Performance Analysis of IEEE 802.15.4 in Smart Grid Environment

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Abstract: In our proposed work, we analyze the various applications of smart grid by deploying the wireless sensor network (WSN). The main characteristics of a smart grid system are duplex communication, integration of renewable energy, metering structure has become automatic and a complete control over all of the power grid system. Wireless Sensors networks are deployed for monitoring and to have a control over smart grid subsystems. Security in a WSN network is a main area of concern. Due to WSN limited processing capabilities it can be easily targeted with cyber attacks. If new approach can be developed to counter cyber attack on WSN than it must be less complex with confidentiality and integrity. The address oriented design and development approach for usual communication network requires a paradigm shift to design data oriented WSN architecture. WSN security is an unavoidable part of smart grid cyber security. In our proposed work, we work on different parameters like throughput, efficiency, end to end delay and packet loss. The simulations have been implemented using NS-2.35.

Keywords: Smart Grid; Wireless Sensor Network (WSN); Topology Control; Zigbee; IEEE802.15.4 Standard; NS-2.35.

I. INTRODUCTION

The electrical power grid first transformed into micro-grid, nano-grid and now it becomes Smart Grid. Smart Grid is fully automatic, classified and take care of every parameters effectively like generation, distribution of energy, and transmission. It is a two-way communication system in which the electricity or data can flow in both the direction at the same time. There are two types of system in control system open and close and smart grid has close loop system for various purposes like controlling and monitoring [1–4]. Smart Grid is very advanced technology and various organization worked together to achieve the target and finally succeeded and smart grid is totally conceptual. Main contribution in developing smart grid mainly by National Institute of Standards and Technology (NIST), IEEE, ETP, IEC, Electric Power Research Institute (EPRI), etc. “A smart grid uses digital technology to enhance reliability, security, and efficiency both in term of economic and energy of electric system from huge generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources” [5]. Smart Grid is a combination of many technologies for example electrical as well as information and communication technologies so that power grid could be more reliable, robust, flexible and efficient. It is an intelligent power grid with assimilation of various alternative and renewable energy resources. Fully automatic monitoring and controlling, data acquisition & control (DAC) and emerging communication technologies are the most prominent features of smart grid deployment. Use of diverse set of communication standards requires analysis and optimization depending upon constraints and requirements [6–9]. These requirements can be decided on the basis of area of coverage, type of application, bandwidth requirement, etc [10]. Smart grid hierarchical communication network classified as:

- Home Area Network (HAN),
- Neighborhood Area Network (NAN)
- Wide Area Network (WAN)

As per the applications of communication technologies at various levels of deployment of smart grid [10]

II. APPLICATION OF WSN IN SMART GRID

Wireless sensor network is a cost effective techniques for control, monitoring, measurement and fau1t diagnosis in smart grid network. A sensor node consists of power supply, actuators, memory, advanced processor, transceiver and actuator. Sensors are used to collect different parameters value for example humidity, temperature (T), current (I), etc. WSN nodes are power driven by battery. Figure 1depicts basic structure of wireless sensor node [11].

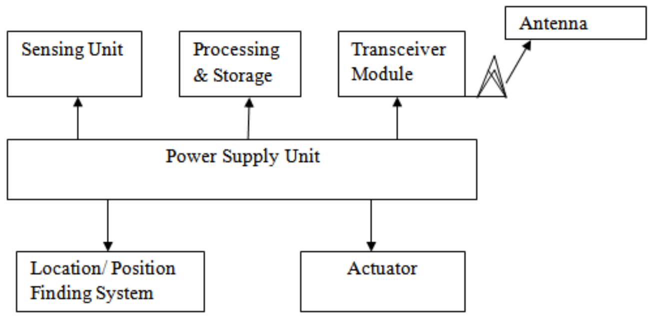

Fig.1. Architecture of WSN

Sensor nodes can be deployed on large scale for the purpose of communication of conditions of various transmission and distribution units. WSN provide cost effective solution for monitoring smart grid which gives high penetration of RES (renewable energy sources). WSN is an important part of AMI (advanced metering infrastructure). Sensing and communication are massive important for PHEV system and which is also known as most favorable and ingenious pars of smart grid system or technology. PHEV have gasoline, diesel engine with an electric motor and besides this also has rechargeable battery [12-14]. An effective approach for remote controlling, monitoring and diagnosis can stop continuous hazards or painful moments and breakdowns. WSN can be used for accuracy for different parameters for example monitoring and controlling of generation of electricity, transmission, and consumption of electricity.

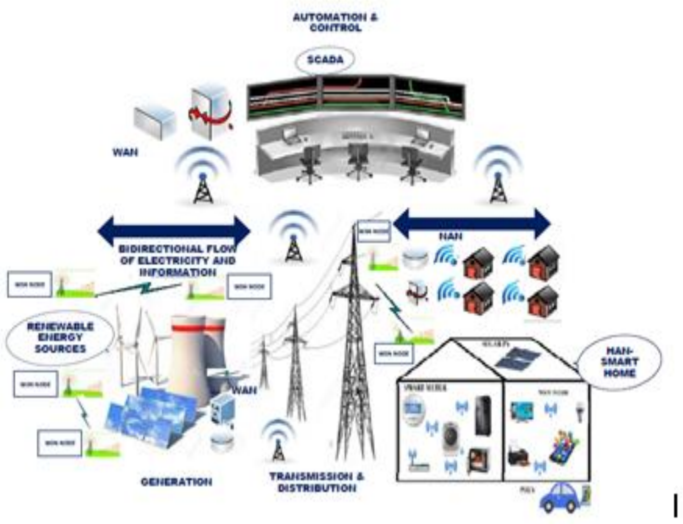

Fig.2. Application of WSN in smart grid hierarchical architecture

- Smart power generation
- Smart power transmission and distribution
- Customer applications

III. ZIGBEE /IEEE 802.15.4

The IEEE 802.15.4 MAC/PHY protocol stack already included in the core release of NS-2 implementation is adopted in our project to fit in the corresponding part of underlying interfaces attached to a mobile node [15]. Considering the fact that the IEEE 802.15.4 MAC/PHY protocol implementation serves as an ideal model intended for software simulation, part of its operational mechanisms remains distinct from that of off-the-shelf ZigBee/IEEE 802.15.4-based devices in realistic environments due to the intrinsic characteristics of NS-2. Also, the organization of nodes in a ZigBee/IEEE 802.15.4 network and the choice of the mode in packet transmission have to be taken into account in terms of the node construction and the setting of simulation scenarios [13].

A. Network Topology and Node Association

In terms of networking architecture, a ZigBee/IEEE 802.15.4 network could operate in either the star topology or the peer-to-peer topology [2]. In a network with a star topology, the communication is established in a centralized way, in which case devices only communicates with the PAN coordinator in the network. Different from the star topology, any device in a network with a peer-to-peer topology is capable of transmitting packets to any other device within its radio range. Meanwhile, the peer-to-peer topology enables nodes to transfer packets through multiple hops to destinations, depending upon the routing strategy at the upper layer. As a matter of fact, a single cluster tree network intended for our simulation scenarios is a typical case of the peer-to-peer topology. Under such circumstances, a FFD or RFD joins the network as a leaf device at the end of a branch of the cluster tree by connecting itself to a FFD equipped with the capacity of association [16]. Device association acts as a key step to form a cluster tree topology which is a special network structure that could be exploited for the routing purpose if necessary. To conduct data transmission, any node must join a ZigBee/IEEE 802.15.4 network through device association procedures so as to identify itself as a member in the network.

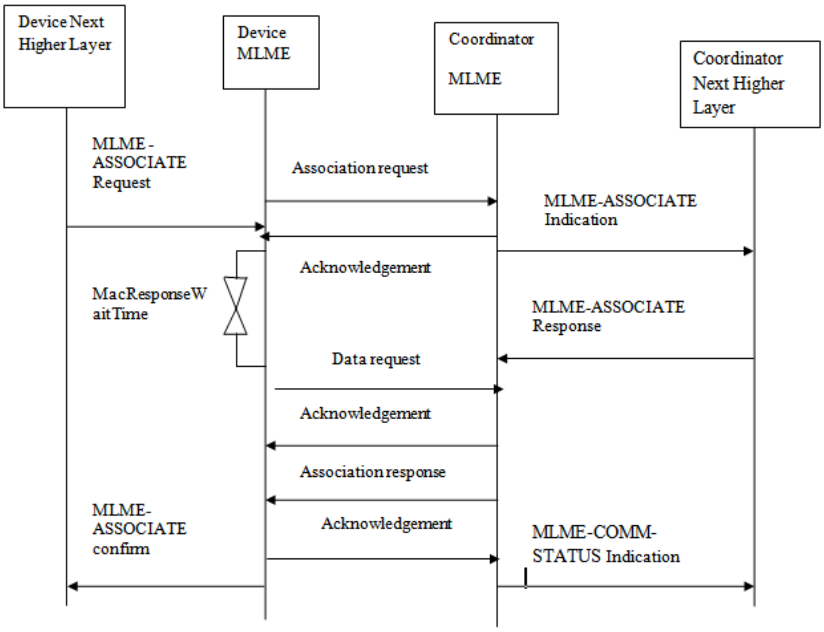

Fig.3. Association sequences of device in a network

First of all, the first node intended for a ZigBee/IEEE 802.15.4 network is set to be the PAN coordinator through scenario scripts. The PAN coordinator establishes the network by choosing an unused PAN identifier unique in the scope of simulations. Following that, any other node is able to join the network for data communication with its node identifier as a fixed address in simulations. A normal device association process begins with a communication channel scanning initiated by an unassociated device in an attempt to locate the existing network and the surrounding coordinators (intermediate nodes or the central controller in our project) that are configured to receive association requests from devices. Subsequently, the device issues an association request with an acknowledge requirement to the coordinator [17]. Upon reception of the request, the coordinator has to make the decision of whether to allow the requesting device to connect to the network through it based on its capacity and resources available for association.

IV. COMMUNICATION STANDARD FOR WSN

Traditional communication network totally depends on network and physical identification of transceiver. As Wireless sensor networks have redundant nodes for compensating signal that are degraded due to any reason the particular address of any node is not of so much concern. The values that are measured have to make a communication between nodes whatever the address of node is. So, Wireless Sensor Network communication is not address oriented but data oriented.

A. Zigbee

Zigbee is based on IEEE 802.15.4 standard and its energy efficient and applicable for short range wireless communication. It works in ISM band. Zigbee works in three bands of frequency 2.4 GHz, 868 MHz and 928 MHz with full duplex communication. The maximum throughput that can be achieved by Zigbee is 250 Kbps. In automatic power system, it can be used for automatic smart meters and also monitoring power system and used in measurement of different electric parameters [6-7]. Smart Grid collects information and is a communication technology through which existing power system can be enhanced. It is a power grid system having capability to self heal, perform interoperations energy efficient and having complete security. Zigbee can play crucial role to maintain and operate power grid, data integration, and different parameter measurement along with security.

Table1. Communication Standards

Protocol	Wi-Fi	Bluetooth	Zigbee
Spectrum	Unlincensed	Unlincensed	Unlincensed
Frequency Band	5.8GHz, 2.4GHz	2.4GHz	868MHz, 915MHz, 2.4GHz
Maximum Throughput	2Mbps to 54Mbps	21Kbps	250Kbps
Coverage Range	Upto 250m	Upto 100m	Upto 100m

V. SIMULATION RESULTS

Software NS-2: We use NS-2 (2.35), a network simulation tool to simulate wireless communication network. It provides a good platform for WSN simulation. The random way point model is selected as a mobility model in a rectangular field (2000 x 2000 m2). AODV is used for simulation at network layer. Nodes send constant bit rate (CBR) traffic at varying rates. The performance of Energy Efficient based Cluster protocol in Wireless Sensor Network (WSN) is being estimated with the help of simulation on network simulator-2. Following results will be calculated by using performance .awk script. Using the output we plotted the bar graphs of following parameters.

- Average End-to-End Delay
- Packet Dropping
- Energy Consumption
- Normalized Routing Load
- Average Throughput

A. Average End-to-End Delay

This is the time from the generation of the packet by the sender up to send at the destination application layer and expressed in second. It therefore include all the delay in the network such as buffer Queue, transmission and delay induced by routing protocol activities and MAC control data exchanges.

End to End delay = [(Sum of Individual data packet delay) / (Total number of data Packets delivered)]

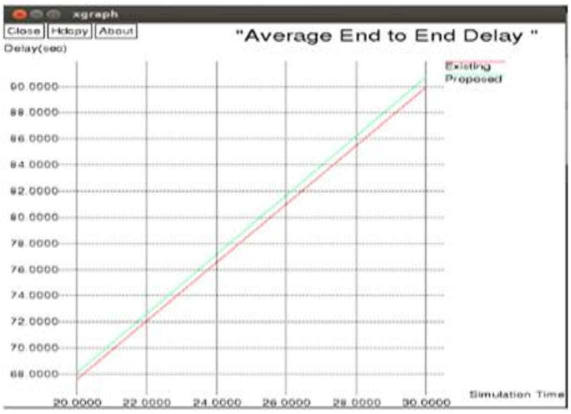

Fig.4. Comparison of average end-to-end delay

B. Packet Dropping

The failure of one or more transmitted packets to arrive at their destination is called as Total Packet Dropped.

Packet Drop Ratio = Data packets sent – Data packets received

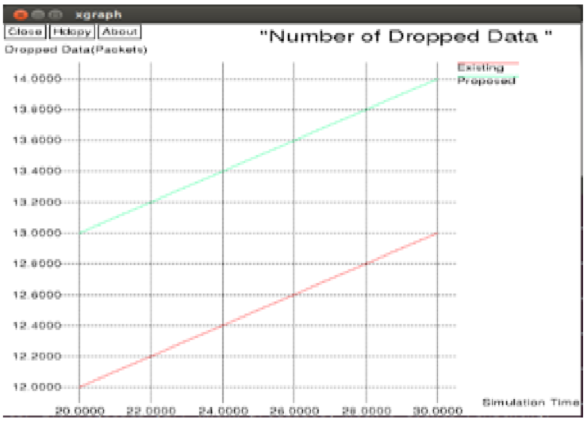

Fig.5. Comparison of dropped data packets

C. Energy Consumption

Energy is converted in joules by multiplying power with time. Graph below shows the energy consumed by mobile nodes in WSN. Energy consumption represented in Joule per Second.

Energy Consumption = [(Sum of Energy expended by each node) / (Total number of data packets delivered)]

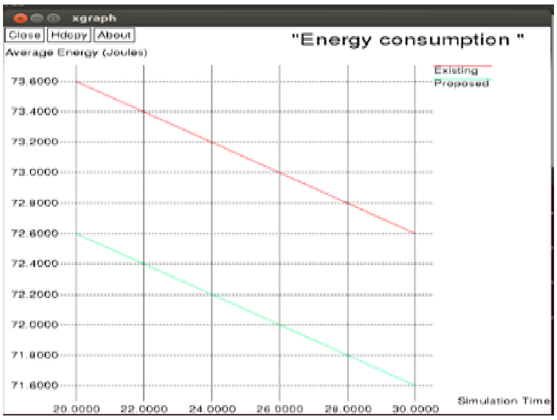

Fig.6. Comparison of Energy Consumption

D. Normalized Routing Load

It is defined as the total number of routing packet transmitted kilo bits per data packet. It is calculate by dividing the total no. of routing packets sent (includes forwarded routing packets) by the total number of data packets received.

NRL = Routing packets/received packets

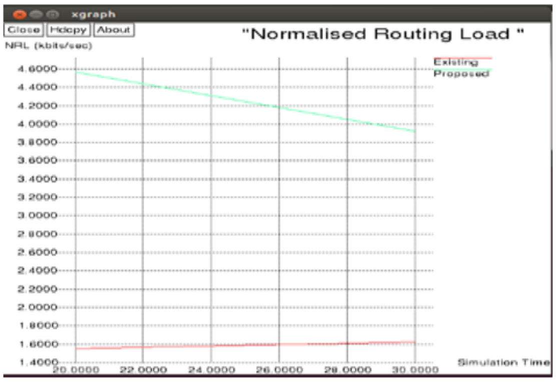

Fig.7. Comparison of NRL

E. Average Throughput

The ratio of total amount of data that reaches from a sender to receiver to the time for the receiver to get the last packet is referred as Throughput. It includes frequent topology changes, unreliable communication of messages, limited bandwidth and insufficient energy in WSN's. A network with high average throughput is desirable.

Throughput = (Number of data packets received*Packet size*8) / Simulation time

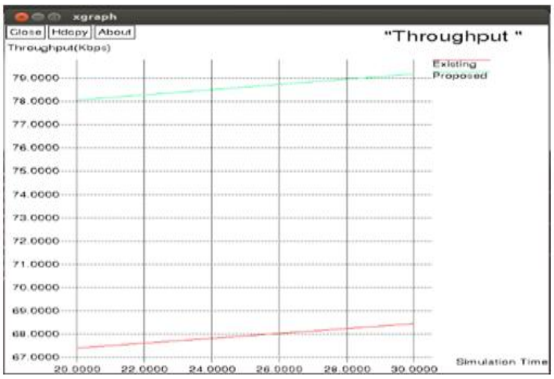

Fig.8. Comparison of Throughput

Table 2. Simulation Parameters

Simulation Tool	NS-2.35
Operating System	Ubuntu 12.04
No. of Nodes	100
MAC/PHY Layer	IEEE 802.15.4
Antenna Model	Omni Directional
Interface Queue Size	50 Packets
Data Payload	512 Bytes
Pause Time	10 Seconds
Examined Protocol	AODV
Transmission Range	250m
Simulation Area	80M*80M
Data Rate	250K
Interface Queue Type	Queue/Drop Tail/Pri Queue

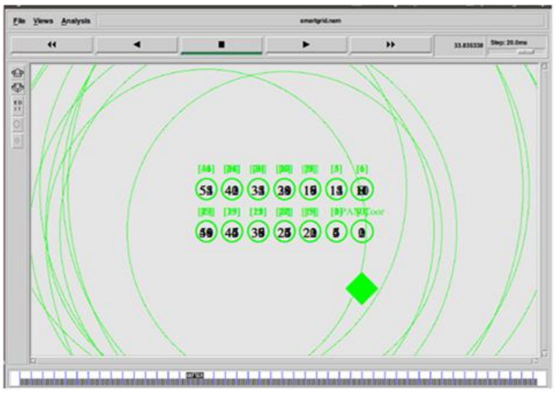

Fig.9. Communication and packet dropping

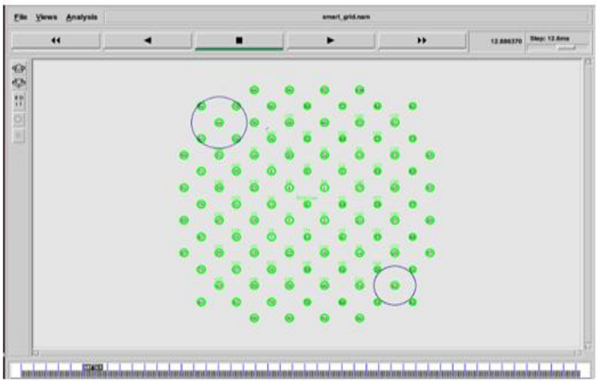

Fig.10. Communication Starting

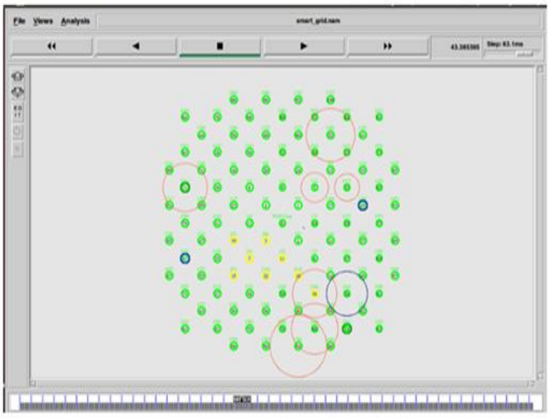

Fig.11. Communication between sensor Devices

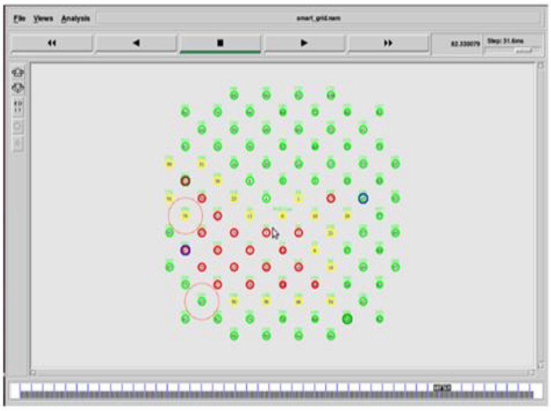

Fig.12. Functionality of Smart Grid Network in WSN

VI. CONCLUSION

In proposed work, we present how power grid is having big transformation by using smart grid technology in WSN. Smart grid is latest, complicated hierarchical network along with heterogeneous. WSN is a famous solution for different real time applications of smart grid. Wireless sensor networks collect the information of various sensors nodes which are located at different location so that important information or parameters like voltage (V), temperature (T), humidity and current (T) can be gathered and that information can be processed further so that hazards can be avoided. These parameters are very crucial and essential so that we can control and monitor various components of smart grid. Today's WSNs are very important solutions for management system of energy in home and industry applications. The energy sensor nodes which are exhausted or very tired can be easily communicated. Traditional communication procedures have physical address and internet protocol (IP) addresses of a particular transmitter and receiver so that successful communication route is setup and this approach of communication is belong to address oriented which is totally different from WSN approach. Future scope of our dissertation work can be carried out in term of attack & cryptographic security. Because security is very important parameters to protect the communication between many sensor nodes so that unauthorized person cannot access information. The main challenge in the WSN network is to have dispersed nodes security because of scarcity in memory.

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