented to the user through the Web Client application or through a website.

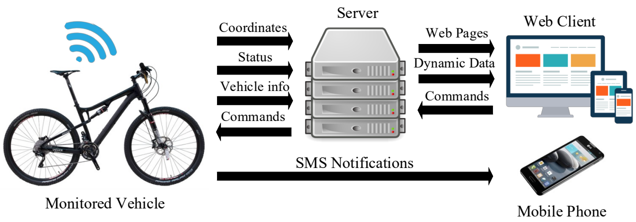

Fig. 11 Software Architecture

The device can receive commands from the server for different actions (deactivation, or car immobilization procedure activation), kill switch activation, etc. As one can observe, there is a bidirectional communication between the device and the server, and a simple bidirectional communication between the device and the mobile terminal. From the mobile phone the user can send a command to the tracking device. If there is no internet connection available (no signal), when a connection can be established, or when a SMS can be sent, the lase GPS position is reported. Since the main objective of the system is the localization and not a complete itinerary of the tracked vehicle, there is no need in sending more than the current position.

D. *Overall view of the system*

In Fig. 12 we have represented the intended use case and logic of our system. The vehicle, that is being tracked or monitored is localized using GPS when the system is triggered (remote, or by movement, through the tilt sensors or accelerometer). Afterwards, the GSM module is activated, and the localization data is sent through SMS to the user and data is uploaded into the cloud. Initially, until the GPS module can compute the coordinates based on GPS signal, and, post-initialization, the GPS coordinates are sent. Data from the cloud can be later used to reconstruct the itinerary of the tracked vehicle. We consider all situations, where the mobile phone can be connected either to cloud, or it can either receive SMS.

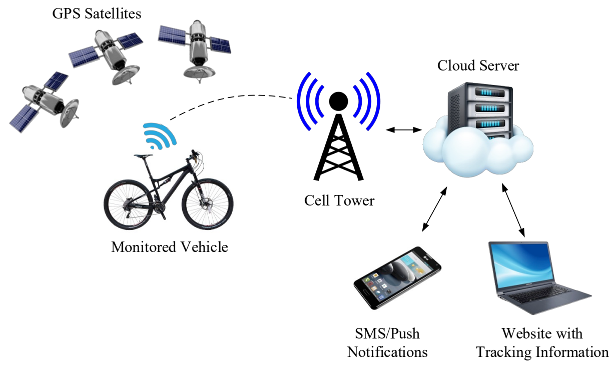

Fig. 12 System Use Case

E. *Modules used in the implementation of the architecture*

To test our architectures and to validate the functionality, the feasibility, and to measure the performance, we have chosen to use the following models:

Accelerometer: ADXL345[10]. We have chosen ADXL345 because of its simplicity, the wide temperature range, ultralow power characteristics and Interrupt Mode working capability. It is used to signal that an event has happen in order to activate the processor from its sleep state.

GSM Module: For the GSM module we have chosen the Quectel M85 GSM module development board that can be easily controlled using AT commands [11].

Bluetooth Module: We have used a HC-06 Slave Bluetooth module, because of its low power consumption and simple command instructions. [12]

Microcontroller: For proof of concept, we have used an Mbed NXP LPC1768 microcontroller. It provided us with enough UART serial communication interfaces, 512KB Flash memory for our software, 32KB RAM and 96MHz of processing power. [13]

GPS Module: We have used a SiRF Start IV 48 channel GPS Receiver EM-506 that can provide superior sensitivity and performance in urban and dense foliage environments. [14]

Tilt switch, alarm, OBD Interface: for the tilt switch we have used a mercury switch, the alarm, for the proof of concept, was implemented with a buzzer and as for the OBD interface we have used a MCP2515 [15].

V. RESULTS

A. GPS positioning

In Fig. 13 we can see the spread of coordinates for 54 measurements given by the GPS module. The average error for latitude is $7.32 * 10^{-5}$ degrees and for longitude is $2.49 * 10^{-5}$.

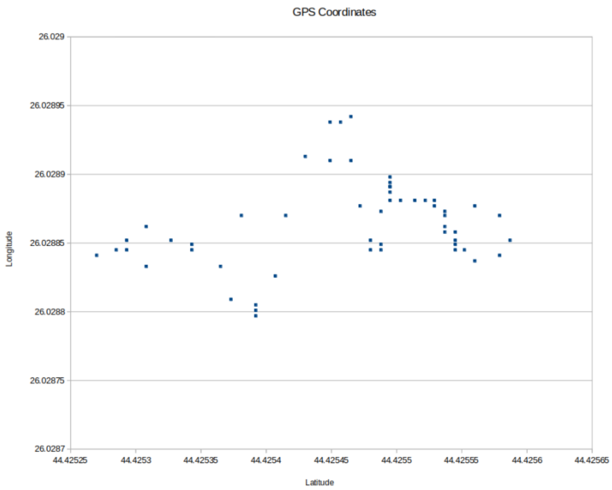

Fig. 13 GPS Measurements Coordinates Spread

Afterwards, we have tested the localization and we have reconstructed, based on the timestamp of the location coordinates the itinerary. In Fig. 14 and Fig. 15, we can see two test results, one in Bucharest, Romania and one in Nis, Serbia.

After a careful analysis of the data, and based on the known itinerary of the vehicles (car in Bucharest, bike in Nis) we have concluded that the reported positions and the mapping of the positions correspond to the real situation.

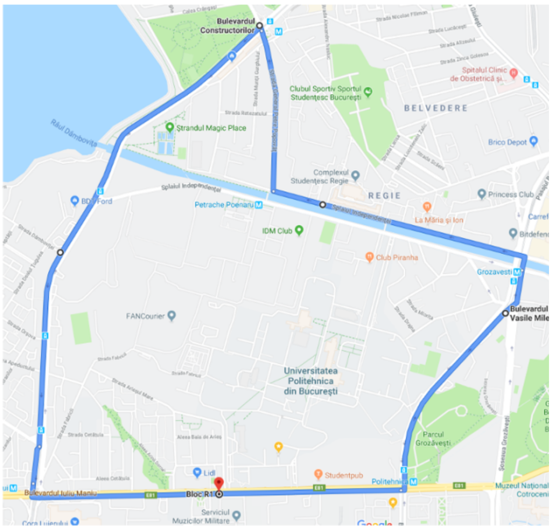

Fig. 14 Bucharest Positioning Test Results

Fig. 15 Nis Positioning Test Results

B. SMS delay

Since the SMS data transmission is *best effort*, a transmission time or even a transmission success cannot be guaranteed. Thus, we have conducted a set of two tests:

- Measurement of transmission delay for SMS packets that contain location information, from the device to the mobile terminal.
- Measurement of transmission delay for SMS packets containing a simple command (such as *Stop Engine/Deactivate Alarm/Enable Alarm)* from the mobile terminal to the tracking device.

In Fig. 16 we show the results of the delay measurement for SMS location data and in Fig. 17 we show the delay for the command SMS. We can observe that the average delay is slightly higher for the location SMS (3.27s) than for the command SMS (2.89s). The difference can be caused by the dimension of the SMS contents. We consider that a difference of less than 0.4s is acceptable for our scenario.

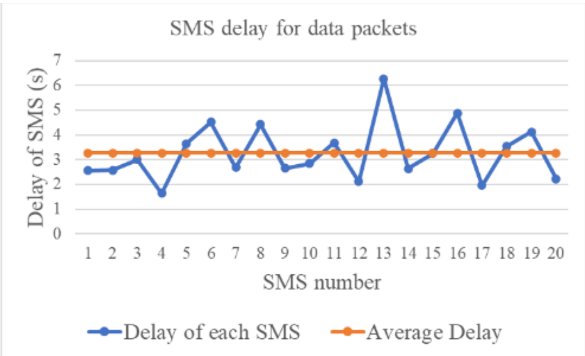

Fig. 16 SMS Delay for Location Data Packets

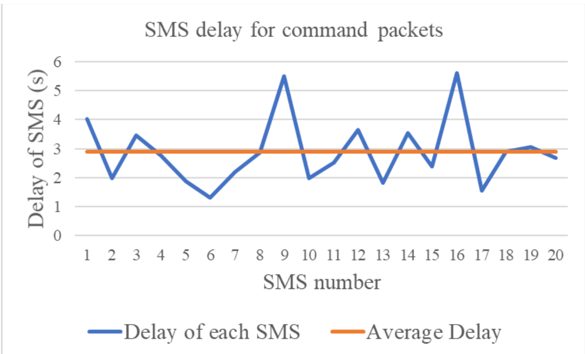

Fig. 17 SMS Delay for Command Packets

C. Conclusion

While there are many commercial and research oriented solutions, some of them with more features and based on newer technologies than others, there is room for improvement.

Considering the IoT character of our solution, we need to address and mitigate security issues. Thus, we need to consider the security issues that arise in the IoT era, such as those described in [16], [17]. Also, we can consider as future work or possible extension/optimization of the solution, interconnecting the tracker with building monitoring systems – such as the one described in [18], for a more holistic approach of large systems.

In our work, we have evaluated the necessity of vehicle tracking devices from the economic and social point of view, we have done a survey on current and past research projects, and based on others experience we have seen that we can contribute to the current state of the art.

In this paper we have:

- Proposed an optimized IoT enabled flexible bike anti-theft tracking system architecture.
- Proposed an optimized IoT enabled flexible vehicle and electric bike/scooter anti-theft tracking system architecture.
- Proposed a software functional architecture that fits both hardware scenarios.
- Evaluated the efficiency and accuracy of off-the shelf GPS modules.
- Evaluated the delay in SMS messaging for such systems.

We have implemented both architectures with off-the-shelf modules, we have tested them and confirmed that they behaved as intended. Although we have tested our architecture with specific modules, the architecture is universal and any other GPS, GSM(2G/3G/4G/5G) modules, accelerometers, alarm modules, etc. can be adapted and fitted easily in the implementation.

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