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Routing Protocol Optimization of Smart Grid Neighborhood Area Network based on IEEE 802.11 Standard

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ABSTRACT

A power 'Grid' is a network that carries electricity from power plants to consumer premises. The grid is made 'smart' as it can monitor and control the distribution system by taking intelligent decisions. Smart Grid is an automated and broadly distributed energy generation, transmission and distribution network. Smart Grid network integrates an electrical distribution system with information and communication network. Communication network protocols are engineered, developed and established based on the layered approach. Each layer is designed to serve a specific functionality in collaboration with other layers. Layered approach for wired communication approach can be modified with cross layer approach for wireless communication for performance enhancement. Smart grid technology comprises of hierarchical and heterogeneous network with diverse set of communication protocols. This demands a divergence from primitive approach and adaptation of an innovative approach. This paper describes network design and optimization of routing protocol for Smart grid Neighborhood Area Network using Riverbed-OPNET software. A Cross layer approach is considered in parameter optimization of IEEE 802.11 standard. The proposed work shows parameter optimization of routing protocol for better network performance using simulation approach.

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INTRODUCTION

Smart grid is a multi-faceted technology with integration of electrical and communication infrastructure. Smart grid communication

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network is a hierarchical and heterogeneous network containing various network layers. Data acquisition for monitoring and control requires diverse set of communication standards based on various applications. Wired as well as wireless communication standards can be used for Smart grid communications (Gungor et al., 2010). Smart grid communication architecture can be designed and optimized on the basis of three network layers based on bandwidth requirement, coverage area and application. These three network layers can be classified as Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN). These layers are interconnected for real time monitoring, control, diagnosis and management of entire grid (Saputro et al., 2012). Each network requires an optimization of specific set of communication standards. Layered architecture supports various applications such as sensing, measurement, smart metering, home automation, SCADA and IoT etc. HAN covers home area monitoring, regulation, control and management. NAN is applicable for distributed generation and distribution automation. WAN shelters HAN and NAN for monitoring and control of entire communication network (Farooq & Jung, 2014). WAN is a gigantic network covering management of generation, transmission, distribution and utilization of entire grid (Mahmood et al., 2015). Smart grid data communication is characterized by intra-network and inter-network communications for operation and management of various components of grid (Erol-Kantarci & Mouftah, 2011). Figure 1 shows the layered communication infrastructure of Smart grid.

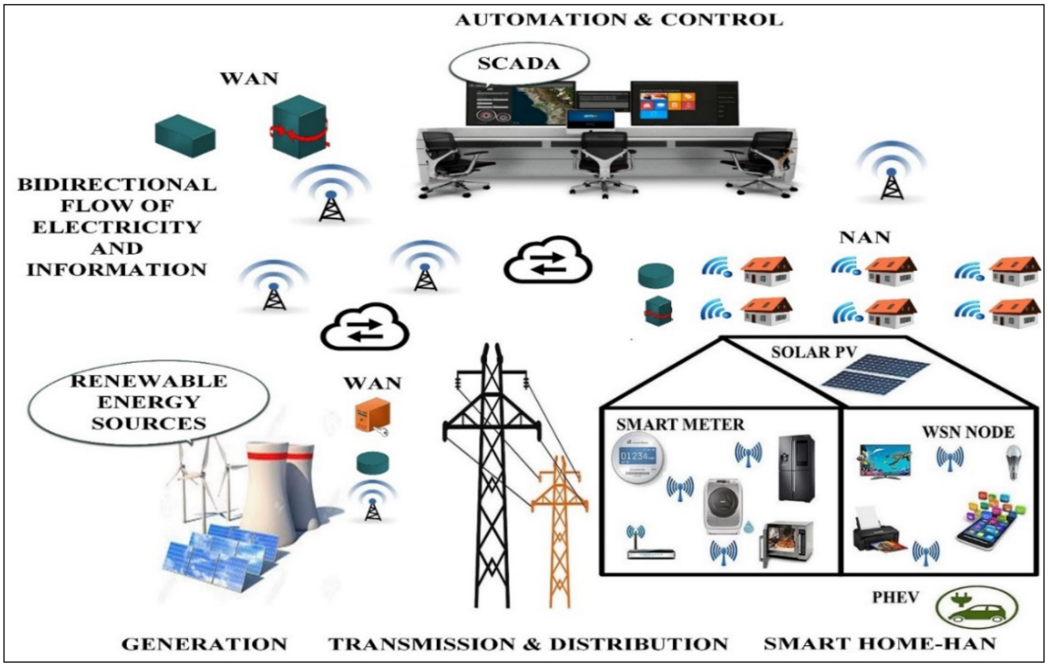

Figure 1. Layered Smart grid infrastructure

Each layer of Smart grid network is optimized for different set of communication protocols (Chen et al., 2006). The various choices available are IEEE 802.11, IEEE 802.15.1, IEEE 802.15.4 and IEEE 802.16 (Sun et al., 2009). Various communication protocols can be used for monitoring and control of various networks (Xu et al., 2014). Communication protocols are chosen for a specific application on the basis of various factors such as data rate, coverage area, and frequency spectrum (Patel et al., 2011).

Application of IEEE 802.11 Standard in Smart Grid

IEEE 802.11 standard is apt for Smart grid applications due to its features such as extensive availability around the world, plug and play devices, high data rates up to 600 Mbps, low cost, operability with IoT applications without protocol translation etc. Security of WLAN network is a crucial issue. IEEE 802.11 uses mainly three security protocols such as WEP (Wired Equivalent Privacy), WPA (Wi-Fi Protected Access) and WPA2 (Wi-Fi Protected Access, version-2) as shown in Figure 2. Various features of these security protocols are depicted in Table 1.

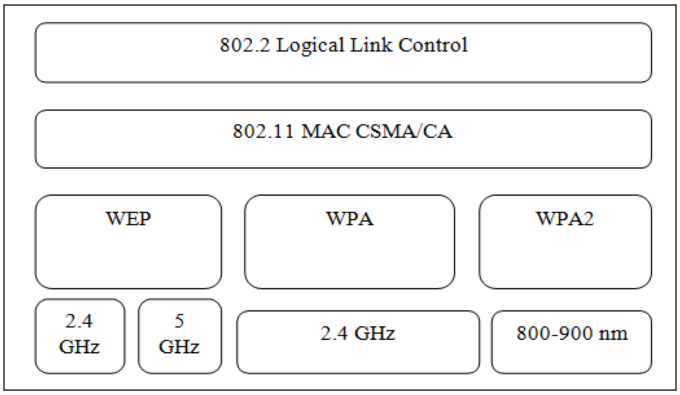

Figure 2. WLAN security protocols

Table 1
Comparison of various WLAN security protocols

PARAMETER	WEP	WPA	WPA2
Key Length	40/104 bits	128 bits	128 bits or higher
Encryption	RC4	TKIP	AES
Key management	Lack of Key Management	Robust mechanism, 4 way handshake	Robust mechanism, 4 way handshake
Data Integrity	CRC-32	Message Integrity code is generated	Cipher Block Chaining Message Authentication Code
Authentication	WEP-Open and Shared	WPA-PSK	WPA-2-Personal & Enterprise
Protection against Replay Attacks	No provision for protection	Sequence counter is implemented	48 bit packet number for attack prevention

From above table, it is apparent that WPA2 is the advanced and better encryption methodology for WLAN security. Moreover, combination of WPA2 and AES is the best solution for security of WLAN network. Wireless network can be made more robust by enabling MAC filtering in router setting. MAC filtering facilitates only limited users to use the network and thus an unauthorized access can be prevented. For commercial networks, network security tools can also be used for prevention of hacking as well as various cyber attacks.

Cross Layer Optimization

Communication network protocols are engineered, developed and established based on the layered approach. Each layer is designed to serve a specific functionality in collaboration with other layers. Thus, various functionalities such as transmission characteristics, error control, flow control, synchronization, routing of information, framing, sequencing of packets, congestion control, application specific services etc. are combined together by some degree of interfacing between various layers for implementation of protocols. Protocol layers are designed and organized in a vertical hierarchical manner. They are designed to ‘’pass on’’ the particular message. Communication is possible only between adjacent layers for the purpose of responding as a part of passing on the information.

In TCP-IP and OSI models, each layer provides services to its upper layer. Layered optimization and design has been a well-established approach for communication network design and development. In layered approach, protocols are designed with independent functionalities of layers. The specific layer uses the services of lower layers irrespective of the process and parameters of the service provided. A specific layer is concerned about a layer located above or below it and that too only for the sake of limited responses and communications.

Layered approach for wired communication approach can be modified with cross layer approach for wireless communication for performance enhancement. For example, cognitive radio technology is meant to provide unused spectrum of primary users to secondary users for enhancing spectrum efficiency. This approach requires continuous monitoring of channel conditions, interference and traffic scenarios. The primitive layered approach is not suitable for cognitive radio technology in which a reliable coordination between layers and adaptation is inevitable for successful operation and management of spectrum. In the context of Smart grid technology, cognitive radio technology is an inevitable approach for gigantic communication network and enormous amount of data communication.

Moreover Smart grid technology comprises hierarchical and heterogeneous network with diverse set of communication protocols (Shah et al., 2013). This demands a divergence from primitive approach and adaptation of an innovative approach.

The cross layer approach can be defined in various ways depending upon its design and functional aspects as described as follow:

- A design approach to explore the synergy and collaboration between various network layers.
- A combined design and optimization approach by considering more than one layer.
- A collaborative approach between different layers by sharing of information between them.
- In the context of multimedia transmission, a cross layer optimization is a process of collective source and channel coding.
- A design and optimization approach by considering the connection between various layers.
- An approach to explore dependence between network layers in contrast to independent layered approach.
- A combined parameter optimization for different layers.

A cross layer approach is a desecration of traditional layered design approach through ‘’Collaborative Optimization”. For Smart grid technology, this approach is a very essence of optimization of communication network protocols. The transmission and reception characteristics are taken into consideration at higher layers and the data communication is considered at lower layer is one of the aspect of cross layer approach. Non adjacent layers are collaboratively designed and optimized for performance enhancement. Cross layer optimization can be achieved for performance enhancement through either combined optimization of parameters pertaining to various network layers or by exchange of information between various network protocol layers. Figure 3 shows the conceptual diagram of cross layer design.

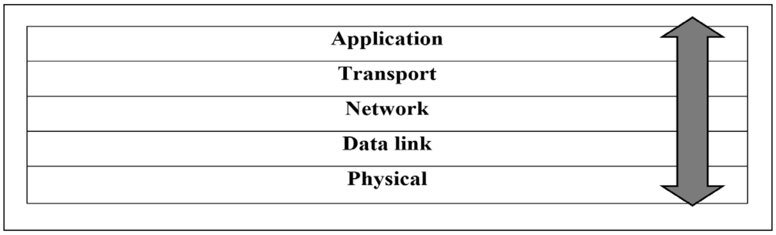

Figure 3. Conceptual diagram of cross layer design

Adhoc wireless networks play a crucial role in Smart grid communication architecture especially in home automation applications. Adhoc wireless networks work on the basis of decentralized or distributed control. This feature imposes difficulty and challenges to serve and support high data throughput and delay constrained applications which are inevitable in Smart grid. The traditional layering methodology used in wired as well as wireless approach in which each layer is unmindful about operation of rest of the layer cannot provide optimum performance under rigorous performance and reliability requirements. The protocol layer optimization of isolated layers may have negative impact on performance and operation of other layers.

The austere performance and operation demands of Smart grid heterogeneous network can only be realized through cross layer optimization (Shakkottai et al., 2003). Cross layer design approach explores interdependencies between diverse network layers through parameter characterization and optimization to optimize an entire network performance. Cross layer design can be used for wired as well as wireless networks. For wireless networks, this approach becomes inevitable to address the challenges such as connectivity, data throughput, QoS and interference. Adaptive power control, signaling, modulation and encryption can address performance challenges. Performance optimization of physical layer parameters can be explored by higher layers to optimize the network performance. Fading and congestion at physical layer can be circumvented by higher layers with the help of adaptive routing for delay minimization. The bottlenecks resulted due to one layer can be avoided if the joint optimization is performed and the operational characteristics of one layer is shared to rest of the layers. If an information regarding data throughput and delay is known to application layer then the solutions such as changing the rate of compression and/or multiple routing can be optimized. Cross layer optimization approach imposes many design challenges as adaptation or deviations at a specific layer must be compensated at that layer in terms of time scale. The variations in the Signal to Interference Ratio (SINR) are faster in terms of microseconds. Variation in the traffic is in terms of few seconds and topology of a network takes considerable time to change. Cross layer optimization must be performed by adaptations or optimization of parameters pertaining to a specific layer. If it is ineffective then the information must be exchanged with higher layer for better response and resolution. For example, if SINR is changing at a very fast rate as a result of fading and the physical layer shares this information to upper layers for the solution of this issue then during that time, SINR will mostly change to some other value or the fading might have reduced to optimum level. So, the problem must be first addressed at that specific layer before exchanging it with other layers. Optimization at other layer must resolve or alleviate the effect of performance degradation.

If SINR is decreasing due to fading then a physical layer may resolve this problem by increasing the transmitter power. But if this problem is a result of mobility or change in the location where the signal power is weak (for example a mobile station enters into the tunnel) then it's a momentary fading which will be resolved as soon as the mobile station is out of it. This type of fading can be resolved by procrastinating the packet transmission at higher layers. For extremely itinerant nodes, the solution can be adaptations in link characteristics, change in network topology or adaptations in routing methodology. WSN has challenging energy and delay constraints which can be solved through joint optimization at network and MAC layer. In joint or adaptive cross layer optimization method, each layer must be tuned to the variations done for performance optimization. Cross layer design is a challenging task as it is complex and requires multidisciplinary expertise. The successive part of this chapter describes various case studies of cross layer optimization.

Parameter Optimization of Neighborhood Area Network

Neighborhood Area Network (NAN) is a combination of Home Area Networks in Smart grid hierarchical network. In this section, NAN is formed in 1.5 Km area using IEEE 802.11 standard. Total 50 nodes are considered for optimization as shown in Figure 4. In this section, various parameters of different routing protocols are optimized and compared.

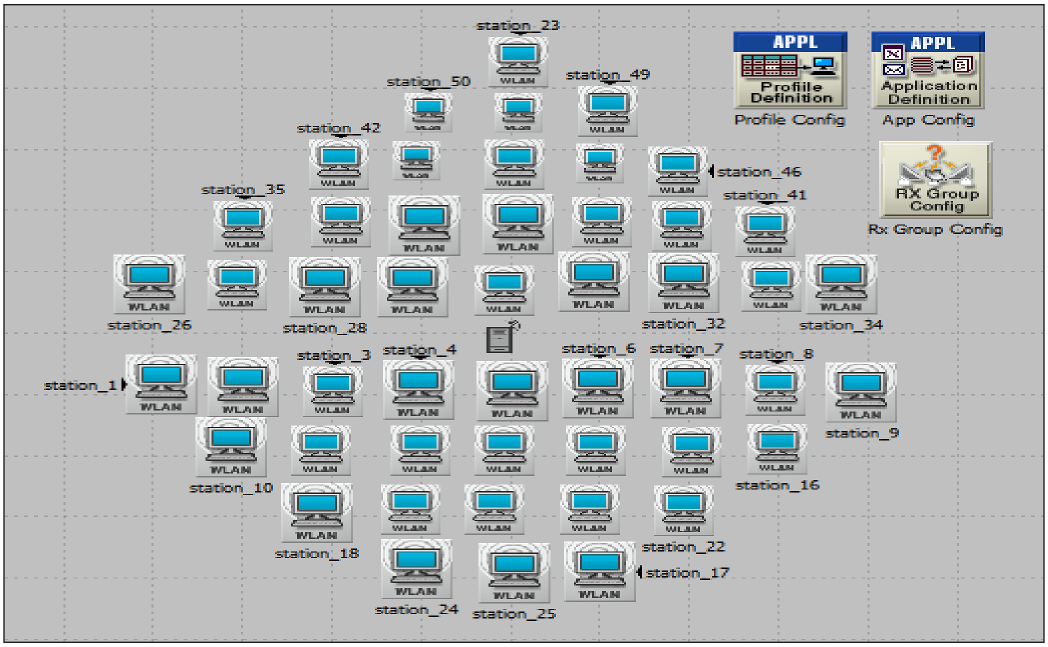

Figure 4. Neighborhood area network

Comparison of WLAN Routing Protocols

In this section, routing protocols are compared for optimization purpose. Table 2 shows the theoretical comparison of various protocols.

Default parameters are considered for all the routing protocols. Adhoc On demand Distance-Vector routing protocol works on the basis of on demand routing, that is, the route is established only when there is a requirement for source node to transmit the packets. The delay caused by set up of connections is lesser in this protocol.

Dynamic source routing protocol restricts the bandwidth consumption through elimination of table update messages. It does not use hello packet approach. Temporally Ordered Routing Algorithm protocol uses loop free multipath ways towards destination. It uses a link reversal algorithm for this purpose. It has less overhead as it restricts the control packets for reconfigurations of routes to a small region.

Optimized link state routing protocol enhances the performance of Link state routing protocol by reducing the size of control packets as well as number of links used to forward the link state packets. OLSR has many advantages such as less overhead, less connection set up time and number of broadcasts. Geographic Routing Protocol is a location based proactive protocol. It uses Global Positioning system for updating flooding information. Results show that OLSR protocol performs better in terms of total delay, media access delay and throughput compared to all other protocols.

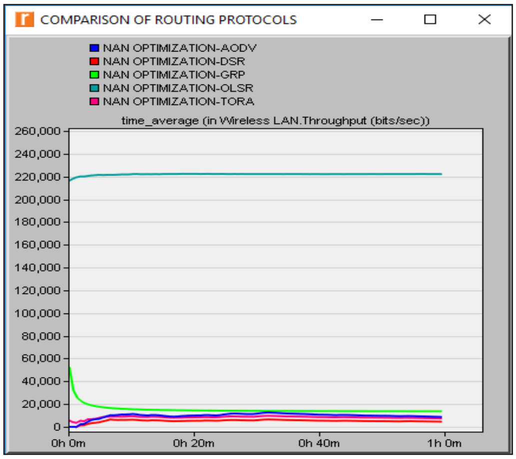

Figure 5. Comparison of throughput of different routing protocols for network optimization

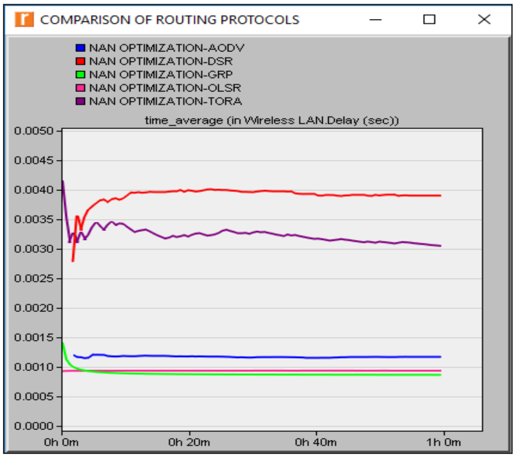

Figure 6. Comparison of WLAN delay of different routing protocols for network optimization

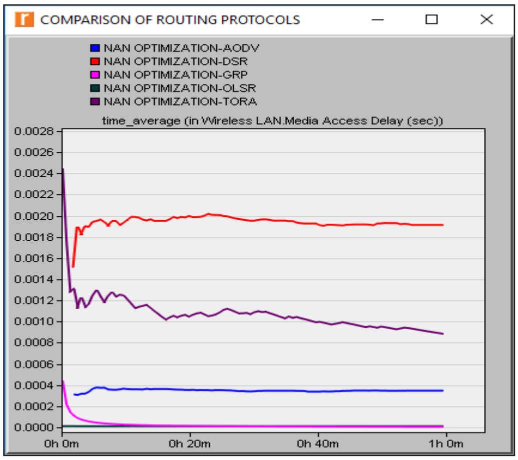

Figure 7. Comparison of WLAN Media access delay of different routing protocols for network optimization

Performance Enhancement in OLSR Protocol

As depicted in above results, OLSR protocol performs better than other routing protocols. It can be further improved by increasing Hello interval, Topology hold time and Duplicate message hold time. TC interval is decreased. The various parameters are described below. As shown in graphical results, WLAN throughput increases significantly as a result of parameter optimization. Table 2 shows the description of various parameters.

Table 2
Description of various parameters

SR NO.	Parameter	Description
1.	Willingness	This attribute defines that whether the node is agree to forward or carry the traffic on behalf of rest of the nodes or not.
2.	Hello Interval	This aspect specifies the time intermission between hello packets. Hello packets are essential to retain adjacencies between various 1 hop or 2 hop adjacent nodes.
3.	TC Interval	This feature states the interlude between TC messages. TC messages are used for routing table calculations and spread the information pertaining to topology of nodes.
4.	Neighbor hold time	This time period defines the duration within which a hello packet should be reached in order to sustain the link with neighbors. It is generally three times the hello interval.
5.	Topology hold time	This characteristic states the termination time for records in topology table. This feature is usually set to 3 times the TC Interval.
6.	Duplicate message hold time	This feature states the finishing time of an entry in the duplicate set table.
7.	Addressing mode	It specifies the protocol IPV4 or IPV6. The packets unsupported by the set parameter will be dropped.

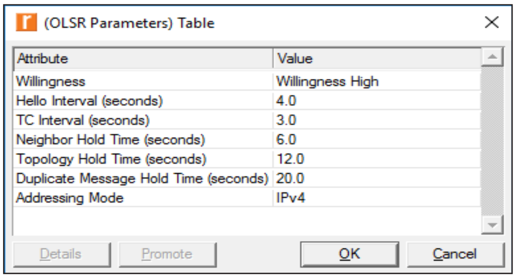

Figure 9. Optimized parameters

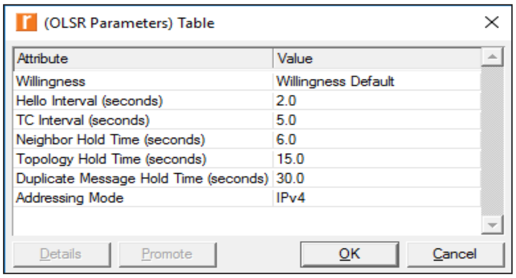

Figure 8. Default parameter

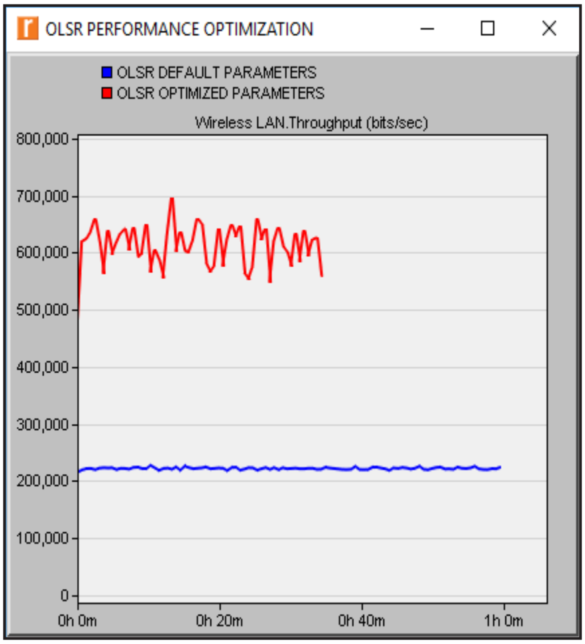

Figure 10. WLAN Throughput for default and optimized OLSR parameters

RESULTS AND DISCUSSION

In this paper, the performances of various routing protocols such as AODV, DSR, GRP, OLSR and TORA are analyzed for Neighborhood Area Network. As shown in Figure 5, the throughput is the highest for OLSR and the lowest for DSR protocol. The delay as well as media access delay is maximum for DSR and minimum for OLSR and GRP protocols as depicted in graphical results shown in Figure 6 and 7 respectively. OLSR performs better compared to rest of the protocols for implemented Adhoc network. For different applications such as high quality multimedia and VoIP, diverse set of protocols can be a suitable choice based on analysis, optimization and performance. Moreover, the network performance is further enhanced by increasing Hello interval, Topology hold time and Duplicate message hold time as shown in Figure 9. TC interval is decreased for performance enhancement. Network performance can be optimized through adaption of various parameters as shown using graphical representation in Figure 10. Thus after cross layer modifications, OLSR outperforms other protocols for Smart grid NAN applications. The paper also includes security protocols and solutions for network security. The combination of WPA2 and AES is an optimum solution for WLAN security. MAC filtering can also be implemented for prevention of unauthorized network access.

CONCLUSION

Smart grid is the most imaginative and advanced technology of present era. It is a hierarchical network comprising of heterogeneous technologies. The layered architecture of Smart grid communication network consists of Home Area Network, Neighborhood Area Network and Wide Area Network. Smart grid is a novel concept which is still in a developing stage. It is a complex and gigantic network of information and electrical infrastructures and equipment. The primitive layered approach for existing communication networks is not apt for optimized performance and operation of Smart grid network. Joint design of different protocol layers provides enhanced network performance. OLSR has average end to end delay which is suitable for applications which demands lesser delay. OLSR routes the information periodically. Sequential delivery of messages is not mandatory for OLSR which makes it independent of link reliability issue. OLSR performs better than rest of the protocols for Smart grid NAN applications but network optimization is inevitable for diverse applications such as multimedia and VoIP applications which require huge bandwidth and real time streaming of bulk data. WLAN is a ubiquities network. So, network security is the utmost priority for WLAN users. Implementation of security measures such as combinational security protocols, MAC filtering and network security tools can make the network robust against hacking attacks.

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