Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2021, 8(3):193-202

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

A Low-Cost Architecture for Monitoring the Average Electromagnetic Field for Public Health

Mamadou Diallo Diouf*, Ibrahima Gueye*, Mamadou Lamine Goudiaby*, Seydina Alioune Ndiaye*

*Laboratory of Information Processing and Intelligence Systems (LTISI), EPT/SENEGAL
mddiouf@ept.sn, igueye@ept.sn, goudiaby.ml@gmail.com, alioundiaye@hotmail.fr

Abstract Nowadays, we are not only witnessing a steady increase in bandwidth-intensive services, but also a drastic demand for these services even in the most remote areas. Indeed, with the advent of Cloud computing, Internet of Things, video on demand, decentralization of certain remote access services, biomedicine, etc., a progressive increasement of cellular infrastructure over time is inevitable. The customer demand for mobility and very high speed leads to the use of radiofrequency signals in the millimeter range (30-300 GHz) in addition of bandwidths used in Classique networks such as Bluetooth, WIFI, WiMAX, 2G, 3G, 4G and actually 5G. This phenomenon of emission of electromagnetic waves leads to a great debate on public health. So in recent years, there has been an increasing public concern about possible health hazard resulting from exposure to electromagnetic (EM) waves. Much attention has been paid to the induced of Specific Absorption Rate (SAR) in the human head for exposure to EM waves emitted from commercial cellular phone antennas. This concern is a major subject which interests the frequency regulation authorities. In this work, we propose a low cost architecture allowing the average electromagnetic field to be measured in real time and in each zone.

Keywords Public Health, electromagnetic fields, Specific Absorption Rate (SAR), Personal explosimeter, Exposure evaluation

1. Introduction

If exposure to electromagnetic fields has always caused through their natural sources (terrestrial magnetic field, cosmic radiation, etc.), it is since the 1900s, with the generalization and expansion of the uses of electricity that human being become exposed to numerous artificial electromagnetic fields. This exposition field are emitted in public environment (transport of electricity, public transport, household appliances, ...), in professional activities (industrial processes, energy uses, ...) and even in houses. Among the electromagnetic waves, characterized by their frequency and wavelength, a distinction is made between ionizing radiation and non-ionizing radiation, including ultraviolet light, visible light, infrared radiation, radio frequencies, electromagnetic fields of extremely low frequencies (EBF) and static fields. During this last century, the sources of electromagnetic fields have multiplied and their uses intensified. This intensification is mostly due to recent developments in telecommunications, transmitters of radio frequencies.

Nowadays the rapid evolution of technology and network infrastructures towards the fifth-generation (5G) systems requires a similar evolution in the methods of assessment in order to face the increasing complexity exposure of electromagnetic waves. This is particularly needed in indoor environments, in which it was estimated that people spend about seventy percent of their daily time. In an indoor environment, the RF exposure depends on outdoor sources such as radio, television and/or mobiles networks antennas, as well as on indoor sources such as mobile phone handsets, DECT base stations, Wireless Local Area Network (WLAN), computers, etc. While radio and television transmitters have a large coverage area and therefore operate at relatively high power levels, the power level inside a building can be up to 100 times lower than that outside the building, depending on the number of windows and the structure of the walls, and the exposure may vary from floor to floor. Indoor sources of electromagnetic fields presents some lack of information such as their number and their locations. This is due especially to their private environments and the structure of the rooms and their furniture. All these aspects mean that the evaluation of exposure to RF-EMF is affected by uncertainties and represents a difficult task especially for the regulatory authorities which are interested in the regulation of the levels of electromagnetic fields.

Thus studies have been carried out by government officials to oblige operators to respect the maximum levels of the values of electromagnetic fields in an area. ICNIRP (International Commission on Non-Ionizing Radiation Protection) [1] is a non-governmental organization officially recognized by the WHO. In 1998, it established limit values for human exposure to all electromagnetic fields [2]. These limit values have been based on the results of studies (mostly on the animal model) and based on the effects appearing at the lowest level of exposure. The thresholds were defined with precautions for extrapolation from the animal model to human. The Council of the European Union Recommendation 1999/519/EC of July 12 1999 limits the exposure to electromagnetic fields. It incorporates the ICNIRP limit values in terms of basic restrictions and reference levels. European Directive 2004/40/EC published in May 2004 by the European Parliament and European Council in 2004 [3] defines the limit value of exposure to electromagnetic fields for professionals. These publications are revised in 2013 by the European Parliament and European Council in 2013 [4]. It incorporates the ICNIRP limit values by defining two new terms:

– Exposure limit values which correspond to the basic restrictions,

– Limit values triggering the action which correspond to the reference levels.

All the works published on the impact of the RF electromagnetic waves on human health specify the limit values of the fields. The measurements and data obtained by the authorities are carried out for each zone and over specified du ration and periods. Regulatory authorities often use drive-test to get the values.

Our proposal focuses on a low-cost architecture for monitoring the average electromagnetic field in each zone to be measured in real time.

Thus, the introduction of our proposal will be followed by a related work in section 2 and a general study of Electromagnetic waves and human life in section 3. Before the presentation of our proposal architecture in system model defined in 5, we have described in section 4 Electromagnetic waves and public health. The performances obtained through our simulations are described in the section 6.

2. Related Work

Public health is a major subject which interests the whole community. Recently, several scientific works have been done to study the impact of electromagnetic waves on populations. In this section, we make a bibliographic study to outline the results previously obtained and we analyze and compare them to our proposal. So several studies on the impact of waves on children's health have been noted in the literature. In 1979 in Colorado, Wertheimer and Leeper [5] study the increased risk of leukemia in children in relation to residential expo sure to electromagnetic fields. This study was followed by many others works such as [7] and [6]. A survey of nine studies was published in 2000 [8]. In this survey, the authors show that the risk of exposure at the residential places are doubling. These results was confirmed by another study in the same year [9]. In 2010, an update of these grouped analyzes, adding 7 new studies published and estimated the increase in risk to 1.56 for an exposure $\geq 0.3\mu T$ and 2.02 for an exposure $\geq 0.4\mu T$ [11]. The Modeling of electromagnetic wave penetration in a human head due to emissions from cellular phone is presented in [10]. The conclusions of this work give the important parameters affecting the Specific Absorption Rate (SAR) in the human head exposed to cellular phone radiation were the operational frequency of the phone and the distance between head and antenna of the cellular phone. In 2017, the authors of [13] did a study on the evaluation of Stationary and Mobile Components of Radiofrequency electromagnetic exposure in the public accessible environments. Their investigations show that, if many users of mobile communication tools are present in the crowd space the resulting of exposure caused by their individual devices may together exceed stationary components. A review presentation is given by [14] on the radio frequency electromagnetic fields exposure assessment in indoor environments in 2019. This study provides a summary of the results obtained in ten years (2008-2018) of research efforts focusing on the assessment of RF-EMF exposure and proving information specific to the levels of exposure in indoor environments. The results included a wide range of sources, both deployed outdoor or indoor the environment in which the exposure level was evaluated, a wide number of different environments, from offices and transportation, to private houses. These results were obtained through different approaches, including spot and long-term measurements, personal measurements and computational methods. Otherwise, in this same year, the proposal in [14] gave the radiofrequency electromagnetic exposures during the use of wireless links of portable computers inside trains without internal WiFi service. Their experience confirmed that the multi-path propagation of EMF signals used by wireless links of portable computer modems (usually at GSM or LTE uplink frequency bands) may produce significantly stronger EMF exposure inside train cars than exposure from WiFi facilities usually used by portable computers inside buildings.

In summary, we can conclude that several results on the effects of electromagnetic fields on public health have been published. But it should be noted that most of the conclusions do not provide the wave measure systems. Also the data obtained are recorded on a specific zone and period. This makes ineffective the supervision of the authorities on the emission of the waves of the operators of wireless networks. This work presents an architecture which measures waves from all frequency holders in real time and displays them on a screen for more effective monitoring.

3. Electromagnetic waves and human life.

Exposure to RF electromagnetic fields is motivated by the constant increase in multimedia services in human life. Previously men needed television and radio. Currently we assist the presence of other services such as mobile telephony provided by the Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE) and now the 5G. One of the lines of specifications for 5G requires a network that can support a very large capacity with more connected devices (even in overcrowded areas). These mobile telecommunications networks wireless, like WIFI, Wireless Local Area Network (WLAN) and WiMAX, Wireless Metropolitan Area Network (WMAN) are also used for the data transmission. In the other hand, smart cities, smart agriculture, connected objects, in short smart cities become now a reality. So the concept of Smart City has received multiple definitions and meanings throughout its existence. Finally we have come to understand that it is not a goal but a way of life, a means, a process of continuous improvement and constant evolution to improve the quality of life and social cohesion of the city in which this must take precedence over the commitment between technology and the actors. Speaking of systems developed in the Smart Cities under the range of IT in the present moment is not only talk about computers, mobile devices, sensors, interconnection networks, visors, etc... is to talk about new concepts and paradigms socio-technological [16] as Internet of Things (IOT), Cloud Computing, Big Data, Augmented reality and vision artificial etc. All of these wireless communication networks use the propagation of radio-frequency electromagnetic field (RF-EMF) with frequencies between 10 MHz and 6 GHz. The table 1 shows a number of communications networks according to their frequency bands of use and application area.

Table 1: Communications networks according to their frequency bands of use

	Location RF-EMF Source	Communication Standard	Frequency (MHz)
Out	Base Station for radio	FM: Frequency Modulation	100
Out	Base Station for radio	DAB: Digital Audio Broadcasting	220
Out	Base Station for television	TERRA: Terrestrial Trunked Radio	390
Out	Base Station for television	AT: Analogue TV	174-223
Out	Base Station for television	DVB/TV: Digital Video Broad casting–Terrestrial	470-830
Out	Base Station for television	UHF: Ultra-high frequency Television	470-860
Out	BS for mobile telecommunications	GFM900 DL: Global System for Mobile Communications	900
Out	BS for mobile	GFM1800 DL: Global System for Mobile	1800

	telecommunications	Communications	
Out	BS for mobile telecommunications	DCS1800 DL : Digital Communication System	1800
Out	Base station/Small cell	UMTS DL: Universal Mobile Telecommunications System	2100
Out	Base station/Small cell	LTE: Long Term Evolution	2600
In	Femtocell WIFI 2G: Wireless	Local Area Networks	2400
In	Femtocell WIFI 4G: Wireless	Local Area Networks	2400
In	Access point	WiMAX: Worldwide Interoperability for Microwave Access	3500
In	Access point	WIFI 5G : Wireless Local Area Networks	5500
In	Access point	GSM 900 UL: Global System for Mobile Communications	900
In	Mobile phone/Tablet	GSM188 UL: Global System for Mobile Communications	1800
In	Mobile phone/Tablet	DCS188 UL : Digital Communication System	1800
In	Mobile phone/Tablet	UMTS UL: Universal Mobile Telecommunications System	2100
In	Mobile phone/Tablet	LTE UL: Long Term Evolution	2600
In	Mobile phone/Tablet	DECT: Digital enhanced cordless telecommunications	1880

4. Electromagnetic waves and public health

4.1. Propagation of electromagnetic waves in a biological medium

An electromagnetic wave is composed of an electric wave and a magnetic wave which are transverse and which verify the Maxwells equations [17]. These equations are established in a propagation medium. The propagation of EM waves in a biological medium is studied mathematically by solving Maxwell's equation under appropriate boundary condition [18]. For simplicity, the biological medium is assumed to be infinite extent, source-free, isotropic, and homogeneous. The medium is isotropic if is a scalar constant, so D and E are the same in every direction. A homogeneous medium is one for which, and µ are constant. For this case, Maxwell's four equations become:

$$\mathrm{div}\vec{\mathrm{D}} = 0 \quad (1)$$

$$\mathrm{div}\vec{\mathrm{B}} = 0 \quad (2)$$

$$\overrightarrow{\mathrm{rot}}\,\vec{\mathrm{H}} = \vec{j} + \frac{\partial \vec{\mathrm{D}}}{\partial t} \quad (3)$$

$$\overrightarrow{\mathrm{rot}}\,\vec{\mathrm{E}} = -\frac{\partial \vec{\mathrm{D}}}{\partial t} \quad (4)$$

The equations (1), (2), (3), (4) are respectively called Maxwell-Gauss's equation, flow conservation equation, Maxwell-Ampere's equation and Maxwell-Faraday's equation. For a medium which assumed to be isotropic and homogeneous, so with a permittivity, permeability, and conductivity are scalars and constants, a deep study of these Maxwell's equations leads to the equations commonly called the waves equations (5), (6) :

$$\nabla^2 E - \mu\sigma\frac{\partial E}{\partial t} - \mu\epsilon\frac{\partial^2 E}{\partial t^2} = 0 \quad (5)$$

$$\nabla^2 H - \mu\sigma\frac{\partial H}{\partial t} - \mu\epsilon\frac{\partial^2 H}{\partial t^2} = 0 \quad (6)$$

In the biological environment, the fields of Maxwell's equations are linear and we can keep in mind that any function varying arbitrarily in time can be expressed as a sum of the number of sinusoidal functions. So the dependence of the field E and H can be given by the factor e^{jwt} Therefore we can deduce from these assumptions that:

$$\frac{\partial}{\partial t} \equiv jw \quad (7)$$

$$\frac{\partial^2}{\partial t^2} \equiv -w^2 \quad (8)$$

Finally, by applying the two relations in equation (5), it is possible to determine the wave equations of the fields E and H. For example the wave equation of the electric field becomes:

$$\nabla^2 E + \gamma^2 E = 0 \quad (9)$$

Where

$$\gamma^2 = w^2 \mu \epsilon - jw\mu\sigma \quad (10)$$

The Finite Difference Time Domain (FDTD) method [19] is used for investigating the interaction between the human body model and EM waves. Information about the properties of tissues is found in the literature which is taken from Gabriel and Gabriel 1996 [20]. FDTD was chosen because it is stable and accurate, doesn't require enormous computational resources and can handle complex geometries.CST Microwave Studio [21] is one of the EM modeling codes that can be used to validate the results of the FDTD technique. It can be used for bio-electromagnetic purposes. If we consider a human body with a certain number of tissues (skin, fat , bone, brain etc.), CST is able to calculate different types of electromagnetic properties such as electric field, magnetic field, power, SAR etc.

The SAR is a measure of the rate at which energy is absorbed by the human body when exposed to a radio frequency (RF) electromagnetic field. It can also refer to absorption of other forms of energy by tissue, including ultrasound. It is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg). This was achieved using equation (11) as the sinusoidal source leads to a steady- state electric field, numerically analogous with the same sinusoidal variation [22].

$$SAR = \frac{\sigma E^2}{2\rho} \quad (11)$$

where σ is the conductivity (S/m) and ρ is the density (Kg/m 3) of a human head.

We offer a low cost architecture to measure in real time all the electromagnetic signals emitted in the area. This architecture will monitor the various kinds of electromagnetic properties such as electric field, magnetic field, total power. From the values of the electric field we can calculate the Specific Absorption Rate (SAR).

4.2. Impact of electromagnetic waves on human health

Several studies show that a complex combination of electric and magnetic fields (fig. 1) [23], also called electro-pollution, can affect a large part of the population. Studies of the works [24-26] show exposure of people, presenting symptoms such as headache, memory loss, sleep disturbances, blurred vision, nausea or fatigue.

Figure 1: Influence IoT area for hypersensitive people

The term electromagnetic hypersensitivity has been used to describe these symptoms. The onset of these symptoms in connection with exposure to mobile phones or base stations has been observed in some epidemiological studies. The potential effects of electromagnetic fields on health, the most studied are cancers, mainly leukemias and tumors of the central nervous system, but also other effects such as neurological manifestations or hypersensitivity. To avoid these problems, WHO and the authors of public health established standards fixing the maximum values of the magnitudes of the electromagnetic field according to the zone and the activities of the population.

The table 2 [27] shows examples of reference values of the electric field, the magnetic field and the power density depending on frequency range: f means the frequency of the wave. These values are published by the Radiation Protection Bureau for Clinical and Consumer Products, Health Canada in 2015.

Table 2: Reference levels on uncontrolled environments

F(MHz)	Electric E(V/m value rms)	Magnetic H(v/m value rms)	Power density (SNR)(W/m)	Reference period (mn)
10 - 20	27,46	0.0728	2	6
20 - 48	$58.07/f^{0.25}$	$0.1540/f^{0.25}$	$8.944/f^{0.5}$	6
48 - 300	22.06	0.05852	1.291	6
300 - 6 000	$3.142f^{0.3417}$	$0.008335\ f^{0.3417}$	$0.02619\ f^{0.6834}$	6
6 000 - 15 000	61.4	0,163	10	6
15 000 - 150 000	61.4	O.163	10	$616000/f^{1.2}$
150 000 - 300 000	$0.158f^{0.5}$	$4,21 \times 10\text{-}4\ f^{0.5}$	6,67 x 10-5 f	$616\ 000\ /\ f^{1,2}$

5. System Model

The diagram in the fig. 2 below shows the end-to-end architecture of our proposal network

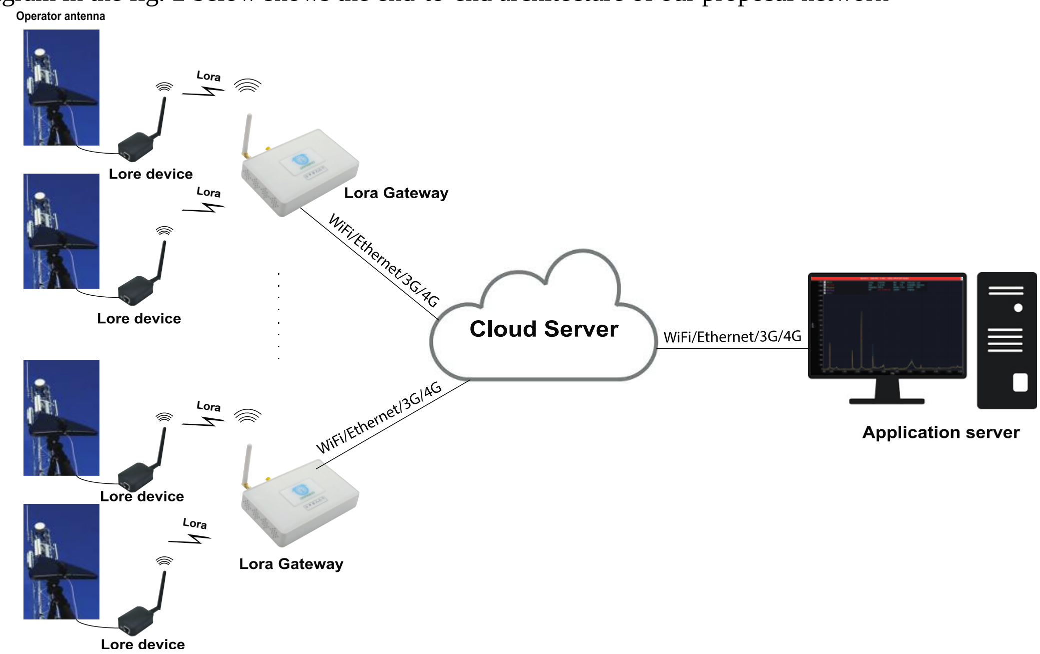

Figure 2: Proposal architecture model

As shown, the topology is organized as a ”star of stars”, with a cloud server connecting to multiple gateways, which in turn connect to multiple devices over a LoRa wireless network [28]. A hyperlog type directive antenna is connected to devices and oriented towards the operator’s antennas. Communication is bidirectional, although upstream communication is the expected predominant IoT traffic type. The four major network elements shown are:

Network endpoints: It is an antenna connected to Lora device. Its main role is to send and receive messages over a LoRa wireless network. The system de- vices are the devices sending data to the Network Server through one Gateways. These devices are connected to a directive antenna which measures all the electromagnetic waves in the environment.

Gateways: Act as relays that send messages from devices to the network server, and vice versa. A LoRa Gateway listens to (usually) 8 or more channels simultaneously and forwards received data from devices to a LoRaWAN network- server. The software running on the LoRa Gateway responsible for receiving and sending is called a Packet Forwarder. Common implementations are the Semtech UDP Packet Forwarder and the Semtech Basic Station Packet Forwarder.

Network Server: Sends and receives LoRaWAN messages to and from de- vices, and communicates with upstream application servers. LoRaWAN Server is a responsible for managing the state of the network. It has knowledge of device activation on the network and is able to handle join-requests when devices want to join the network. When data is received by multiple LoRA gateways, the Server will de-duplicate this data and forward it as one payload to the Application Server.

Application Server: The destination for device application data sent as pay- load in LoRaWAN messages. The Application Server is compatible with the Net- work Server. It provides an interface and APIs for management of users, organizations, applications, gateways and devices. Received uplink data is forwarded to one or multiple configured integration. For our case study, it contains a spectrum analyzer allowing to visualize the evolution of the electromagnetic waves measured in the area. It can integrate an application allowing to provide an alert if a frequency holder does not respect the values authorized by the standard.

6. Simulation and Results

In the architecture, a hyperlog type directive antenna for the frequency band from 680MHz-9.4GHz is oriented towards a pylon containing the operator’s base stations. The directive antenna picks up the signals transmitted by all of these base stations and all the signals which radiate around them. The received signals are transmitted to the application server and viewed by a spectrum analyzer. The simulation results are shown in the following figures.

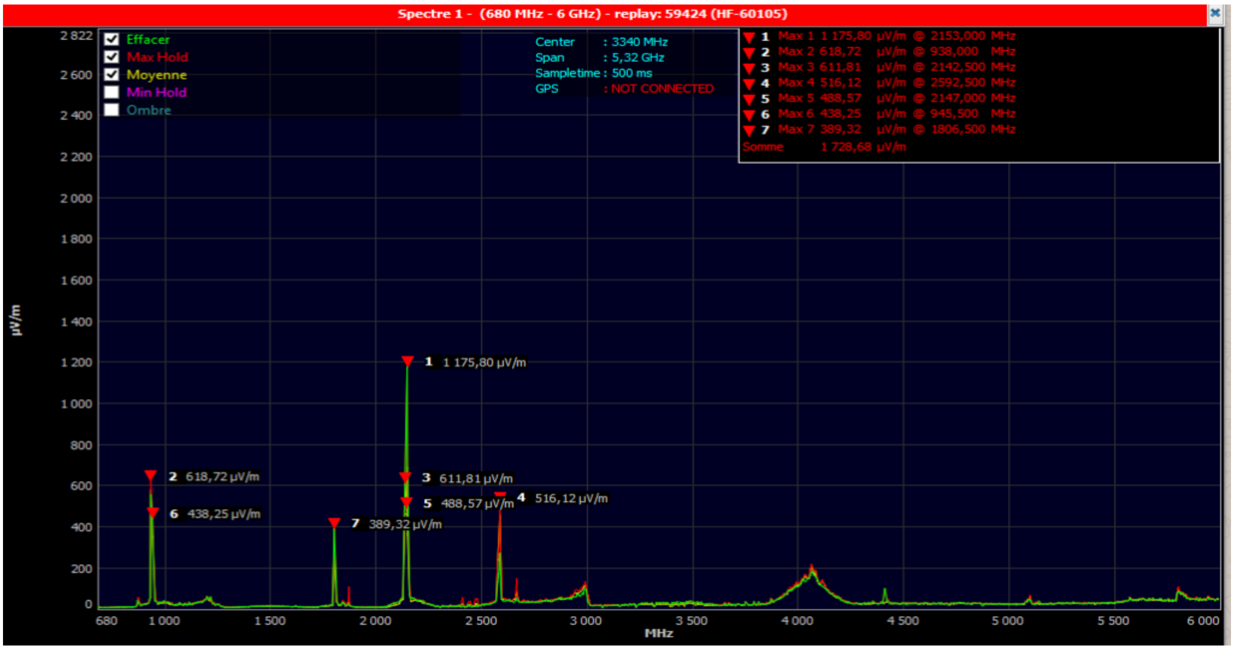

Figure 3: Electric field depending on frequency

The figure3 shows the electric fields of the electromagnetic waves of the band 680MHz-6GHz present in the area. It displays the presence of several networks such as WiFi, GSM, 3G depending on their frequencies. Through this figure it is possible to control the signals of the operators by verifying the respect of the maximum value of the electric field authorized by the standard according to the service or the frequency.

Figure 4: Total power of the electromagnetic field

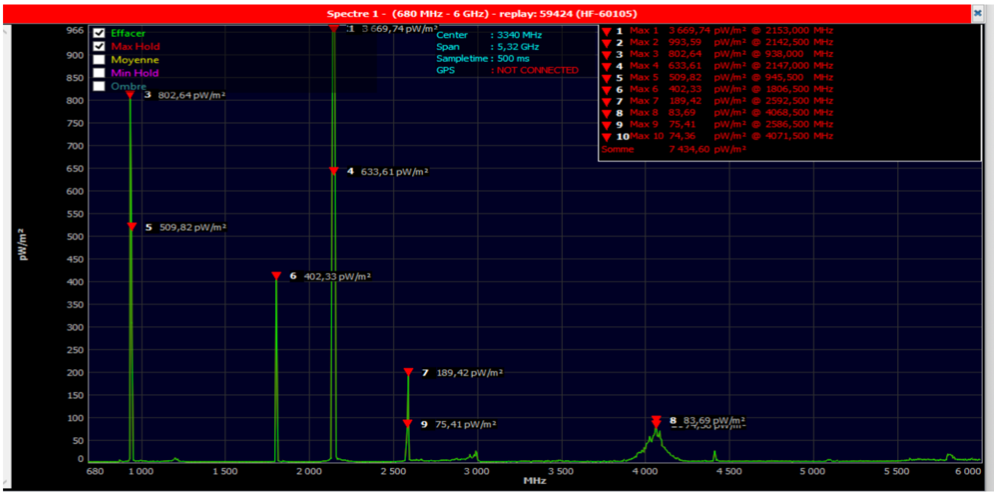

Figure 5: The power density of the electromagnetic field

The figure 4 and the figure 5 show the values of the total power and the power density respectively of the field vector H of the electromagnetic waves of the band 680MHz-6GHz in the area. The signal power density expresses the value of the power per meter as a function of the signal frequency.

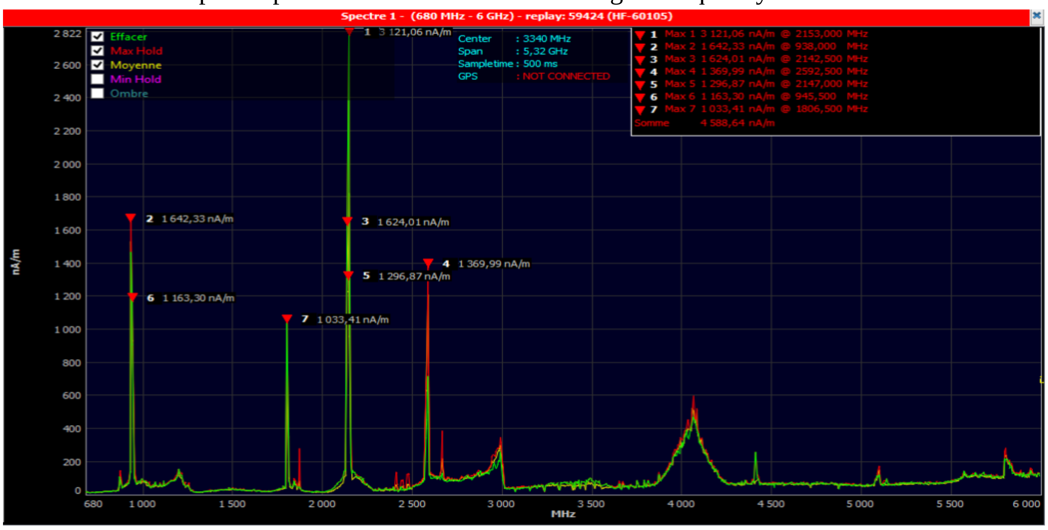

Figure 6: Magnetic field depending on frequency

The figure 6 presents the values of the field vector H of the electromagnetic waves of the band 680MHz-6GHz present in the area. The values obtained are for WiFi the frequency 2.4GHz, for GSM, 3G. Through these values, the regulatory authority can also monitor compliance with the values of the H fields standardized by the community.

7. Conclusion and Futures Works

In our studies, we focus on a low-cost architecture to monitor the average electromagnetic field in each area to be measured in real time. This architecture will help the telecommunications regulatory authorities to monitor the signals of the mobile phone operators and those of all the holders of regulated frequencies and oblige them to respect the values set by the regulations. Exceeding these thresholds exposes the environment to RF electromagnetic waves and can lead to a public health problem. In future work, we plan to extend the study to a larger area with a strong presence of electromagnetic signals. A complete architecture to cover a large area will be proposed.

References

[1]. https://www.icnirp.org Last accessed 24 March 2020
[2]. https://www.icnirp.org/cms/upload/publications/ICNIRPemfgdl.pdf, Last accessed 24 March 2020
[3]. https://ec.europa.eu/health/sites/health/files/files/eudralex/vol-/reg_2004_726/reg_2004_726_en.pdf Last accessed 24 March 2020
[4]. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:3201R1303 Last accessed 24 March 2020
[5]. Wertheimer, N., and Leeper, E. Electrical wiring configurations and childhood cancer. Am. J. Epidemiol. 109: 273-284 (1979).
[6]. Milham, S., Jr. Mortality from leukemia in workers exposed to electrical and magnetic fields. N. Engl. J. Med. 307: 249 (1982).
[7]. Wright, W. E., Peters, J. M., and Mack, T. M. Leukemia in workers exposed to electrical and magnetic fields. Lancet ii: 1160 (1982).
[8]. Ahlbom A, Day N, Feychting M, et al. A pooled analysis of magnetic fields and childhood leukaemia. Br J Cancer. 2000; 83(5):692–698. doi:10.1054/bjoc.2000.1376
[9]. Greenland, Sander; Sheppard, Asher R.; Kaune, William T.; Poole, Charles; Kelsh, Michael A. for the Childhood Leukemia-EMF Study Group : A Pooled Analysis of Magnetic Fields, Wire Codes, and Childhood Leukemia, Epidemiology: November 2000 - Volume 11 - Issue 6 - p 624-634
[10]. N. B. Ismail and M. Z. B. MohdJenu, ”Modeling of electromagnetic wave penetration in a human head due to emissions from cellular phone,” 2007 Asia-Pacific Conference on Applied Electromagnetics, Melaka, 2007, pp. 1-5.
[11]. Kheifets, L et al. “Pooled analysis of recent studies on magnetic fields and childhood leukaemia.” British journal of cancer vol. 103, 7 (2010): 1128-35. doi:10.1038/sj.bjc.6605838
[12]. I. Calvente, M.F. Fernandez, J. Villalba, N. Olea, M.I. Nunez, Exposure to electromagnetic fields (non-ionizing radiation) and its relationship with childhood leukemia: A systematic review, Science of The Total Environment, Volume 408, Issue 16,2010,Pages 3062-3069, ISSN 0048-9697,
[13]. J. Karpowicz et al., ”The evaluation of stationary and mobile components of radiofrequency electromagnetic exposure in the public accessible environment,” 2017 International Symposium on Electromagnetic Compatibility - EMC EUROPE, Angers, 2017, pp. 1-4.
[14]. Chiaramello, E., Bonato, M., Fiocchi, S., Tognola, G., Parazzini, M., Ravazzani, P., Wiart, J. (2019). Radio Frequency Electromagnetic Fields Exposure Assessment in Indoor Environments: A Review. International journal of environmental research and public health, 16(6), 955. https://doi.org/10.3390/ijerph16060955
[15]. K. Gryz and J. Karpowicz, ”Radiofrequency electromagnetic exposures during the use of wireless links of portable computers inside trains without internal WiFi services,” 2019 International Symposium on Electromagnetic Compatibility - EMC EUROPE, Barcelona, Spain, 2019, pp. 1030-1033.

[16]. Jose Vicente Berna-Martinez, Francisco MaciaPerez, Jose Manuel Sanchez Bernabeu "Monitoring and Prevention the Smart Cities" International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682 Vol.31, No.31, November 2014
[17]. http://pages.upf.pf/Pascal.Ortega/ENSEIGNEMENT/CoursEM/Electromagnetique4.pdf. Last accessed 28 February 2020.
[18]. Riadh W. Y. Habash, "Electromagnetic Fields and Radiation: Human Bioeffects and Safety" New York: Marcel Dekker, 2002.
[19]. Matthew N. O. Sadiku (2001), "Numerical Techniques in Electromagnetics." New York: CRC
[20]. M Martinez – Burdalo, A Martin, M Anguiano, R Villar, "Comparison of FDTD calculated specific absorption rate in adults and children when using a mobile phone at 900 and 1800 MHz." Institute of Physics Publishing, Phys. Med. Biol.49, 345-354, 2004.
[21]. https://www.3ds.com/fr/produits-et-services/simulia/produits/cst-studio-suite
[22]. S. Khalatbari, D. Sardari, A. A. Mirzaee, and H. A. Sadafi," Calculating SAR in Two Models of the Human Head Exposed to Mobile Phones Radiations at 900 and 1800MHz." Progress In Electromagnetics Research Symposium 2006, Cam bridge, USA, March 26-29
[23]. Berna-Martinez, Jose Macia Perez, Francisco Bernabeu, Jose Manuel. (2014). Monitoring and Prevention the Smart Cities. International Journal of Advanced Information Science and Technology 2319-2682.32.60.
[24]. M. Havas, Electromagnetic hypersensitivity: biological effects of dirty electricity with emphasis on diabetes and multiple sclerosis, Electromagn Biol Med, Vol. 25, n. 4, pp. 259-268, 2006.
[25]. A. Caragliu, C. Del Bo, P.Nijkamp, Smarts cities in Europe, Journal of urban technology, Vol. 18, n. 2, pp. 65-82,2011.
[26]. A. Ahlbom., U. Bergqvist, J.H. Bernhardt, J.P. Cesarini. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Physics. Vol. 74, n.4, pp. 494-521, 1998.
[27]. https://www.canada.ca/fr/sante-canada/services/publications/securite-et-risque-pour-sante/limites-exposition-humaine-energie-electromagnetique-radioelectriqhtml
[28]. https://learn.pi-supply.com/make/introduction-to-lora-technology