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Short Paper

Part II: A Heuristic Approach to Classifying Different Multiple Urban Settings for Ambient RF Energy Harvesting Potential using FM Technology as an RF Energy Source

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Abstract

Purpose – This paper is an extension of the previous study on "A Heuristic Approach to Classifying Different Multiple Urban Settings for Ambient RF Energy Harvesting Potential using TV Technology as an RF Energy Source." The study now focuses on FM technology which was quite different from the TV technology in terms of frequency range that was previously published by the authors on February 9, 2022. Thus, it aims to expand a

Graphical Footprint Model (GFM) that will verify radio frequency (RF) energy harvesting capabilities of RF energy sources, such as frequency modulation (FM), television (TV), and cellular technology (Cell) at different classified multiple urban settings.

Method – The Budget link from the Communications Engineering Formula was utilized to get the Power Received Level of Radio Frequency potentials in dBm, in order to know the classified multi-settings collectively with the RF sources for RF harvesting capabilities. A scoring scheme called GFM model was developed in order to know the energy capabilities based on -20 dBm and up regarding Power Received Level (PRL) at various classified multiple urban settings, such as Line of Sight (LOS), Rural (R), Suburban (S), Urban High (UH), Urban Very High (UVH), and Non-Line of Sight (NLOS) settings.

Result – The outcome of the study revealed a percentage acceptability range of 84% with a Mean Square Error (MSE) of 14 along with a mean average distance accuracy range of 1451 meters. To establish whether the GFM can anticipate heuristically with the use of a weighted mean, the analysis comprised spread-out data points over a large range of values, regard as a standard deviation of 3091. The grand mean achieved an intensity score of 3, with the initial voltage range from 70mV to 125 mV. This shows a remarkably good level for GFM to forecast heuristically the RF potential. In determining a benchmark for the GFM, a review of twenty-one research studies undertaken for data analytics.

Conclusion – The Graphical Footprint Model will advance future design engineers and installers of RF harvesters. Graphical Footprint Model can offer the essential information to know the locations and distances for Radio Frequency potential coming from FM technology as an energy source in various classified multiple settings.

Recommendation – The Radio Frequency harvester designers may use the model for their design specification because it shows preliminary evaluations of the selected urban setting for Radio Frequency harvesting potentials and provides a map to distinguish the best sites for energy harvesting.

Practical Implication – The Graphical Footprints Model study will serve as a map to illustrate the best sites for Radio Frequency harvesting potentials in which in turn can be utilized for design considerations and specifications even in an off scheme versus the traditional surveying on-site to get the PRL and the only effort needed is the reading and following the values of the Energy Graphical Footprints Model.

Keywords–RF, Energy, Source, Harvesting, Heuristic, Potential, FM Technology

INTRODUCTION

Energy and the Internet of Things (IoT)

Ambient energy scavenging is the process of acquiring power from radio frequency transmitter sources from the surroundings and converting them into usable electrical energy. In this era of connectivity, people are connected through wireless communication devices. Conveyance is through wireless communications systems such as TV, Radio, and Cell transmitters, which are set up and visible in every corner. This means a huge amount of RF ambient energy out there that can be harvested. As the Radio Frequency (RF) harvester apparatus gets smaller, more of these apparatuses are being needed posing a challenge to operations and maintenance.

The world is increasingly surrounded by low-powered digital sensors that can be energized at a voltage, even at a fraction of microvolts like the Internet of Things and communication devices that send cloud-based data for analysis. Military may use sensors within their uniforms and other linked equipment for exchanges of data for immediate course of solutions (Cameron, 2018). The resort to the use of connected sensors such as temperature sensors, proximity sensors, and others being developed is expected in the coming years. However, powering these devices poses sustainability challenges to maintenance and operations, particularly the need for battery replacement, which will not be cost effective over time (Nowi, 2019). Transmitter technologies can power up different types of sensors for IoT with the use of RF harvester.

The RF Harvester

Electromagnetic fields coming from cellular phones, Wi-Fi access points, and other transmitter technologies create disturbances that can be measured, which in turn potential energy that varies over time or distance. To be able to use the electromagnetic fields, RF energy harvesting technology is used (Nechibvute et al., 2017) to directly power up battery-less and remote battery recharging systems (Shrestha et al. 2013).

RF energy in power density can be harvested coming from different sources like the Global System for Mobile Communications (GSM), Television (TV), and Frequency Modulation (FM) radio frequency sources using RF harvester. RF harvester can be use to harvest FM signals from an ambient environment that can power up different wireless sensors (Urrehman et al., 2017). FM broadcast, GSM 900, GSM 1800, 3G and Wi-Fi has potentials for RF energy in a semi-urban area (Khalid et al., 2020). The paper aims to provide a guide model footprint for preliminary Potential energy harvesting capabilities coming from FM sources in different multiple urban settings because of the emerging technology of IoT peripherals and massive research and designs of RF energy harvesters.

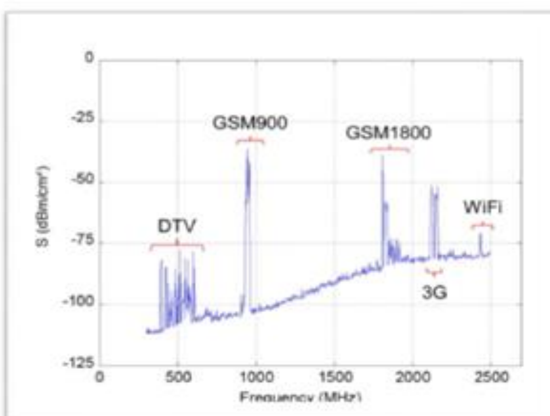
LITERATURE REVIEW

Harvesting RF Energy and the Environment

A survey of measurements was carried out in the urban city of Tokyo, which showed that several wireless activities of TV broadcasts would give an average field intensity of .9 v/m (-17dbm) found. With the use of the electric field incident, a dipole RF harvester was designed. The performance of the designed RF harvester was evaluated through a field test at 6,500 meters from the Tokyo TV tower. The results showed that the RF harvester can be charged by a tank with a voltage of 2.9 volts and used for a battery-less wireless sensor operation in an urban-type environment (Vyas et al., 2012).

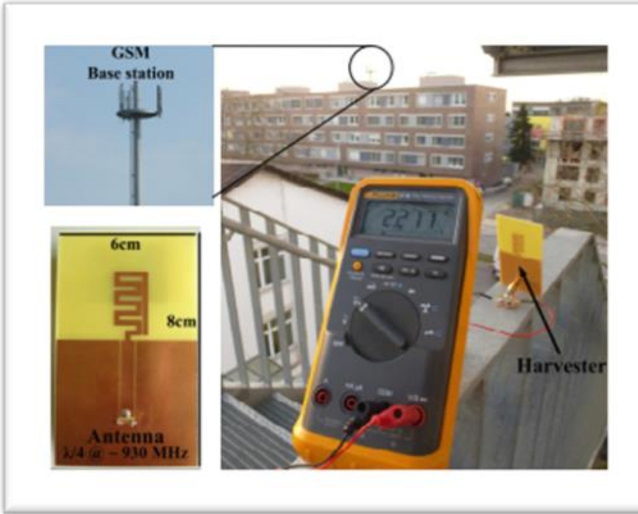
Piñuela et al. (2013) conducted a study entitled "Ambient RF Energy Harvesting in Urban and Semi-urban Environments" which surveyed a city-wide RF in different points of London. The study showed that different power density results in urban and semi-urban places because of the number of stations, proximity distance, propagation characteristics, and line of sight scenario. The survey concluded that DTV, GSM 900, GSM 1800, and 3g were potentially useful ambient sources of RF energy and used these as the bases of the design of an RF harvester. The cell RF harvester they made demonstrated its operating level at Power Conversion Efficiencies (PCE) of 40% at – 25 dBm in a semi-urban environment (Figure 1).

Parks et al. (2013) developed an RF harvester through characterized bench testing simulations. Their RF harvester was tested in a real-world urban environment which operated a sensor at 10.4 km and 200 meters with a 1 MW TV station and a cellular-based cell-site station. The study demonstrated that the minimal RF input power for an RF harvester to operate was -18dbm.



From Pinuela et. al., (2013)

Figure 1. Input Power Measurements Outside the Northfields London



From Nimoet al. (2015)

Figure 2. Setup for Measuring the Voltage from a Cell Site source and the RF Harvester Got a Measured Average Voltage of 2.3 Volts

In the study of Zhang et al. (2014), the group made simulations for the design of a wideband cross dipole RF energy harvester to optimize the urban environments' 200 uW / cm2 and below power density. This power density ranging from 5 to 200 uW/cm2 (-4dBm to 12dBm) was inputted to the RF harvester for design considerations and through simulations achieved a maximum Power Conversion Efficiency (PCE) of 57 to 120%. The result gave good qualities for RF energy scavenging/ harvesting.

Nimo et al. (2015) in their works entitled "Analysis of Passive RF to DC Rectification and Wireless RF Energy for Micro-Watt Sensors" made an RF harvester through simulations and designs using different Power Received Level (PRL) inputs in an 868 MHz ISM band. Their work got a measurement of 1 volt at -14.4dBm and 6 volts at 5dBm. They tested the RF harvester in an ambient environment after simulations and with the power levels of -27dBm to -50dBm along with the distance of 110 meters a Direct Current (DC) voltage of 2.3 volts was obtained (Figure 2).

In the works of Song et al. (2015) entitled "A Broadband Efficient Rectenna Array for wireless energy harvesting" the city of Liverpool was surveyed through the use of a spectrum analyzer, which showed a -30dbm to -10dbm power density/ power received levels. The results of the survey were used as an input for the design optimization of RF harvester for frequency bands 1.8 to 2.5 GHz, which was tested at a distance of 1 meter. The test showed that the RF rectenna harvester could give a maximum conversion efficiency of 55% at –10dbm and enable power up a wireless sensor.

Borges et al. (2015) in their study entitled "Radio Frequency harvesting for Wearable Sensors" presented a small biomedical sensor that was fabricated and designed for urban and suburban areas with the use of computer simulations to determine the potential of cell sites' 900 and 1800 MHz as a source for RF energy harvesting in urban and suburban places. Through testing and designing by inputting different Power levels, the RF harvester got 3.61 Volts, 2.34 Volts, and 1.4 Volts for -2dBm, -5dBm, and -10dBm respectively along with the highest efficiency of 27 % attained at 6dBm.

Gabrillo et al. (2015) in their study on "Enhanced RF to DC converter with LC resonant circuit" used a loop antenna via experimental testing in an urban setup and found out that at 77.84 meters from a TV signal output power of 1.80 MW / 2.55dbm can be measured. The harvester can power a device without battery maintenance which has better applications in wireless sensor setups. Shariati et al. (2015) made an RF harvester for urban environments that power electronic gadgets that require only a small amount of power. Through experimentations and simulations, the RF harvester gave a voltage of 772.8 mV at an input power of -10dBm. The D.C. output harvested at different RF energy sources increased by3.14 and 7.24 units? over the frequency of 490 and 860 MHz respectively. Shariati et. al tested the RF harvester in the suburban area of Melbourne, Australia, and perpetual RF harvesting for energizing low-powered systems was achieved.

Khemar et al. (2017) exploited the use of 3G technology as an RF energy source for powering wireless sensor nodes. The group fabricated an RF harvester for a frequency band ranging from 917 MHz to 3 GHz and thru simulations obtained a 50% efficiency at -7dBm Power Received Levels (PRL). The field test measurements with an obtained voltage of 190 mV. A measured PRL of -10dBm to -7dBm was obtained for an urban environment which was relatively high.

Mutee-ur-Rehman et al. (2017) made an RF harvester for an FM ambient environment. Through simulations with a power level of -10dBm to -30dBm, their experiment showed that at this power level, an RF harvester can harvest FM signals from an ambient environment that can power up different wireless sensors. The RF harvester was tested on a building for performance checking via a spectrum analyzer and demonstrated that at -14.2 dBm Power Received Level (PRL), the equivalent distance from an FM source under an ambient environment was 10 meters.

Milanezi et al. (2017) In their study entitled "Radiofrequency Energy Harvesting System Based on a Rectenna Array in Urban Environments" Milanezi et al. (2017) conducted measurements with the use of a spectrum analyzer to evaluate the feasible energy power levels in Brasilia, Brazil at a reference distance of 300 to 1000 meters from the RF energy source. Their study showed an 11dBm average incident power from the urban environment at 91.7 MHz, which was used as an input for the design of their harvester. Their harvester acquired a converted energy efficiency of 18%. They stated that a 42 RF harvester at -3dBm or a 2 RF harvester at 10dBm can charge a cell phone for about an hour.

In the paper of Khemar et al. (2018) entitled "Design and experiments of a dual-band Rectenna for ambient RF energy harvesting in urban environments," a survey was made outside Paris. A -7dBm highest peak power was measured this peak power level was used to design an antenna. The test results of the proposed RF harvester got a Power Conversion Efficiency (PCE) of 33 % for a frequency of 1800 MHz along with an incident Power Received Level (PRL) of -7dBm in an urban zone. The authors concluded that a temperature sensor can be activated using the RF harvester.

Takhedmit et al. (2018) in their work "RF Energy Harvesting in Urban Environments using Transparent Rectenna," showed their RF harvester antenna array design intended for an urban environment. The urban environment measurements used were based on the study of Pinuela et al. 2013. Their harvester for ISM band 2.45 GHz was designed thru simulations at the input of 1 to 10 uW / cm2 power density and regarding this power density, the output of voltages varies. The Rectenna / Antenna array in their studies showed a measured output voltage of .55, 1.4, and 2.13 V together with an energy conversion efficiency of 16, 28, and 36 % at 1, 5, and 10 uW/cm2, (-11dBm, -4dBm, -1dBm). They concluded that (DC) output properties are suitable in an urban area.

In the study of Waguaf et al. (2018) entitled "Energy Harvesting with 2.45 GHz Rectenna for urban application", they simulated electromagnetic experiments via computer software applications. They set up an emitting station and received RF harvesters at 2 meters apart and with this setup, developed an RF to DC boosting RF harvester. They concluded that the boosting antenna for RF harvester can give an output voltage of up to 140 mV for a 1uW/cm2 (-11dBm) power density.

Zeng et al. (2018) presented a compact dual-band rectenna antenna rectifier RF harvester designed for urban areas via computer simulations to which measured a peak efficiency of 62% at 0.88 GHz along with 15.9 µW/cm2 power density (-1dBm) and 50% at 1.85 GHz along with 19.1 µW/cm2 power density (-10dBm). The energy harvester enabled activation of an LCD watch at 1.275 Volts output at a distance of 25 meters away from a cellular station.

Caselli et al. (2019) in their study entitled "Analysis and design of an Integrated RF energy harvester for ultra-low power environments" showed that the surveyed measurements of urban and semi-urban environments got an average of -22 and -29dBm power levels with respect to RF energy source 700 and 1000 MHz band. The RF harvester through post simulations recharged a capacitor at 2 V about 950 MHz input frequency along with -18dBm input power.

Khalid et al. (2020) in their study entitled "Quad Band 3D Rectenna Array for Ambient RF Energy Harvesting" surveyed a semi-urban area and found out that FM broadcast, GSM 900, GSM 1800, 3G, and Wi-Fi has potentials for RF energy. To harvest this energy, a multi-band antenna with an inclusion of a monopole antenna was made and designed via computer simulations concerning FM transmitter as a source along with the surveyed measurement results in a semi-urban area. The results about the RF harvester got a maximum efficiency of 80% at –6dBm and through field testing in an ambient environment at 300 meters reference distance from the nearest tower, the RF harvester got a conversion efficiency of 31.3% at -15dBm PRL. The study showed that RF harvester is acceptable for sensor applications.

Path Loss Models

Garah et al. (2017) did a study on the calculation of the GSM path loss (908 to 957 Mhz). They assessed the area environments of Batna, Algeria. The data gathered path loss was compared to path loss measured by empirical models such as Cost 123, Hata, SUI, and Egli model. It showed that the model Cost 231 leads the Hata. SUI and Egli model via Root Mean Square Error calculation results. Onuu et al. (2017) made a comparative analysis between the Hata and Egli model via GSM path loss prediction calculations in some major towns in Akwa State. The Mean Square Error (MSE) results showed that the Egli model with the MSE value of 5.97 dB is suitable for path loss prediction in a non-uniform landscape.

Fanan et al. (2017) looked into the finest amalgamation of an empirical model of data terrain for forecasting TV white space via investigating the performance of Extended-Hata, Davidson-Hata, and Egli model with the TV band ranging from 470 to 790 Mhz at 1000m, 100 m and 30 m respectively when compared to various locations in the United Kingdom. The findings showed that the Egli model manifested a good performance compared to other models. Akanni and Oliseloke (2020) scrutinized a radio signal propagation with respect to 88 Mhz frequency at different degrees of altitude. Using a digital distance meter, the LOS of several data points from the transmission source was established. The outcomes were verified and compared to LOS, Egli, and Longley-Rice Model. The results showed satisfactory acceptance of the Egli model with respect to different degrees of altitude.

SYNTHESIS

The Egli model outperforms other empirical models regarding path loss measurements in terms of accuracy. This is the reason why this formula was put into use with respect to the heuristic modeling. All authors concluded that there is a good potential for RF energy harvesting from different RF Transmitters located in different environments such as urban, semi-urban, and ambient environments. They optimized the power density/levels coming from these sources with their RF harvester designs the reason why the output of their harvester got a higher voltage for powering up an IoT and can harvest RF energy at a farther distance.

In the survey of Song et al. (2015), Adam et al. (2017), and Piñuela et al. (2013) the measured power densities differ per environment. According to the study of Pinuela et al. (2013), results vary because of proximity distance, propagation characteristics, and line-of-sight scenario. The study further showed that there is a corresponding relation between the surroundings and the RF station energy sources such as the propagation of waves. In this investigation, the behavior of wave and radio frequency propagations were assessed per multi-urban settings to classify the area along with an omnidirectional antenna. The antenna serves as an assumed device because it radiates in all directions perpendicular to an axis, which is very beneficial for a heuristic model as often used by radio network stations and base stations.

Power densities that are viable for energy harvesting can be as low as –30dBm up can be harvested from the ambient surroundings specifically, urban, semi-urban, urban high. Any frequencies that are given whether it be a TV, GSM, LTE, or any other frequency there is only one common factor which is the power density/ power level.

METHODOLOGY

This section gives a clear picture of how the study was implemented based on the fundamentals of radio propagation.

Link Budget for Power Received Level (dBm) of FM, TV, and Cell

The book of Alexander entitled "Optical Communication Receiver Design" published by SPIE Optical Engineering Press, 1997 positioned that the performance of an optical communications system is quantified using a Link Budget, which is also used in microwave links. All losses and gains in the transmitter power are all accounted for. To know the performance of the communications, the Budget Link formula according to the book of Elbert may be presented as:

Power Received (dBm) = Power of the transmitter (dBm) plus all gains (dB) and minus all the losses (dB). *Equation 1*

The formula is supported by Alexander's book on "Optical Communication Receiver Design" and Elbert's book on "Introduction to Satellite Communication" This formula can determine the RF potentials in terms of the PRL in dBm per different classified multi-settings.

Log path distance Loss in different Environments (dB) of FM, TV Cell

The difference between Received Signal Power (RSP) and Transmitted Power (TP) is called Path Loss. The received power falls as the distance between radios increases. The energy decreases based on the free Space Model according to Gutierrez in his book entitled "Selected Readings on Telecommunications and Networking" published by IGI Global Inc., 2009. Gutierrez also stated that the Free-space model is not accurate because it assumes a clear line of sight when it comes to different environments. The use of the Log distance path loss model would be the best formula to use instead of free space.

The Formula for Path Loss Model is:

Path Loss dB= 10 N Log d/do *Equation 2*

Where:
N= Path Loss Exponent
D= distance in meters, do= Reference distance

Environment	Path Loss Exponent (n)
Los	2
Rural	2.5
Suburban	3
Urban High	3.5
Urban Very High	4
Non- Line of Sight	5

Figure 3. Environment and the Path Loss Exponents

Path Log distance model has Path Loss exponents (n) ranging from 2 to 5 that represent different types of environments. Saad et al. in their book entitled "Wireless Communications and Networking for Unmanned Aerial Vehicles "published by Cambridge University Press, 2020 stated that Log path distance Loss is being widely used for various designs of wireless communications systems.

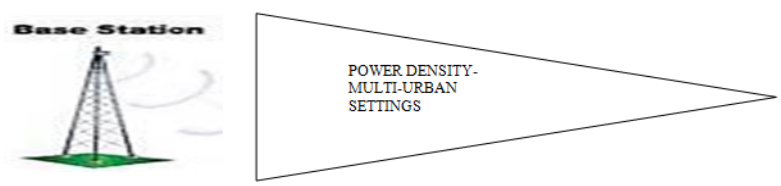
The Egli Path Loss (dB) for Frequency ranges from 30 to 1000 Mhz

Giannattasio et al. in their book entitled "A guide to the Wireless Engineering Body of Knowledge" published by A. John Wiley and Sons, Inc., Publication, 2009 stated that Radio propagation relies on the approximation for different frequencies. The Egli Model can be used for the frequency which ranges from 30 to 1000 Mhz having distances of 1 to 80 Km. The Okumura-Hata model for the frequency ranges from 150 to 1500 Mhz according to Mishra, in his book entitled "Advanced Cellular Network Planning and Optimization" published by A. John Wiley and Sons, Inc., Publication, 2007.

The theoretical underpinning of the study was based on the book of Wills et al. (2009) concerning different frequencies in which the Egli model can be used for the frequency ranges from 30 to 1000 Mhz that having distances of 1 to 80 Km. The source transmitters such as FM are not within the coverage in the Okumura –Hata model which has frequency ranges from 150 to 1500 Mhz. RF power density at -20dBm for energy harvesting that has capabilities for powering small electronic devices.

This study is anchored on the Energy Harvesting Principles by Mikeka and Arai (2011) stating that electronic devices may employ power coming from different energy harvesting techniques. They identified as one of the techniques for RF sources optimization with the power density of .01 uW / cm2 which is equal to a Power Received Level (PRL) at a minimum of -20dBm. These values were also postulated from the book of Khan and Yuce entitled "Internet of Things (IoT): Systems and Applications" published by Jenny Stanford Publishing Ltd., in 2019 and from the book of Gungor and Hancke entitled "Industrial Wireless Sensor Networks" published by CRC Press in 2013.

The framework gives a clear picture of how the study was implemented starting from the recognition of the type of multi-urban setting, determining the losses regarding the effects of the environment to propagations of waves, and the effects of radiofrequency propagation which were subtracted from the Power made by the transmitter resulting to a PRL in dBm. The PRL that can enable power harvesting systems and IoT and small electronic devices were all selected. All the selected power levels in dBm were converted into graphs and tables which can be a useful tool for having a heuristic prediction regarding RF energy potential (Figure 4).



Power Density Levels	0 dBm	-5dBm	-10 dBm	-15 dBm	-20 dBm
	way up to nearest point	0dBm	-5 dBm	-10 dBm	-15 dBm
	of the transmitter tower				
Power in Watts					
Voltage in milli-Volts					
Distance Radius in meters					
SCORE	5	4	3	2	1
LEVELS	EXCELLENT -HOT ZONE	SATISFACTORY	VERY GOOD	GOOD	FAIR

Figure 4. Conceptual Framework

Procedure

The goal is to classify different multiple urban settings such as Line of Sight (LOS), Rural (R), Suburban (S), Urban high (UH), Urban Very High (UVH), and Area with Obstructions or Non-line of Sight (NLOS) for ambient energy harvesting potential capabilities per wave propagations behavior of FM, TV, and Cell with their corresponding environment, and RF propagations. The procedure aims to find the distance radius range from the antenna tower that has the PRL -20dBm up to 0dBm way up to the nearest point of the antenna tower, labeled into scores with their corresponding Voltage (milli-Volts) and Power (Watts) that has good viability for energy harvesting (Figure 3 and Figure 4).

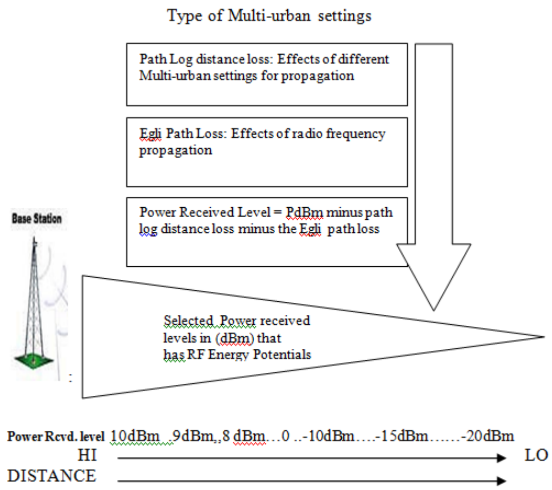


Figure 5. Power Density/Levels Labeled into Scores with their Corresponding Power, Voltage, Distance and Levels such as Hot Zone, Satisfactory, Very Good, Good, and Fair

The -20dBm and up - The Power levels with the potential for RF energy harvesting and their scores

Power levels with potential viability for Energy harvesting such as -20dB to -15dBm, -15dBm to -10dBm, -10dBm to -5dBm, -5dBm to 0 dBm, and 0 dBm way up to the point to the nearest transmitter were labeled into scores as 1 (Fair with 22mV to 40mV initial voltage), 2 (Good with 400mV to 70mV initial voltage), 3 (Very Good with 70mV to 125 mV initial voltage), 4 (Satisfactory with 125 mV to 223 mV), and 5 (Excellent-Hot Zone with 223 mV and up) respectively (*see Figure 5*). Then the power densities are converted into their corresponding Powers (P) in Watts with the formula:

POWER CONVERSION FORMULA FOR dBm TO WATTS

$$P(W) = 1W \times \frac{10^{\frac{P(dBm)}{10}}}{1000} = 10^{\frac{P(dBm)-30}{10}}$$

Equation 3

and Voltages with the formula: $V = \sqrt{Px}\ 50\ ohms$. The results were put into a table together with the Power Received Levels (PRLs), Voltages. (See table 2)

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
Transmitter: FM Multi-Urban Settings: Rural	SCORE 1 (-20dBm to -15dBm) RF VOLTAGES Energy potentials Power Watts	SCORE 2 (-15dBm to -10dBm) RF VOLTAGES Energy potentials Power Watts	SCORE 3 (-10dBm to -5dBm) RF VOLTAGES Energy potentials Power Watts	SCORE 4 (-5dBm to 0dBm) RF VOLTAGES Energy potentials Power Watts	SCORE 5 (0dBm way up to the nearest point of the tower transmitter) RF VOLTAGES Energy potentials Power Watts
Transmitter Power Antenna Height FT	DISTANCE IN METERS	DISTANCE IN METERS	DISTANCE IN METERS	DISTANCE IN METERS	DISTANCE IN METERS

Figure 6. Table of the Intensity of Scores. Finding the distance that has Power Received Levels (PRLs) of -20dBm and up concerning multi-urban settings.

Determining the distance estimation of PRL shown in (*Figure* 6) per given multiple urban settings is through the use of the Budget link equation may be presented as:

$$PRL = P\,(dBm) - [10 \times (n) \times \log distance\,(m) / do\,(m)]\,dB - [117 + 40 \log D\,(m) + 20 \log f\,(MHz) - 20 \operatorname{Log} ht\,(ft) \times 20]\,dB \quad \textit{Equation 4}$$

where PRL is the Power Received Level in dBm, P is the Power in dBm, n is the path loss exponent, do is the reference distance in meters of the source transmitter, f is the frequency in Megahertz and ht is the height of the antenna in ft. With the use of MS Excel spreadsheet by inputting distance, the antenna height, power of transmitter resulting to a PRL in dBm. The PRL that ranges from -20dBm and up with their corresponding distance, antenna height, were selected and were put into tables and graphs.

By using the budget link with the assistance of the excel (Microsoft Excel TM) spreadsheet's What- if -Analysis – Goal seek function, the PRLs in dBm were computed with the following steps: (Note: by the use of Goal seek or via the Trial and Error method in which different distances were continuously inputted to the Excel formula until the results would be -20dBm and up ranges were spotted such that -20dBm to -15 dBm as 1, -15 to -10dBm as 2, -10dBm to -5dBm as 3,-5dBm to 0dBm as 4, and 0dBm up to the nearest point of the transmitter power as 5 as excellent for RF harvesting as hot zone radius to know the distance that has RF potentials)

1. Rural score from 1 to 5 of FM PRL in dBm for less than 25 Kilowatts of FM transmitter power at an antenna height of 500 ft and below.
2. Rural score from 1 to 5 of FM PRL in dBm for less than 25 Kilowatts of FM transmitter power at antenna height of 500 ft and up.
3. Rural score from 1 to 5 of FM PRL in dBm for 25 to 50 Kilowatts of FM transmitter power at antenna height of fewer than 500 ft.
4. Rural score from 1 to 5 of FM PRL in dBm for 25 to 50 Kilowatts of FM transmitter power at antenna height of 500 ft. and up

5. Rural score from 1 to 5 of FM PRL in dBm for 50 to 75 Kilowatts of FM transmitter power at antenna height of fewer than 500 ft.
6. Rural score from 1 to 5 of FM PRL in dBm for 50 to 75 Kilowatts of FM transmitter power at antenna height of 500 ft. and up.
7. Rural score from 1 to 5 of FM PRL in dBm for 75 to 100 Kilowatts of FM transmitter power at antenna height of fewer than 500 ft.
8. Rural score from 1 to 5 FM PRL in dBm for 75 to 100 Kilowatts of FM transmitter at antenna height of 500 ft. and up. Note that with the results, the distance can be already seen with the corresponding scores such as Power in dBm, Voltages in Volts, Power in Watts for potential harvesting of An FM source located in a rural area. All of these results were put into a table and plotted on a graph.
9. Same procedures from 1 to 8 were used to the Line of sight (LOS), Suburban (S), Urban high (UH), Urban very high (UVH), and Area with obstructions multi-urban settings or Non-Line of Sight (NLOS).

Statistical Treatment

The statistical techniques used in analyzing and interpreting the results with the model were Percentage Range of Accuracy and Mean Squared Error (MSE) to measure the accuracy and predictive error for power levels used in the studies by different authors as a benchmark for energy RF energy harvesting to determine the acceptability of the model. The formula may be presented as follow (Equation 5):

$$RA = NCP/TNOP \times 100 \qquad \textit{Equation 5}$$

Where RA stands for Percentage Range of Accuracy; NCP, number of correct predictions; TNOP, Total number of predictions. For MSE formula (Equation 6):

$$MSE = SSE/N \qquad \textit{Equation 6}$$

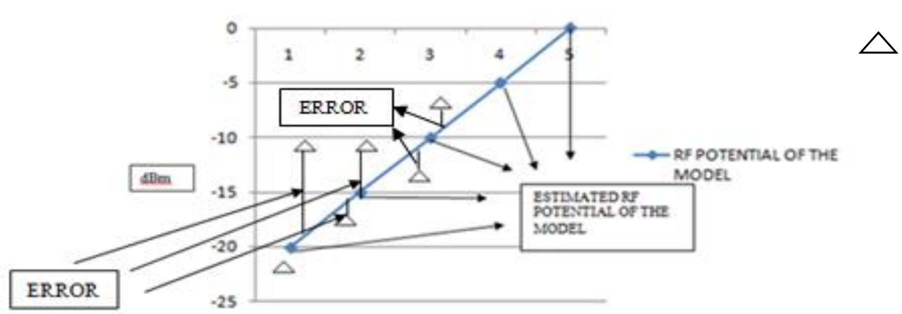


Figure 7. Representation of a Mean Squared Error (MSE) for Measuring the Predictive Error of the Model (Note: Different Authors' Actual RF Potential =: △)

Representation of an MSE (see *Figure 7)* for measuring the predictive error of the model where MSE stands for Mean Square Error; SSE, Sum Squared of Error; n, Number of the population (Figure 5), and in the addendum to determine if the models' scoring system can predict the RF potentials of different authors, or if the results of the authors were within the scope of the model's scoring system. Weighted mean was used with the formula (Equation 7):

$$\bar{x} = \Sigma fx / \Sigma x \qquad \textit{Equation 7}$$

Where x̄ stands for the Weighted Mean; Σfx, summation of the weights times the sample; Σx, the sum of the weights with the use of the scale scoring of 5, 4, 3, 2,1 and 0, as Excellent Hot Zone (E) for RF potentials, Satisfactory (S) level for RF potentials, Very Good (VG) level for RF potentials, Good (G) level for RF potentials, Fair (F) level for RF potentials, and 0 levels for RF potentials respectively.

Standard Deviation and Mean were used to determine the model's average meters distance accuracy and measurements regarding how the number's variability in accordance to different authors' studies and works as a benchmark for the model.

The formulae were as follows (Equation 8):

$$\mathrm{SD} = \sqrt{\frac{\sum |x - \mu|^2}{N}} \qquad \textit{Equation 8}$$

Where SD stands for Standard Deviation; ∑, the sum of; x, value in the data set; μ, mean of the data Set; n, number of data points.

RESULTS

This section shows the results of the heuristic approach to classifying different multiple urban settings regarding RF harvesting capabilities such as Line of Sight (LOS), Rural (R), Suburban (S), Urban High (UH), Urban Very High (UVH), Non-Line of Sight (NLOS) in accordance to transmitter technologies like FM, TV, and Cell. Prediction of the distance radius from the transmitter for viable RF harvesting can be easily determined without tedious calculations.

Table 1. (Researchers' Scoring Model). The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from an FM Source in a Classified-Line-of- Sight (LOS) Multiple Urban Setting

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
FM at Line of Sight Area	SCORE 1 (-20 dBm to -15dBm) **22 mV to 40 mV** RF energy potentials Fair	SCORE 2 (-15dBm to -10dBm) **40mV to 70 mV** RF energy potentials Good	SCORE 3 (-10dBm to -5dBm) **70 mV to 125mV** RF energy potentials) Very Good	SCORE 4 (-5dBm to 0dBm) **125 mV to 223 mV** RF energy potentials Satisfactory	SCORE 5 (0dBm way up to the nearest point of the tower transmitter) **223 mV and up** RF energy potentials Excellent/ Hot zone
< 25 kW Power at < 500 Ft. Antenna Height	1400 to 1140 m	1140 to 940 m	940 to 770 m	770 to 600 m	600 meters way up to the nearest point to the transmitter
< 25 kWPower at 500 Ft. to 1000 Ft. antenna height	1780 to 1450 m	1450 to 1190 m	1190 to 980 m	980 to 770 m	770 meters way up to the closest point to the Tower transmitter
25 kWto 50 kWPower at < 500 Ft. Antenna Height	1575 to 1295 m	1295 to 1055 m	1055 to 865 m	865 to 685 m	685 meters way up to the closest Tower Transmitter
25 kWto 50 kWPower at 500 Ft. to 1000 Ft	2000 to 1640	1640 to 1340	1340 to 1100	1100 to 870	870 meters way up to the Transmitter Tower
50 kW to75 kW power at less than 500 Ft	1690 to 1380	1380 to 1130	1130 to 930	930 to 730	730 meters way up to the nearest point to Transmitter tower
50 kWto 75 kW power at 500 FT to 1000 FT. antenna height	2150 to 1760	1760 to 1440	1440 to 1180	1180 to 930	930 meters way up to the nearest point to the transmitter tower
75 kWto 100 kWpower at less than or equal to 500 Ft.	1775 to 1455	1455 to 1195	1195 to 975	975 to 765	765 meters way up to the nearest point of the tower transmitter
75 kWto 100 kWpower at 500 ft to 1000 FT antenna height	2175 to 1840	1840 to 1520	1520 to 1240	1240 to 980	980 meters up to the nearest point of the tower transmitter

Table 2. The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from an FM Source in a Classified Rural Multiple Urban Setting (Researchers' Scoring Model)

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
FM in a Rural Area classified multi-settings	SCORE 1 (-20 dBm to -15dBm) **22 mV to 40 mV** RF energy potentials Fair	SCORE 2 (-15dBm to -10dBm) **40mV to 70 mV** RF energy potentials Good	SCORE 3 (-10dBm to -5dBm) **70 mV to 125mV** RF energy potentials) Very Good	SCORE 4 (-5dBm to 0dBm) **125 mV to 223 mV** RF energy potentials Satisfactory	SCORE 5 (0dBm way up to the nearest point of the tower transmitter) **223 mV and up** RF energy potentials Excellent/ Hot zone
< 25 kWPower at < 500 Ft. Antenna Height	1050 to 880 m	880 to 740 m	740 to 620 m	620 to 500 m	500 meters way up to the nearest point to the transmitter
< 25 kWPower at 500 Ft. to 1000 Ft. antenna height	1300 to 1090 m	1090 to 910 m	, 910 to 760 m	760 to 620 m	620 meters way up to the closest point to the Tower transmitter
25 kWto 50 kWPower at < 500 Ft. Antenna Height	1165 to 975 m	975 to 815 m	815 to 685 m	685 to 555 m	555 meters way up to the closest Tower Transmitter
25 kWto 50 kWPower at 500 Ft. to 1000 Ft	1450 to 1210	1210 to 1010	1010 to 830	830 to 690	690 meters way up to the Transmitter Tower
50 KW to75 kWpower at less than 500 Ft	1240 to 1040	1040 to 870	870 to 730	730 to 590	590 meters way up to the nearest point to Transmitter tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	1540 to 1290	1290 to 1080	1080 to 900	900 to 730	730 meters way up to the nearest point to the transmitter tower
75 kWto 100 kWpower at less than or equal to 500 Ft.	1305 to 1085	1085 to 915	915 to 765	765 to 615	615 meters way up to the nearest point of the tower transmitter
75 kWto 100 kWpower at 500 ft to 1000 FT antenna height	1610 to 1350	1350 to 1120	1120 to 950	950 to 760	760 meters up to the nearest point of the tower transmitter

Table 3. The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from a FM Source in a Classified Suburban Multiple Urban Setting (Researchers' Scoring Model)

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
FM in a classified Suburban Area multi-settings	SCORE 1 (-20 dBm to -15dBm) **22 mV to 40 mV** RF energy potentials Fair	SCORE 2 (-15dBm to -10dBm) **40mV to 70 mV** RF energy potentials Good	SCORE 3 (-10dBm to -5dBm) **70 mV to 125mV** RF energy potentials) Very Good	SCORE 4 (-5dBm to 0dBm) **125 mV to 223 mV** RF energy potentials Satisfactory	SCORE 5 (0dBm way up to the nearest point of the tower transmitter) **223 mV and up** RF energy potentials Excellent/ Hot zone
< 25 kW Power at < 500 Ft. Antenna Height	890 to 750 m	750 to 640 m	640 to 540 m	540 to 440 m	440 meters way up to the nearest point to the transmitter
< 25 kWPower at 500 Ft. to 1000 Ft. antenna height	1080 to 920 m	920 to 780 m	, 780 to 660 m	660 to 540 m	540 meters way up to the closest point to the Tower transmitter
25 kWto 50 kWPower at < 500 Ft. Antenna Height	975 to 835 m	835 to 705 m	705 to 595 m	595 to 485 m	485 meters way up to the closest Tower Transmitter
25 kWto 50 kWPower at 500 Ft. to 1000 Ft	1190 to 1010	1010 to 860	860 to 720	720 to 600	600 meters way up to the Transmitter Tower
50 kWto75 kWpower at less than 500 Ft	1040 to 880	880 to 750	750 to 630	630 to 520	520 meters way up to the nearest point to Transmitter tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	1270 to 1070	1070 to 910	910 to 760	760 to 620	620 meters way up to the nearest point to the transmitter tower
75 kWto 100 kWpower at less than or equal to 500 Ft.	1085 to 915	915 to 775	775 to 655	655 to 535	535 meters way up to the nearest point of the tower transmitter
75 kWto 100 kWpower at 500 ft to 1000 FT antenna height	1320 to 1120	1120 to 950	950 to 800	800 to 650	650 meters up to the nearest point of the tower transmitter

Table 4. The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from a FM Source in a Classified Urban High Multiple Urban Setting (Researchers' Scoring Model)

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
FM in a classified Urban High area	1 (-20 dBm to -15dBm) **22 mV to 40 mV** RF energy potentials Fair	2 (-15dBm to -10dBm) **40mV to 70 mV** RF energy potentials Good	3 (-10dBm to -5dBm) **70 mV to 125mV** RF energy potentials) Very Good	4 (-5dBm to 0dBm) **125 mV to 223 mV** RF energy potentials Satisfactory	5 (0dBm way up to the nearest point of the tower transmitter) **223 mV and up** RF energy potentials Excellent/ Hot zone
< 25 kW Power at < 500 Ft. Antenna Height	770 to 660 m	660 to 560 m	560 to 480 m	480 to 400 m	400 meters way up to the nearest point to the transmitter
< 25 kWPower at 500 Ft. to 1000 Ft. antenna height	920 to 780 m	780to 680 m	, 680 to 580 m	580 to 480 m	480 meters way up to the closest point to the Tower transmitter
25 kWto 50 kWPower at < 500 Ft. Antenna Height	845 to 715 m	715 to 605 m	605 to 525 m	525 to 435 m	435 meters way up to the closest Tower Transmitter
25 kWto 50 kWPower at 500 Ft. to 1000 Ft	1010 to 870	870 to 740	740 to 640	640 to 530	530 meters way up to the Transmitter Tower
50 kWto75 kWpower at less than 500 Ft	890 to 760	760 to 650	650 to 560	560 to 460	460 meters way up to the nearest point to Transmitter tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	1070 to 920	920 to 780	780 to 670	670 to 560	560 meters way up to the nearest point to the transmitter tower
75 kWto 100 kWpower at less than or equal to 500 Ft.	925 to 795	795 to 675	675 to 575	575 to 485	485 meters way up to the nearest point of the tower transmitter
75 kWto 100 kWpower at 500 ft to 1000 FT antenna height	1110 to 950	950 to 800	800 to 700	700 to 580	580 meters up to the nearest point of the tower transmitter

Table 5. The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from a FM Source in a Classified Urban Very High Multiple Urban Setting (Researchers' Scoring Model)

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
FM in a classified Urban Very High multi-settings	SCORE 1 (-20 dBm to -15dBm) **22 mV to 40 mV** RF energy potentials Fair	SCORE 2 (-15dBm to -10dBm) **40mV to 70 mV** RF energy potentials Good	SCORE 3 (-10dBm to -5dBm) **70 mV to 125mV** RF energy potentials) Very Good	SCORE 4 (-5dBm to 0dBm) **125 mV to 223 mV** RF energy potentials Satisfactory	SCORE 5 (0dBm way up to the nearest point of the tower transmitter) **223 mV and up** RF energy potentials Excellent/ Hot zone
< 25 kW Power at < 500 Ft. Antenna Height	670 to 580 m	580 to 500 m	500 to 430 m	430 to 370 m	370 meters way up to the nearest point to the transmitter
< 25 kWPower at 500 Ft. to 1000 Ft. antenna height	801 to 691 m	691 to 601 m	601 to 521 m	521 to 431 m	431 meters way up to the closest point to the Tower transmitter
25 kWto 50 kWPower at < 500 Ft. Antenna Height	735 to 635 m	635 to 545 m	545 to 475 m	475 to 395 m	395meters way up to the closest Tower Transmitter
25 kWto 50 kWPower at 500 Ft. to 1000 Ft	860 to 750	750 to 650	650 to 570	570 to 480	480 meters way up to the Transmitter Tower
50 kWto75 kWpower at less than 500 Ft	770 to 670	670 to 580	580 to 500	500 to 420	420 meters way up to the nearest point to Transmitter tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	920 to 800	800 to 690	690 to 600	600 to 500	500 meters way up to the nearest point to the transmitter tower
75 kWto 100 kWpower at less than or equal to 500 Ft.	805 to 695	695 to 595	595 to 515	515 to 435	435 meters way up to the nearest point of the tower transmitter
75 kWto 100 kWpower at 500 ft to 1000 FT antenna height	950 to 810	810 to 700	700 to 610	610 to 520	520 meters up to the nearest point of the tower transmitter

Table 6. The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from a FM Source in a Classified with Obstructions / Non-Line-of-Sight Multiple Urban Setting (Researchers' Scoring Model)

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
FM With Obstructions Area	1 (-20 dBm to -15dBm) **22 mV to 40 mV** RF energy potentials Fair	2 (-15dBm to -10dBm) **40mV to 70 mV** RF energy potentials Good	3 (-10dBm to -5dBm) **70 mV to 125mV** RF energy potentials) Very Good	4 (-5dBm to 0dBm) **125 mV to 223 mV** RF energy potentials Satisfactory	5 (0dBm way up to the nearest point of the tower transmitter) **223 mV and up** RF energy potentials Excellent/ Hot zone
< 25 kW Power at < 500 Ft. Antenna Height	460 to 410 m	410 to 360 m	360 to 320 m	320 to 280 m	280 meters way up to the nearest point to the transmitter
< 25 kWPower at 500 Ft. to 1000 Ft. antenna height	530 to 470 m	470 to 420 m	420 to 370 m	370 to 425 m	425 meters way up to the closest point to the Tower transmitter
25 kWto 50 kWPower at < 500 Ft. Antenna Height	495 to 435 m	435 to 385 m	385 to 345 m	345 to 300 m	300 meters way up to the closest Tower Transmitter
25 kWto 50 kWPower at 500 Ft. to 1000 Ft	560 to 500	500 to 450	450 to 400	400 to 350	350 meters way up to the Transmitter Tower
50 kWto75 kWpower at less than 500 Ft	510 to 460	460 to 410	410 to 360	360 to 315	315 meters way up to the nearest point to Transmitter tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	590 to 520	520 to 470	470 to 415	415 to 365	365 meters way up to the nearest point to the transmitter tower
75 kWto 100 kWpower at less than or equal to 500 Ft.	525 to 465	465 to 415	415 to 375	375 to 325	325 meters way up to the nearest point of the tower transmitter
75 kWto 100 kWpower at 500 ft to 1000 FT antenna height	610 to 540	540 to 480	480 to 430	430 to 370	370 meters up to the nearest point of the tower transmitter

The RF Energy Graphical Footprints Model (GFM)

Figures 8, 9, 10, 11, 12 and 13 show the RF Energy Graphical Footprints Model (GFM) of the distance and scores intensity for RF energy potentials for power and antenna heights in a classified LOS multiple urban settings. This can be used by RF installers and designers for RF harvesters.

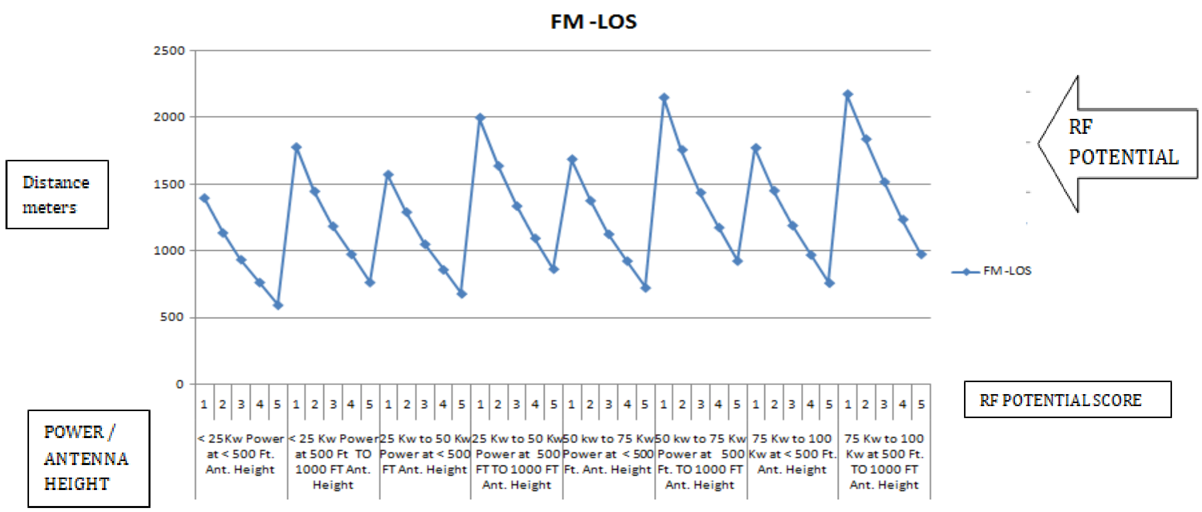


Figure 8. GFM, Graph of the Distance and Scores Intensity for RF Energy Potentials of a FM Source with respect to Power and Antenna Heights in Classified Line-of-Sight (LOS) Multiple Urban Settings

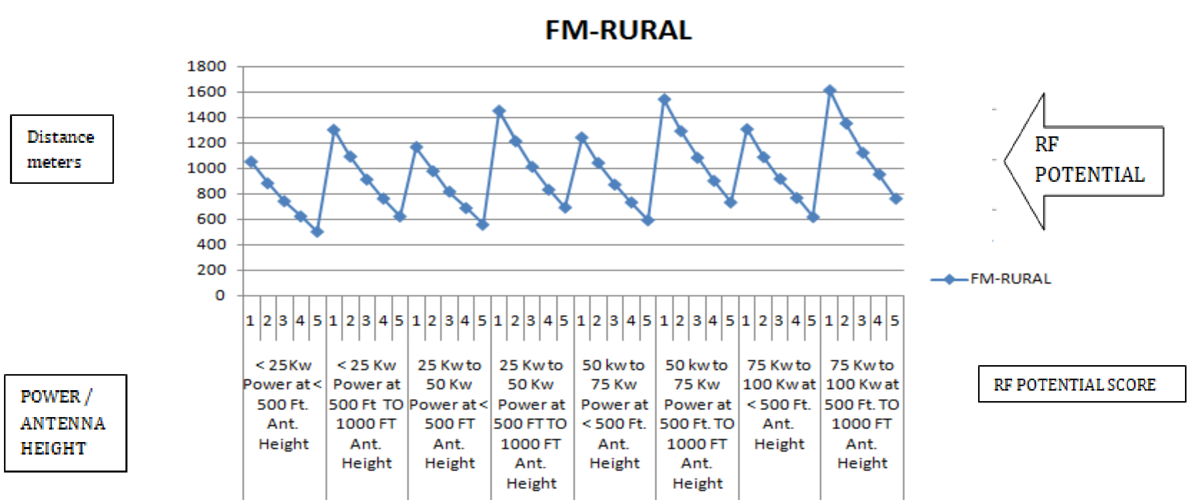


Figure 9. GFM, Graph of the distance and Scores Intensity for RF Energy Potentials of an FM Source with respect to Power and Antenna Heights in a Classified Rural Area Multiple Urban Setting

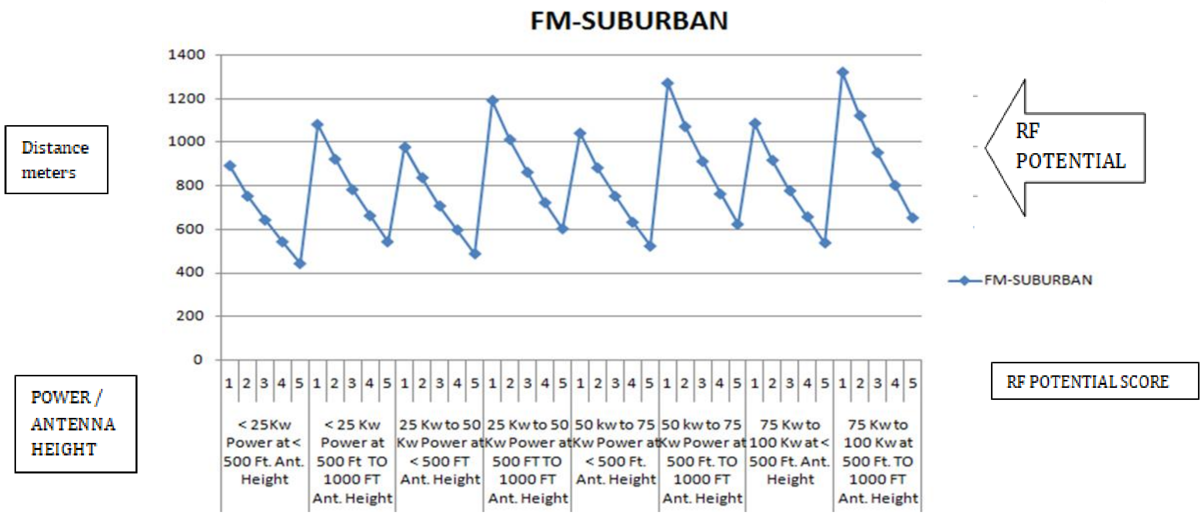


Figure 10. GFM, Graph of the distance and Scores Intensity for RF Energy Potentials of an FM Source with respect to Power and Antenna Heights in a Classified Suburban Multiple Urban Setting

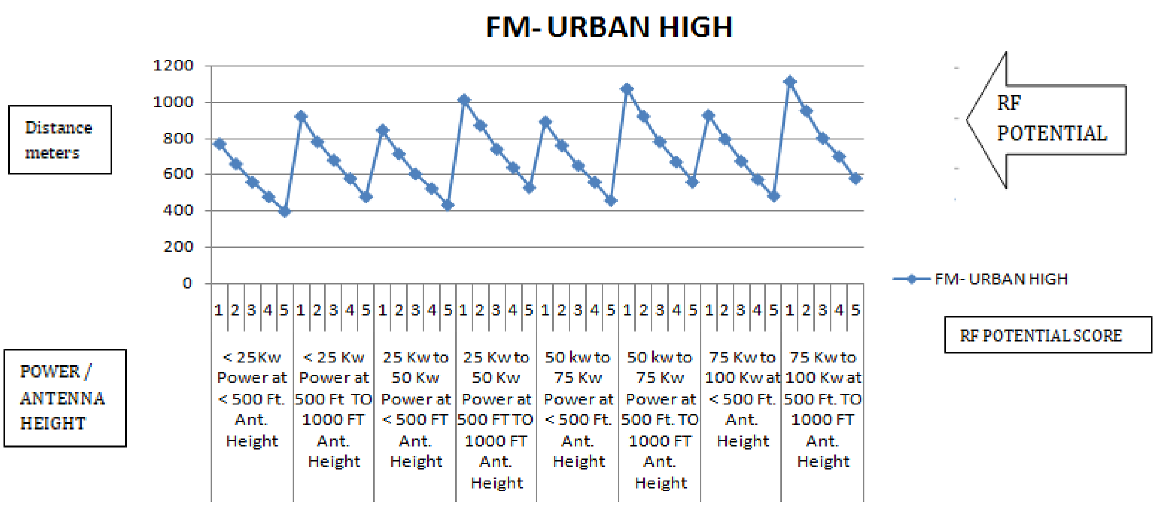


Figure 11. GFM, Graph of the distance and Scores Intensity for RF Energy Potentials of an FM Source with respect to Power and Antenna Heights in a Classified Urban Area Multiple Urban Setting

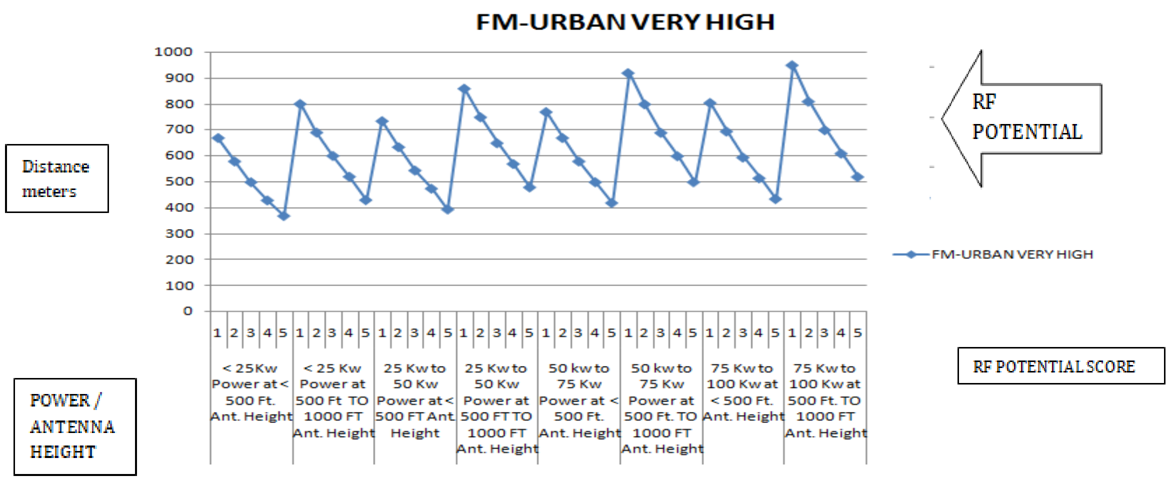


Figure 12. GFM, Graph of the Distance and Scores Intensity for RF Energy Potentials of an FM Source with respect to Power and Antenna Heights in a Classified Urban Very High Area Multiple Urban Setting

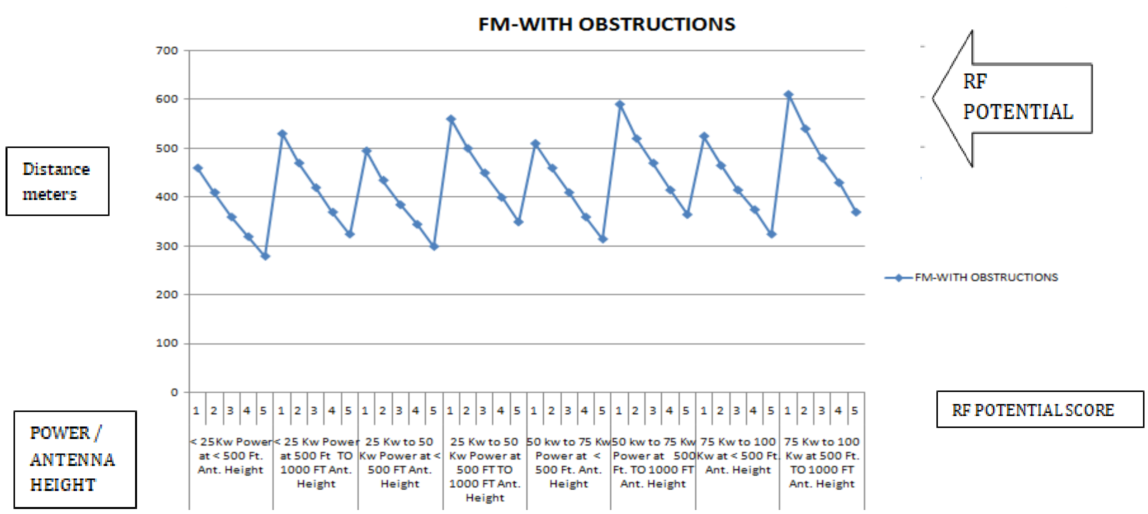


Figure 13. GFM, Graph of the Distance and Scores Intensity for RF Energy Potentials of an FM Source with respect to Power and Antenna Heights in a Classified Non-Line-of-Sight Multiple Urban Setting

Procedure (GFM and Table)

For example, the given Rural Multi Urban settings the farthest average distance radius for RF energy potentials from the sources such as TV, FM, and cell in classified Rural (R) multiple urban settings. A 75 Kilowatts to 100 Kilowatts of power with an antenna height ranging from 500 to 1000 ft., would give an RF energy potentials intensity score of 1 at a distance range of 1935 to 1620 meters from a TV source (See Part 1). In FM when used as an energy source, RF potentials can be found at1610 to 1350 meters with a score of 1 but has more distance coverage for energy harvesting due to the higher power and antenna height. Table 4 presents the distance of RF energy potentials of an FM Technology as a source in the classified rural area multiple urban settings. (Same procedure for Line-of-Sight, Suburban, Urban High, Urban Very High, and Non-Line-of-Sight Multi Urban Settings.

The RF Energy Graphical Footprints Model (GFM) / Researchers' scoring model as a Guide for RF Energy Harvester Installers and Designers

RF installers and designers can use the GFM as a guide for their RF harvesters, to determine the RF energy potentials, classify the area, then evaluate if RF sources and the harvester is within the radius scope of area for approximations. For example, an estimated distance range of 1620 meters away from the antenna tower of an FM station in classified rural multi-settings with a power of 75 kW to 100 KW at 500 ft. antenna tower, the researcher can distinguished the scores By simply looking at the RF energy GFM regarding viabilities for RF energy harvesting.

RF designers can also use the GFM for the design considerations of their RF harvesters because they can view the Power Received Levels (PRLs) for RF harvesting through intensity scores and temporal scores if operating hours were considered for the design.

Statistical results

The percentage acceptability range of the RF footprints graph model compared with different authors' past studies as a benchmark showed a percentage acceptability range of 84% with a mean squared prediction error of 14 along with an accuracy range of 1451 meters. In comparison with the work of different authors on RF harvesting, the grand weighted mean was a score of 3 which is within the boundaries of the model scores, reflecting a Very Good level for RF potentials. Therefore, the model RF energy GFM is acceptable.

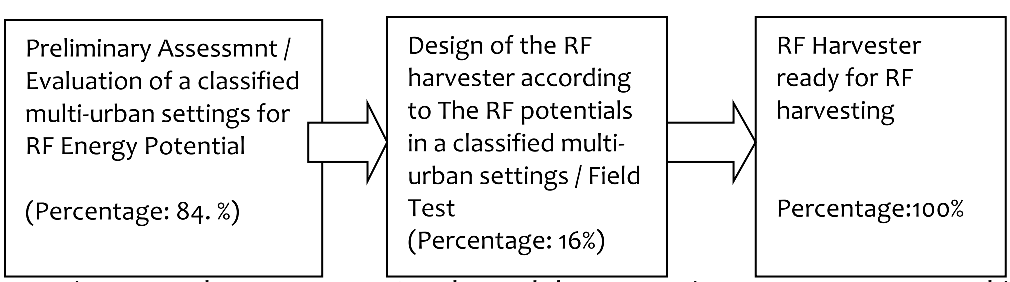


Figure 14. The RF Energy Graph Model as a Part in an RF Harvester Making

Figure 14 notes that the RF Energy GFM is mainly used for preliminary assessments for RF harvesting in different classified multi-urban settings for RF energy potentials with

84% acceptability. The remaining 16% is for the designing of the RF harvesters which is not within the scope of this paper. If the design of RF harvesters were to be included, the total would be 100%.

Comparison of Study with Other Works

Range of Accuracy and the Mean Squared Error computation to measure the predictive error for Power Received Levels (PRLs) used in the studies from different authors as a benchmark for RF energy harvesting to determine the acceptability of the model.

Mean Square Error (MSE) formula: MSE =SSE/N

Where MSE stands for Mean squared error; SSE, Sum Squared of Error; n, Number of population.

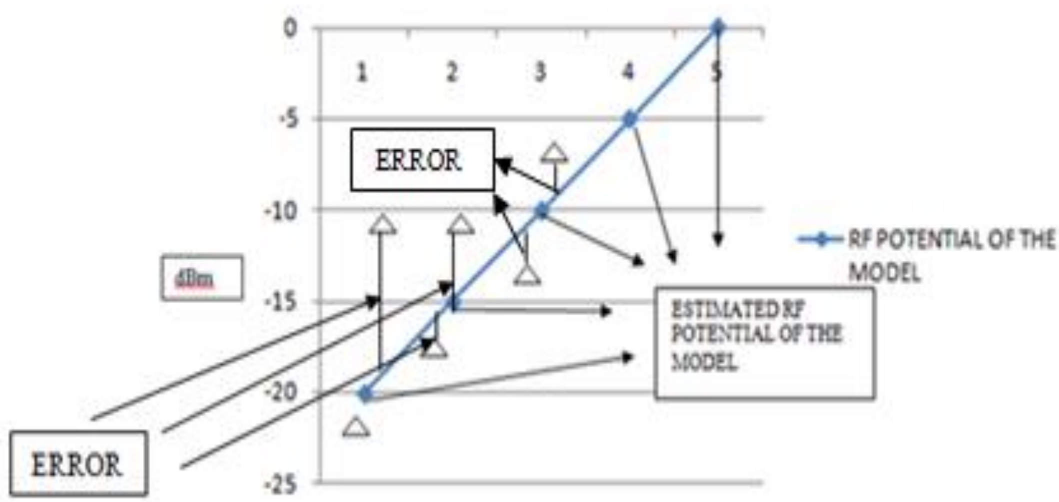


Figure 15. Representation of a Mean square error Note Different Authors Actual RF Potential =: △

DISCUSSION

The RF Energy Graphical Footprints Model (GFM) intensity scores range from 1 to 5 in accordance with initial voltage, power, and distance. RF harvesting potential can be made heuristically with FM, TV, and cell technologies through a simple Graphical Footprints Model (GFM) per urban multiple settings. Designers of RF harvesters can see where they can put their systems and determine the PRL in dBm, power in watts, voltage in milli-Volts, and distance in meters through intensity scores. Due to attenuation for different multiple urban surroundings, the PRL for viable RF energy potentials coming from TV, cell, and FM vary based on the distances for this can be seen in the model Footprints for RF energy potentials.

Classified Line-of-Sight (LOS) multiple urban settings for RF Energy Potential categorized as transmitting source and the RF harvesting device are in clear view of each other without any obstacle LOS can be applied to rural areas, suburban areas, urban high areas, and urban very high areas if the RF harvester and the transmitter RF energy source are in clear view of each other.

The classified rural area multiple urban setting, categorized as an area that has small houses or hard to see one or two buildings and encompassing a big landscape of trees, mountains, hills, and valleys. The classified suburban multiple urban setting, categorized as a combined fraction of peopled district within a city where some structures are closely spaced and with hard-to-see buildings that may produce obstructions of signals to the RF harvester.

In a classified Rural multi-urban setting, the farthest average distance radius for RF energy potentials for RF harvesting from an FM source is 1610 meters but has a lesser distance for RF potentials if compared to the results in the classified LOS multi-urban setting. The farthest average distance that is fair for RF harvesting from an FM source in a classified Suburban multi-settings area is 1320 meters with an intensity score of 1 and the results regarding the RF potentials distances are lesser than to rural and LOS classified multi-settings.

RF designers and installers can harvest RF energy from an FM Transmitter source in a classified Urban High multi-setting at 1110 meters range with an intensity score of 1, but due to the area/environment path loss exponent, the results have a lesser distance compared to Rural, Suburban, Line of Sight Multi-settings. In a classified Urban Very High multi-setting, RF designers and installers can harvest RF energy as far as 950 meters from an FM RF energy source with an intensity score of 1. The distance of Urban Very High has a much lesser radius range than at Urban High due to the loss exponent environment.

The farthest average distance radius for RF energy potentials from an FM source in classified NLOS multi-settings is 610 meters with an intensity score of 1. The distance for RF potentials of an NLOS area has the lowest radius range because of the environment. RF designers as much as possible must take a deep precaution regarding designs in this classified area if they are able to extend their RF harvester antenna to make it as a Line of sight with the source is highly recommended.

CONCLUSIONS AND RECOMMENDATIONS

The RF Energy GFM has an acceptability percentage of 84% with a Mean Squared Prediction Error of 14 for the RF Energy Footprints Graph model. The model for Weighted Mean results perceived coming from the different authors regarding their RF harvesters received a score of 3 which means Very Good level for RF potentials. Therefore, the model is acceptable as well as the average range distance of the RF Energy Graph Model of1451 meters. Since the model is part of RF harvesting as a preliminary tool, the model will give information to the designers and installers regarding RF energy potentials before going to the area.

A classified Rural, Suburban, Urban High, and Urban Very High can turn into a classified NLOS due to mountains, hills, trees, electric posts, and building obstructions. Simple height adjustments regarding RF harvesters will do to make it into a classified LOS for a much better RF harvesting the same thing must be done with the classified NLOS area.

The model, along with the studies of different authors shows that Power density / received levels ranging from -20dBm and up, have the potential for RF energy and RF harvesting with an average percent accuracy of 84% with 14 Mean Squared Error and with Mean average accuracy for a distance of 1451 meters.

The RF Energy Graphical Footprints Model (GFM) for energy potential capabilities is a plot of Power Received Level thru scores based on a -20 dBm and up with corresponding scores, initial voltages, Power densities, and Power in accordance to classified multi-settings that are viable for energy capabilities can be determined without any computations and the only effort required is the reading and following of values of the Energy GFM.

The RF Energy GFM serves as a tool for easy preliminary assessments of selected urban settings for RF energy harvesting in place of too many communications engineering computations to get the Power Received Level. The RF GFM will assist the RF designers to determine the best locations for their harvesters even in an off scheme compared to tedious surveying on-site to get the Power Received Level. The GFM will act as a map to show the best place for RF harvesting capabilities which can be used for design considerations.

RECOMMENDATION FOR FUTURE WORK

The RF GFM is one major contribution to ambient RF energy scavenging technology. RF harvester designers may use the model for their design considerations because it entails easy preliminary assessments of the selected urban setting for RF energy harvesting capabilities and serves as a map to identify the best locations for harvesting.

RF Energy GFM can be programmed into an application software by inputting needed parameters to determine the score of certain urban settings or by taking pictures through an android mobile phone in a 360° of a given map with different transmitters area and it will give already a corresponding score and succeeding researchers may improve the model by having a much smaller Mean Squared Error at below 14.

The future paper works include a study on RF energy GFM with wifi sources with the inclusion of prototype RF harvesters to be used in accordance with the RF Energy Potentials Graph model.

IMPLICATIONS

The RF Energy GFM serves as a tool for easy preliminary assessments of selected urban settings for RF energy harvesting in place of too many communications engineering computations to get the Power Received Level.

The GFM will act as a map to show the best place for RF harvesting capabilities which can be used for design considerations even in an off scheme compared to tedious surveying on-site to get the Power Received Level and the only effort required is the reading and following of values of the Energy GFM.

DECLARATIONS

Conflict of Interest

The authors declare no competing interest in this study.

Informed Consent

Not applicable since this study does not involve human participants.

Ethics Approval

Not applicable since this study does not involve human participants.

REFERENCES

Adam, I., Yasin, M. N. M., Malek, M. F. A., Rahim, H. A., Shakhirul, M. S., & Razalli, M. S. (2017). Feasibility study on RF energy harvesting in Malaysia. *Advanced Science Letters, 23*(6), 5034-5038.

Akanni, A.O. & Oliseloke, A.N. (2020). Validation of Egli Model and Estimation of Pathloss Exponent of a Radio Signal at VHF Band in Hilly Terrain.

Borges, L. M., Chávez-Santiago, R., Barroca, N., Velez, F. J., & Balasingham, I. (2015). Radio-frequency energy harvesting for wearable sensors. *Healthcare technology letters*, 2(1), 22-27.

Cameron, L. (2018, March). *Internet of Things Meets the Military and Battlefield*. Computer.org http://surl.li/eweia

Caselli, M., Tonelli, M., & Boni, A. (2019). Analysis and design of an integrated RF energy harvester for ultra low-power environments. *International Journal of Circuit Theory and Applications, 47*(7), 1086-1104.

Fanan, A. M., Riley, N. G., Mehdawi, M., & Alfahad, O. (2017). Performance of a TV white space database with different terrain resolutions and propagation models. *Telfor Journal, 9*(2), 80-85.

Gabrillo, L. J., Galesand, M. G., & Hora, J. A. (2015, April). Enhanced RF to DC converter with LC resonant circuit. In *IOP Conference Series: Materials Science and Engineering* (Vol. 79, No. 1, p. 012011). IOP Publishing.

Garah, M., Djouane, L., Oudira, H., & Hamdiken, N. (2017). Path loss models optimization for mobile communication in different areas. *Indonesian Journal of Electrical Engineering and Computer Science, 3*(1), 126-35.

Ho, D. K., Ngo, V. D., Kharrat, I., Vuong, T. P., Nguyen, Q. C., & Le, M. T. (2017). A novel dual-band rectenna for ambient RF energy harvesting at GSM 900 MHz and 1800 MHz. *Advances in Science, Technology and Engineering Systems Journal, 2*(3), 612-616.

Jawhly, T., & Tiwari, R. C. (2020). The special case of Egli and Hata model optimization using least-square approximation method. *SN Applied Sciences, 2*(7), 1-10.

Khalid, F., Saeed, W., Shoaib, N., Khan, M. U., & Cheema, H. M. (2020). Quad-band 3D rectenna array for ambient RF energy harvesting. *International Journal of Antennas and Propagation*, *2020*, Article ID 7169846. https://doi.org/10.1155/2020/7169846

Khemar, A., Kacha, A., Takhedmit, H., & Abib, G. (2017). Design and experiments of a 3G-band rectenna for radio frequency energy harvesting. *Rev. Roum. Sci. Techn–Électrotechn. et Énerg, 62*(1), 82-86.

Khemar, A., Kacha, A., Takhedmit, H., & Abib, G. (2018). Design and experiments of a dual-band rectenna for ambient RF energy harvesting in urban environments. *IET Microwaves, Antennas & Propagation, 12*(1), 49-55.

Milanezi, J., Ferreira, R. S., da Costa[1], J. P. C., del Galdo, G., Miranda, R. K., Felber, W., & de Freitas, E. P. (2017, May). Radiofrequency energy harvesting system based on a rectenna array in urban environments. In *2017 International Conference on Signals and Systems* (ICSigSys) (pp. 151-157). IEEE.

Mutee-ur-Rehman, Qureshi, M.I., Ahmad, W., & Khan, W.T. (2017). Radio frequency energy harvesting from ambient FM signals for making battery-less sensor nodes for wireless sensor networks. *2017 IEEE Asia* Pacific *Microwave Conference* (APMC), pp. 487-490.

Nechibvute, A., Chawanda, A., Taruvinga, N., & Luhanga, P. (2017). Radio frequency energy harvesting sources. *Acta Electrotechnica et Informatica, 17*(4), 19-27. https://dx.doi.org/10.15546/aeei-2017-0030

Nimo, A., Beckedahl, T., Ostertag, T., & Reindl, L. (2015). Analysis of passive RF-DC power rectification and harvesting wireless RF energy for micro-watt sensors. *AIMS Energy, 3*(2), 184-200.

Nowi (2019, January). *Internet of Things with Energy Harvesting.* Youtube. https://www.youtube.com/watch?v=xsttMt4Kt0M

Onuu, M. U., & Usanga, E. M. (2017). Path Loss Prediction for Some GSM Networks for Akwa Ibom State, Nigeria. *Global Journal of Research In Engineering*, *17*(D2), 15-27.

Parks, A. N., Sample, A. P., Zhao, Y., & Smith, J. R. (2013, January). A wireless sensing platform utilizing ambient RF energy. In *2013 IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems* (pp. 154-156). IEEE.

Piñuela, M., Mitcheson, P. D., & Lucyszyn, S. (2013). Ambient RF energy harvesting in urban and semi-urban environments. I*EEE Transactions on microwave theory and techniques,* 61(7), 2715-2726.

Qureshi, M. I., Ahmad, W., & Khan, W. T. (2017, November). Radiofrequency energy harvesting from ambient FM signals for making battery-less sensor nodes for wireless sensor networks. In *2017 IEEE Asia Pacific Microwave Conference* (APMC) (pp. 487-490). IEEE.

Shariati, N., Rowe, W. S., Scott, J. R., & Ghorbani, K. (2015). Multi-service highly sensitive rectifier for enhanced RF energy scavenging. *Scientific Reports,* 5(1), 1-9.

Shrestha, S., Noh, S. K., & Choi, D. Y. (2013). Comparative study of antenna designs for RF energy harvesting. *International Journal of Antennas and Propagation*, 2013, Article ID 385260. https://doi.org/10.1155/2013/385260

Song, C., Huang, Y., Zhou, J., Yuan, S., Xu, Q., & Carter, P. (2015, April). A broadband efficient rectenna array for wireless energy harvesting. In 2015 9th European Conference on Antennas and Propagation (EuCAP) (pp. 1-5). IEEE.

Takhedmit, H., Bellal, S., Costa, F., Picon, O., and Cirio, L. (2018). RF Energy harvesting in urban environment using transparent rectenna arrays.

Urrehman, M., Qureshi, M.I., Ahmad, W. and Khan, W.T. (2017) Radio Frequency Energy Harvesting from Ambient FM Signals for Making Battery-Less Sensor Nodes for Wireless Sensor Networks

Vyas, R., Nishimoto, H., Tentzeris, M., Kawahara, Y., and Asami, T. (2012). A battery-less, energy harvesting device for long range scavenging of wireless power from terrestrial TV broadcasts.

Waguaf, A., Alvernhe, R., Fadel, L., & Grzeskowiak, M. (2018, December). Energy Harvesting with 2.45 GHz Rectenna for urban application. In *2018 25th IEEE International Conference on Electronics, Circuits, and Systems* (ICECS) (pp. 345-348). IEEE.

Zeng, M., Li, Z., Andrenko, A. S., Zeng, Y., & Tan, H. Z. (2018). A compact dual-band rectenna for GSM900 and GSM1800 energy harvesting. *International Journal of Antennas and Propagation*, *2018*, Article ID 4781465. https://doi.org/10.1155/2018/4781465.

Zhang, J. W., Huang, Y., & Cao, P. (2014). An investigation of wideband rectennas for wireless energy harvesting. *Wireless Engineering and Technology,* 5(04), 107.

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