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WiFi coverage range characterization for smart space applications

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***Abstract*—Recently, humans are more and more dependent to communication technologies (CT) in their everyday life to get services, exchange information and communicate with their relatives. Hence, many researches have been made in order to propose convenient and low-cost solutions compatible with the context of smart spaces. This paper characterizes the range of WiFi for outdoor applications in comparison with most known empirical path loss models, and analyzes its impact for smart space services like Internet of Things (IoT). The obtained range is 550m tested with a Samsung Galaxy S5 smartphone, and the comparison with empirical model showed a good difference. Hence the validity and accuracy of those models will be examined for this context, in order to develop an empirical model taking into account environmental effect during our future research. As solutions based on WiFi are generally low cost, its technical characteristics are illustrated and a wide deployment scenario based on this technology is explained on light of obtained results.**

Keywords: Smart space, WiFi, coverage range, radio link quality, wireless internet service.

I. INTRODUCTION

Recently, people are more and more interacting with their environment through various devices or computing platforms thanks to technological progress. These entities are widely used in our everyday activities and spread in an omnipresent way around us, to get required services and information intuitively and easily, whatever is our place or time through many communication technologies (CT). Therefore, ubiquitous computing is the integration of computational power in all sides or objects of our life, and places, where these entities are integrated, and are called smart places or cities.

Thus, CT provided the means for smart spaces' applications and services to emerge by allowing their different entities to communicate together in order to monitor, process and react to environmental change or user needs. Hence, people are able to exchange data across thousands of Kilometers in less than a second, in such a way that world has become like a small village. As smart space applications are diversified such as smart home, smart healthcare, smart grids, and smart traffic; hence requirements of supporting CT are diversified too. Those requirements include various technical specifications such as the networking architecture, data rate, received signal level, the frequency band, coverage area, accessibility, capacity, security, robustness, privacy, and cost. Unfortunately, even with technological advancements, there is no unique communication solution to satisfy all smart space applications at the same time due to their diversified requirements and conditions [1, 2, 3, 4, 5].

Hence, researchers must find a fair equilibrium between applications' requirements, and achieved investments to develop convenient CT in order to support those services. Furthermore, they have to prioritize specifications that highly affect final performances. This goal is achieved by a deep comprehension of smart space conditions, needs, environments, and parameters, in addition to available communication solutions to adopt the most convenient technology to those needs.

In this context, wireless solutions are essential to provide services for people within smart spaces, in order to ease their life, improve their comfort and safety while moving or doing their daily activities. Thus, many researches have been accomplished in order to examine their different challenges and advantages. Those activities are justified by many advantages of wireless technologies such as reduced space overcrowding, lower cost, easy deployment, high coverage, high scalability, and dynamic network formation.

Among all wireless technologies, WiFi can offer a good compromise between the low power consumption of IoT compatible CT like Sigfox [43], low deployment and equipment cost of personal technologies such as Bluetooth, high data rate and wide coverage range of mobile communications such as LTE and WiMAX [44], in addition to its free of charge ISM (Industrial, Scientific and Medical) radio frequencies bands.

For those reasons, in addition to its popularity and availability in smartphones, the purpose of this paper is the evaluation of the coverage range of WiFi technology for outdoor applications as antennas manufacturing companies do not propose or provides the approach to use outdoor WiFi to directly connect the final consumer devices. Then we will discuss the effect of those results on the provision of wireless internet services (WIS) in the context of smart spaces applications like IoT. In addition, obtained results are compared with most known empirical path loss models in order to verify their accuracy in this context.

This paper is organized as follows: Section 2 discusses the state of the art by examining related work, and by giving an overview of wireless internet service and used technologies. In this section, a special focus is given to WiFi and technical characteristics of its versions and a brief description of many empirical path loss models is given. Section 3 describes the scenario we have used to characterize the WiFi range, Section 4 details results that we have obtained in comparison with empirical path loss model, Section 5 discusses the impact of obtained results on IoT applications, and Section 6 discussed threat of validity for obtained results. Finally, a conclusion is given in Section 7.

II. STATE OF THE ART

A. Related Work

In general, Smartphones are WiFi enabled, as a consequence many research activities tried to characterize this communication protocol. Berezin et al. [6] investigated if it is feasible to use WiFi in urban areas for mobile Internet access and which type of applications can benefit from the provided Internet access. They also analyzed the characteristics of WiFi coverage and connectivity of mobile users using different mobility speeds and varying some AP settings. Cai et al. [7] discussed an incentive mechanism for the operator to encourage users to delay their cellular

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network services and switch to WiFi network in order to offload cellular mobile traffic. Lindner et al. [8] described four exemplary possibilities of exploiting the wireless local area network (WLAN) infrastructure for additional services, provided that WLAN is almost ubiquitous in a coherent area. In addition, many research activities have been made to evaluate and optimize the WiFi range for Sensor network applications [9-11]. The study in [12] is one of the first to analytically describe how businesses, governments, and other organizations are creating large WiFi and wireless internet clouds. This report also described the types of wireless coverage. Seneviratne et al. [13] characterized the WiFi connection set-up process in order to extend a known mathematical model, which will help in the dimensioning of WiFi networks for pedestrian smartphone users. As WiFi is mostly used for indoor applications, many papers tried to characterize its range or other properties for in-building use [14-16]. Actually many applications are using it such as Communication service for rural areas [17], Healthcareservices [18], during extreme events [19], mobile internet services [20], smart home applications [21], or smart city services [22]. In spite of the wide number of research made about communication technologies in smart spaces, there is a lack of characterization of the coverage range of WiFi for outdoor applications because it is mostly used for indoor services. Also, specification sheets of the majority of antennas manufacturing companies [40, 45, 46] do not propose or provide a synthesized process for the use of WiFi to directly connect the final consumer outdoor devices.

B. *Wireless internet service (WIS)*

1) *Introduction*

Due to their countable advantages, wireless technologies (WT) knew a huge development and appear to be a really exciting analysis space for the researchers. Hence, WIS can be defined as the operation of wireless devices or systems used to connect two locations with a radio or other wireless links [23]. In addition, some communication providers call this technology as Wireless To The Home (WTTH) [70]. The deployment of WIS can be explained as a network of wireless access point (AP) having connectivity to the internet. Each AP can connect remotely many Customer Premises Equipments (CPE). A CPE can be installed on the roof of a home or any other high place on the location that we which to connect to the internet. Then CPE is connected to users inside equipments such as wireless routers, or computers by wires to link them to the internet.

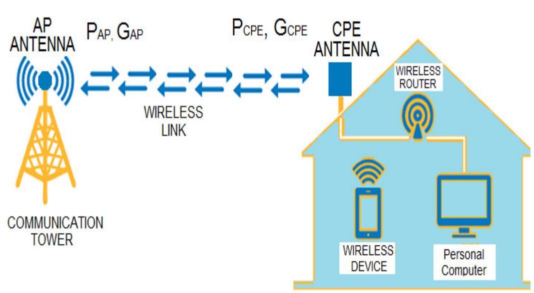

Figure 1. Deployment example of WIS network.

Actually, WIS has gained a wide place in the internet services to provide connectivity for population located in rural areas [24, 70, 72]. For example, WIS is available for 82% people around Canada [25]. Furthermore, this service is used widely in healthcare especially in remote monitoring of patients with chronic diseases while they do their daily routines. Its application in this domain aims to provide autonomy while increasing the quality of life for chronic disease patients and decrease the load of health establishments [26] at the same time. It can also be used during extreme events such as natural disaster as a secondary link to provide internet connection to rescue personnel or damaged population [19, 71].

2) *Used Communication Technology*

Many communication technologies are used by WIS or WTTH providers like WiMAX, LTE, Whitespace [27, 28]. But WiFi particularly attracted the attention, as it provides important characteristics and attributes that smart spaces require even in harsh environment [72]. Those critical requirements include:

- Coverage is a very interesting subject because the greater the scope of coverage, the concerned population is increased. A major advantage of WiFi network is its signal coverage [29], which is typically 100 m, it is also tested for outdoor use and its coverage reached 500m [19]. For point-to-point or point to multi-point links, its coverage can be extended until many tens of km [30] by using the configuration described in Figure 1.

TABLE I. A COMPARISON BETWEEN MOST RELEVANT CHARACTERISTICS OF POPULAR WIRELESS CT.

	Bluetooth	WiFi	LORA	SIGFOX	WIMAX	LTE	5G
Power	L	L	VL	VL	H	VH	M
Range	L	H	VH	VH	VH	VH	VH
Data rate	L	H	VL	VL	H	H	VH
Cost	VL	L	L	L	VH	VH	VH
Ref.	[47-50]	[30], [51-54]	[55, 56]	[57, 58]	[59-62]	[63-65]	[66-68]

Very low: VL	Good:
Low: L	Neutral:
High: H	Bad:
Medium : M	
Very high: VH	

- WiFi is typically employed for its lower deployment cost [19, 28, 31]. In the context of smart space, a huge number of connected devices are required. Hence, a low-cost technology can decrease needed investments when covering new areas or while upgrading already covered areas to newer technologies. This quality is particularly important for developing countries where fewer resources are available. In this context, even if ad hoc technologies are less costly as they do not require infrastructures; but they still unusable due to reduced data rates and increased latency when the number of nodes joining the network rises.

- The number of nodes is essential to connect the largest number of people or things especially in the context of smart spaces where a high number of IoT devices are interconnected. In this context, Lee et al. [32] confirm that the maximum number of nodes for WiFi ad hoc network could be unlimited.
- Data rate identifies the amount of information that the network can support. The higher the data rate the greater amount of information can be transmitted between devices. Hence, the data rate of the new version of WiFi surpasses easily 1 Gbps. This property is very important for smart spaces context where a huge amount of information of many types like video, images, text, IoT data or social networks applications are transferred through communication networks.
- As mobility becomes the major trend of our modern life, communication with less power becomes an essential subject to extend the life of batteries without the need for recharging or being connected to a power socket. It is stated that WiFi has the best energy efficiency [33] among WT; which is defined as the power consumed by a given CT in order to transfer a fixed amount of data.
- In general, even if a given technology is absolutely the most effective to support communication, but if it is not available on Smartphones, then it becomes useless in the context of smart spaces. According to information provided by Nokia [34] and Sony [35], Bluetooth and WiFi technologies are available on the majority of current Smartphones [36].
- The area to be covered may have many profiles of geography, vegetation and weather. As the wireless signal penetration can vary according to those environmental effects; the radio frequency is customized accordingly from lower frequency for high penetration through vegetation, buildings or hills to higher frequencies for line of sight links. WiFi can fulfill those requirements while being exempt of license fees at the same time, through the use of ISM radio frequency bands.
- Channel bandwidth need to be adjusted according to the data transfer need, from lower bandwidth for simple text application to high bandwidth for video streaming services. WiFi bandwidth range varies from 5 Mhz for low throughput applications to more than 160 MHz for high data transfer services.

As we can deduce, according to table I, WiFi seems to be among the best suitable choices for the smart space context. Its wide range and the big number of nodes allow covering a large geographic zone and a maximum number of devices. In addition, its high data rate maximizes information transfer and prevent network breakdown due to congestion. In addition, this technology is easy to deploy due to its availability on most smartphones and its reduced cost. Furthermore, it has low power consumption in order to extend the battery life of portable devices and improve users' mobility. Moreover, the frequency and channel bandwidth can be customized according to environmental conditions and throughput for various penetrations and data transfer profiles respectively.

3) *General description of WiFi(IEEE 802.11)*

Wireless fidelity (WiFi) is the radio technology for wireless devices operating in the IEEE 802.11. As the IEEE organization does not verify the compliance of conceived devices with its standards, hundreds of manufacturers around the world have met to form the WiFi alliance. Their aim is to verify the interoperability of their devices operating in 802.11 standards. Indoor WiFi is a single-hop network using IP stack to allow users to surf the Internet at broadband speed when they are connected to their wireless routers. The current solution to extend network range for outdoor use is to use repeaters or a wired LAN to interconnect a group of WiFi APs. New methods are designed by allowing stations to communicate directly without any AP [37]. Thus, WLAN can be formed without pre-planning; it is often referred to ad hoc network [38]. The drawback of this solution is the reduction of performances in terms of link's throughput and latency each time a new node is added to the network. Other solutions are proposed and used in many commercial applications through the use of high-gain antennas for AP and user side (CPE) [73, 74]. By using this solution, the range of WiFi networks can be extended to many tens of Kilometers [31].

4) *Technological Characteristics*

IEEE 802.11 includes a set of specifications of the physical layer and media access control (MAC) for the deployment of a wireless network. This standard allows many different radio frequencies bandwidth to be used within ISM bands for half duplex communications: 900 MHz, 2.4, 3.6, 5, and 60 GHz frequency bands. Wireless links using 2.4 and 5 GHz may probably suffer interference from many other devices operating in the same unlicensed frequencies such as Bluetooth devices or cordless phones. To reduce the interference, many techniques can be used such as orthogonal frequency division multiplexing (OFDM), dynamic frequency allocation or GPS synchronization.

TABLE II. TECHNICAL CHARACTERISTICS OF MOST USED 802.11 STANDARDS

	802.11a	**802.11b**	**802.11g**	**802.11n**	**802.11ac**	**802.11ax**
Frequency (GHz)	3.6, 5	2.4	2.4	2.4, 5	5	2.4, 5
Bandwidth (MHz)	20	22	20	20, 40	20, 40, 80, 160	20, 40, 80, 160
Data rate (Mbps)	6, 9, 12, 18, 24, 36, 48, 54	1, 2, 5.5, 11	6, 9, 12, 18, 24, 36, 48, 54	Up to 600 for 40 MHz and 4 Streams	Up to 3466.8 for 160 MHz band and 4 Streams	Up to 10,530 for 160 MHz band and 4 Streams
Modulation	OFDM-64QAM	DSSS	OFDM-64QAM	OFDM-64QAM	OFDM-256QAM	OFDM-1024QAM
MIMO streams	-	-	-	4	8	8

With technological advances, many versions of this standard have been made available to satisfy the diversified users' and industries' needs. The most used and known standards are the following: 802.11a, 802.11b, 802.11g, 802.11n, 802.11ac, 802.11ax (Wi-Fi 6), 802.11ad, and 802.11ah. The part of this standard dedicated to radio frequency spectrum allocation may vary according to countries, because each one applies its own strategies or regulations for bandwidth sharing, used frequency channels, maximum transmission power.

The 2.4 GHz frequency refers to the ISM band between 2.4 and 2.5 GHz. The 5 GHz frequency is the band between 4.915 and 5.825 GHz. The 3.6 frequency is between 3.65 and 3.7 GHz. The 900 MHz frequency corresponds to the bands 902-930 MHz. Each band is divided into many sub-channels with a precise central frequency, channel space, and bandwidth. For example, the 2.4 GHz is divided into 14 sub channel spaced of 5 MHz; the central frequency of the first channel is 2.412 GHz and 2.484 for the last channel. The availability of channels may differ between countries according to the spectrum allocations of various services made by regulation.

The bandwidth frequency allows more data rates, for example, if a 20 MHz bandwidth provides 300 Mbps, then the 40 MHz one allows 600 Mbps. Data rate refers to the speed of data transfer, each standard has its own data speed profile, the higher the received signal level, the higher the connection speed.

Furthermore, MIMO stream indicates the number of receiving or emitting antennas and it can make the same effect as the bandwidth makes to the data transfer rate. Hence, if 1 stream makes 300 Mbps then 2 streams are able to provide 600 Mbps.

C. *Link quality and coverage range prediction*

The wireless link quality may be estimated by the link budget formulas [39]:

$$P_{RX}(\mathrm{dBm}) = P_{TX}(\mathrm{dBm}) + G_{TX}(\mathrm{dB}) + G_{RX}(\mathrm{dB}) - L(\mathrm{dB}) \quad (1)$$

Where:

P_{rx}: is the received signal power by the receiver

P_{tx}: is the transmitted signal power by the transmitter

G_{tx}: is the gain of the transmitter antenna

G_{rx}: is the gain of the receiver antenna

L: is the total loss of the link; it includes internal device losses and path losses. Internal device losses can be known by their data sheets, such as connectors' losses. Path losses are the signal attenuation on his way between transmitter and receiver. A lot of research activities have been made to model the propagation effects on path losses, in order to ease network planning and performance prediction. Those models can be classified into three basic types: Empirical, deterministic, and stochastic [76]. Empirical models can give the best tradeoff between the accuracy of deterministic models and the decreased processing requirements off stochastic models. The free air loss [39] is the simplest empirical model and it is represented by the following formula:

$$L_{FS}(dB) = 20\log\frac{4\pi D}{\lambda} \quad (2)$$

Where D is the distance between transmitter and receiver, λ is the wave length of the radio frequency signal.

This model suppose that the attenuation of signal is due to the free air without taking into account other environmental effects such as buildings, multipath fading, antennas heights etc. Thus, several other models have been developed, the most known are the following ones [77]: Cost231, Stanford university interim, Ericson, Hata, Walfisch-Ikegami, Hata-Okumura. Unfortunately, each of these models has different limits of validity than the others and does not perfectly fit measured path losses without making some adjustments [78, 79]. During our research we will compare measured values to most known path loss empirical models in order to find which one fits the best the usage case for outdoor WiFi in the 2.4 GHz frequency band. In addition, environmental effects include all other losses such as attenuation of the wireless signal when it crosses the vegetation, snow, rain, or humidity. Those effects are not easy to estimate because they depend on many unpredictable and random parameters such as weather and leaf density. For the purpose of simplicity, we will consider only the line of sight study without taking into account environmental losses. However, we will consider the estimation of those effects during our future researches.

After the received signal is estimated for a given location, it will be compared with the sensitivity values of the receiver and then the data rate can be known by the nearest sensitivity value. For example, if the receiver is a Ubiquitous Rocket M2 radio [40], and the estimated received signal is -77 dBm, by using Table III, which is provided by the manufacturer of the receiver, we can estimate the data rate of the wireless link as MCS6.

Also, the maximum range can be estimated by the following formula [39]:

$$D = \frac{\lambda \times 10^{\frac{P_{TX}+G_{TX}+G_{RX}-P_{SENS}}{20}}}{4\pi} \quad (3)$$

Where Psens is the lowest detectable power by the receiver. When the receiver detects a radio signal with this power value, the data transfer speed of the link corresponds to the lowest possible data rate, MCS0, and the coverage range is the widest because Tx power is bigger and the sensitivity is lower. Thus if the receiver goes wider than this distance, the radio link fails and the receiver disconnects. Also, this power may correspond to wished operation data rate; in this case the distance is limited to the range where the received signal does not go lower to keep the data rate within specified limits. To extend the coverage while staying within this specification, the whole area is divided into many cells, where each one is covered by an AP as in Figure 3.

TABLE III. TRANSMIT POWER AND RECEIVER SENSITIVITIES FOR UBIQUITY ROCKET M2 RADIO [40] USING 802.11N PROTOCOL (2.4 GHZ) USING ONE MIMO STREAM.

Data Rate	Avg. TX (dBm)	Sensitivity (dBm)
MCS0	28	-96
MCS1	28	-95
MCS2	28	-92
MCS3	28	-90
MCS4	27	-86
MCS5	25	-83
MCS6	23	-77
MCS7	22	-74

III. SCENARION OF USE

Our scenario is presented in Figure 2. It contains WiFi AP connected to a router or networking device that has a link to the internet, the covered zone by the AP contains WiFi-enabled mobile devices. The aim of routing or switching device is to make firewalling, other network operations and to ensure the link between AP and the Internet.

In this scenario, AP may connect all WiFi enabled devices to cover the whole smart space area in order to provide mobile internet service. AP ensures links directly without intermediate devices, contrary to WiFi P2P networks which require many hopes before accessing to the internet [37]. By using high gain antennas, we can ensure a wide range capacity; AP can cover the whole zones including bridges, trees, buildings, and homes. The advantage of having direct connectivity to the Internet is the high data rate; contrarily to ad hoc devices where the network capability is decreased when traffic goes through intermediate devices. To ensure the widest range, it is recommended to install AP in a high place as in the top of a mountain, building or even in a balloon. Consequently, high antennas installation may provide a line of sight, reliable radio link and high data rate.

Our scenario has many advantages in comparison to the model proposed by Ajami and Mcheick [37] or other Ad hoc solutions, where a WiFi Peer to peer network technology is created in uncovered area. In their proposition, the coverage is extended from 100 meters to several kilometers by passing information from one WiFi P2P device to another. The major problem is that devices may not be compatible with each other and a solution that supports IOS devices have to be proposed. Another weakness of their model is the necessity of WiFi direct devices to be spread to all the area to ensure continuity of the coverage. Sometimes, the last condition is difficult to satisfy due to geographic issues. The short range of Ad hoc devices limited to about 100m may increase uncovered area. Unfortunately, we cannot extend this range because it depends on mobile phone devices' constructors and normalization organisms.

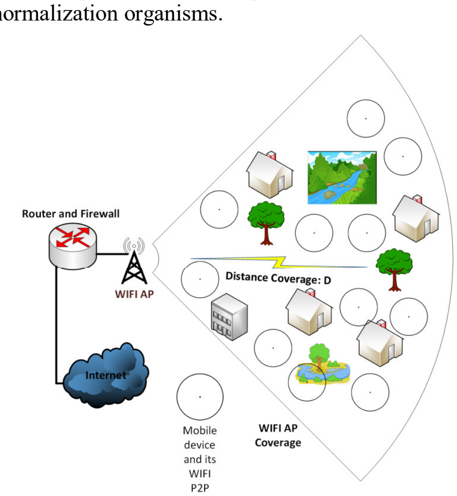

Figure 2. A scenario case study scheme.

AP antenna is chosen according to the area of smart space to be covered; in the market, we can find omnidirectional antennas if users are distributed uniformly around the antenna. If we need to cover a more specific zone, we can choose sector antennas; which have many radiation angles of 120, 90 or 60 degrees [73, 74]. As antenna gain decreases each time radiation angle increases, it is recommended to choose the lowest radiation angle, if possible, to widen the radiation distance.

The most used frequencies for WiFi are 2.4 and 5.8 GHz, which are available for most WiFi enabled devices. It is possible to use other frequencies like 900 MHz and 3.65 GHz but the network may require frequency conversion devices [75]. It is recommended to use 900 MHz and 2.4 GHz for AP due to their high penetration rate. Licensed 3 GHz is recommended to use for backbone link in high interference area. For ease line of sight backbone link, the 5 GHz is recommended for its high capacity and data rate.

IV. VALIDATION AND RESULT

Our validation test includes the following devices:

- A smartphone: Samsung Galaxy S5
- AP antenna: Ubiquity Airmax AM-2G16-90 [41]
- Radio module with integrated router for AP: Rocket M2 [42]
- Power over Ethernet (POE) injector
- Two SMA pigtails
- AC, DC and RJ45 wires with Power supply

The AP antenna is installed in a way to give a direct line of sight to the test area. The test area has been chosen in an open air place, where the effect of vegetation and buildings is minimized. The AP antenna is connected to the radio through two SMA pigtails as it has two MIMO streams. The radio module includes an integrated router that is connected to the internet through RJ45 wire. It is powered through a POE injector from the router side. The radio is configured in a way to choose a clear bandwidth frequency by using its integrated snooping capability in order to minimize interference with nearby devices. It is configured with a Dynamic Host Configuration Protocol (DHCP) server in order to give a direct access to the internet for the Samsung Galaxy S5 smartphone.

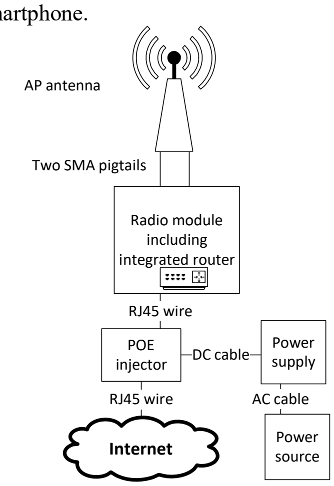

Figure 3. Diagram of the AP installation.

After powering on the power supply, we stayed near of the AP in order to insure that the smart phone is well connected to the internet through it. After then, we moved away gradually while checking the connectivity of the smartphone to the internet. The maximum distance we have gotten before it disconnects was 550m.

In Figure 4, the measured coverage is compared with many other prediction models. The radio characteristics of smartphone and AP are the same as those presented in [19], their height is 1.5 m. The Hata model gives the closest result with 0.258 Km. The free air loss gives a distance prediction of 30.78 Km and Walfisch-Ikegami is 5.682 Km, we did not put their complete distance value on the graph for the sake of clarity for the results of other models.

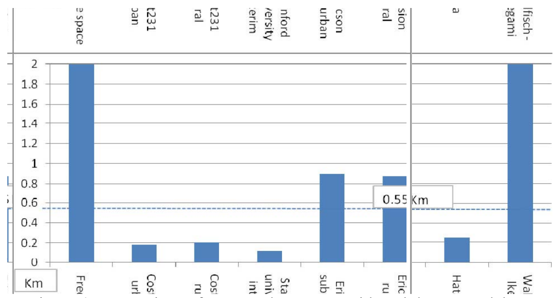

Figure 4. Comparison of measured coverage with path losses models

In most empiric models [77 - 79] the coverage range, depends on following parameters: Antennas gain, frequency, transmitting power, distance, height and obstacles. Those models are essentially developed and fitted basing on measured data in precise environmental conditions for a given technology. Thus, it is difficult to get very good prediction accuracy on all environments and all CT unless the limits of each model are respected. This observation can be justified according to Figure 4, where the best predicted distance has 40 % of difference from the measure, and in figure 5 the accuracy of result vary according to AP height. In the same way as AP height, all environmental conditions have an influence on prediction accuracy; during our future research we will detail, model and express their effects on outdoor WiFi for WIS application by using more data.

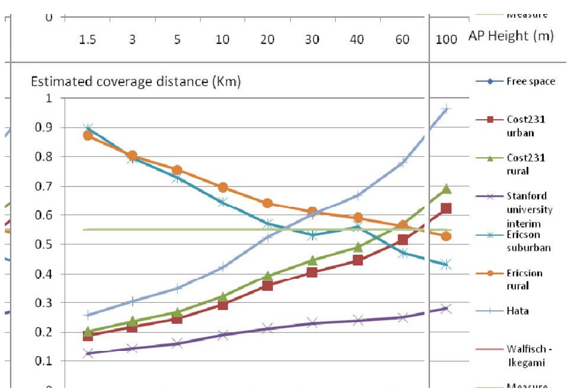

Figure 6. Estimated coverage of most known models over Height of AP

As a result, we can estimate the total area of a cell that can be covered by a WiFi AP. This area is similar to a circle, where its centre is the location of the WiFi AP and its diameter is about 1 km. If the smart space area is wider than the total coverage of a cell, we can install many AP in a way similar to Figure 3. Thus, the total area is divided into many sub-areas; each one is covered by a WiFi AP. The configuration can be done according to the table I, the frequency is chosen to reduce the interference between neighboring cells. The frequency bandwidth is configured according to the required global throughput; the population number in each cell can be a good index to estimate this parameter. An automatic configuration algorithm will be proposed for a similar context during our future researches.

V. CONSEQUENCES FOR IOT APPLICATIONS

Actually, IoT is clearly a trend hat cannot be ignored. According to CISCO [69], IoT connections are becoming bigger than other daily connections, and IoT traffic will double by 2020. Furthermore, IoT applications are diversified in terms of connectivity specifications such as data transfer, coverage range, energy efficiency and cost. The data transfer requirement vary from small and intermittent connectivity for some utility sensors and meters to large amount of continuous data flow such as video surveillance or drones activities. In addition, the power need may vary from high intensive power consumption applications to very high battery lifetime of many years' sensors. Equally, the coverage may vary from easy to access small indoor building into hard to access very wide area forests.

The WiFi connectivity is a good choice as it is almost ubiquitous for indoor buildings, campus environments and urban areas. In addition, it has the advantage of being able to support easily high data rate application, such as data streaming, with reasonable coverage range and power consumption with a lower cost. In addition, this technology can get a higher coverage range through the use of lower ISM frequency bands in order to improve its penetration through vegetation and hills for IoT devices to be used as fire forest sensors, covering a wide area and requiring lower power consumption and low data rate. Moreover, Lora and Sigfox technologies can be good alternatives for such IoT applications as they have extended battery life and convenient transmission capacity.

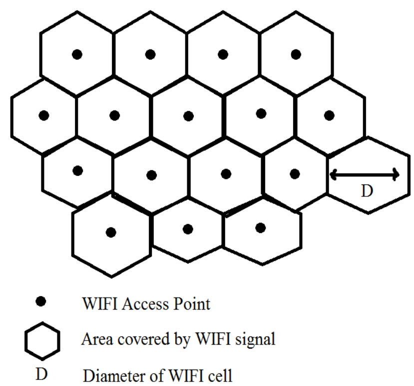

Figure 5. Wide range deployment model for WiFi.

At the other hand, for devices scattered across a large area and requiring a good throughput, such as drones broadcasting video, we can make a WiFi configuration like the one presented in figure 3. The advantage is that WiFi can support unlimited number of wireless connections, and it has many bandwidth frequency configurations in order to adjust throughput according to applications needs while keeping a good mobility at the same time. Furthermore, this technology is well adapted for developing countries' context, as it does not require high investing as its infrastructure cost is low in addition to the free frequency licenses; which helps to spread IoT in poor countries.

VI. THREATS TO VALIDITY

Our test has been done in an urban environment, hence the high spectrum congestion of WiFi inducing interference effects has been taken into account. Even if the test have been made for line of site configuration but fading and multi path propagation of radio frequency signal have been taken into account. In addition, more measures will be done during our future research in order verify the accuracy of various path loss models and develop other models, if needed for the context of WIS deployment. Environmental effects such as seasons, weather, and vegetation will be taken into account during our future researches. A test configuration taking into account many AP will be proposed in our future researches.

VII. CONCLUSION

This paper characterized the coverage range of WiFi for outdoor applications, and analyzed its consequences for smart space services like IoT. As WiFi is generally low cost, its technical characteristics are explained and a deployment scenario based on this technology is explained on light of obtained results. It is also available on all mobile devices and it is supported by a majority of used internet enabled objects. Therefore, investments to develop new compatible technologies on other devices are saved. In addition, this technology is well suited to resolve the small coverage of Ad hoc P2P networks and the necessity to have continuity of enabled P2P devices into the entire needed zone. Obtained outdoor coverage range is 550 m, it is characterized for a clear line of sight links. The comparison between the values of coverage distance obtained during measure with most known empirical path loss models showed an important difference. During our future researches we will verify the accuracy of empirical models for the context of outdoor WiFi on WIS deployment by using more measures. A new empirical model satisfying this context will be proposed by taking into account environmental effects such as weather, season and vegetation on the QoS of outdoor WiFi signals. In addition, we will propose a method to automate the configuration of WiFi APs covering a whole area in order to satisfy specific requirements and fasten their deployment.

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