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Data Analytics of Electromagnetics Field Measurements in Smart Meters

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Abstract. The smart meters are considered the main component of the smart grid allowing communication and processing of electrical energy measurement data to utilities. Nowadays, there is a great concern that smart meters' data which is communicated mainly by wireless or wired communication means produce electromagnetic fields which be harmful to human health. In this work, a study of data analytics is presented on the readings produced by the smart meters made with statistical and machine learning probabilistic techniques in order to compare the data with reference values and determine if they are harmful or not for the human health.

Keywords: Data Analytics; Electromagnetic Fields Measurements; Smart Meter

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1 Introduction

Smart Meters (SM) are the key factor in the Smart Grid (SG). The SG is the combination between Power Electrical Grid and Information and Communication Technologies (ICT). With the SG new applications has been introduced to the final-user, one of them, the Smart Metering Systems (SMS).

The SMS allow the final-user, real-time monitoring of their energy consumption through the SM. The SM measures the energy consumption and also energy production, and reports this data to the utilities. For this reason, it is necessary a geographical-broadband-communication network through all the power grid [1].

The most common implemented technology for SMS is the Advanced Metering Infrastructure (AMI). AMI allows not only the communication of consumption/production readings through the SM, but allows the automatic connection and disconnection, demand-response events and dynamic electrical price according to offer and demand.

AMI uses intermediate equipment called Data Concentrator (DC). The DC recollects all the measurements of SM in a specific geographical area. This area is typically a neighborhood which is the reason why they form with SM a Neighborhood Area Network (NAN). The DC sends all the measurements of SM to the data center in the utility. The main components of AMI architecture are shown in Figure 1.

In Mexico, the SMs rollout is very new. The first installation began in 2014, but in the next years, the use of SM is going to increase (Secretaría de Energía, 2017).

Despite the enormous advantages of SMS, it has a lot of challenges and opportunities; one of them, it is related with the data transmission through wireless and wired communication means due to they involve Electromagnetic Fields (EMF) which could be harmful to humans.

In this paper, the authors describe through data analytics of measurements of EMF in SM if an SM could be dangerous for human health.

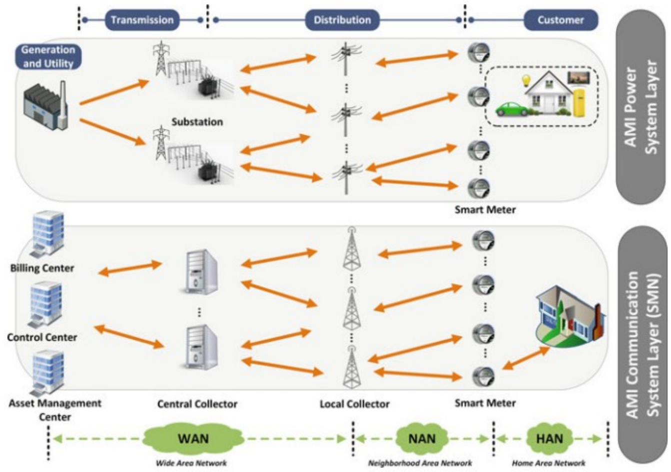

Fig. 1. AMI General Architecture

2 Using Electromagnetic Fields in Smart Meters

EMFs are mainly characterized in terms of frequency and strength. Frequency is related to the number of waves that pass a fixed place in a given amount of time. It is measured in Hertz (Hz) which expresses the number of waves per second. Typically, the EM signals are divided into two categories, non-ionizing and ionizing [3]. The ionizing EMF radiation is harmful to live beings. Although, non-ionizing EMF could be dangerous for human beings if the density, time, and strength of the signals are high. Figure 2 shows a chart with the spectrum of EM waves.

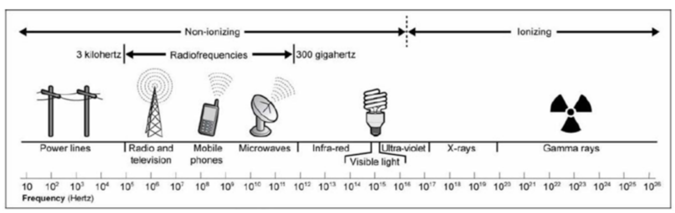

Fig. 2. EM Spectrum [3].

Signal strengths (power density) are measured in different units, according to the frequency and the nature of the signal: Gauss (G), Volts (V), Watts (W), among others [4].

SMs work with wireless network interface cards (NIC) in Radio Frequency (RF) spectrum between 900 MHz to 2.45 GHz. There are not standard units for measuring RF radiation, but the most common are: (µW/m2), (µW/cm2), and (V/m).

Electronic devices, such as mobile phones, microwave ovens, refrigerators, and wireless SMs produce RF emissions. Exposure to RF emissions may lead to thermal and non-thermal effects. On the other hand, the Internet of Things (IoT) devices and other electronic devices have been incremented RF pollution.

Thermal effects on humans have been extensively studied and appear to be well understood. The Federal Communications Commission (FCC) has established guidelines to protect public health from known hazards associated with the thermal impacts of RF: tissue heating from absorbing energy associated with RF emissions [5]. Electromagnetic waves carry energy, and EMF absorbed by the body can increase the temperature of human tissue. The scientific consensus is that body temperatures must increase at least 1^{o}C to lead to potential biological impacts from the heat [6].

Non-thermal effects, however, including cumulative or prolonged exposure to lower levels of RF emissions, are not well understood. Some studies have suggested non-thermal effects may include fatigue, headache, irritability, or even cancer [5].

The current duty cycles of the SM transmitter (that is, the percent of the time that the meter operates) would then typically be 1%, or in some cases where the meter is frequently used as a relay, as much as 2-4% [4]. This means that SM does not transmit data very often (in AMI a typical time for data reporting is 15 minutes), but in the future, if new applications and functionality are added to SM the data transmission period could increase the SM duty cycles. For instance, if power quality events are reported in real-time, the duty cycles in SM could be reached 100% like as T.V. or FM Radio broadcast.

Table 1 shows the average time exposure of some electronic devices. Figure 3 shows the maximums and minimums of instantaneous RF power density levels in some electronic devices.

Table 1. Time of Exposure

Device	Max density	Time (s)
SM	1%	0.1
Microwave Oven	25%	15
Cell phone	5%	1000
Lights	7%	10,000
T&D wires*	0.05%	>10,000

Also, SMs can be used with other public services such as water and gas. This could be incrementing the RF exposure for human beings in the next years.

The health concerns surrounding RF from SMs are similar to those from many other devices that we use in our daily lives, including cordless and mobile telephones, microwave ovens, wireless routers, hairdryers, and wireless-enabled laptop computers [13]. The health issues could be increased if SMs are in a multifamily building such as an apartment house due to there are together several SMs in the same location, but it is necessary around 100 SMs or more and stay in the electrical facilities for more than 30 minutes.

There are several studies around the world [8, 9, 10, 11, 12], but in Mexico does not exist a formal study about the relation between SMs and human health.

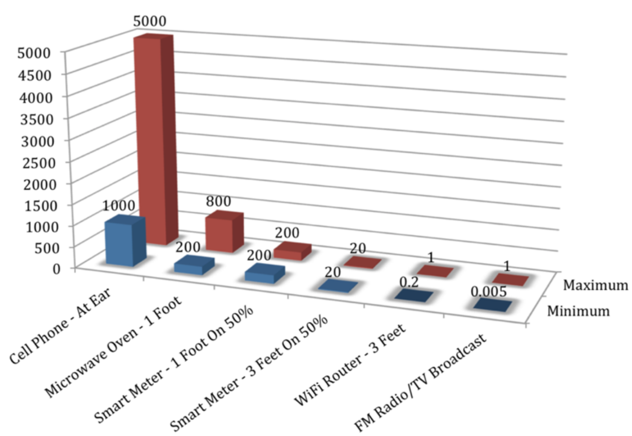

Fig. 3. Instantaneous RF Power Density Levels in Common Devices (in W/m2) [1].

The recommendable levels of EMF radiation in some devices are shown in Table 2 [13]. The *f* represents frequency. The * represents plane-wave equivalent power density. The average time of these values is 30 seconds. Table 3 shows different levels of RF in common electronic devices include SM.

Table 2. Maximum exposure guidelines adopted by FCC, IEEE, and ICNIRP, adapted from [13].

Frequency Range (MHz)	**Power Density (μW/cm^2)**
0.3 – 1.34	(100)*
1.34 – 30	(180/f^2)*
30 - 300	0.2
300 – 1,500	f/1500
1,500 - 100,000	1.0

Table 3. Maximum RF levels in some devices [7].

Source	**Frequency**	**Exposure Level ($\mu W/cm^2$)**	**Distance**	**Time**	**Spatial Characteristic**
Mobile phone	900 MHz, 1800 MHz	1 - 5	At ear	During call	Highly localized
Microwave oven	2.45 GHz	50.05 – 0.2	5 cm, 60 cm	During used	Localized, non-uniform
WLAN	2.4 – 5 GHz	0.001, 0.0002	1 m	Constant when nearby	Localized, non-uniform
Radio/TV broadcast	Wide spectrum	0.001	Far from source	Constant	Relatively uniform

3 Materials and Methods

For this research, the authors used their own design SM composite of a Raspberry Pi Model 3B+ and SmartPi energy monitor board (nD-eneserve, 2019). This new SM used a WiFi 802.11 b/g/n/ac dual-band (2.4 GHz and 5 GHz) NIC (see Figure 4). Four SMs were used in the test.

Fig. 4. Hardware implemented.

For the EMF measurements, the authors used two devices for getting better results: Electromagnetic Radiation Detector Acoustimeter AM-10 (up to 8 GHz) [15] and Electromagnetic Radiation Tester Kmoon GM3120 (Up to 3 GHz). Additionally, the authors measure EMF for some appliances such as Radio/TV, mobile phone, microwave oven, among others.

For testing, SMs have placed 1 M height and 30 cm away in a horizontal manner due to most of the studies and norms recommend these distances [16]. The methodology used in this research is shown in Figure 5. To get medical data, the tests with people were realized inside 24 households. The SMs were located in the garage of the houses. The number of people analyzed was 143, and the variables of interest were weight, blood pressure, fatigue, headache, irritability, and cancer.

Some stats of the patients are:

- Age: 91 adults and 52 kids.
- Sex: 80 females and 63 males.
- 33 people live in an apartment, 110 lives in two-floor houses.

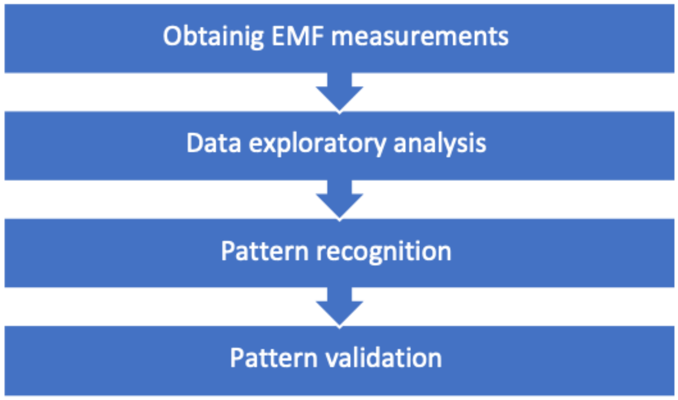

Figure 5. Methodology implemented.

For the Recognition Patterns Phase the author used the Association Rules Techniques because they are designed to discover interesting relationships among sets of items in the transaction database.

Association rule mining can be stated as follows: Given I = {i1, i2, . . . , im} is a set of items, D = {T1, T1, . . . , Tn} is a set of transactions. Each transaction T is a set of items such that $T \subset I$. An association rule is an implication of the form: $X \Rightarrow Y$, where $X \subset Y$, $Y \subset I$, $X \cap Y = \varphi$, both X and Y are itemsets. Support and confidence are two of the most important metrics for evaluating the interestingness of a rule. Support of an association rule $X \Rightarrow Y$ is defined as the percentage of records that contain X and Y to the total number of transactions in the database. The confidence of an association rule is defined as the percentage of the number of transactions that contain both X and Y to the total number of transactions that contain X [17].

4 Experimentation

The measurements reported in Table 4 and Table 5 are the result of the average of 1,000 SMs readings and other devices. The time between each measurement was 15 minutes. The duty cycle of SMs were 1% approximately.

Table 4. The Relation between distance and power density in some devices (normal use).

Device	**Distance ($\mu W/cm^2$)**		
	30 cm	**3 m**	**30 m**
SM (2.4 GHz)	0.01	0.001	0.000001
SM (5 GHz)	0.005	0.0005	0.000001
Power Meter	0.9	0.1	0.001
Access Point	0.14	0.4	0.004

Table 5. The Relation between distance and power density in some devices (frequent use).

Device	**Distance ($\mu W/cm^2$)**		
	30 cm	**3 m**	**30 m**
SM (2.4GHz)	0.5	0.05	0.0001
SM (5 GHz)	0.25	0.025	0.0001
Power Meter	0.9	0.1	0.001
Access Point	0.14	0.4	0.004

All the measurements were taken inside a house nearby distances (30 cm and 3 m). In a manual way, the authors discard other signals (the measuring devices used in the test do not discard in an automatic way).

The reader can observe that a longer distance is less the power density of the EMF signal. On the other hand, the obtained values in Table 4 about SMs and other devices are according to data reported in Table 2 and Table 3, thus the SM readings are apparently permissible values and they are not harmful to humans. If the time for measuring increase to 1 second, the duty cycle of SMs were 95%.

The readers can observe that the Power Meter and Access Point readings are the same than in Table 4 due to these devices are always working and their duty cycles are considered as 100%. In a general way, these values are considered as not harmful.

Data of 6 months patients are shown in Table 6 and Table 7. Table 6 shows the initial value meanwhile Table 7 shows the final values. In both tables, the results are the average of the 14 patients in the test.

Table 6. Initial values of patients in the test.

Weight	**Blood pressure**	**Fatigue**	**Headache**	**Irritability**	**Cancer**
63.2 Kg	123.2/81.1	4/14	4/14	3/14	0/14

Table 7. Final values of patients in the test.

Weight	**Blood pressure**	**Fatigue**	**Headache**	**Irritability**	**Cancer**
64.7 Kg	124.1/81.9	7/14	5/14	6/14	0/14

The weight was measured by a scale while blood pressure was measured by Blood Pressure Monitoring Equipment (baumanometer). The cancer diagnostics was checked by radiography. The variables: fatigue, headache, and irritability were measured asking the patients about symptoms. The readers can observe that according to statistical data there were an apparently increment of all variables except cancer.

The variables used in the association rules were: A) fatigue, B) headache, C) irritability, D) sex, E) type of person (adult or kid), and F) type of house. These variables can be expressed in Boolean values. The cancer variable was discarded because any transaction contains it. The variables weight and blood pressure cannot be expressed as a logical value (true or false). The most important associated rules founded are listed in Table 8.

Table 8. Final values of patients in the test.

Rule	**Support**	**Confidence**
C -> F	50%	66.66%
ABC -> DE	28.57%	75%
DE -> A	28.57%	50%
AC -> F	28.57%	75%
BC -> DF	21.42%	100%

The readers can observe the first rule has more transactions and it indicates that 50% of all transactions which contains irritability presents implies that 66.6% of these transactions contain a two-floor house, perhaps the last transaction indicates that 21.42% of all transaction contains headache with fatigue this subset of transactions contain in 100% confidence the variables sex (female) and type of person (adult).

5 Conclusions and Further work

To date, scientific studies have not identified or confirmed negative health effects from potential non-thermal impacts of RF emissions such as those produced by existing common household electronic devices and SMs.

Wireless SMs, when installed and properly maintained, result in much smaller levels of radiofrequency (RF) exposure than many existing common household electronic devices, particularly mobile phones and microwave ovens. Particularly, if SMs could transmit data in real-time, the EMF exposure for human beings could be more dangerous.

For further work, it is necessary obtaining better datasets related to human health induced EMF exposures. On the other hand, it is mandatory to obtain data for more people and measure during more periods. Also, it is required a better clinical diagnosis of the patients in the test. The test must be isolated for other EMF devices in a better way. Additionally, it is necessary to integrate into the SM hardware EMF sensors for reporting in the SM when EMF could be considered as harmful to humans.

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