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NETWORK HARDWARE REVIEW FOR A LOCATION SYSTEM

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Abstract - Although some wireless technologies present application of industrial nature, generally used for real-time process variables monitoring, as well as data transmission in personal networks (PANS), like tablets, smartphones and laptops, other ways of use it outside these areas have been developed by researchers when it comes to detection networks, as a finder. This work is a survey of the characteristics of the main wireless technologies like ZigBee®, Bluetooth® and Wi-Fi®, relating operation and applications, when it comes to estimation of a point location. Here is highlighted each technology performance when they are employed at indoor environments, presenting descriptive and comparative studies, pointing out properties such as signal power, operating frequency and mainly range, which are considered important factors, according to the related publications about the subject, based on a bibliographic review.

Key-words: Wireless Technology. Wi-fi®. ZigBee®. Bluetooth®. Point Location.

I. INTRODUCTION

Wireless network has become a relevant technology, when remote activities analysis or execution have to be performed, such as, real time monitoring, data measurement, positioning, localization and control tools in general.

These activities generally involve data or message transmission and reception, which indicate and quantify some control variable depending on the process or system.

The use of wireless networks provides a way where system information can transit in a network with a common goal. In this context, much work has been done, aiming to evaluate which network hardware provides better operation conditions, as well as high performance and high reliability of the network.

In this work, we consider the necessity of evaluating a wireless network for a location system. In many applications, the position of a target (which can be a person, a machine, a vehicle etc) is one of the most important context information that can be used to construct a displacement profile; in other words, the goal of using these networks is intrinsic to the environment and user behavior and dynamics. (Harter et al., 2008).

Being more specific, Radio Frequency technologies are widespread in the wireless network usage, providing a varied portfolio of systems and standards, each one with its own characteristics.

The topics that have to be observed in this work are related to baud rate, range and interoperability, where all of these are related to the location. Based in these aspects, the following communication standards will be studied:

i) IEEE 802.11: Wi-Fi.

ii) IEEE 802.15.1: *Bluetooth*

iii) IEEE 802.15.4/ZigBee

II. WIRELESS NETWORK: CHARACTERISTICS AND APPLICATION

2.1 Wi-fi: IEEE 802.11

According to Rodrigues (2008), the first system based in radio frequency to perform location was the wireless Ethernet. This technology was developed so it could contribute with local wireless networks in various environments, offering a support for moving or static location elements, from a series of techniques, such as triangulation.

This type of network uses radio bearers for communication. The data is modulated and transmitted by electromagnetic waves. A positive point to list is that even though there are many radio bearers, one does not interfere in the other, since the receptor only tunes to a specific frequency. This is really important when dealing with location, and good position estimation are required.

It is known that the quality of a network depends a lot on the environment where it is inserted and on the peripherals used in order to guarantee a higher performance. Based on this assumption, it is possible to use these networks on indoor and outdoor environments.

In contemporary literature, there are many works related to indoor environments location, with some variations in the location method. However, this is not the goal of this work.

Chintalapudi, et al. (2010) presents a location system for mobile devices that have the Wi-Fi technology and (Figure 1). The authors begin with a building location, pointing out three assumptions: i) The existence of enough access points (APs); ii) All users have a device with Wi-Fi module; iii) All the devices can obtain a fixed location based on another location system, such as GPS.

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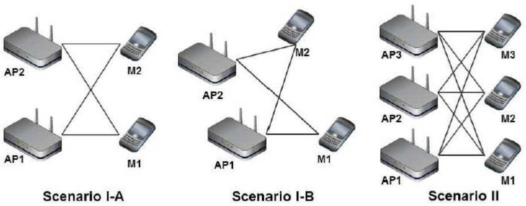
Figure 1- Location estimation scheme of a moving point, from an access point.



The assumption i) points out that the more APs in an area, the bigger is the coverage, providing a higher possibility of success, as opposed to environmental infrastructure. The assumption ii) points out the fact that not only mobile devices such as cell phones, tablets etc, but target objects must be equipped with Wi-Fi module or with some other electronic device that can interpret the data in the same protocol. The assumption iii) considers the possibility of an estimation error, and because of that a start point can be located by another system, in order to fix a target object first point.

These assumptions are the base of the EZ algorithm, which consists of a system where, all the time, the mobile devices measure the Received Signal Strength Indication (RSSI) by the Wi-Fi APs that are performing its coverage, making a local correction and reporting these values to a central server. This server process and learn the radiofrequency propagation characteristics, based on the RSSI to estimate the location. Usually, based on absolute coordinates, latitude and longitude.

The Wi-Fi transmission technology can also be divided in many standards. The main characteristics that differentiate each other are: Frequency Band (FB), Bandwidth (BW) and spread spectrum technique (SST). Among the many Wi-Fi networks standards, it can highlight the Table 1, the main ones:

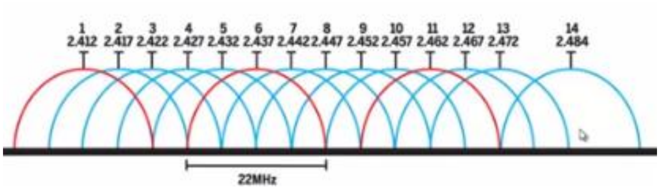
Table 1 – Main IEEE 802.11 Standards.

Standard	Potência (W)	LB	SST
802.11a	5 GHz	20 MHz	OFDM
802.11b	2,4 GHz	22 MHz	DSSS
802.11g	2,4 GHz	20 MHz	OFDM
802.11n	2,4 GHz	20/40 MHz	MIMO-OFDM

The 2.4GHz band presents 14 channels with a bandwidth of approximately 22MHz. However it is important to emphasize the difference between the frequency nominal value and the frequency actual value. Based on that, it is possible to state that the three channels work without interfering the others. The channels 1, 6 and 11 present an actual operation range of 2.401 to 2.423GHz, 2.426 to 2.448Ghz and 2.451 to 2.473GHz, respectively, which means that even though these three channels are used in the same environment, one will not interfere in the other, which does not happen with other ranges, or in a configuration where there are other frequency ranges.

The non interference indication guarantees the network high speed transmission capacity, with safe and precise data. In a practical application, for example, where it is necessary to monitor a point location in real time, these channels are indicated to establish the network, where a hardware configuration is needed.

Figure 2. Frequency spectrum of the 2.4GHz Channels.



Regarding the spread technique, the OFDM (Orthogonal Frequency Division Multiplexing) consists in dividing and transmitting a signal in multiple frequencies. Considering the standard 802.11a, for example, that has about 52 subcarriers, thus making possible the transmission of signals in packages without interference, depending also on the modulation (PINTO, et.al, 2002). OFDM is usually used in pairs, with a channel codification system called COFDM, which corrects the multiplexing. DSSS (Direct Sequence Spread Spectrum) consists in a system that spreads the signal in a very low power spectral density, requiring a bigger frequency range, as we can see in the Table 1. MIMO-OFDM presents the same principle as OFDM. The growth factor refers to the multiple inputs and multiple outputs that represent an increase in the multiple signals transmission by multiple antennas, increasing the network speed. This technique is widely used in mobile devices, being an important tool for wireless communication technologies, such as mobile telephony.

Based on this analysis, it is possible to evaluate in Table 2, by these characteristics, other two important factors related to location: Baud Rate (BR), Range (R) (coverage).

Table 2 – Main IEEE 802.11 Standards.

Standard	Baud Rate	Range	
		Indoor	Outodoor
802.11a	6-54Mbps	20 MHz	OFDM
802.11b	1-11Mbps	22 MHz	DSSS
802.11g	6-54Mbps	20 MHz	OFDM
802.11n	7.2-72 Mbps$^{(1)}$ 15-150Mbps$^{(2)}$	70m$^{(1),(2)}$	250$^{(1),(2)}$

(1) On 2,4Ghz band.
(2) On 5GHz band.

The network performance depends on the environment characteristics and also, as to locate a moving point, on the displacement behavior. In this sense, electronic devices can be used to increase the signal intensity, replicating gain in the network, among which we can highlight high-gain antennas etc.

As a support tool to the location from the Wi-Fi networks, wireless network virtual scanners can be used, such as Vistumbler, which can identify the relative position from the access point to the user, by identifying the networks or access points around the user, combining with other location modules.

Vistumbler not only locates the Wi-Fi access points, but also offers information about the signal power, authentication, cryptography, using channel and which standard the network uses. Using this software with a GPS module, it is possible to determine spatially and with views the location of access points and possible ad hoc networks that might exist around the reference where the software is being executed.

Depending on the application, it is possible to state that the networks based on the IEEE 802.11 standard offer good resources, as long as a technology for the network is chosen.

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2.2 Bluetooth: IEEE 802.15.1

Initially developed to provide data transmission among small networks composed with mobile devices (cell phones, tablets, notebook), Bluetooth technology has gained space in more elaborated application, once they operate in a short range, low power and are very low cost (Kurose, 2013).

WPAN (Wireless Personal Area Networks) are based on the Bluetooth protocol specifications, regarding the data link and physical layers. These protocols allow safe data transmission between devices when they are paired (synchronized) (Tanenbaum, 2011).

As a great part of the researches that have been developed, location system using Bluetooth with fingerprint technique can be highlighted. This technique creates a database from signal power indicators defined position points, which has been used by many works as the main tool for position estimation.

Diaz *et.al* (2010) proposes the creation of a location system based on Bluetooth for an indoor environment. It is known that Bluetooth devices communicate with each other as from access request and authorization. This characteristic developed a location subsystem, from a client-server model, in order to characterize the environment in which the target object is located.

The Bluepass system was composed of 4 components: A local server, a central server, Bluetooth detection program and mobile applications. In an environment with defined dimensions, it was presented an interface which represents a map of the area where the users were at.

The user would request the system access, using the application, by a local server and this request would work as a signature that defines the map where the device is. The base stations would provide data to the location algorithm, using methods like multilateration and signal density. The central server, based on these characteristics, would provide the user data and the map representing the room layout to the local servers.

This way, the Bluepass provides data to spatially distant maps, once it obtains the signal power only from the region where the local server is located, which is the same as where the target object is, by using the Bluetooth detection program.

Bluetooth is divided in classes, which are typically related to the signal power, depending on the environment and also on some other device that allows the amplification of signal gain.

These characteristics are important to a location system because of the range. Depending on the application, a higher range with interference-prove network makes the position estimation more reliable. This is also a low cost technology but presents a lower transmission speed, when comparing with other standards like IEEE 802.11 as shown in Table 3.

Table 3 – IEEE 802.15.1 standard classes.

Class	Power (mW/dbm)	Range
1	100 / 20	Until 100m
2	2.5 / 4	Until 10m
3	1 / 0	Until 1m

For the 1.2, 2.0 e 3.0 versions, we have a transmission rate of 1, 6 and 24 Mbps, respectively. The applications are characterized by, for example, ad hoc networks (where it is not necessary to have a network infrastructure). A small Bluetooth network can accommodate up to 8 active devices in a master-slave system, as well as up to 255 stationary devices, which can be activated by only one master node.

In general, this network uses the frequency band of 2.4GHz, divided in 79 channels, with 1MHz bandwidth. The spectrum spread technique is the FHSS (Frequency-Hopping Spread Spectrum), which allows, during the transmission, the data jump between the channels, thus making the receptor to receive the signal, if it is synchronized, and to recognize the frequency series in which the transmitter works.

Despite the fact that it presents more channels, comparing to the IEEE 802.11 standard, the bandwidth is approximately 95% smaller. In other words, this refers to the transmission rate and network speed, which can be noted when comparing the Bluetooth versions on Table 2.

2.3 IEEE 802.15.4/ZigBee Standart

In order to standardize the communication in environments that require low transmission resources for the local networks such as personal networks, it was developed the IEEE 802.15.4 standard, which defines the transmission rules based on the architecture that has two basic layers: Physical layer (PHY) and Media Access Control layer (MAC).

Figure 3. Xbee and Xbee-PRO.

This standard is the base for new low cost and low power communication technologies such as ZigBee. Despite the fact that they present similar levels, they are not the same, once ZigBee uses the layers from the IEEE 802.15.4 standard plus two network and application layers, in order to complete its protocol pile. Besides, the existent ZigBee models present a combination of hardware and firmware to form a module as shown in Figure 3.

Based on that, the firmware, that is used in the protocol piles of the Xbee modules, define the algorithm structure, thus defining the communication. It is important to note that the basic difference between the most basic ZigBee models is the transmission power, that can reach up to 316 mV, in the modules that operates in the 868 MHz band and up to 63 mV in the modules the operates in the 2.4 GHz band.

Other characteristics are also inherent to the Xbee module series and the present two basic differences: The range and the presence of a 32 kB flash memory (EPROM) and 2kB RAM memory. This comparison and characteristics of the XBee series are described below:

- *Series 1*: It has two firmware types (IEEE 802.15.4 and *Digimesh®* protocol). They are available in the conventional version and in the PRO version. For indoor environments, they present a range of 30 to 90m, and 90 a 1600m for outdoor environments. Both present a 250 kbps transmission rate, operating in the 2.4GHz band. They cannot be programmed using the memory.

- *Series 2, 2B e 2C:* They have ZigBee and Smart Energy protocols. They are available in the XBee2 and PRO2 versions. For indoor environments, they present a range of 40 to 120m, and 90 a 3200m for outdoor environments. Both present a 250 kbps transmission rate and operate in the 2.4 GHz band. They cannot be programmed using the memory. The 2B series modules can be programmed and also have the same firmware and characteristics of series 2. 2C series modules also have the programming capacity and also can communicate via SPI, with transmission rates going up to 5 Mbps. In a conventional version of this series, which has a lower power, can reach up to 1200m in outdoor environments. It uses the ZigBee protocol in the convention and PRO2 version, with transmission rates up to 250 Kbps.

 Series 3, 3B: Both have the *Digi® Multipoint* protocol, which presents 25 communication channels and operates in the 900MHz frequency band. They are available only in the PRO version, its transmission power goes up to 100mV and the transmission rate goes from 10 to 20 kbps. This characteristic does not have a big impact, since it has a bigger range, when comparing with modules from other series. The main difference is on indoor environments, where it can reach from 370m to 610m, and on outdoor environments, where it can reach from 9600 to 45000m. This performance can only be obtained if signal amplifiers are linked, such as dipole antennas and high gain antennas.

- *Series 4:* It has the *Digi® Multipoint* protocol and the *DigiMesh®* protocol and operates in the 900 MHz band, reaching from 3 to 10 km, when combined with high gain antennas. It is available only in the PRO version and its transmission rate goes up to 156kbps.

- *Series 5:* It has only the *Digi® Multipoint* protocol and are available in the PRO version, operating in the 868 MHz band, reaching from 40000 to 80000m, when combined with high gain antennas.

- *Series 6:* Also called as *ZigBee Wi-fi*, it has IEEE 802.11 protocol, standard b, g and n. It operates in the 2.4 GHz band, using it for the Wi-fi protocol. Its transmission rate can go up to 72 Mbps, depending on the chosen standard.

Qingming (2007) proposed a system for location based on wireless networks using ZigBee module with the IEEE 802.15.4 standard firmware. This system was based on the Fingerprint (strength mapping) technique, mainly related to the signal power, which, according the author, is the basic function to create a RSSI database.

With the proposed methodology, a local cluster was defined to admit signals through a ZigBee network installed in the coverage area necessary for the experiment execution, which was something about 30m for indoor environments, because it was an office room with 168.48m2. The local clusters represented a power database for a determined region in the room (rooms division).

All the data collection points were ZigBee modules equipped with batteries and microcontrollers, which estimated the position, based on the power emission by a moving point, using an algorithm. The comparison was made based on an off-line training, with the relative power of the stationary points, when they were closer. This technique reached a precision percentage of 70%, with an error of approximately 0.5m, considering the dimensions of the environment where the experiment was held. What made this technology more and more used not only in automation tasks, but also in remote control and even clinical patients monitoring, is the fact that its applications targets low power and low transmission rate systems (Farahani, 2008).Another important point the operation of a network based on IEEE 802.15.4 standard, when looking at the functions they can represent. There are basically two types of devices:

- Full Function Device (FFD): It has a pile of complete instructions and can communicate with any other device, also acting as a node manager in the network.

- Reduced Function Device (RFD): It has a smaller protocol pile and limited tasks. It does not perform any managment tasks and only communicates with FFD.

In order to have the conception of a ZigBee protocol based network, it is necessary to define the communication mode, command type (AT or API) and transmission frame data. Also it is required to define the network function that the modules will perform:

 ZigBee Router: These are intermediate devices, who are responsible for the data frames routing, route definition and repair that the data must follow, considering the network architecture.

 ZigBee Coordinator: These are devices that will select the communication channel and network identification and also may allow other devices to be routers or end devices.

 ZigBee End Device: These are devices that usually join the network to transmit data and present a reduced function, generally dedicated to the transmission of information data by RF.

In the same way we talked about the devices defined by the IEEE 802.15.4 standard, we can also affirm that the devices in a ZigBee network are, respectively, personal area network coordinator with complete function, coordinators, and devices which can be RFD or FFD.

As for the low power consumption, the ZigBee modules present operation modes, by which there is a synchronization between the energy consumption with the data transmission and reception operations, as well as with the operation absence.

According to Ramos (2012), ZigBee presents a Coexistence characteristic, which means interoperability that allows communication with other device types and connection to other networks, such as Wi-Fi in the sub standards b, g e n, Bluetooth, both working in the 2.4 GHz band.

The concern about interference can be noticed when analyzing the spectrum spread techniques and mainly regarding with the guarantee of a safe communication, which is usually fought with the CSMA-CD mechanism, avoiding data collision in the same network.

III. QUALITATIVE AND QUANTITATIVE COMPARISON

As the main focus for a location system, since it is necessary to have measurements accuracy, the main factors that can contribute in the definition of which technology may offer the most cost benefit, depending on the application, are the range, signal power, energy consumption, as well as the firmware to be used by the devices in the network.

As for the range, using peripherals, such as dipole antennas or high gain antennas, can offer bigger network coverage, as we can see in the 2.3 Section, about the Xbee modules.

However, and the most important, what will provide to the network and its batteries a longer operation time is the intelligence of the network devices, when controlling the energy levels in data transmission and reception, and also when nothing is happening (sleep mode).

On Table 4, the qualitative and quantitative aspects of the wireless technologies studied in this work are presented.

Table 4 – Wi-Fi, Bluetooth and ZigBee: Main Characteristics.

Technology		*Firmware*	*Operational Frequency (Hz)*	*Number of Channels*	*Spread Spectrum Technique*	*Range(m)*	*Baud Rate*
WiFi™	802.11a	IEEE 802.11x	2,4 GHz	11	OFDM	35 - 120	6 a 54 Mpbs
	802.11b				DSSS	35 - 140	1 a 11 Mbps
	802.11g				OFDM	38-140	6 a 54 Mbps
	802.11n		2,4 e 5 GHz		MIMO_OFDM	70-250	7,2 a 72 Mbps (2,4 GHz) 15 s 150 Mbps (5 GHz)
	Class 1	Bluetooth (1.0;2.0;3.0)	2,4 GHz	79	FHSS	1	1 Mbps
	Class 2					10	6 Mbps
	Class 3					100	24 Mbps
ZigBee® Alliance Wireless Control That Simply Works	Series 1	IEEE 802.15.4 Digimesh®	2,4 GHz	12 a 16	DSSS	30 - 90 90 - 1600	250 Kbps
	Series 2	ZigBee Smart Energy	2,4 GHz	14 a 16		40 - 120 90 - 3200	250 Kbps
	Series 3	Multipoint®	900 MHz	25		370 - 610 9600 - 45000	10 a 20 Kbps
	Series 4	Multipoint® Digimesh®	900 MHz	5 a 12		3000 - 10000	156 Kbps
	Series 5	Multipoint®	868 MHz	1		40000-80000	24 Kbps
	Series 6	IEEE 802.11x	2,4 GHz	11		-	72 Mpbs

It is possible to observe, when looking at the Wi-Fi, the possibility of maximizing the transmission rate by using the 5GHz band. The major fact is the usage of dual band routers that also operate in the 5GHz band, which may offer transmission rates up to 150 Mbps and a minimum range of 250m. This can be expanded using amplifiers such as the high gain antennas, by concentrating the reception in order to amplify it. A characteristic of this type of device is the fact that they are directional, which means, the need to be pointed to the network main signal emission point. This contributes a lot in the choice of the location technique, since it provides the system geometry conception, with relation to the target object.

This characteristic is favorable when you want to increase the coverage area, which ends up setting, with the information on Table 4, the advantage for the Wi-Fi and ZigBee technology, simply because the hardware already provides medium range with real usage possibility.

When analyzing another point, the series 6 Xbee module, also called ZigBee Wi-Fi, presents an expansion characteristic, similar to the Wi-Fi itself. The coverage, in practical means, will be defined by the routing capacity and the antenna usage. This already configures a higher interoperability, when talking about the IEEE 802.11 firmware.

As for the frequency, Wi-Fi, Bluetooth and ZigBee, in some models, operate in the 2.4 GHz band, which does not require a license in order to use it. To the other frequencies (868 or 915MHz) are rather not available or require a license, once they can interfere in other communication channels, such as the mobile telephony.

As emphasized in this work, it is necessary to highlight not only the technologies hardware characteristics, but also the energy consumption, depending on the application amplitude. It is possible to affirm that each technology, rather as a set or isolated, must be chosen in order to obtain the gains according to the cost benefit.

The usage of Wi-Fi and ZigBee are more frequent in the literature because they both have favorable properties for industrial application, as well as for location, as seen and verified with the Vistumbler, for example. Rodrigues (2012) rather use multiple technologies in order to create a location system, based on the interoperability principle. And once again, the Wi-Fi / ZigBee combination presents favorable results in this application, especially regarding to the position error, which in this work was considered small when comparing to the whole application.

All the aspects that were approached in this work, even though they are theoretical and some experimental, are very important when we talk about the place where the system will be implanted. It is necessary to considerate the characteristics addressed in section 1, when you want pinpoint accuracy in an environment that is subject to many interferences and possible transmission, reception and signal process failures. All of this hardwares, in fact, can compose a location system. To do it, it’s necessary use a location method which combined with one this hardwares,can show regular results about estimation accucary. Many papers use methods like, Time of Arrival, to estimate distance through the signal transmission and reception in a wireless network. Other methods Angle of Arrival, RSSI and *fingerprint* can be used in some network hardwares which was highlighted is this paper.

IV. CONCLUSION

In fact, the usage of wireless technologies has provided the development of new application, regarding the real time monitoring of a variable. The most important thing that was highlighted in this work is the availability of many options, for different hardware and software, as well as for various applications, not limiting to the location, having the same effect in the industrial use.

The learning of spectrum spread techniques allows us to observe how the wireless technologies deal, by using the protocols and algorithms, with the data transmission, putting as main goal the integrity of the signal. We cannot forget to mention the possibility of interoperability between these devices, which allows a technology combination also from the hardware. The main focus in this paper is related to network hardware range and baud rate. With these both, it's possible to design a location system, with a network hardware and correct method (for example, the cited ones) and obtain real-time systems characteristics.

In this same point of view, we must exalt the possibility of providing a location system by using multiple technologies, alternating the network clusters, in order to obtain a maximum performance, which has as main goal the estimation of the spatial coordinates of a point in real time.

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