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Implementation of Network Coded Wireless Transmission Scheme for Smart Grid Applications

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Abstract: 'Network Coding' is the proven technology used in internet data transfer and satellite communications, which can use the available bandwidth to the maximum as well as ensure data security. In this paper, the concepts of Network Coding is implemented and tested for Smart Grid applications using the wireless protocols namely Zigbee, Bluetooth and Wifi. The performance parameters were studied for each protocol by transmitting multiple data packets stored in a database. Further, an algorithm is developed to run at the destination end which determines, from the data it has received, whether the load demand exceeds the generation or there is a surplus of generated power available. This was demonstrated using Wi-Fi protocol.

Keywords: Zigbee, Bluetooth, Wifi, Smart Grid, Network Coding.

I. INTRODUCTION

Smart grids are information-based electric grids which rely on information gathering equipments and devices for collecting the various electrical parameters at various nodes and transmission of these parameters in parallel with the electric power. It relies on smart meters installed at both the generating and the consumer end for gathering the various electrical parameters like voltage, current, phase angle, etc. These, along with control signals, need to be transmitted through reliable communication channels to a data collecting centre, where a decision making algorithm is run and further, control signals are generated based on the actual input power available and the current demand. If the demand is more, more power need to be generated. But if this demand cannot be met, some of the load need to be shut down based on the priority. The advantages of smart grids compared to traditional grids are dynamic billing, reliability, sustainability, renewable energy usage and efficiency. A two way communication is the basic necessity of smart grids in which data need to flow from the generating centre as well as from the load centre. Along with reliability, security of data being transmitted, need to be ensured. As the grid becomes more and more complicated with multiple generating stations scattered over a large area and the constantly fluctuating load demand, the amount of data to be handled becomes large and poses a heavy stress on the communication link as well as the data processing centre. Communication using wireless channel is attracting major attention because of the good bandwidth available, less erection cost and data security is ensured by suitably encrypting the data.

In traditional information flow networks, the data packets transmitted from a source node are simply received by an intermediate node and transmitted to the next node based on the channel availability. This process, called 'store-and-forward method' of data transmission, is continued till the data packets reach the destination node. Later in July 2000, Rudolf Ahlswede, Ning Cai, Shuo-Yen Robert Li and Raymond W. Yeung, in their pioneering work, “Network Information Flow” proposed that the Max-flow Min-cut Theorem for network information flow can only be realized by means of some processing done at the intermediate nodes. This led to the development of the concept of Network Coding. Hence a network coded data communication network relies on suitably combining the data packets arriving at the node before they are transmitted to the next node. This technique, when compared to the store-and-forward method has the advantage that it utilizes the available bandwidth for data communication to the maximum.

In this paper, a wireless communication scheme is implemented for smart grid applications. In smart grids, informations need to be transmitted from the generating station to a central node. This central node also receives various electrical parameters and an algorithm is run which tells when the load demand exceeds the total generation. This could be used for generating control signals for taking decisions, which are to be done real-time. It also aims at developing a suitable coding scheme for the data packets arriving from a source, so as to ensure security. This was successfully tried out and implemented for the communication protocols – Zigbee, Bluetooth and Wi-Fi.

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The data were assumed to be coming from four different sources each having an unique ID so that the destination node knows from where the data are coming. Besides this, the data parameter - such as voltage, current or phase - being transmitted is also identified.

II. OVERALL SMART GRID ARCHITECTURE

Figure 1 shows the block diagram of the overall architecture of the smart grid assuming the sources to be thermal, wind, solar and hydro.

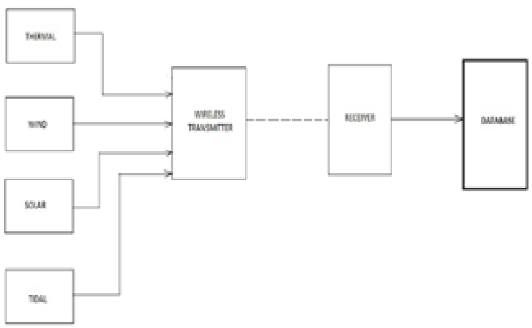


Fig. 1 Block diagram of the overall architecture of smart grid

At the source end, the user can input the various parameters as queried by the program developed in Python Shell. Also, provision for multiple data transmission is made by creating a database using Sqlite3. The embedded kits used for developing the project include LPC2148 microcontroller based development board with Zigbee module, Rabbit RCM3100 microcontroller based development board with Bluetooth module and the RCM5600w board for Wi-Fi. After developing the necessary support using Python, multiple data were transmitted simultaneously to observe the various performance parameters.

III XOR CODING FOR BUTTERFLY NETWORK

XOR coding is the simplest of the network coding scheme, which was implemented for a Butterfly network. Figure 2 shows the MATLAB simulation model implemented for the butterfly network. By means of transmitting XORed data packets over the air, it is possible to ensure data security as described.

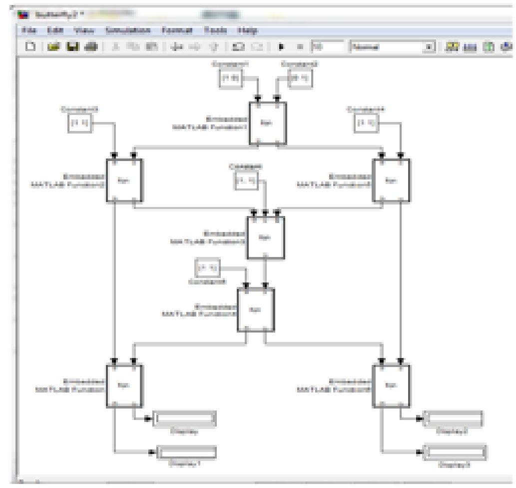
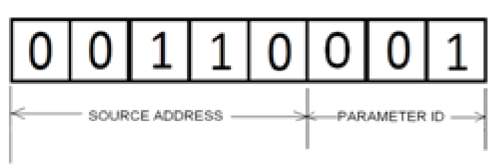


Fig. 2 MATLAB simulation of Butterfly network

Here, instead of transmitting the data as such, the data will be XORed with a random bit pattern at the source end and transmitted to the destination. And at the receiving end, the obtained data is again XORed with the same bit pattern to recover the original data being transmitted. Since this bit pattern is known only to the source and the destination, an intermediate person will not be able to identify the data being transmitted. After obtaining the data from the smart meters and before the data transmission, XOR coding is performed. In order to find which pattern is used for XORing, a key is transmitted along with the data packets. This key is used by the destination node to correctly identify the bit pattern to be used for decoding the data. In this paper, an 8-bit data is treated as the smallest individual data being transmitted and received. And this will be viewed as a character by serial communication protocol. In order to transmit more parameters attached to the particular data to be transmitted, more data packets are used to form a meaningful unit. This methodology implemented has the advantage that it is supported by all the embedded kits used for developing the application as only 8-bit data need to be processed at any time. When multiple packets are put together, it becomes a meaningful unit.

IV PACKET FORMAT

In this paper, a total of five characters are used to form an individual packet. The details contained in individual characters are shown below.



Address Frame

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TABLE 1 PARAMETER ID

First three LSB content (Parameter ID)	Representing Parameter
000	Measured Voltage
001	Measured Current
010	Measured Phase (Lead)
011	Measured Phase (Lag)
1XX	Left for future expansion

X = 0 or 1

Frame 0:
The first three LSBs are used for representing the parameter being transmitted as given in Table 1. The remaining five bits are used to represent the source address. A total of 32 sources could be identified.

Frame 1:
This entire frame of 8-bits is used to identify the order of the packet to take care of the out-of-order packets arriving at the destination end. This also helps in identifying at what instance the value is generated and transmitted. A maximum number of 256 discrete data packet order could be identified.

Frame 2:
This entire frame of 8-bits is used to identify the key-ID used for coding the data part (Frame 3 and Frame 4) of the packet. A maximum of 256 different keys could be generated and used in random to code the data, each identified by the key ID attached to the packet if the same key is used for coding both the integer part and the decimal part of the data.

Frame 3:
This entire frame of 8-bits is used to represent the coded integer part of the data. A maximum value of 255 could be represented using this scheme.

Frame 4:
This entire frame of 8-bits is used to represent the coded decimal part of the data. A maximum of upto two decimal places could be represented using this scheme.

V METHODOLOGY

Source end:
The data generated is split into two - the integer part and the decimal part, each of 8-bit size. Each part is then XORed with a random bit pattern, identified by a key ID. The data frames thus generated are then assembled together along with the address frame, packet order frame and the key ID frame. These are then transmitted in the order: address frame, packet order frame, key ID frame, coded integer data frame and the coded decimal data frame.

Destination end:
Data are received at the receiver end in the order: address frame, packet order frame, key ID frame, coded integer data frame and the coded decimal data frame. The receiver node separated each frame from the data packet received. From the address part (Frame 1), the source ID and the parameter ID are separated to understand which parameter is contained in the data part of the received frame and from which source it is coming from. Frame 2 of the received packet is used to identify the order of the generated packet. Frame 3 of the received packet is used to identify which random bit pattern is used to code the data frames: Frame 4 and Frame 5. Frames 4 and 5 are XORed with the random bit pattern identified from Frame 3 in the previous step. Now, the integer part and the decimal part are combined to represent the transmitted data upto five significant figures. Thus in this paper, a maximum value that could be received is 255.99.

VI ZIGBEE IMPLEMENTATION

Zigbee is a low-cost, low-power wireless specification based on the IEEE802.15.4 standard used mainly for wireless sensor applications. In this work, a Zigbee RF Module Development Kit is used to implement the Zigbee communication.The kit is capable of carrying both the Zigbee and the Zigbee PRO radio devices. A wired communication is made possible between the Zigbee and the PC or microcontroller by means of serial protocol. The default configuration tool available is the X-CTU. The various parameter set during configuration include mainly the network address and the destination address as shown in Figure 3. The destination address is used for wireless communication through the device. Another hardware used in the project for Zigbee communication is the ARM-7 based microcontroller

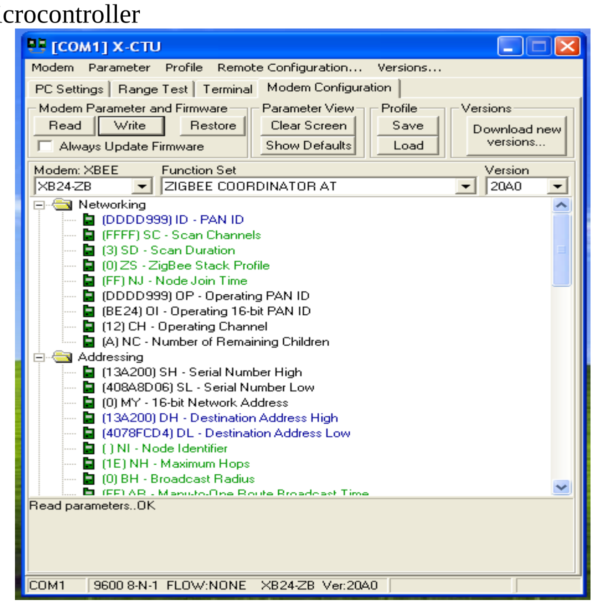

Fig. 3 Parameter configuration using X-CTU

LPC2148 development board manufactured by JRM Technologies shown in Figure 4. It has two serial ports – Port-0 and Port-1. The program for controlling the Zigbee radio is downloaded to this kit through Port-0 by means of a

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tool called Flash Magic. The application program is written in C-language using the Keil IDE.

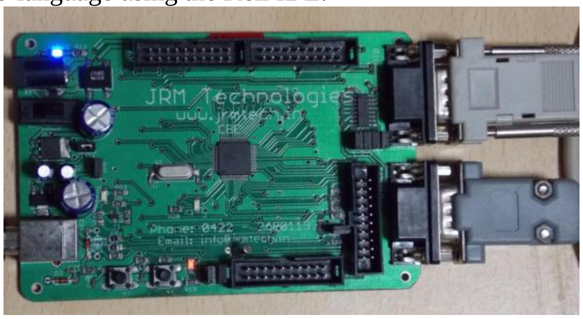

Fig. 4 LPC2148 microcontroller development board

In this paper, a total of five nodes are implemented – four source nodes and one destination node. A single node comprises of the Zigbee radio and the PC or the Zigbee radio, the LPC2148 board and PC combination. In the node containing Zigbee radio and the PC, a serial program running on the Python Shell inputs the voltage, current and the phase values by querying the user. This is then coded and transmitted to the destination node wirelessly through the Zigbee radio. In the node containing Zigbee radio, LPC2148 board and PC combination, a serial program running on the Python Shell inputs the voltage, current and the phase values by querying the user. This is then split up into characters and transmitted to the LPC2148 board through the serial port, which is running the program for coding and transmission through the Zigbee.A program written in Python language running on the PC helps in user input and transfers this data to the respective kits. Screenshot of source node is shown in Figure 5. The data reaching the zigbee will be transmitted to the destination node, whose address is already configured in the zigbee.

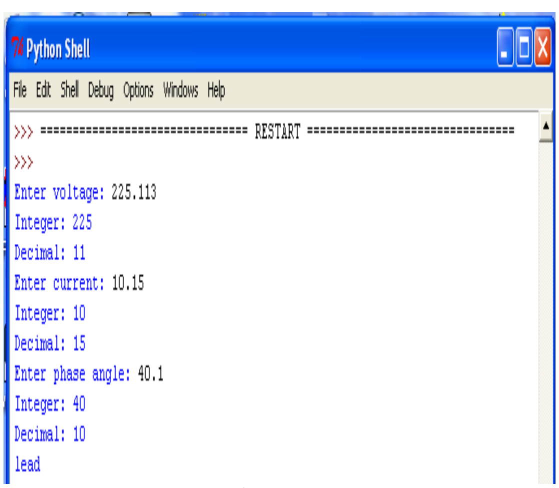

Fig. 5 Screen shot of source node (wind)- Zigbee

The Zigbee radio attached to the PC receives the data packets in the order: address frame, order frame, key id frame, data-1 frame, data-2 frame and passes on to the PC running the receiver program written in Python language through the serial port. Figure 6 shows the screen shot of destination node.

VII BLUETOOTH IMPLEMENTATION

Bluetooth is yet another wireless communication technology based on the IEEE 802.15.1 standard. In this paper, a Bluetooth Development Kit is used which comprises of the Bluetooth board manufactured by A7 Engineering Ltd, attached to a Rabbit 3100 based development board carrying a RCM3100 microcontroller. The programming for this development board is written using the Dynamic C IDE. Besides, a USB Bluetooth Dongle is used for equipping a PC to act as a node capable of Bluetooth communication. Out of five nodes, each node comprises of the Bluetooth development kit and the PC or the USB Bluetooth dongle and the PC combination.

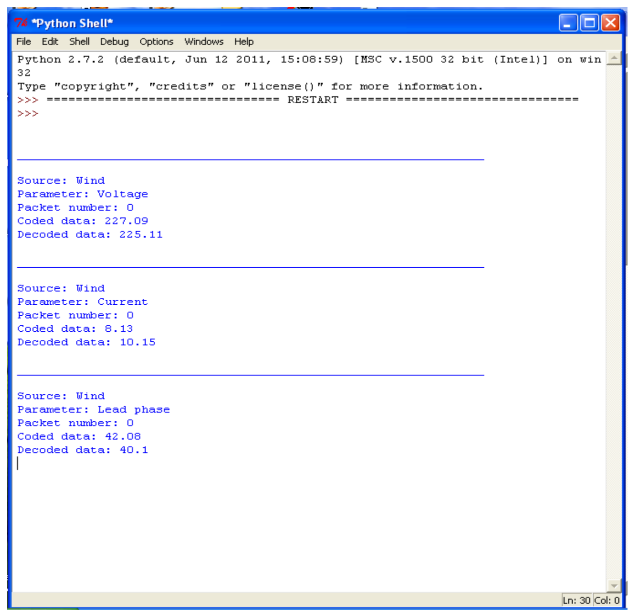

Fig. 6 Screen shot of destination node-Zigbee

In the node containing the USB bluetooth dongle and the PC, a serial program running on the Python Shell inputs the voltage, current and the phase values by querying the user. This is then coded and transmitted to the destination node wirelessly through the USB Bluetooth dongle.Data are entered using the PC. A program written in Python language running on the PC helps in user input and transfers this data to the respective kits. Initially all the source nodes are paired with the destination node. Then a virtual serial port is opened at each node. The voltage, current and phase data packets each containing the frames in the order: address frame, order frame, key ID frame, data-1 frame, data-2 frame. Figure 7 shows the screenshot of source node. The data reaching the USB Bluetooth dongle will be transmitted to the destination node, to which it is already paired. Figure

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8 shows the data reception by the Bluetooth dongle. The USB Bluetooth dongle attached to the PC receives the data packets in the order: address frame, order frame, key id frame, data-1 frame, data-2 frame and passes on to the PC running the receiver program written in Python language through the virtual serial port. Figure 9 shows the screenshot of destination node.

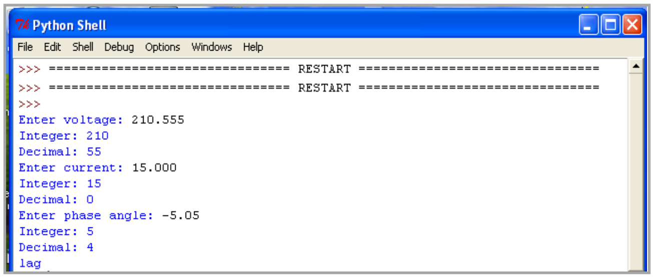

Fig. 7 Screenshot of source node-Bluetooth

Fig. 8 Data reception by the Bluetooth dongle

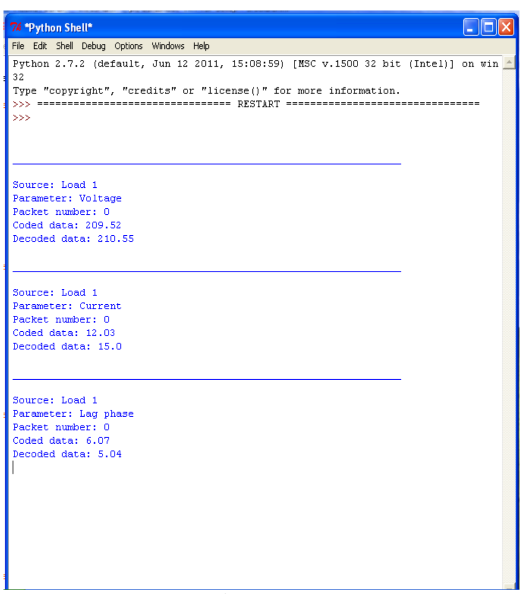

Fig. 9 Screenshot of destination node-Bluetooth

VIII WI-FI IMPLEMENTATION

Wi-Fi is a wireless communication technology based on the IEEE 802.11 standard. It is managed by the Wi-Fi Alliance. In this paper, a PC equipped with a Wi-Fi card is used for implementing the Wi-Fi communication. The device is configured and an ad-hoc network is created at channel 11 using the configuration tool – Netgear as shown in Figure 10. Programming is written in Python language to run on the Python Shell. Out of five nodes, each node comprises of the PC equipped with the Wi-Fi card. At each source node, a socket program running on the Python Shell inputs the voltage, current and the phase values by querying the user. This is then coded and transmitted to the destination node wirelessly through the Wi-Fi card. Data are entered using the PC.

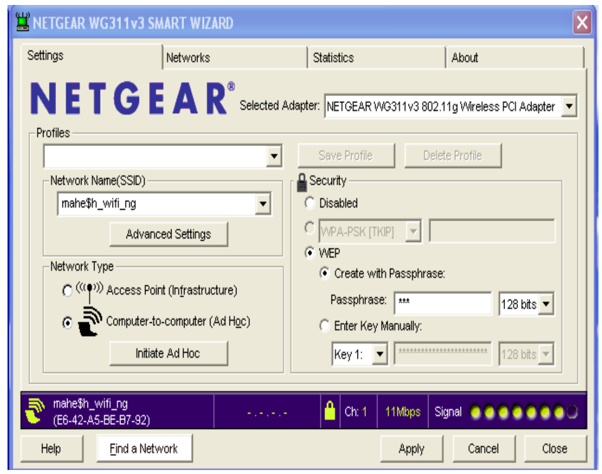

Fig. 10 Configuration tool-Netgear for Wi-Fi card

A program written in Python language running on the PC helps in user input and transfers this data to the destination as explained in the following algorithm steps. Initially all the nodes are joined to the same network by issuing the same SSID using Netgear. Then a socket is opened at each node by the Python program. The socket is opened at the destination node and data are transmitted for voltage, current and phase data packets, each containing the frames in the order: address frame, order frame, key id frame, data-1 frame, and data-2 frame. The data will be transmitted to the destination node, to which it is already addressed. Figure 11 shows the source node where the data are entered. The Wifi card attached to the PC receives the data packets in the order: address frame, order frame, key id frame, data-1 frame, data-2 frame and passes on to the PC running the receiver program written in Python language through the socket opened. Figure 12 shows the screenshot of destination node.

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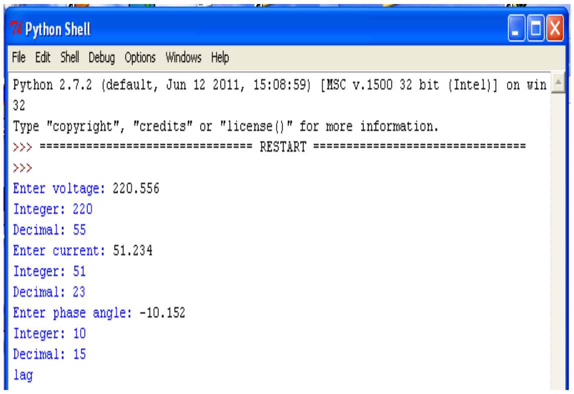

Fig. 11 Screenshot of source node-Wi-Fi

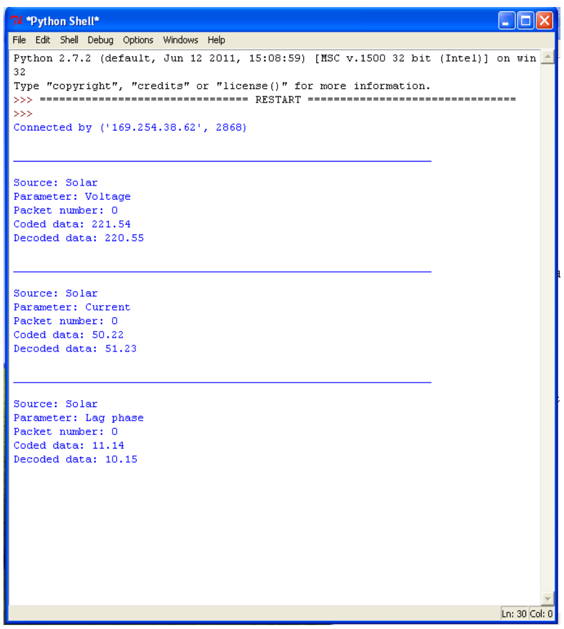

Fig. 12 Screen shot of destination node-Wi-Fi

IX DATABASE IMPLEMENTATION AND PERFORMANCE EVALUATION

The data collected at a node may be put in a database, which need to be retrieved and transmitted. Besides the various parameters – performance, packet rate, packet loss, etc. – are compared for different protocols used for wireless communication. Figure 13 shows the data transmission using database for the source end Solar. For realizing this, random data for voltage, current and phase were generated and stored in a database using Sqlite3 in python. These data are then retrieved and transmitted in the sequence. The objective of this was to find the time required for transferring about 100 data frames from each node simultaneously and note the time required for all the packets to reach the destination node. Also, the number of packets lost during the bulk transmission of data could be found. It was found after repeated trials that all packets were successfully received. The collisions that occur during simultaneous data transfer are taken care by the corresponding transmission protocol. With more interference, the packet gets delayed more as several retries occur for each frame. Figure 14 shows the data received at the destination node. Table 2 shows the comparison of various wireless communication protocols.

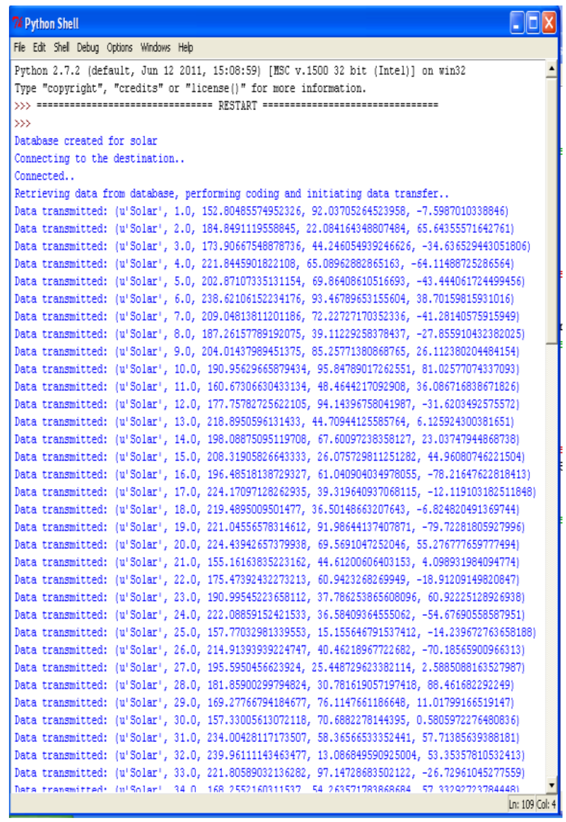

Fig.13 Data transmission from the source end solar

TABLE 2 PERFORMANCE COMPARISON OF PROTOCOLS IMPLEMENTED FOR WIRELESS COMMUNICATION

PARAMETER	ZIGBEE	BLUETOOTH	WIFI
Packet delivery against time	High	Low	Medium
Packet delay against time	Low	Medium	High
Packet drop against time	Low	High	Medium
Packet delivery against speed	High	Low	NA
Packet delay against speed	Low	High	NA
Packet drop against speed	Low	High	NA

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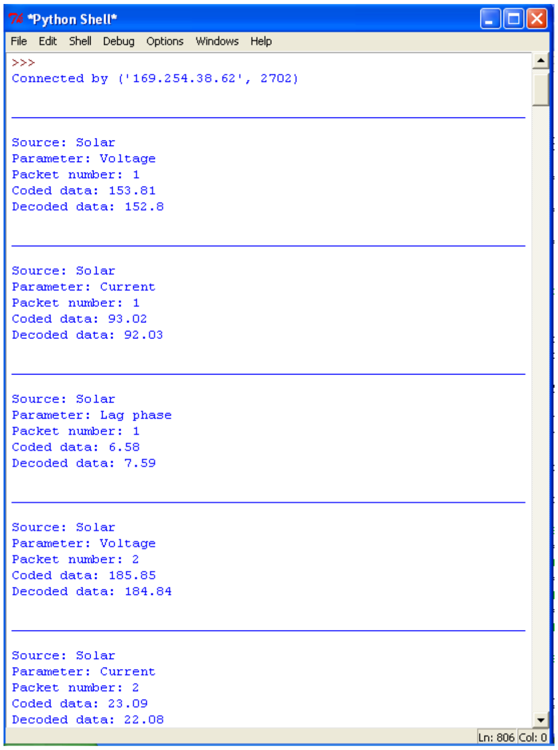

Fig. 14 Screenshot of data reception

From the resuls, it is inferred that Zigbee is a very reliable communication scheme for short distance communications with good packet delivery, less packet delay and packet drop. Hence it is widely used in home automation and such applications. But it has a very low bandwidth of only 250Kbps, and limited range of about 100 metre, which limits its application in larger networks spread over larger area. Bluetooth has medium performance characteristics compared to Zigbee and Wi-Fi. Class – 2 Bluetooth devices have very low range of about 10 metre eventhough it has a theoretical speed of 1Mbps. Hence its application is restricted to Personal Area Networks (PAN). Wi-Fi is the proven technology for larger area and bandwidth upto 11Mbps for IEEE802.11b and 54Mbps for IEEE802.11g networks.

X DECISION ALGORITHM

The objective was to implement a decision making algorithm which reports when the total demand at any instance exceeds the total generation. This is a very important factor in smart grids to implement several of the decision algorithms.In order to realize this objective, two of the nodes were treated as loads and two as the generating stations. Data were sent from each node using Wi-Fi protocol. By accessing the database multiple data were transmitted from each source, which is collected at the receiving end. There, the sum of the power demand is compared with the total power generated and a message is displayed accordingly as shown in Figure 15.

XI CONCLUSION

In this paper, the concepts of Network Coding was implemented and tested for Smart Grid applications using the wireless protocols: Zigbee, Bluetooth and Wifi. Four nodes were considered to be the source nodes namely solar, wind, tidal and thermal and the performance parameters were studied for each protocol by transmitting multiple data packets stored in a database and the characteristics were plotted and compared. Further, an algorithm which reports whether the current load demand exceeds the total generated power or there is a surplus of generated power available, was developed and run at the destination. For this, two of the nodes were assumed to be the generating stations and the other two as the loads. This was demonstrated using Wi-Fi protocol. Development of a new protocol capable of longer transmission ranges is yet another area to be investigated in the future. This will lead to a new and reliable wireless communication scheme for practical Smart Grid applications.

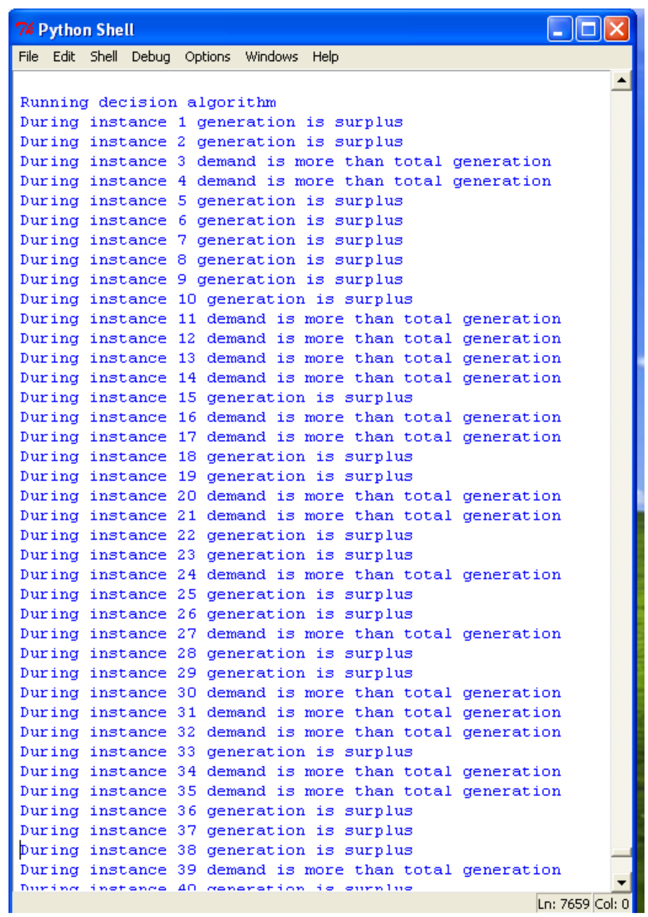

Fig. 15 Decision making algorithm using Wi-fi protocol

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