BLE Network Applications for Smart Mobility Solutions

A technical review in the framework of the EU's Tetramax Programme

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1. Introduction

Tetramax[1] is an EU-funded innovation hub for digitizing European industries in the domain of customised and low-energy computing (CLEC). Its mission is to boost innovation for SMEs in search of leading-edge digital technologies and solutions. In the framework of this programme, the company Etelätär Innovation (together with partners Intelligent Parking and Semab) is undertaking the BLEUN project[2] (*Bluetooth Low Energy Urban Networks*), which aims to deploy accurate geolocation services for smart mobility applications and several other market segments in the Smart City.

1.1. RTLS systems and applications

RTLS (Real Time Location Services) has been a major disruptive technology in transportation for the past 20 years. The possibility to calculate your exact position, together with routing algorithms and software allows a large number of new mobility applications. RTLS is not exactly new as some applications exist since 1940's, but the inclusion of these technologies in mobility applications has only become available for the general public with the arrival of mobile devices such as portable GPS and smartphones.

RTLS (Real Time Location Services) can be provided by using different existing systems, such as the GPS (global positioning system), RFID, UWB or Bluetooth. However, modern nomad devices such as smartphones, offers new functionalities that can open the gate to a full new spectrum of mobility applications. Bluetooth may be the most promising, and we are going to present its advantages and possible applications.

GPS is a radio-navigation system operated by U.S. Air Force. GPS satellites continuously transmit data about their current time and position. A GPS receiver monitors multiple satellites and solves equations to determine the precise position of the receiver and its deviation from true time. At a minimum, four satellites must be in view of the receiver for it to determine its position.

GPS Signals are relatively week and can be easily blocked by mountains, trees, buildings, etc, thus, the receiver device needs to allocate a certain amount of energy to the antenna to scan for these signals. A 2016 study by computer engineering professors in the UK and Saudi Arabia found that under a good signal strength, a battery depletes 13 percent while a weak signal could cause the battery to drop up to 38 percent[3]. It takes about 12 to 30 seconds for a smartphone to receive a transmission from a satellite, but if it needs to receive signals from all nearby satellites, and this could take up to 12 minutes. The exchange is done at 50 bits/s and during this time, the device cannot enter in sleep mode.

1 www.tetramax.eu.
2 http://etelatar.com/bleun.
3 Tawalbeh, Mohammad & Eardley, Alan & Tawalbeh, Loai. (2016). Studying the Energy Consumption in Mobile Devices. Procedia Computer Science. 94. 183-189. 10.1016/j.procs.2016.08.028.

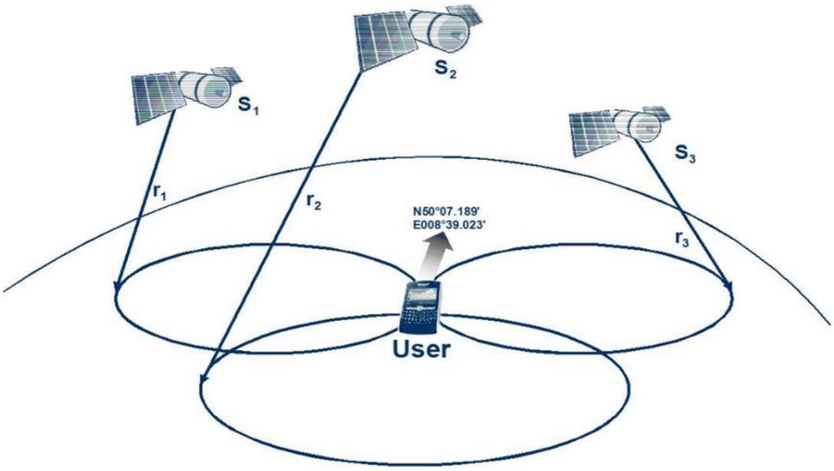

Figure 1: GPS

For this reason, GPS devices reach energy consumptions of 200 mAh in many cases, which would be equivalent to 1 watt/hour. In terms of CO_2, if we calculate 8,760W of yearly consumption for a device that is connected 24h/day, the CO_2 generated would be 5,694g, following the formula published by the EU. In comparison, a BLE Beacon only needs 5µA, which translates in less than 1W per year, or 0.65g of CO_2.

RFID (Radio Frequency Identification) exists since 1940's and it is used for tracking assets and people in almost every sector. One big advantage of this system is that while the "reader" device cost is very high, passive "tags" are, on the contrary, very inexpensive compared with other systems. At the same time, RFID offers very short range, meaning that in order to cover a big area with RFID, many reading devices are needed. RFID is, then, only ideal when a large number of "tags", but only a few "readers" are needed (As, for example, for access control).

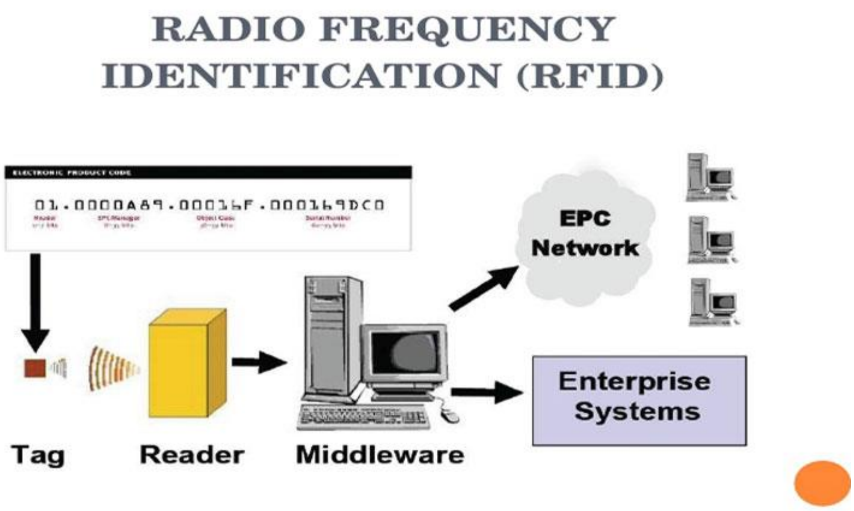

Figure 2: RFID

Also, compared with RFID, due to the widespread adaptation of the Bluetooth standard, BLE solutions are cheaper and easier to integrate into other systems and everyday devices. In fact, nearly all phones are already equipped with the technology. So BLE greatly simplifies every step of the process when smartphones and devices can be used as part of the real time location system.

We can find a similar situation with UWB (Ultra Wide Band). This system is very attractive due to the level of location precision afforded by ultra-wideband positioning systems. This precision is achieved thanks to the ability to accurately measure the time it takes for an encoded signal to travel from a transmitter to a receiver. However, this precision comes at an elevated cost.

This elevated cost — as much as 10 times costlier than a Bluetooth (BLE) system - is due to the high price of the devices and the complexity of the system implementation. UWB location systems require at least three receivers to receive signals from tags. These readers are very expensive, and they must be precisely synchronized down to the nanosecond for the system to calculate location accurately.

Finally, UWB is not available in most smartphones currently in the market which makes it definitely not suitable for any application requiring the use of these devices.

Though BLE can certainly not totally replace GPS, RFID or UWB in the market, as these systems have some very strong use cases, it clearly offers some net advantages for the needs of this project.

2. BLE Devices

There are 2 kinds of BLE devices: Beacons and receivers. Both can be fixed or mobile. Mobile beacons are usually called ‘tags’ or ‘trackers’ and fixed receivers are often referred as ‘readers’, ‘nodes’ when they are part of a network, or ‘gateways’ when they also send the information to the internet. Of course, there are many different models, sizes and specifications for each of these devices.

Smartphones can function both as beacons or receivers, thus, 6 different combination of smartphones with fixed beacons, roaming beacons, receivers and software can be implemented to adapt to the environment and the purpose of the network.

Depending on the intended use and environment, there are 2 basic architectures:

- *Client-Based*: is used for positioning and navigation. The app at the user’s device (smartphone) is triggered by the beacon signal or calculates its position from the signals received.
- *Server-Based*: Mostly used for tracking. The receiver nodes detect the signal from a roaming BLE device (beacon or smartphone) and send this information to a server and it is the server software, which determines its position of the device (with other possible information or statistics).

2.1. Beacons

Beacons are IoT devices that transmit a Bluetooth signal or code in a certain format. The mentioned advantages of BLE technology compared with other RTLS allow these beacons to be produced in very small sizes, and to run for months or even years with batteries. They can be used for different purposes:

1) *Proximity marketing*: the customer (with a smartphone and specific app) gets some info, or an app is triggered when enters in the range of the beacon.

2) *Positioning/navigation*: The beacon is fixed in a known position and sends a signal with a short information packet periodically (i.e. every 30 seconds) to identify itself. When a smartphone with a navigation app enters the beacons range, it can calculate the distance to the beacon based on the power of the signal received from it. If the smartphone is in the range of at least 3 beacons it can determine its position with a high level of accuracy.

3) *Tracking*: The beacon is the roaming device and a series of receiver nodes detect the signal and send this information to gateways connected to the management centre to determine the position of the roaming beacon.

2.2. Receivers

There is a great variety of BLE receivers, also referred as readers, trackers, nodes or gateways, depending on manufacturers and the integrated functionalities. They may be powered by batteries or by an external power source, such as the grid or a solar panel.

A receiver searches for every BLE device within range -some models can track hundreds of devices per second- capture the data they receive from the sender (i.e. smartphone or beacon) and forward them to the server, which processes the data.

The communication system with the server is one of the main characteristics of the receiver, as this determine the possible use and installation requirements of the device. The data exchange with other receivers and the server can be wired or wireless, and many different options are available: Ethernet, USB, UMTS, Wi-Fi, Bluetooth, LoRa, etc.

These devices also function as beacon controllers to monitor fixed beacons, for example in the context of a client-based indoor navigation, and to carry out possible reconfigurations of the beacon network.

In addition to this, every Smartphone of the user's community that adopt this solution can act as a BLE receiver through a program that is running in the background of the smartphone, helping this way to build a "denser" detection network that contributes to improve the accuracy in detecting beacons.

3. BLE network configurations and applications

BLE nodes allow us to build networks using extended MESH topology, where each device (node) transmits its own data as well as serves as a relay for other nodes. This topology is based on non-hierarchical and dynamically self-organize and self-configure network and was originally developed for military communications, providing a robust and easily installed network.

The redundant nature of mesh networks is an essential characteristic sought out, as in the event of a hardware failure, many routes are available to continue the network communication process. Therefore, high performance and scalable broadband networks can be built at very low cost using a mesh net. Autonomous roaming devices can join the network and exchange data with the nodes, extending this way the network coverage.

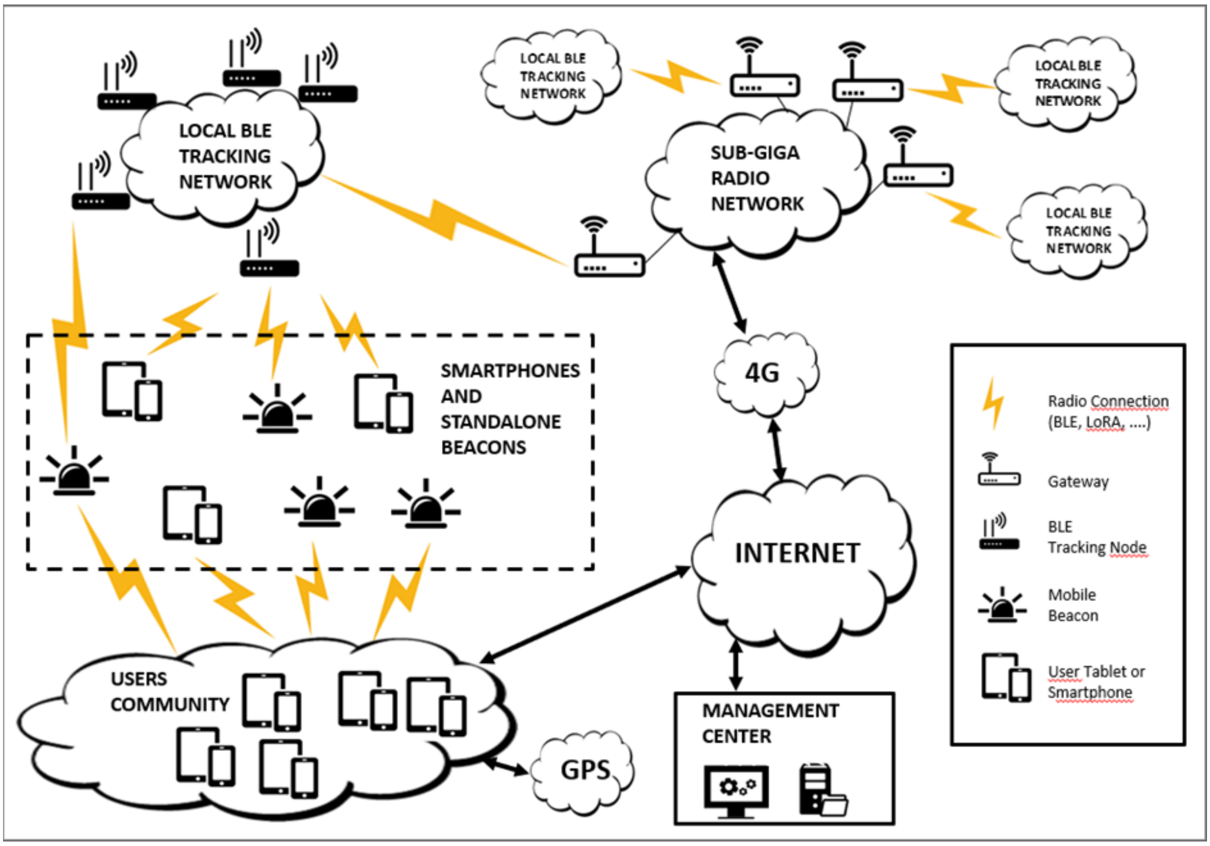

Figure 3: BLE network configuration

Depending on the architecture and the type of devices used, there are 6 possible configurations for a BLE network.

3.1. Fixed beacons, mobile devices (Location/Navigation and Proximity)

This configuration is relatively simple and consists of fixed beacons deployed creating a “signal grid” and user’s devices (smartphones) with a specific application. Beacons broadcast either their location, or any other relevant information regarding their location and user’s applications are able to respond to those signals when in range.
For proximity applications, the beacon signal can trigger an event in the user’s application, like advertising, or PoI (Point of Interest) information. If we want to implement a location/navigation application, beacons will broadcast their position and the user’s device triangulate its own position based on the signals received. The number of signals (beacons) needed for this, will depend on the accuracy required.

Advantages:

- Easy to implement, no installation required.
- Uses existing smartphone devices.
- Cost effective way to identify many different areas or 'zones'.
- Persistent location tracking even when smartphone is asleep, or the app is running in the background.

Disadvantages:

- Can only be used to guide smartphones.
- Requires all users to install a mobile application.

3.2. Mobile devices, mobile asset beacons (Proximity)

This configuration will only allow proximity applications. Some use cases include identification of Bus or train by the user application, to answer the typical question: “is this my bus?” Can also work the other way, so the driver can identify the passenger in case of people with disabilities, or at arrivals. Another typical use case is location of lost assets, pets or children.

Advantages:

- No deployment of hardware infrastructure required.
- Quickly read nearby assets without requiring individual scanning (unlike passive RFID tags).
- Provide information relating to nearby objects.

Disadvantages:

- Cannot provide location awareness without additional sensors or inputs.
- Requires all users to install mobile application.

3.3. Fixed BLE receivers, mobile asset beacons (Tracking)

This is one of the most extended configurations. Receivers will create a grid that will be able to track all beacons moving in range and send this information to a server. In can provide numerous services in the transport sector: vehicle location, anti-theft, usage data collection, etc…

Advantages:

- Does not require mobile application.
- Automatically track the location of thousands of assets in real-time.
- Hard-wired BLE receivers do not rely on battery power and can provide more frequent readings.
- Rough trilateration and two-dimensional positioning possible with multiple receivers.

Disadvantages:

- Requires mounting where power is available.
- Requires stable Wi-Fi or cellular data.
- Higher installation and hardware costs.

3.4. Fixed beacons, mobile devices and beacons (tracking without permanent BLE Receivers)

If a tracking system is required, but permanent BLE receivers cannot be installed, this configuration will allow tracking, based on the location of the device (smartphone). It can be used to extend the tracking network beyond the BLE grid in some cases, especially when a large community of users have the required application.

Advantages:

- Easy to implement, no wiring or installation required.
- Tracking of both users and assets without requirement for additional hardware.

Disadvantages:

- Update of asset location dependent on presence of mobile device and app.
- Moving mobile devices can cause reduced accuracy of asset location.

3.5. Fixed beacons and BLE receivers, mobile devices and beacons (Tracking users and Assets)

Combining fixed Beacons and receivers allows higher accuracy and expands the possible applications. This configuration is ideal for tracking applications, wherever it is possible to implement.

Advantages:

- Track users and assets with greater accuracy.
- Maximize coverage and efficiency of deployment, whilst minimizing hardware cost.
- Increase the number of BLE receivers over time as you find spots where mobile users are not active.

Disadvantages:

- Cost of setup and deployment.

3.6. Combining BLE with GPS, LoRa or Wi-Fi

For very extensive areas, and multiple simultaneous applications (indoor-outdoor), BLE technology can combine with other existing technologies such as GPS, Geo-Fencing, LoRa communications, RFID, etc, in order to increase functionalities or compensate for shortcomings of BLE technology such as limited range, while still profiting of its advantages (low energy consuming, availability, etc.)

Advantages:

- Take advantage of existing location services, whilst using beacons to tag nearby devices.
- Move seamlessly from indoor to outdoor environments.
- Minimize battery drain by only using location services when required.

Disadvantages:

- Dependency on mobile application on devices.

4. Conclusions

The BLE technology offers almost infinite possible applications for mobility and the transport sector in general. From tracking of vehicles and users, allowing a precise managing of the public transport network, exact location of buses, arrivals to stations, etc, to user-friendly applications for users to navigate precisely or interact with existing and future transport systems. All this, with the advantage of availability, low-cost and low-energy consumption.

The BLE technology also clears the path for the new mobility concept that we are currently developing: crowd-sourced mobility. Users will be able to intercommunicate co-creating low-cost, peer-to-peer mobility networks in a free, spontaneous way. It takes a leap forward towards mobility freedom, by connecting smartphones with IoT proximity technologies and open data to accurately guide you to meet your peers or share your bike, car or parking spot.