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Application and Analysis of Smart Meter Data along with RTL SDR and GNU Radio

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Abstract

Introduction of smart meter offered fine grained information about the energy consumption of customers. To categorize the appliances consuming the energy, the Electromagnetic Interferences emitted by them are measured using Realtek Software Defined Radio. To avoid the frequency range mismatch of the interferences and the input frequency range of Realtek Software Defined Radio, an up converter is used. The interferences can be processed by using a GNU radio. The time stamped signals are stored as DAT file format. Disaggregation of appliances consuming the power is attained by comparing the results with that of smart meter results. To achieve this task smart meters are employed to calculate the total energy consumption. Smart meter data will also be time stamped. The data collected by the smart meter is processed by Raspberry Pi and is stored in memory. Both the GNU radio data and smart meter data are compared to conclude final results. This algorithm is superior to the existing one as it helps to disintegrate the multiple appliances consuming power at the same time.

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Keywords: Smart meter; GNU radio; RTLSDR; antenna.

1. Introduction

One among the basic necessities for the development of the country is energy. Electric energy is the most important as a result of which its consumption is rising day by day. Differentiating the power used by various appliances is remarkable and smart meter turned out to be the most obvious tool for it. Smart metering along with the Home Area Networking allows the utility to measure the energy consumption of each major device. The analysis of

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energy consumption by the smart meter educate the consumers about their usage pattern there by enable them to take informed decisions to reduce the consumption. This indirectly reduces the peak demand.

Smart meter is basically an electronic device which measures the energy consumption regularly and reports this to the consumers, utility companies and also third party service providers. These meters are equipped with units for measurement, local processing and communication. Measurement unit records the energy consumption. The processing unit can process and stores measured data where as a communication unit allows remote access to the measurement data, configuration and maintenance interfaces [1]. Smart meters measures current, voltage, active power and reactive power and transmit this data to the utility through internet [2].The quick feedback gives a better idea regarding the power consumption, increases the efficiency of the system and reduces the stress level of the bus bar. This makes it possible for both the users to figure out the inefficient devices and the service provider to know the device malfunctions that reduces the efficiency of the overall system [3].

This paper focuses on improving the performance of the overall system by integrating Realtek Software Defined Radio(RTLSDR) and GNU radio along with the smart meter. The efficiency of the setup is enhanced by monitoring the high frequency Electro Magnetic Interferences (EMI) emitted by the electrical appliances. Recent works [6] revealed that the energy disaggregation is possible by using the high frequency EMI that is being emitted when the appliance change its mode of operation. Each appliance has its own unique EMI signals for each state of operation. The emitted EMI from each appliance is measured and compared with that of the power signal observed from the smart meter. To identify the identical appliances operating at the same time, advanced antennas can be included. Each device will have unique transients. But it is important to reconstruct the switching transients for the identification of each device. The switching transient generated is very much affected by the point on the voltage wave where the device is switched. So to generalise the switching transient of each device, the device is switched many times so that it have a good coverage between 0 - 180° phase variation in the voltage wave. Voltages can be used to calculate these angles and current can be used to identify the starting and ending of transients [20].

2. Methodology

2.1 Smart Meter

The smart meter is an electronic equipment used by the utilities to measure their energy consumption and to communicate the same with the service provider [7]. They allow the consumers to monitor the energy usage and track the same with the help of internet. In smart metering system there is a Home Area Network (HAN) which helps to communicate with all meters, communication hubs, in-home display and control devices within the boundary; also a Wide Area Network (WAN) which helps to communicate between premises and other control centres. .

Unlike all other meters, smart meters are fully packed with most modern facilities and techniques. It involves two way communication between the base station and the meter, load profiling, remote disconnection and reconnection of load and power outage measurement. Hence smart meters are developed by including certain communication infrastructure, signal acquisition unit, signal processing unit, analog to digital convertor and computation unit. Input parameters are fed to the meter by voltage and current sensor. Signal conditioning, analog to digital conversion and computation happens inside a micro controller chip. Simple resistor divider circuit acts as a voltage sensor in smart meter. Smart meter uses different types of current sensors. Current transformers, shunt resistors, rogowski coils are different types of current sensors used. There will be independent Energy Measurement Unit (EMU) for performing the signal processing, analog to digital conversion and computation. EMU can either be a standard energy measurement unit or the system micro controller unit(MCU). Some of the famous EMU manufacturers are Microchip, Teridian, NXP, STMicroelectronics and Analog Devices. MCU performs most of the important functions of the smart meter and it is considered as the core of the meter. It controls the communication with EMU, smartcard reading, performs the calculations based on the data received and communication with other meters. The data collected from the smart meter must keep a track of current time. This is achieved with the help of a real time clock in the smart meter. Most of the meters have a separate driven real time clock unit which can be easily accessed by the meter MCU. Meters which are connected to the network must be properly synchronised to reduce the time drifts.

Advanced Metering Infrastructure (AMI) consists of HAN, Neighbouring Area Network (NAN), WAN. HAN establish connection between smart meter and appliances, in-home display and other meters . It is possible to have wired or wireless communication protocol. Widely used communication protocols are Zig-Bee, Z-wave and WiFi, among which Zig-Bee is the most economic, power efficient and reliable. NAN transfers the data between neighbouring meters for which Zig-Bee protocol is mainly used. The transfer of smart meter data to the remote server can be established by WAN. This connection is established through a data concentrator. GSM, GPRS, 3G, and WiMax are the communication protocols used to make the connection of meter with WAN. Even though GSM is not economically feasible, it provides a very good coverage than any other protocols. The functional block diagram of smart meter is shown in Fig.1.

Fig. 1. Functional block diagram of smart meter.

Smart meters are an upcoming technique. Many governments and other private organisations are trying to establish different standards and policies. Among many standards which are used for accuracy measurement of smart meters, the most commonly used are IEC and ANSI standards. The standards can be locally or internationally developed. The meter hardware parts and the functions should be certified by these standards.

Some of the standards developed for the smartmeter specification are as follows:

- Intentional and unintentional radio emissions, and safety related to RF exposure (FCC standards, parts 1 and 2 of the FCC's Rules and Regulations [47 C.F.R.1.1307(b), 1.1310, 2.1091, 2.1093.
- Meter accuracy and performance (ANSI C12.1,12.10 and 12.20 specifications).
- Local technical code and requirements
- Utility specifications designed for special area requirements
- Functional tests to satisfy the utilities technical and business requirements.

Some of the regulations used for installing smart meter are as follows:

- The National Electric Saftey Code (NESC) for the utility wiring.
- The National Electric Code (NEC) for home wiring.
- ANSI C12.1-Code for Electricity Metering.
- Local building codes [8].

2.2 *Existing Setup*

2.2.1 *Raspberry Pi*

Raspberry Pi is very tiny general purpose computer. Moreover it has powerful multimedia and 3D graphics capabilities [9]. The device uses ARM processor which can be considered as the brain of the device. These processors are extremely small, efficient and fast enough to perform complex computations. Therefore it can be widely used in Raspberry Pi. Like all other computers Raspberry Pi do not have a hard disk instead it uses SD card. SD card must contain the operating system, program and the data needed to run the Raspberry Pi. It is the function of the operating system to inform the Raspberry Pi on how to perform the operations, how to make use of the input from the user, how to handle the program while it's running. The system consists of a micro USB power port which supplies the power, an HDMI port to plug into monitors, Ethernet port to connect to the internet, USB port to connect to the keyboard or mouse, an audio output which can be plugged in to the external audio sources, GPIO headers to connect the system to other external devices and an ARM processor which acts as the processor of the system [10]. Including all the above mentioned features Raspberry Pi can be used in many applications. In this paper, Raspberry Pi is used to store the Smart meter data and also act as a two way communication link between the utility and the consumers.

2.2.2 Experimental Procedure

Smart meters provide the fine grained demand of the energy for each house hold. The meter accurately monitors the energy demand in a house hold at regular intervals of time thereby disclosing the demand behaviour of each customer. From the data collected by the smart meter the nature of energy consumption for each device can be revealed [11]. The observed data is provided to Raspberry Pi. It acts as a co-ordination device by observing the incoming measured data transmitted by the meter. The data is read and stored with a unique identifier. The data is made available to all customers as the raspberry pi runs on a web server [1]. The smart meter data alone can identify the human behaviour at corresponding apartments based on the energy consumption. Algorithms such as Hidden Markov Model (HMM) can be effectively applied for the same [12]. The disaggregation of energy consumption of each appliance in a house hold cannot be fulfilled with the set up. The set up fails to distinguish two appliances when working at the same time. The difficulty is rectified by further developing the existing system.

2.3 Advanced Setup

2.3.1 Antenna

Antenna is the device used to transmit or receive the electromagnetic waves which are often called as radio waves. It is to be noted that the antennas must be tuned to the proper frequency of the radio system to which it is connected so that there will not be any transmission reception delays and errors [13]. Antennas for long wave can mainly be classified into two categories. One is sensitive to the magnetic field and the other which receives the electric field. Loop antennas can be used to receive the magnetic field and the active antennas called as the whip antennas can be classified into next category. Antenna collects the low frequency EMI which are emitted by the electrical appliances and provides it as the input to the up-converter to receive the EMI signal using RTL-SDR.

2.3.2 Up Converter

The main objective of the up-converter is to shift the frequency range of the incoming signal to tunable frequency range. It converts the low frequency or medium frequency signals to very high frequency signals with the aid of a mixer. The mixer takes two input signals, one is the low frequency received signal and other will be the continuous wave signal with higher frequency from the local oscillator [15]. The local oscillator frequency range required for the RTLSDR may vary from 50 Hz to 150 Hz. The output of the mixer will be the sum and difference frequencies of both signals. For further analysis the low frequency signals are being filtered out in up converter [16]. The main use of up converter is that the EMI signals which are being collected are of low frequency range. The receiver of the whole set up which is the RTLSDR has an intake capability of high frequency range. This adversity is rectified by means of an up converter. The up converter which is used is the 'dxpatrol' up converters.

2.3.3 RTL SDR

Software defined radio (SDR) is an advanced radio which moves much of the hardware into the software implementation. SDR receives the radio signals in analog format and works by converting it into digital format by using analog to digital convertor. RTLSDR is an extremely cheap SDR and is based on Digital HD TV USB (DVB-T TV) receiver dongles that have RTL2832U chip. Most of the RTLSDR allows the users to select the sampling rate as same as that of the bandwidth although both are not the same. This is because the RTLSDR uses I/Q sampling with two ADCs. One ADC is used for the minus part of the DC offset and other for the positive part of the same. But it is possible to include any external low noise amplifier to improve the signal quality. It is preferable to use an amplifier like LNA4ALL to improve the signal quality. It has got a good noise figure there by it is possible to reduce the noise to a great range. LNAs are mostly used for frequencies above 50MHz. To point out the main drawback, it is not possible to receive any signals below 30MHz. To receive such signals two methods can be put into action, either direct sampling mode or an external up-converter can be used. In direct sampling mode the RF signals are entered directly to the chip RTL2832U by attaching an antenna to it. In this mode some changes in software part is also to be made. An up converter converts the low frequency signals to the input range of RTLSDR. The up-convertor is to be connected to the antenna before RTLSDR. It increases the frequency of the signals to about 100 MHz. In most of the up-converters, includes a local oscillator which makes use of frequencies of around 100MHz and adds this frequency to all signals. To receive the low frequency signals in RTLSDR with an up-converter, it is required to tune the desired low frequency plus the local oscillator frequency. The RTLSDR is used to collect the EMIs that different appliances emit while there happens to be a change in the existing state. Thus the RTLSDR acts as a receiver to collect the required frequencies. The low frequencies which are being emitted from the equipment are shifted to the higher frequencies by means of an up converter [16].

2.3.4 GNU Radio

GNU radio is an open source software kit which is mainly used for signal processing and its spectrum analysis. It has a collection of signal processing blocks and the glue to tie it all together. It processes the signals from SDR hardware. In GNU radio applications the graphical user interface is built in Python. They are hardware independent [17]. It can be used without any hardware, like simulation purposes; or can be used with low cost RF hardware to create software defined radio. The system is capable of performing most of the basic mathematical and logical operations [18]. It is to be noted that both C++ and Python languages are used in this GNU radio. All signal processing and performance critical block are written in C++ whereas the network is created by Python which glue together all the blocks. To include the C++ modules in Python two methods are commonly used. In one method the C++ is built into an executable file and Python built in function is used to call the same. In second method a powerful tool in Python called as the SWIG is used to glue the C++ blocks to Python [19]. In this paper signal from the RTLSDR is being processed in the GNU radio. The final conclusion is drawn about the equipment which generates the EMI. The Fourier spectrum of the EMI signal produced by equipment is compared with those of the received signal.

2.3.5 Experimental Procedure

Inability of the existing system to identify the individual electrical appliances among different powered appliances is rectified in advanced set up. Few modifications are carried out on the existing set up. The main modification is to capture the EMI established during sudden change in state of devices. While each device changes its mode of operation they produce a unique interference, which is employed to identify the different devices utilizing the energy at the same time. For this purpose a receiver and GNU radio are added to the existing set-up. The EMI signals are observed to be in the range of 9 kHz to 30 MHz. These signals can be captured by Universal Software Radio Peripheral (USRP) with the help of an antenna. In order to compensate the high cost of USRP; they are replaced by RTLSDR. The EMI thus generated can be grouped into low frequency signals, but the RTLSDR which acts as the receiver has a high frequency intake range. RTLSDR have a frequency range of 67MHz to 1.8GHz. To bypass such imbalances an up converter is introduced before RTLSDR. So initially a whip antenna is used to capture the low frequency EMI. This is fed to the up converter which converts the low frequency signals to high frequency. The signals can now be fed directly to the RTLSDR. Fig. 2 shows the block diagram of the advanced experimental setup and Fig. 3 represents the experimental setup in the laboratory.

The receiver accepts the signal and provides it to the GNU radio for processing. The set up measures the EMI generated by each appliances at that particular time. The spikes thus observed will be time stamped. On the other hand the smart meter will provide the energy consumed by each appliance with the respective time stamp. The observations made by the smart meter and the RTLSDR set up at the same time will be compared and results are concluded. If more than one particular device is switched on, then the RTLSDR will have that many individual EMIs. Thus the EMI with the matching time stamps are compared and the results are analyzed. This will provide the accurate information regarding the equipment which has been switched on if there were more than one at a time.

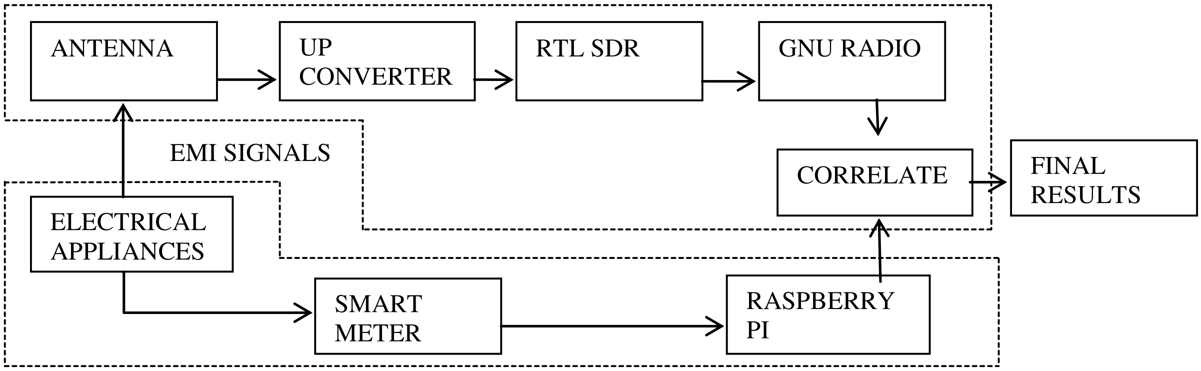

Fig. 2. Block diagram of advanced Experimental setup

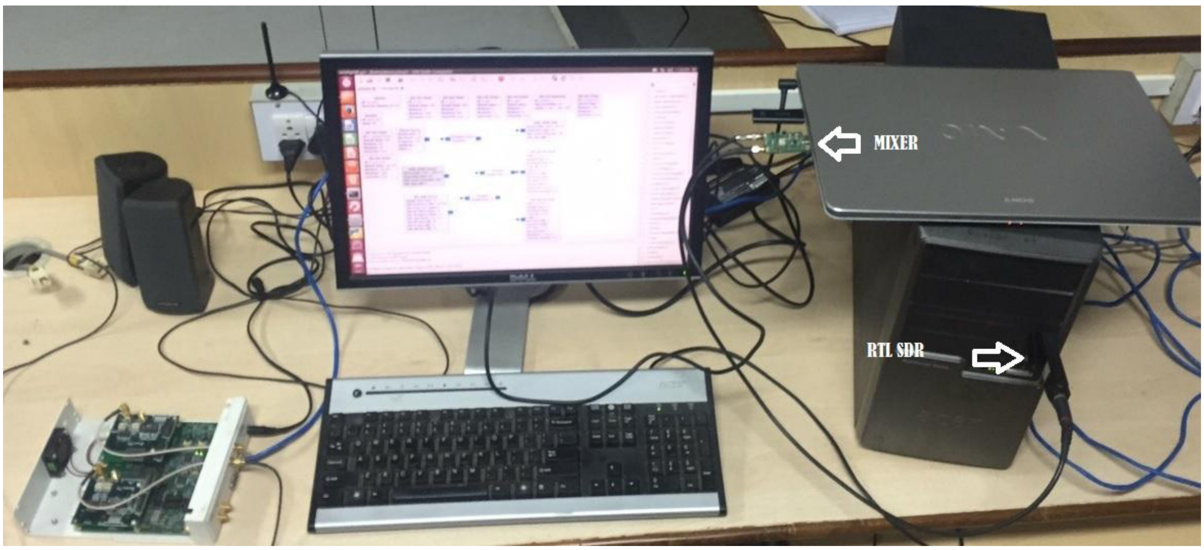

Fig. 3. Experimental setup

3 Results and Analysis

In this paper, some of the key observations based on the study of EMI signals from different appliances are analyzed and results were concluded. The environment for analysis of the EMI signals neglects the surrounding noises and other external disturbances. This may lead to some errors which are to be considered in better setup. In this experiment the different appliances utilizing energy at the same time is analyzed. This is performed by analyzing the EMI emitted from different appliances. Fig. 4. shows the no load condition. The EMI signals are observed to be the minimum. When a fan is switched on, a sudden peak is observed. This peak is shown in Fig. 5. This peak is unique as it never happens to any other loads. Comparing the peak observed with the smart meter result, final conclusion can be drawn. Thus it is observed that when there is any change in mode of operation of the appliances, the EMI generated changes. The EMI thus generated along with the smart meter data can be effectively used to analyse the mode of operation of each appliance. From this analysis the identical appliances operating at the same time can be differentiated. Fig. 6 and Fig. 7 show EMI generated for power pug point and CFL respectively.

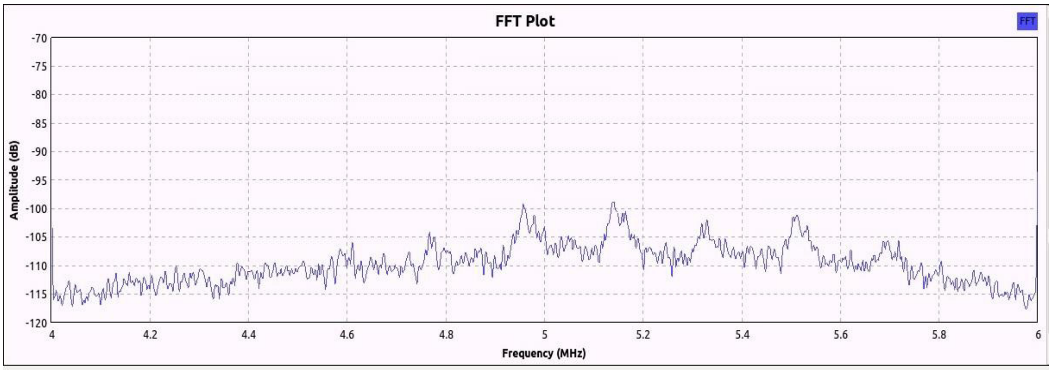

Fig.4. no load condition

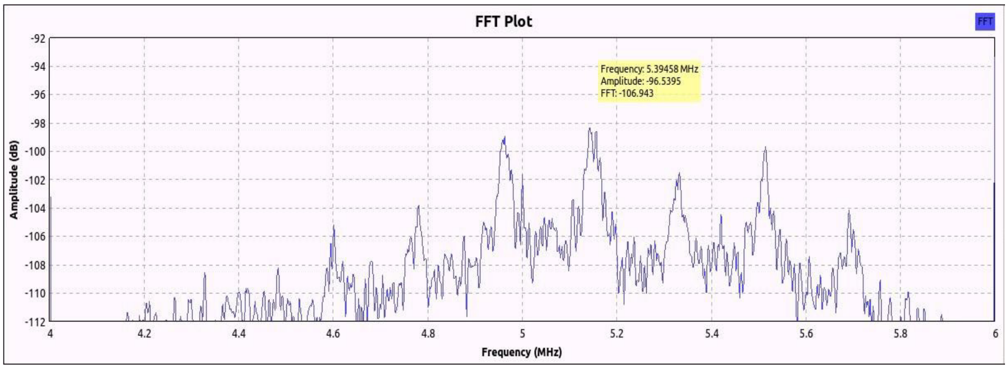

Fig. 5. EMI generated when fan is switched on

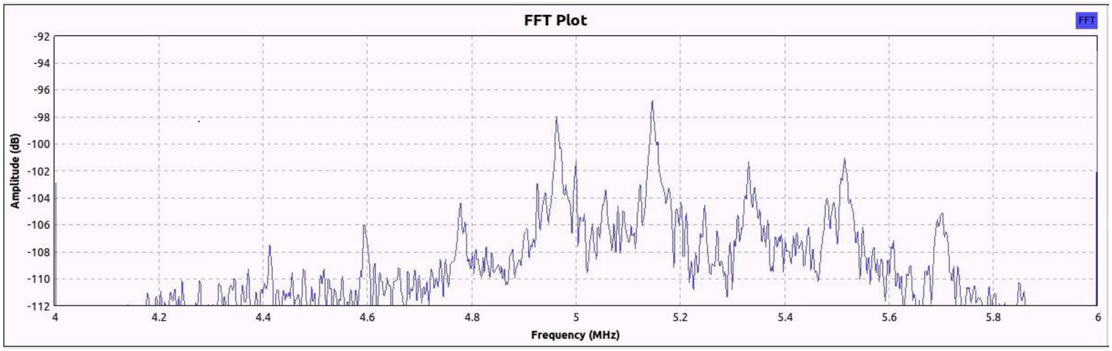

Fig. 6.Variation in EMI when a power plug is plugged

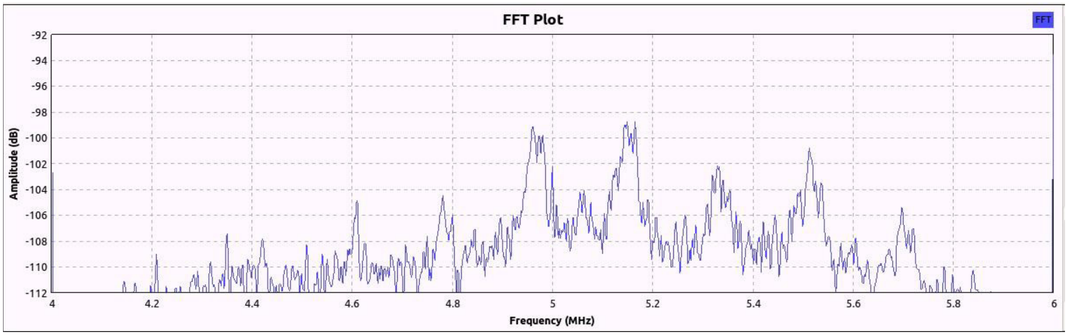

Fig. 7. EMI generated at a load of CFLs

4 Conclusion

A detailed description about the smart meter and the method to differentiate the appliances operating at the same time are included in this paper. Many components such as RTLSDR, up converter, GNU radio were included for detailed analysis. Therefore from the combined results it is possible to identify each devices operating at the same time. This result can further be analysed for the proper estimation of power consumed by each devices. It is possible to figure out if any devices are consuming more power. It is to be noted that if more than one identical appliance are consuming the power then the idea implemented in this paper is not enough to distinguish the appliances. To draw a better outcome in such a situation further modifications are to be carried out. To distinguish the identical appliances the direction of arrival of EMI of each device is to be monitored. To achieve this task the whip antenna used in this set up can be replaced by an array of antennas. So it is possible to estimate the direction of arrival of EMI from each electrical appliance. Intelligent inferences can be made by comparing the later with the processed smart meter results.

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