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Long Paper

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

Jesus Victor G. Lacerna
Energy Engineering, University of the Philippines Diliman, Philippines
(corresponding author)

Erwin E. Guerra
College of Computer Science, University of Makati, Philippines
ORCID: 0000-0003-3286-6661

Joel Joseph Marciano Jr.
Electrical and Electronics Engineering, University of the Philippines Diliman, Philippines

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Abstract

Purpose – This paper aims to develop a Graphical Footprint Model (GFM) that will validate 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. In this paper, the researchers focus more on TV technology sources.

Method – The Communications Engineering Formula Budget link was used to get the PRL for RF potentials in dBm, to determine the classified multi-settings together with the RF sources for RF harvesting capabilities. The GFM is a scoring scheme for energy capabilities based on a -20dBm and up of Power Received Levels (PRL) at different classified multiple urban settings, which includes Line of Sight (LOS), Rural (R), Suburban (S), Urban High (UH), Urban Very High (UVH), and Non-Line of Sight (NLOS) settings.

Result – The result of the exercise showed a percentage acceptability range of 84.00 % with a Mean Square Error (MSE) of 14 along with a mean average distance accuracy range of 1451 meters. To determine whether the GFM can predict heuristically with the use of a weighted mean, the analysis covered spread-out data points over a large range of values, considering a standard deviation of 3091. The grand mean obtained was an intensity score of 3, with the initial voltage range from 70mV to 125 mV. This presents a particularly good level for GFM to predict heuristically the RF potential. In establishing a benchmark for the GFM, a review of twenty-one research studies was undertaken for data analytics.

Conclusion – The GFM will benefit future design engineers and installers of RF harvesters. GFM can provide them the necessary information to determine the locations and distances for RF potential emitted from TV technology as an energy source in different classified multiple settings.

Recommendation – The 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.

Practical Implication – The study on GFM will act as a map to show the best place for RF harvesting capabilities in 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 the values of the Energy GFM.

Keywords **–** RF, energy, source, harvesting, heuristic, potential, TV technology

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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. 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 energies 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 thru the use of RF harvester. The use of TV RF harvesters such as loop antenna design can also get energy from a TV Station (Gabrilloet al. 2015). Such a square antenna array design can also have the ability to harness 1 Volt from a TV broadcast tower (Nechibvute et al. 2017). The paper aims to provide a guide model footprint for preliminary Potential energy harvesting capabilities coming from TV 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

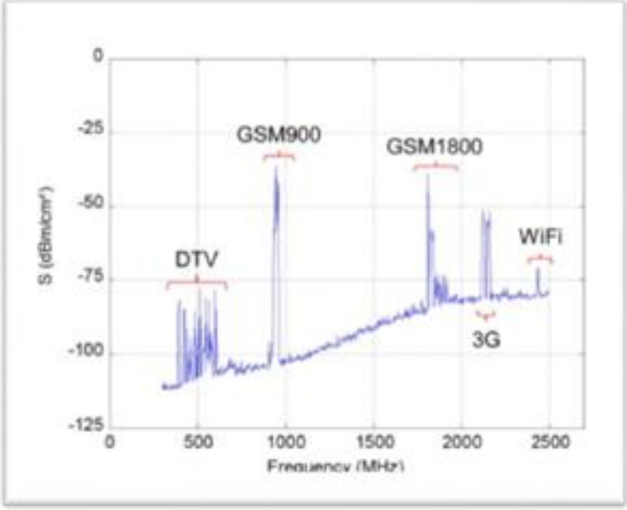
Harvesting RF Energy and the Environment

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 a distance of 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).

Pinuelaet 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, 3g? were potentially useful ambient sources of RF energy (figure 1) 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.

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 a distance of 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.

In the study of Zhang et al. (2014) entitled "An Investigation of Wideband Rectennas for Wireless Energy Harvesting," 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.



From Pimuela et. al., (2013)

Figure 1. Input Power Measurements Outside the Northfields London

Nimoet 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).

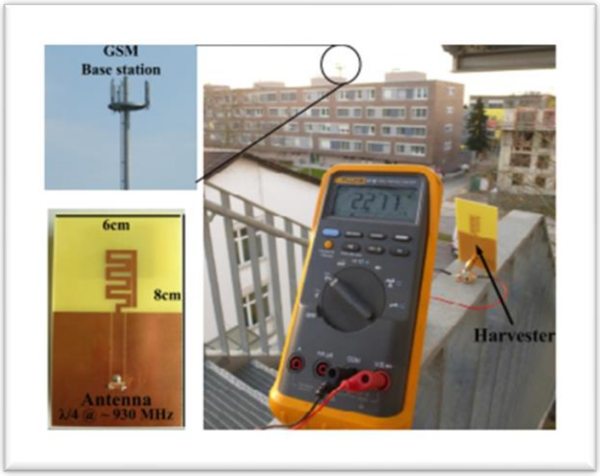


Figure 2. Setup for Measuring the Voltage from a Cell Site source and the RF Harvester Got a Measured Average Voltage of 2.3 Volts (from Nimo et al., 2015)

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.

Adam et al. (2015) in their paper entitled "Feasibility study on RF energy harvesting in Malaysia", made measurements in the urban and semi-urban area in which they designated the Penang and Kedah as urban zone and semi-urban zone. The group found out that GSM 1800 got the highest obtained power of -1.29dBm in an urban area while GSM 900 bands acquired the power of –22.66dbm in a semi-urban section. The outcome of the survey was then used as an input to the RF harvester design considerations, where harvester GSM 900 got a .42 V from a –25dBm and a 2.5 V at -10dBm. On the other hand, harvester GSM 1800 at -15dBm resulted in a 1.2 V and at -1.3dBm got an outcome of 4.4 V. The overall result showed that GSM 900 and 1800 gave good power for energy harnessing.

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.

Gabrilloet 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.

Adel et al. (2017) In their works entitled "Design and experiments of a 3G band rectenna for Radio Frequency energy harvesting" Adel 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.

Urrehmanet 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.

Milaneziet al. (2017) In their study entitled "Radiofrequency Energy Harvesting System Based on a Rectenna Array in Urban Environments" Milaneziet 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 Khemaret 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.

Takhedmitet 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 Pinuelaet 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 Waguafet 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.

Casseli 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.

Ho et al. (2017) presented a GSM 900/ GSM 1800 novel dual-band RF harvester for an ambient environment. This harvester can be used for low-powered electronic devices. The rectifier was optimized and designed at –20dBm input and they made a fabricated prototype via simulations to which a 20% and 40.8 % Power Conversion Efficiency (PCE) for an input level of -20dBm along with an output voltage of 183 to 415mV was obtained.

Path Loss Models

Garah et al. (2016) 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. Onuuet 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 et al. (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 of the dissertation. 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. (2015), and Pinuelaet al. (2013) the measured power densities differ per environment. According to the study of Pinuelaet 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.

Theoretical Framework

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) andminus 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

Table 1. Environment and the Path Loss Exponents

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

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

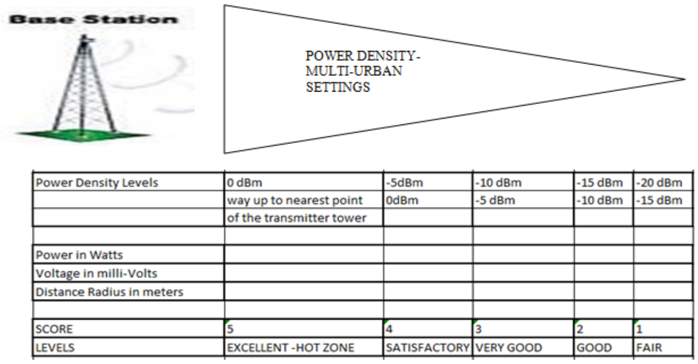
Giannattasio et al. in their book entitled "A guide to the Wireless Engineering Body of Knowledge" published by A. John Wiley and Sons, Inc., Publication, 2009 stated that Radio propagation relies on the approximation for different frequencies. The Egli Model can be used for the frequency which ranges 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.

CONCEPTUAL FRAMEWORK

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 3).



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 3. 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).

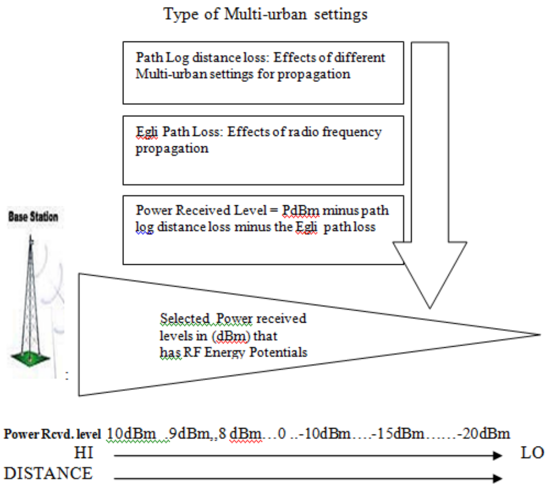
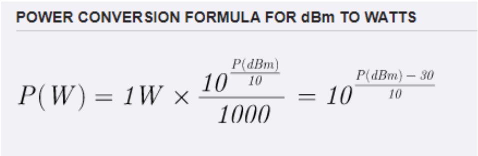


Figure 4. Power Density/Levels Labeled into Scores with their Corresponding Power, Voltage, Distance and Levels such as Hot Zone, Satisfactory, Very Good, Good, and Fair

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. 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)

Table 2. Table of the Intensity of Scores. Finding the distance that has Power Received Levels (PRLs) of -20dBm and up concerning multi-urban settings.

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

Determining the distance estimation of PRL per given multiple urban settings is through the use of the Budget link equation may be presented as:

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

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

5. Rural score from 1 to 5 of TV PRL in dBm for 50 to 75 Kilowatts of TV transmitter power at antenna height of fewer than 500 ft.
6. Rural score from 1 to 5 of TV PRL in dBm for 50 to 75 Kilowatts of TV transmitter power at antenna height of 500 ft. and up.
7. Rural score from 1 to 5 of TV PRL in dBm for 75 to 100 Kilowatts of TV transmitter power at antenna height of fewer than 500 ft.
8. Rural score from 1 to 5 TV PRL in dBm for 75 to 100 Kilowatts of TV 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 a TV 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 acce *Equation 5* he model. The formula may be presented as follow (Equation 5):

$$RA = NCP/TNOP \text{ x } 100$$

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

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

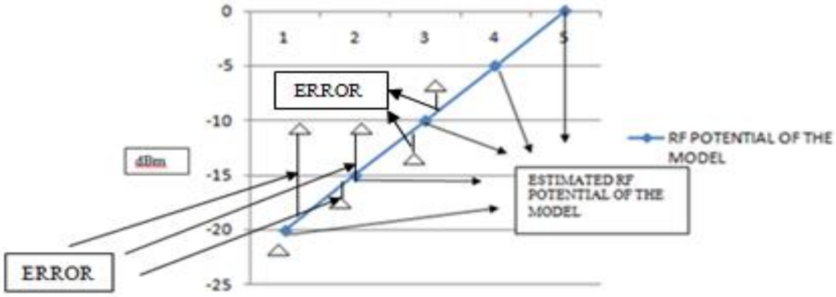


Figure 5. Representation of a Mean Squared Error (MSE) for Measuring the Predictive Error of the Model (Note: Different Authors' Actual RF Potential =: △)

Figure 5. Representation of an MSE 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):

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

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):

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

Where SD stands for Standard Deviation; ∑, the sum of; x, value in the data set; μ, mean of the dataSet; 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 3. (Researchers' Scoring Model)

The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from a TV Source in a Classified-Line-of- Sight (LOS) Multiple Urban Setting

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
TV 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	1700 to 1358	1358 to 1151	1151 to 915	915 to 741	741 meters way up to the nearest point to the transmitter
< 25 kW Power at 500 ft. to 1000 ft. antenna height	2178 to 1750 m	1750 to 1411 m	1411 to 1156 m	1156 to 913 m	913 meters way up to the closest point to the Tower transmitter
25 kW to 50 kW Power at < 500 Ft. Antenna Height	1860 to 1527 m	1527 to 1300 m	1300 to 1027 m	1027 to 809 m	809 meters way up to the closest Tower Transmitter
25 kW to 50 kW Power at 500 Ft. to 1000 Ft	2400 to 2000 m	2000 to 1600 m	1600 to 1303 m	1303 to 1063 m	1063 meters way up to the Transmitter Tower
50 kW to 75 kW power at less than 500 Ft	2000 to 1695 m	1695 to 1341 m	1341 to 1102 m	1102 to 869 m	869 meters way up to the nearest point to the Transmitter tower
50 kW to 75 kW power at 500 FT to 1000 FT. antenna height	2600 to 2078 m	2078 to 1770 m	1770 to 1450 m	1450 to 1144 m	1144 meters way up to the nearest point to the transmitter tower
75 kW to 100 kW power at less than or equal to 500 Ft.	2177 to 1785 m	1785 to 1464 m	1464 to 1200 m	1200 to 911 m	911 meters way up to the nearest point of the tower transmitter
75 kW to 100 kW power at 500 ft to 1000 FT antenna height	2768 to 2267 m	2267 to 1860 m	1860 to 1500 m	1500 to 1200 m	1200 meters up to the nearest point of the tower transmitter

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

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
TV in a Rural classified 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	1262 to 1022	1022 to 857	857 to 719	719 to 581	581meters way up to the nearest point to the transmitter
< 25 kW power at 500 ft. to 1000 ft. antenna height	1564 to 1267 m	1267 to 1060 m	1060 to 917 m	917 to 719 m	719 meters way up to the closest point to the Tower transmitter
25 kW to 50 kW Power at < 500 Ft. Antenna Height	1405 to 1177 m	1177 to 985 m	985 to 826 m	826 to 647 m	647 meters way up to the closest Tower Transmitter
25 kWto 50 kWPower at 500 Ft. to 1000 Ft	1700 to 1408 m	1408 to 1189 m	1189 to 1000 m	1000 to 809 m	809 meters way up to the Transmitter Tower
50 kWto75 kW power at less than 500 Ft	1496 to 1253 m	1253 to 1049 m	1049 to 878 m	878 to 700 m	700 meters way up to the nearest point to the Transmitter tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	1800 to 1549 m	1549 to 1297 m	1297 to 1051 m	1051 to 860 m	860 meters way up to the nearest point to the transmitter tower
75 kW to 100 kW power at less than or equal to 500 Ft.	1562 to 1310 m	1310 to 1097 m	1097 to 917 m	917 to 718 m	718 meters way up to the nearest point of the tower transmitter
75 kW to 100 kW power at 500 ft to 1000 FT antenna height	1935 to 1620 m	1620 to 1356 m	1356 to 1136 m	1136 to 918 m	918 meters up to the nearest point of the tower transmitter

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

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
TV in a classified Suburban Area multi-settings	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	1052 to 866	866 to 737	737 to 623	623 to 512	512 meters way up to the nearest point to the transmitter
< 25 kW Power at 500 ft. to 1000 ft. antenna height	1274 to 1058 m	1058 to 896 m	896 to 761 m	761 to 626 m	626 meters way up to the closest point to the Tower transmitter
25 kW to 50 kW Power at < 500 Ft. Antenna Height	1163 to 986 m	986 to 836 m	836 to 689 m	689 to 578 m	578 meters way up to the closest Tower Transmitter
25 kW to 50 kW Power at 500 Ft. to 1000 Ft	1418 to 1196 m	1196 to 1001 m	1001 to 839 m	839 to 700 m	700 meters way up to the Transmitter Tower
50 kW to75 kW power at less than 500 Ft	1231 to 1045 m	1045 to 886 m	886 to 751 m	751 to 600 m	600 meters way up to the nearest point to the Transmitter tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	1502 to 1274 m	1274 to 1082 m	1082 to 917 m	917 to 730 m	730 meters way up to the nearest point to the transmitter tower
75 kW to 100 kW power at less than or equal to 500 ft.	1285 to 1090 m	1090 to 922 m	922 to 784 m	784 to 642 m	642 meters way up to the nearest point of the tower transmitter
75 kW to 100 kW Power at 500 ft. to 1000 ft. antenna height	1566 to 1329 m	1329 to 1127 m	1127 to 956 m	956 to 783 m	783 meters up to the nearest point of the tower transmitter

Table 6. (Researchers' Scoring Model)
The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from a TV Source in a Classified Urban High Multiple Urban Setting

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
TV 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	899 to 752	752 to 644	644 to 554	554 to 459	459 meters way up to the nearest point to the transmitter
< 25 kW power at 500 ft. to 1000 ft. antenna height	1082 to 929 m	929 to 776 m	776 to 665 m	665 to 563 m	563 meters way up to the closest point to the Tower transmitter
25 kW to 50 kW Power at < 500 ft. Antenna Height	986 to 824 m	824 to 707 m	707 to 614 m	614 to 506 m	506 meters way up to the closest Tower Transmitter
25 kWto 50 kWPower at 500 ft. to 1000 ft.	1189 to 1000 m	1000 to 850 m	850 to 730 m	730 to 623 m	623 meters way up to the Transmitter Tower
50 kWto75 kW power at less than 500 ft.	1041 to 894 m	894 to 765 m	765 to 657 m	657 to 545 m	545 meters way up to the nearest point to Transmittertower
50 kWto 75 kWpower at 500 ft. to 1000 ft. antenna height	1255 to 1075 m	1075 to 922 m	922 to 790 m	790 to 656 m	656 meters way up to the nearest point to the transmitter tower
75 kW to 100 kW power at less than or equal to 500 Ft.	1083 to 927 m	927 to 795 m	795 to 681 m	681 to 563 m	563 meters way up to the nearest point of the tower transmitter
75 kW to 100 kW power at 500 ft to 1000 FT antenna height	1302 to 1116 m	1116 to 957 m	957 to 822 m	822 to 684 m	684 meters up to the nearest point of the tower transmitter

Table 7. (Researchers' Scoring Model)
The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from a TV Source in a Classified Urban Very High Multiple Urban Setting

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
TV in a classified Urban Very 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	783 to 663	663 to 573	573 to 498	498 to 417	417 meters way up to the nearest point to the transmitter
< 25 kW power at 500 ft. to 1000 ft. antenna height	932 to 788 m	788 to 683 m	683 to 590 m	590 to 500 m	500 meters way up to the closest point to the Tower transmitter
25 kW to 50 kW Power at < 500 ft. Antenna Height	854 to 740 m	740 to 641 m	641 to 554 m	554 to 455 m	455 meters way up to the closest Tower Transmitter
25 kW to 50 kW Power at 500 ft. to 1000 ft.	1018 to 880 m	880 to 754 m	754 to 659 m	659 to 542 m	542 meters way up to the Transmitter Tower
50 kWto75 kW power at less than 500 ft.	899 to 779 m	779 to 674 m	674 to 584 m	584 to 490 m	490 meters way up to the nearest point to Transmitter. Tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	1070 to 926 m	926 to 803 m	803 to 695 m	695 to 584 m	584 meters way up to the nearest point to the transmitter tower
75 kW to 100 kW Power at less than or equal to 500 ft.	932 to 806 m	806 to 698 m	698 to 605 m	605 to 509 m	509 meters way up to the nearest point of the tower transmitter
75 k Wto 100 kW Power at 500 ft. to 1000 ft antenna height	1110 to 960 m	960 to 831 m	831 to 720 m	720 to 606 m	606 meters up to the nearest point of the tower transmitter

Table 8. (Researchers' Scoring Model)
The Distance and Power Density / Power Level and Initial Voltage for RF Energy Potentials from a TV Source in a Classified with Obstructions / Non-Line-of-SightMultiple Urban Setting

POWER/ ANTENNA HEIGHTS	INTENSITY SCORES / DISTANCE				
TV with Obstructions Area / Non-Line-of-Sight	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	519 to 453	453 to 405	405 to 360	360 to 315	315 meters way up to the nearest point to the transmitter
< 25 kW power at 500 ft. to 1000 ft. antenna height	584 to 530 m	530 to 473 m	473 to 416 m	416 to 362 m	362 meters way up to the closest point to the Tower transmitter
25 kW to 50 kW Power at < 500 ft. Antenna Height	557 to 488 m	488 to 434 m	434 to 386 m	386 to 338 m	338 meters way up to the closest Tower Transmitter
25 kWto kWKW Power at 500 Ft. to 1000 Ft	640 to 570 m	570 to 500 m	500 to 450 m	450 to 390 m	390 meters way up to the Transmitter Tower
50 kWto75 kW power at less than 500 Ft	580 to 408 m	408 to 451 m	451 to 403 m	403 to 351 m	351 meters way up to the nearest point to Transmitter. tower
50 kWto 75 kWpower at 500 FT to 1000 FT. antenna height	665 to 581 m	581 to 518 m	518 to 462 m	462 to 402 m	402 meters way up to the nearest point to the transmitter tower
75 kW to 100 kW Power at less than or equal to 500 ft.	596 to 530 m	530 to 474 m	474 to 420 m	420 to 366 m	366 meters way up to the nearest point of the tower transmitter
75 kW to 100 kW power at 500 ft. to 1000 ft. antenna height	684 to 609m	609 to 543 m	543 to 483 m	483 to 423 m	423 meters up to the nearest point of the tower transmitter

TheRF Energy Graphical Footprints Model (GFM)

Figures 6, 7, 8, 9, 10, and 11 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.

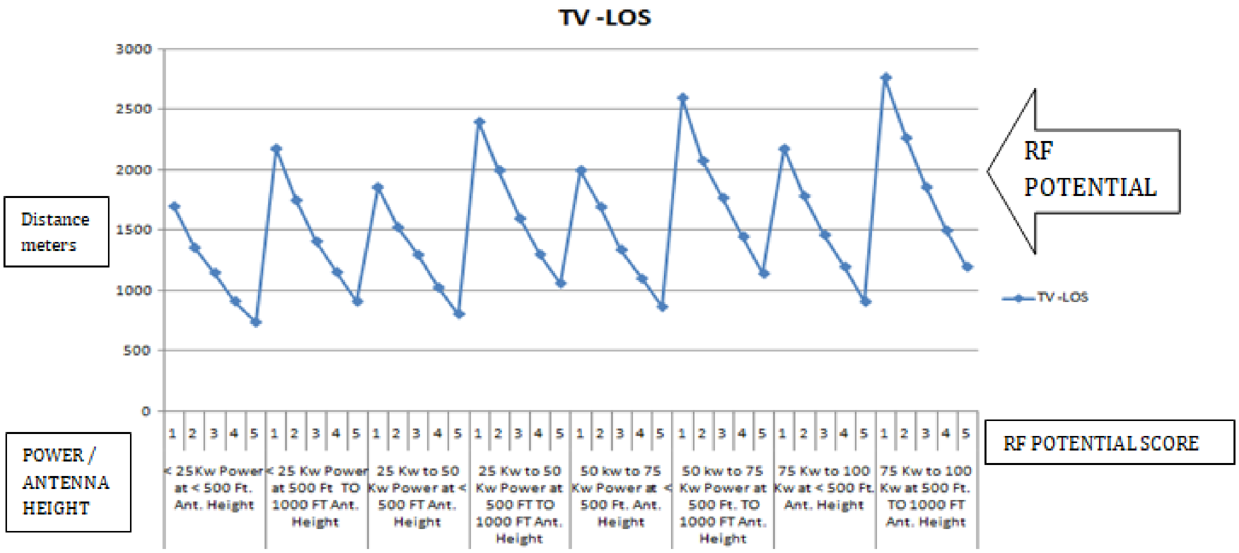


Figure 6. GFM, Graph of the Distance and Scores Intensity for RF Energy Potentials of a TV Source with respect to Power and Antenna Heights in ClassifiedLine-of-Sight (LOS) Multiple Urban Settings

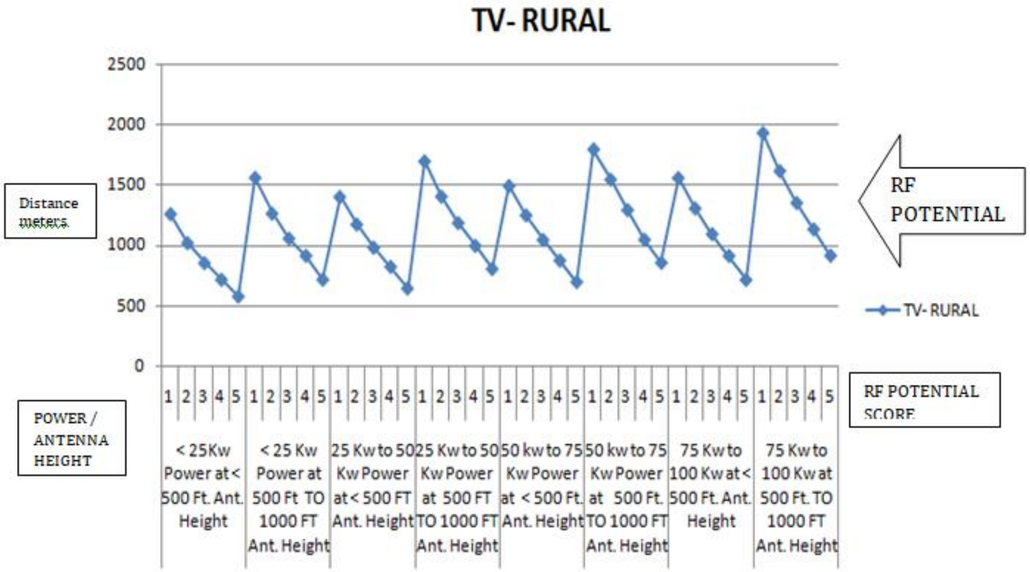


Figure 7. GFM, Graph of the distance and Scores Intensity for RF Energy Potentials of a TV Source with respect to Power and Antenna Heights in a Classified Rural Area Multiple Urban Setting

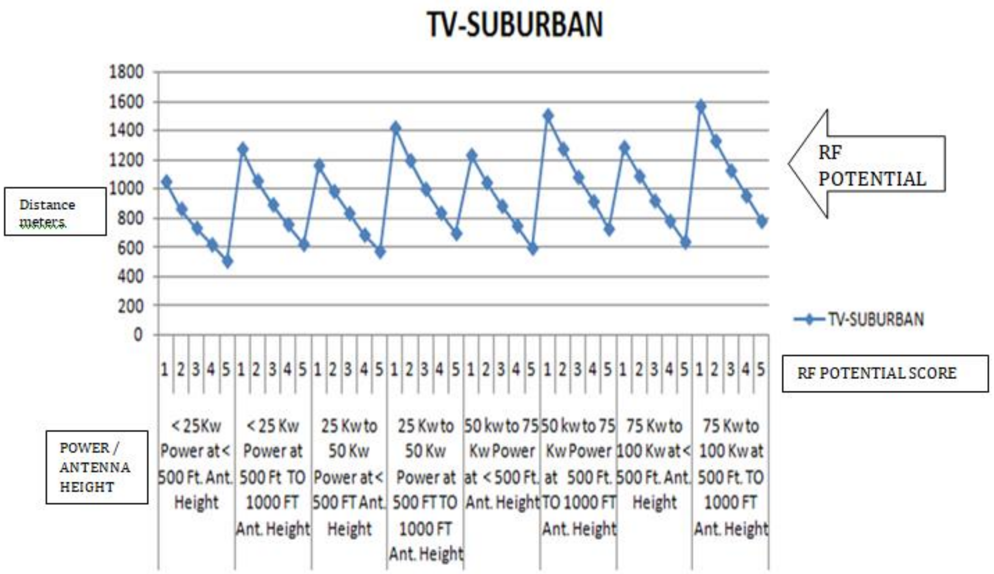


Figure 8. GFM, Graph of the distance and Scores Intensity for RF Energy Potentials of a TV Source with respect to Power and Antenna Heights in a Classified Suburban Multiple Urban Setting

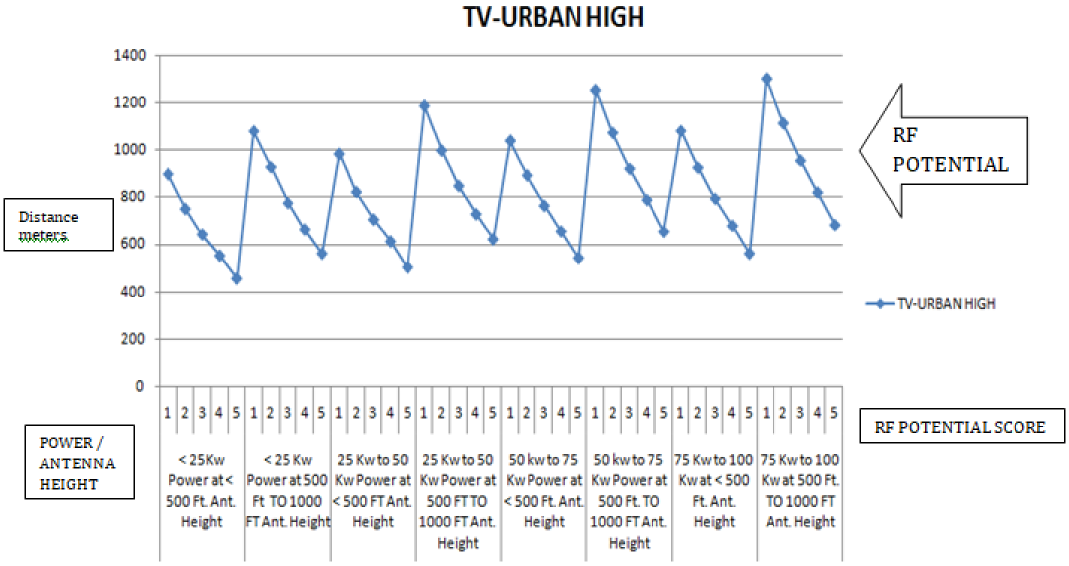


Figure 9. GFM, Graph of the distance and Scores Intensity for RF Energy Potentials of a TV Source with respect to Power and Antenna Heights in a Classified Urban Area Multiple Urban Setting

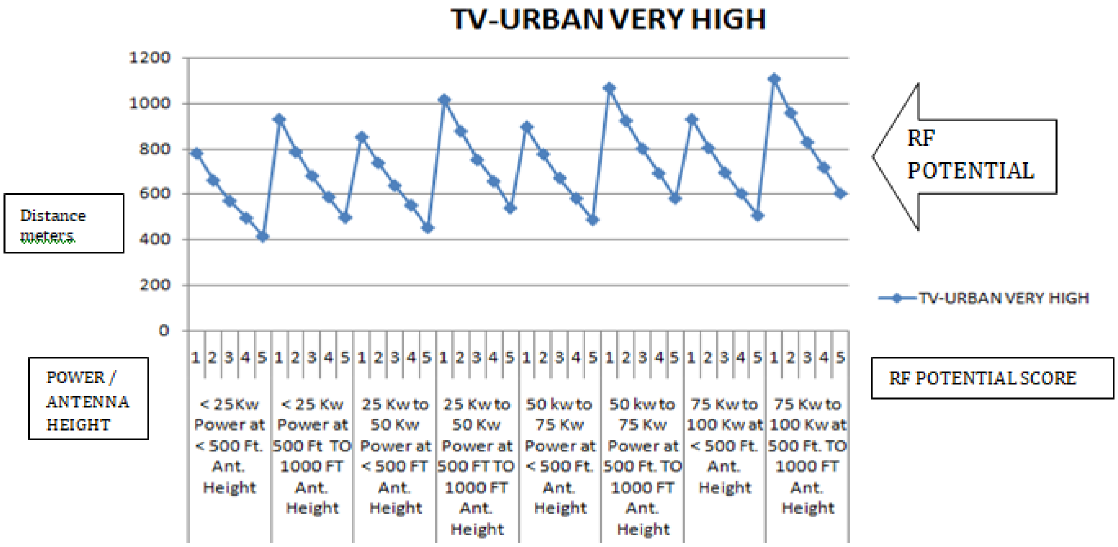


Figure 10. GFM, Graph of the Distance and Scores Intensity for RF Energy Potentials of a TV Source with respect to Power and Antenna Heights in a Classified Urban Very High Area Multiple Urban Setting

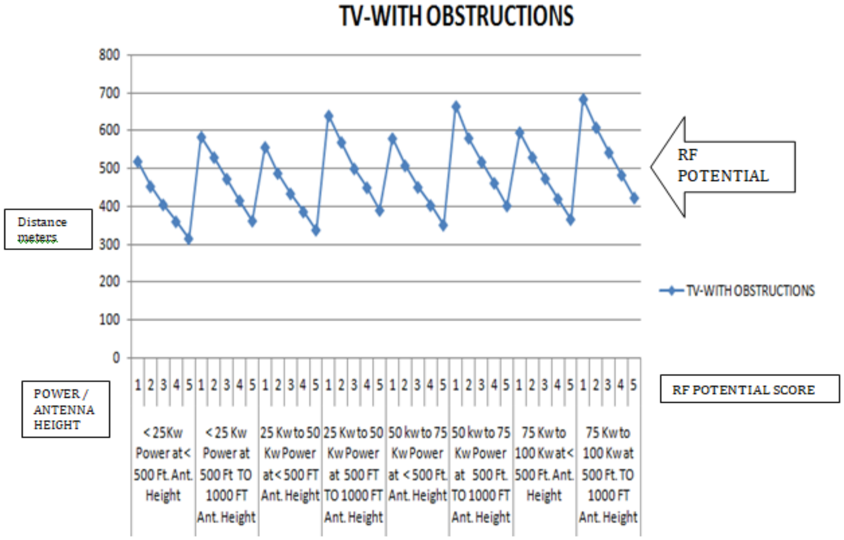


Figure 11. GFM, Graph of the Distance and Scores Intensity for RF Energy Potentials of an FM Source with respect to Power and Antenna Heights in a Classified Non-Line-of-Sight Multiple Urban Setting

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. 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. Cell Site, when used as an RF energy source in a classified rural area multiple settings at 75 W to 100 W power and 150 to 300 ft., has a distance coverage of 103 to 85 meters with a score of 1 with less distance coverage compared to TV and FM due to smaller Cell site power. Tables 3, 4, 5, 6, 7, and 8 present the distance for RF energy potentials of a TV, FM, and cell respectively 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 800 meters away from the antenna tower of a TV station in classified urban high multi-settings is less than 25 kW at less than 500 ft. antenna tower. By simply looking at the RF energy GFM, which is the locations of distance and their scores, they can easily see the 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.

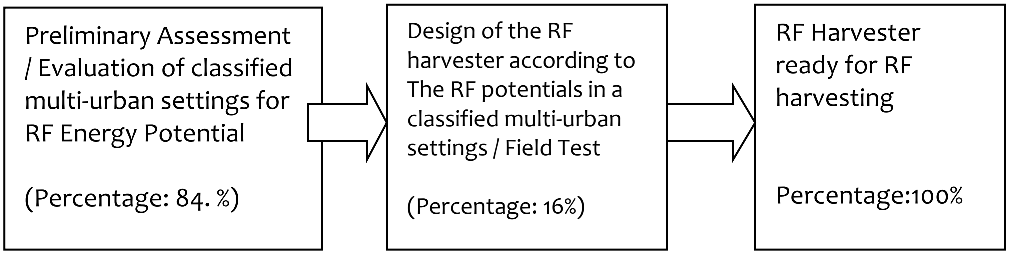


*Figure 12.*The RF Energy Graph Model as a Part in an RF Harvester Making

Figure 12 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%.

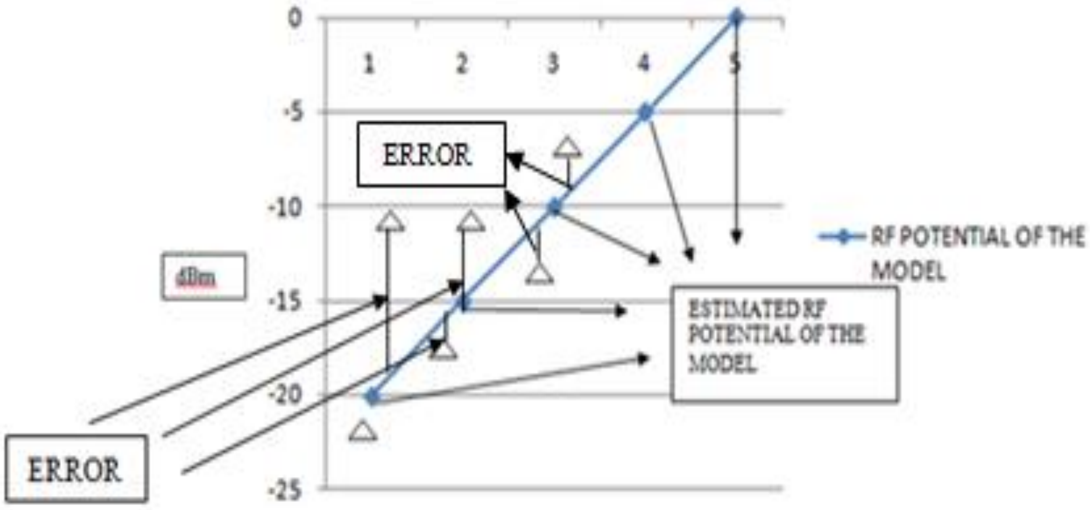


Figure 13. Representation of a Mean square error Note Different Authors Actual RF Potential =: △

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 (Figure 13).

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

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

of population

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 Potentialcategorized 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 as long as 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.

The farthest average radius distance for RF energy potentials from the sources such as TV in classified LOS multiple urban setting**s.** It can be deduced that with 75 Kilowatts to 100 Kilowatts of power with an antenna height ranging from 500 to 1000 ft., the distance range for TV is between 2768 to 2267 meters with an intensity score of 1 for RF energy potentials indicated in Table 3.

The farthest average distance radius for RF energy potentials from the sources such as TV 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 indicated in Table 4.

The farthest average distance radius for RF energy potentials from the sources such as TV in classified Suburban (S) Multiple urban settings.TV as an RF energy source at a distance of 1566 to 1329 meters up to the nearest point of the transmitter tower has an intensity score of 1 at a power of 75 kW to 100 kW in Table 5.

The classified urban high area in multiple urban settings categorized as area combinations of low-rise and medium-rise buildings of 1 to 15 floors and high-rise buildings and very tall buildings that have 16 to 60 floors and 60 floors and up respectively, where low-rise buildings are much greater than the high-rise and very tall buildings.

The farthest average distance radius for RF energy potentials from the sources such as TV in classified Urban High (UH) multiple urban setting shows that in a classified urban high area multiple setting, TV RF energy harvesting can be done at an average radius of 1302 meters from the TV transmitter that has power ranges from 75 kW to 100 kW and has an average tower height of 500 ft. to 1000 ft indicated in Table 6.   4.4.1.

The classified urban very high area in multiple urban settings, categorized as an area with combinations of excessive numbers of high-rise and very tall buildings with 16 to 60 and 60 floors and up that may cause a lot of shadowing. The farthest average distance radius for RF energy potentials from the sources such as TV in a classified Urban Very High (UVH) multiple urban setting.TV as an RF energy source at a distance of 1110 to 960, 960 to 831, 831 to 720, 720 to 606, and 606 meters up to the nearest point of the transmitter tower has an intensity score of 1, 2, 3, 4 and 5 respectively at a power of 75 kW to 100 kW at antenna height of fewer than 500 ft. to 1000 ft indicated in Table 7.

The classified non-line of sight/with obstructions classified multiple urban settings categorized as an area that has impediments of stumbling blocks that cause non-line-of-sight conditions. Classified NLOS can be applied to classified rural, suburban, urban high, and urban very high in multiple settings where blocks that may cause hindrances can be trees, mountains, and electrical posts.

The farthest average distance radius for RF energy potentials from the sources such as TV in classified non- line sight (NLOS) multiple urban settings. It shows that in a classified urban high area multi-setting, TV RF energy harvesting can be done at an average radius of 684 to 609 meters from the TV transmitter that has a power ranging from 75 kW to 100 kW and has an average tower height of 500 ft. to 1000 ft indicated in Table 8.

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.TheRF 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. A funding request is being prepared to the Commission on Higher Educations' Faculty Development Plan 2.

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.

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