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Performance Analysis of Wireless Sensor Network with IEEE 802.15.4 Protocol

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Abstract

Wireless sensor networks are set of connections of nodes comprising of several sensor nodes connected to every additional in the course of a wireless environment. Wireless sensor nodes consists of some composite functions such as the detection of signals, collection of signals and data, deviousness and routing of nearby data by implanting them either randomly or by following a specific approach into various areas. In the present paper, the IEEE 802.15.4 protocol was considered which can be used vastly in communication networks. The performance of this protocol was analyzed in this paper through graphical representation. It consists of various useful standards for communication with respect to the wireless sensor network considerations like usage of battery for applications by sensors, the power consumption by various sensors should be low, they provide very extraordinary performance over sensors which works at very short distance and makes it likely to use nearly various frequency bands in the real time applications. The present simulator we had considered was RIVERBED Academic Edition 17.5, which is proficient of producing precise outcomes and gives user a detailed analysis of results which helps in identifying the actual behavior of the real system for real time applications or user designed applications. By using this simulator program, the performance of the network with respect to throughput of the nodes with number of nodes was analyzed which helps in designing a new real time network.

Keywords*: Wireless Sensor Networks, IEEE 802.15.4, RIVERBED (OPNET), Wireless Network Topology, Performance Analysis of the network in terms of throughput which is dependent on number of nodes.*

1. Introduction

A wireless sensor network is a group of sensor nodes connected together to form a network and to transfer of data between these nodes will accumulates the essential data from the environment where they were placed with given instructions, conditions and transmits the requisite data to a base station with the help of several other sensor nodes after via other sensor nodes after handling the data with them [1]. As the size of a wireless sensor network was in small size, the installation, the communication between devices has become easier. Sensors play different roles in the processing of communication networks and their data which collect data from other sources also and saves them in specific

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locations to call them whenever they were required. The current wireless sensor networks can be used for almost all the cases like automation of the household applications, manufacturing, the armed field, sickbays *etc*. Furthermore, we can place these wireless sensors at different places like isolated places such as highlands and more vulnerability zones where the individuals cannot work or cannot stand for a duration of long times.

The sensor networks or the sensors which can be used in these networks are considered as location specific. These types of networks can be used as the place where the temperature varies from 10 degrees of temperature to the 35 degrees or more of the temperatures. These sensors networks can be used at places where the human beings finds difficult to work or to stay at places such that to collect the data or to identify the readings from those places or at those areas of works. The sensors which we use in these networks are data centric. Some of the other type of sensors is the location centric or the location specific. The data centric sensors or nodes can be used for collecting the data from various places of the area with various formats of data like temperature, distance *etc*.

A typical electronic device called transducer is used to track or identify or to collect the data which was in physical format. It also consists of a small timer device which was used to store the data at particular point of times. It also consists of a small memory to store the data that was being collected periodically before it was being sent for transmission or for the processing of the collected data at the network or at the station. It also consists of a wireless transceiver which can used as both as a transmitter and also as a receiver. The final goal for designing or working on a wireless network or the collection of nodes forming to a network was the provision of providing the quality of service to the users or the customers whoever using this particular network or the people who were associated with this type of networks. The parameter or the property that providing quality of service to the end user was considered as the complete performance of the network.

The performance of this network was observed by the end users whoever using this particular network. Providing the best quality of service to the customer's whoever using this network was the major goal or the task of these networks. Some of the features or the measures that can explain the extent of the quality of service that was being provided by the existing or the newly developed network to the users or the customers. These features or the measures are throughput of the nodes in the network, error rates in the data that was being transmitted, bit rates of the data that was being transmitted, delay in the transmission and the jitter of the network *etc*. The values or the performance values of these parameters will make an influence on the performance of the network and hence the quality of the service that was being provided by the network was influenced. The bitrate in the communication networks can be taken as the number of bits that were being processed per unit of time. In other words the number of bits that were being transmitted per unit of time. It is represented as bit/sec in general representation of the data or values in the network.

The other performance measure that can influence highly the working of a sensor network was the throughput. It can be explained or treated as the maximum rate at which the data can be processed at a node for a point of time. The processing of the data can take as either transmission of the data or receiving the data. The throughput in a communication network or the network throughput can be calculated or can be referred as the efficacious transfer of data or packets to the receiver or the receiving end of the user. The data that was being delivered or transferred to the end user can be in the form of either in the physical link or in the logical link that was being connected to a node in the network. This measure was measures in various formats at various situations in the networks. Some of them are bits per second or the data packets per second. The throughput of a system can be obtained by adding all the data rates or the data that was being sending through the network to all the nodes or the terminals in that particular network. The throughput in the networks can be analyzed in the sensor networks with the help of using the queuing theory.

In most of the applications, the queuing theory was applied by many users to analyze or to identify the throughput of a network. The throughput plays a vital role in analyzing the performance of a communication system. Hence this parameter can be observed carefully in the working of a sensor network. This throughput is also affected by various parameters like the behavior of the users at the end or the end users and the power that was required to process the data at all the components of the network. The delay in networks can be of two types *i.e.*, transmission delay and the receiving delay. The transmission delay can be considered as the delay that was being observed at the point of transmission and the delay that was being observed at the receiver end. The delay can be treated as the time taken to transfer the data or to receive the data at the specified point or at the specified node in the network. The other parameter that was to be considered as important which influences the performance of the network was the jitter.

By using the Riverbed simulator using the IEEE 802.15.4 protocol, the performance analysis of wireless network topology was analyzed in detail in this paper. The outcomes attained could be used to suggest an elucidation to some of the problems rising in the level of designing a real time system adaptation. Numerous researchers had utilized various simulation tools like TOSSIM, J-Sim, JIST/SWANS, GLOMOSIM and QUALNET, OMNET++, Network Simulator (NS-2), EmStar and SensorSim. On the other hand, the RIVERBED Modeler Academic Edition 17.5 simulation program was utilized. The present simulator offers the performance analysis of wireless sensor networks pertaining to providing the service to the customers with high quality in detail. IEEE 802.15.4 protocol was used for bus topology and provides the excellence in provision factors like the delay to be calculated from one node to the end of another node, Mac load and traffic, throughput of the nodes were calculated and analyzed.

2. Wireless Sensor Networks

This type of sensor networks was having dispersed model of network structures in which several sensors networks were connected wirelessly to transfer the data between these sensors. In the wireless communication, the data will be shared or transferred from sender to receiver by using various wireless technologies like either light or electromagnetic waves. The gadgets used in electrical applications which identify signals are titled as sensors or probes. These sensors will have a volume of identifying numerous physical entities and possessions like length from the device to device or length from device to network, the sensor node coverage area, volume of the nodes and its networks and its related data, strength of the nodes in terms of distance and power for withstanding, temperature of the sensor device and the temperature of the surroundings, transfer of heat from one device to other and one node to other node and networks, voltage of the nodes and the network with group of sensor nodes, resistance that was being generated from each node and the other nodes in the network *etc*.

The main and important constituents of a sensor node are the memory, the receiver for receiving the signals, the transmitter for transmitting the signals to other nodes and to the network and other networks, for processing of the data at a particular node the microcontroller was being used, for working of the sensor node, a power supply was being established continuously or a battery with good life was equipped in a sensor which works at higher altitudes which takes longer time to replace and sometimes it is not possible to replace the battery or power supply to the sensor node. The wireless sensor networks will have an advantage of working in the environments where a human being can work. This feature enables them to be used in many applications at many places in real time nature. It is having several characteristics that specify them to be special in terms of work and other areas of the networks.

The major characteristics of these networks are the low cost in terms of operation and in terms of maintenance, efficiency in energy has to be more, the power that has be

needed to compute the applications, the capacity of the nodes to communicate with other networks or the other nodes in the other networks, providing security to the data in the network and also providing privacy to the existing network, the designing of the network should be in the optimized format, design technologies to be used for designing the network and various techniques required to analyze and develop the network and the network to be analyzed in terms of both quality of the network and in terms of the quantity of the network.

It is very important for any user to select or to design a wireless sensor network for any application in terms of cost of the design and its maintenance. Only the networks which were built by large industries or the other major companies can afford the high cost if the installing a wireless network. The small users or the users whoever designing or developing a network with small number of nodes highly influences the cost of the network or the usage of the network. If the cost of the network is high, the establishment or the usage of the network becomes very less. It is very evident that the cost in terms of developing a network with sensors mainly focuses on its cost. If it becomes huge in cost for establishment of a network at remote places, then the usage of these networks may reduce. The network should be very useful in terms of energy. The energy which emits by a network or the total energy that should be possessed by a network should be in less in size. The network always should be in a mode of efficient in terms of energy it is going to emit or to be used by these sensor networks.

If the networks using the high energy during its operations at various remote places, it becomes very difficult for us to replace the devices or batteries. Hence, it is desired always by a user to be these networks should use at a highly energy efficient mode. These devices should use as small energy as required for the working of these devices in the network. The other important characteristic to be considered was the power that was required for a node to process the data or to compute the value form a physical area. In some cases, it might be in a small area to compute and in other cases the area might be large in size. The other important consideration to be considered is the capacity of node for its communication. The node in a wireless network can have the capacity to transmit the data at various ranges. The communication in a network can be of either unidirectional or bidirectional. Both types of transmissions can be operated or performed by these sensor networks.

The channel that was being used for the communication between both the receiver and the sender was in unidirectional and bidirectional. The other important characteristics to be considered are the security that was being observed in these sensor networks. The nodes that were being used in these networks are vulnerable to be attacked by other users or the hackers at different places with different attitudes. Several nodes had observed the attacks from various users who were not authorized. These nodes are vulnerable for attacks from various unauthorized users at different places. In some cases, it is also possible for the nodes to be facing the problem of damaging or neutralizing the data that was stored in the sensor nodes in these wireless networks. The data that was being stored or processed at various nodes will carry important data that might be hacked or destroyed. Hence, it is required to provide some security to the data at various nodes in the networks.

The other important characteristics of the wireless sensor network were the designing issues of the network. It is very important for considering the several aspects like the number of nodes to be considered for designing the network, the load to be placed at each in the network and the amount of data that has to process by each node in the network and the throughput of the each node in the network. Hence, while designing a wireless sensor network, it is to be considered the important aspect in terms of the number of nodes that were going to be placed in the network. It is also important that the cost of these sensors was high. Hence, the number of nodes to be placed in a network is also one of the important considerations while designing a wireless sensor network. Hence the design of

the network should always be in an optimized manner in terms of number of nodes in the network and the utilization of the network.

The other most important characteristics to be considered were the techniques and the technology to be adapted and should be used for designing a wireless sensor network. The technology that was selected for designing a sensor network should always be the latest technology. One should have a good knowledge of selecting or adapting the latest technologies for design in these networks in terms of bot he the selection of nodes, connecting the nodes and the protocols that were being used to transmit and receive the data from these networks. Always the techniques we choose to implement in these networks should be optimistic in nature, very latest such that to reduce the size of the data to be stored at each node, the power consumption should be low at each node and the processing of the data at each node should be at high speeds which decreases the execution time for each node. By using the existing and new technologies in the networks, the quality of the network in terms of its working and its performance should be increased. The analysis which we are going to get from these sensor nodes should be always in quality in nature and the results should be qualitative too in term so f results when compared with the other networks with similar configurations.

These wireless sensor networks make the most of the layers in OSI (Open Systems Interconnection) structure. The layers which were observed in OSI model are physical layer, data link layer, network layer, transport layer and application layer. The communication of data packages in the network layer is very important. Hence, this task of communicating the data packages in this network layer can be performed by using data link layer, physical layer and transport layer *etc*. with the help of some of the routing algorithms available for the users. Even though these networks frequently maintain various network topologies for communicating the data between these nodes, the main IEEE802.15.4 base model sensor network topologies which were mainly used are star, tree, mesh, cluster tree. This protocol is mostly used for various household applications and it is being detached from various other communication standards like Bluetooth, WiFi and WiMAX by considering some of the major considerations for the performance of the network like the data transmission should be in small in size and consumption of the power is very small.

3. The IEEE 802.15.4 Standard

The earlier protocol standard IEEE 802.15 was used for network analysis and later on this protocol was progressed to the development of IEEE 802.15.4 which could be used to deal with wireless networks with low transmission rates. The newly developed standard provides importance to consumption of low-power, working on less-rate and working at a low- cost which aims at supporting combined standard for persons or family. The characteristics of this protocol standard are mostly useful and can be used vastly for the networks which are working on the same type of sensor nodes or same network configuration. Hence, this protocol was being considered as mostly useful for sensor networks and can be used by most of the research institutions for the testing and verification of their network problems. The newly developed standard will possess the following features like, [3-5]:

- This wireless network standard works at operating data rates of 40 kbps, 200 kbps and 250 kbps.
- It supports several topologies of the networks like star and peer to peer.
- It possesses 16-bit short and 64-bit IEEE addressing modes
- It optionally provisions for allocation of various time slots
- It possesses in total 27 channels of which one channel in the 868 MHz band, 10

channels in the 915 MHz ISM band and 16 channels in the 2.45 GHz ISM band.

- It works at very low power consumption mode

The present protocol IEEE 802.15.4 standard was also be named as the zigbee protocol. It is one among the set of wireless sensor network protocols used mostly for the operations in the sensor networks. These protocols mainly used for the routing of the data or the packets in the networks, assigning the sources, destinations and the routes to be selected for transferring the data from source to the destinations. The present protocol has several advanced and most useful features when compared to the other protocols in the sensor networks. The present network protocol was operates at several data rates at 40 kilobits per seconds, 200 kilobits per second and 250 kilobits per second. This protocol supports and works well on the several network topologies like star and peer to peer topologies. It works on various addressing modes like 1-bit and 64-bit addressing modes. It consists of several working channels of which some will work on one band of frequency and the other will work on some other frequency.

4. Simulation of the System Design

The IEEE 802.15.4 protocol was recently developed and was very helpful in solving the problems involved in sensor networks. This protocol was mainly used for the analysis of several network models like the star and peer to peer network topology. In the present article, two networks are considered for study as simulation scenarios, a cluster of tree network and mesh network. These two topologies are mostly used and analyzed to study the performance and very few properties of IEEE802.15.4. Cluster tree network can be considered as an explicit model of peer to peer network model. In a cluster tree model network, an FFD will act like a coordinator which can be used to manage the further devices and provides synchronization in various facilities to the end users. The important point to be remembered in this type of networks is that there exists only one unique FFD which act like a coordinator in the whole network.

The performance of any network that might be either a wired network or a wireless network should be analyzed. The analysis should be always in a fruitful manner such that it should be useful for the researchers and other users whoever using the similar type of networks with similar set of nodes at various configurations. It is very important for us to consider the need of developing or performing a simulation study of a wireless sensor network. The performance of any network can be analyzed or can be obtained in various parameters like graphs, tables and other mode of representations. The need for simulating a network model arises only when the user cannot be able to develop or implement it in any form of other modes.

In general, the network or its performance can be observed or to be calculated in terms of three modes. The first mode is the development of the physical setup which gives us the actual phenomenon or the actual behavior of the network that required for us. But, designing the actual model or the physical model will give us the bit pain of financial matters. It might be costs in some times very low and in some cases it might be very huge in terms of cost of establishing the actual or physical network. It is always not possible to establish a physical network by all types of users. Only the users who got sponsorships for their research may establish the physical setup.

Hence, it is not possible for all the users in the market to establish a physical network of the desired configurations. To overcome this problem, the other model which was available with the users was the mathematical modeling of the problem. By using various mathematical models with the help of various differential equations, linear equations and integral equations we can develop the similar model of the network with mathematical equations. By solving these equations we can get solution that could be assumed as the expected results from the behavior of the network that we are working on it. Several tools

and software's were available in the market for finding the solution to the generated or the developed mathematical models.

The third type of the model that was available with the users was the simulation model. The user can create the same scenario that he was willing to test in the real time scenario and he might check the performance of the network in terms of various graphical and tabular results. These simulators are of two types among which the open source simulators and the other were the paid simulators. The open source simulators may not get all the features required for the users to analyze the actual behavior of the network. The paid simulators or the commercial simulators will have all the features that were required to analyze the performance of the network in detail. The other model of the network design was to implement the same phenomenon in the programming language by using the languages like MATLAB in which we can write a program and test the behavior of the model by assuming various coordinates as the various point or nodes in the sensor networks.

All the above discussed three models of designing a network for finding the performance of a wireless sensor network with respect to throughput of the network and the delay in the network was analyzed. It is desired to develop a model in the physical setup but due to its financial model, we had opted the choice of designing a model of the network in the simulator of OPNET and had analyzed the performance of the network in terms of both the number of nodes with respect to the throughput of the network and the delay in the network.

4.1. Performance Evaluation of the Model

The performance of the IEEE 802.15.4 was analyzed by studying the following parameters. The study was to determine the effect of increase in number of nodes in the network with respect to the throughput of the network, delay in the network *etc*.

- **Throughout of a node:** The throughput of a node can be calculated as the total number of bits that were being forwarded from a node in a network. The performance of the network was mainly considered with respect to the throughput of the nodes in the network. The value of this parameter plays a vital role in analyzing the performance of the considered or developed network model. There might be a good change in the performance of the network with increase or decrease in the number of packets or the number of nodes that were being changing from a certain number of nods to a particular amount of nodes in a network. As the number of nods in the network increases, the behavior in the network performance and the delay in the network was also influenced. This might be observed and analyzed in detail at the results section.

- **Delay:** The delay in time can be calculated as the time that took by a packet to travel from one node to another node in the same network. In wired or wireless networks, the users can observe various types of delays like transmission delay which is observed at the time of transmission of packets from a node, propagation delay is the time taken for a packet to propagate from a node in the network, processing delay is the time taken by a packet for identifying the network and the senders address and receivers address for the successful delivery of the packets and the queuing delay is the time taken for a packet to be delivered to the destination in an order from its order of transmission form the transmitter.

- **Reception ratio of a packet:** It is the important consideration to analyze the performance of the network in terms of reception ratio. This ratio will give us the value of ratio from the packets that were being sent from the sender to the packets

that were being received at the receiver end in the Medium Access layer of the OSI model.

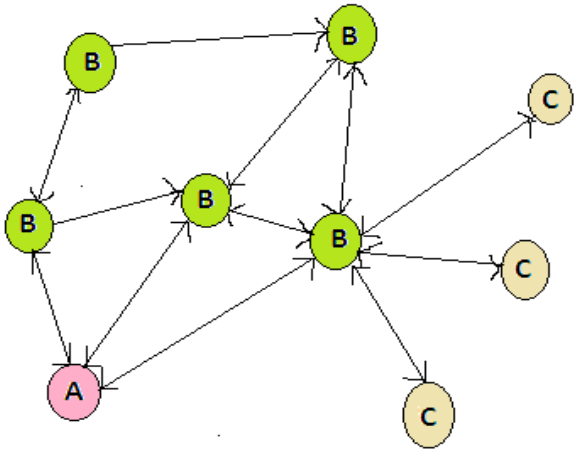

Figure 1. Mesh Topology Network

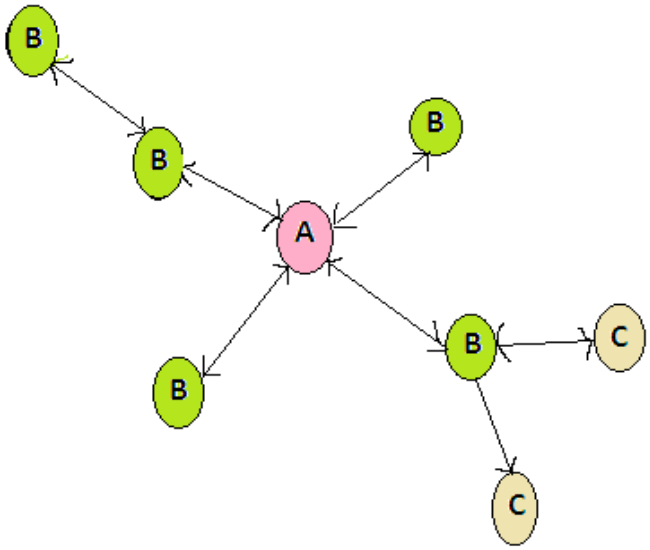

Figure 2. Cluster Tree Topology Network Model

The network models which were being considered and processed in this paper are given in detail above in terms of names as Figure 1 and Figure 2. The Figure 1 shows the architecture model of mesh topology which can be processed by using this IEEE 802.15.4 protocol. The second Figure 2 shows the model of cluster tree topology which we had considered in this model of problem for analysis. The detailed description for the analysis of this model was given with graphical representation. There were several network models or topologies available in the networks. Some of them are the star topology, bus topology, ring topology and the best utilized mesh topology. Each of the above said topologies having various advantages and disadvantages when compared to each other network topologies or the network models.

The ring topology might be used in the cities or the small towns. The bus topology may be used or might be used mostly in the organizations having multiple buildings or multiple floors in the single building. The LAN topology can be best used for colleges and schools with several class rooms and several offices at a single place even in a single

building in some cases. The mesh topology was mostly used in research purposes for large number of nodes and their load considerations at various places. Most of the wireless sensor networks might use these mesh topology network models which helps in various research findings and their analysis.

5. Experiment and Simulation Analysis

In this section, the performance of the network model is analyzed by using the present scenario with technical details. In the present scenario around 500 nodes are distributed randomly in a 100 × 100 m2 area. The source packets in the present scenario obey Exponential distribution. The application layer consists of messages which are of size 1024 bits. In the present experiment, two types of propagations were considered for the execution out of which the first one is direct propagation path and the second one is the ground reflection path. In the present model, we are trying to solve the consequence of the presence of the nodes of the number of extent they were present on the performance of the system. The present model is considered to identify behavior of the parameters like throughput of the nodes and the delay in nodes with respect to the nodes.

It is always evident that the performance of any wireless sensor network should be analyzed in terms of graphical representations and tabular representations. It is easy to understand the graphical representation of any devices performance. In the present application in the networks, the protocol was being implemented in the sensor network and the results from the analysis were placed in terms of graphical representation. It is important to consider the throughput of the network and delay of the network. The throughput of the network was the number of packets or the amount of data that was being transmitted through the nodes at a point of time and here in the following graph it is represented with various time slots with various numbers of nodes.

From the Figures 3 and 4, it is observed that the number of nodes is to be considered is from 200 and 500, the throughput of nodes increases as the number of nodes from time to time in the network. Conversely, as the problem of network congestion was observed, as the node number is greater than 200, the average amount of throughput in the network decreases likewise. As the number of nodes increases in number, the collision between the packets increases which results in increase of collision ratio between packets as of result the delay also increases accordingly.

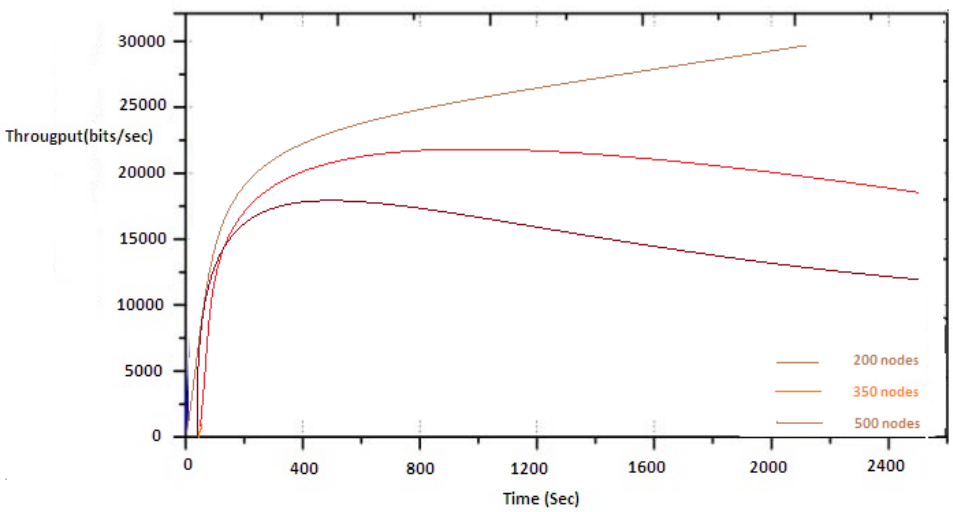

Figure 3. Throughput vs. Time (Sec)

In the above graphical representation, time taking for each node in the network with respect to the thrpughput of the nmodes in the network was represented. Here, we had considered the three set of nodes and taken as three combination of nodes. These three combinations are 200 nodes, 350 nodes and 500 nodes. The throughput of the network with respect to the number fo nodes was analyzed here with respect to the protocol IEEE 802.15.4 zigbee protocol. From the results that were being obtained from the analysis, it is clearly observed that the increase in the node number in the network decreases the throughput of the network. As the node number increases from 200 nodes to 350 nodes, the throughpiut decreases from 25000 bits /sec to 19000 bits/sec. As the node number increases further from 350 nodes to 500 nodes in the network, the throughput of the network further reduces from 19000 bits.\/sec to 14000 bits/sec. From the above results it is observed that the numebr of noes in the network increases the throughput of the network decreases.

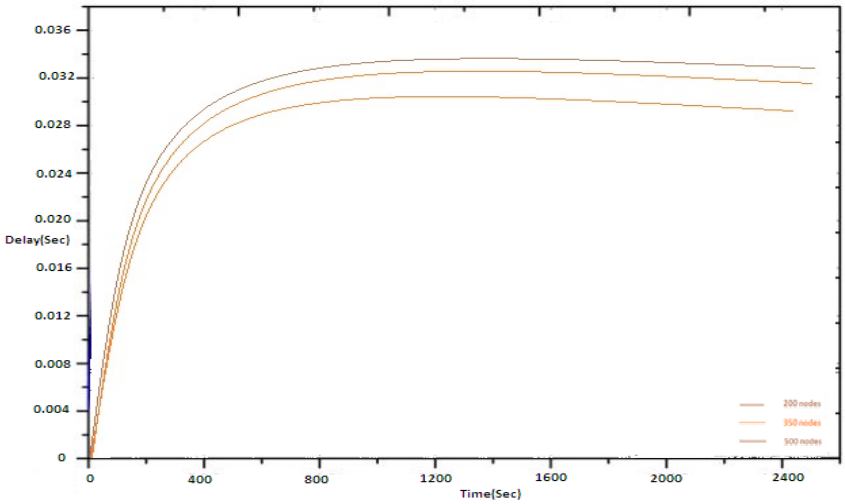

Figure 4. Delay vs. Time (Sec)

The above Figure 4 gives the representation of the delay in the network to the time of the network in terms of number of nods in the network. As the number of nodes in the network increases to some extent the delay in the network decreases. The number of nodes that were being increased in the number are from 250 nodes, 350 nodes and 500 nodes respectively. As the number of nodes increases, the delay in the network decreases from 0.033 sec of time to 0.026 m sec and decreases further to the 0.028 sec with increase in the number of nodes. Hence, from the above graphical representation it is evident that the increase in the number of nodes in the network might reduce the delay in the network. This result might help in increasing the number of nodes in the network whenever we need to establish a new network or we should like to increase the number in terms of nodes in the network. This might helpful to many researchers as the basic point to be considered whenever they were intended to design a wireless sensor network with various combinations of nodes and with loads on each node in the network.

6. Conclusions

The wireless network standard IEEE 802.15.4 was aimed at meeting the requirements of the users who needs to run the wireless network with little cost for operation and small power consumption during the working of the network. This standard has a very useful

features for the users like low transmission rate at small networks, the communication range is small for smaller networks such the power consumption is reduced and it is very easy to install by a new user with very less knowledge about the simulators. In the present paper, the present scenario which is built here was established on Riverbed OPNET for analyzing and studying the performance of IEEE802.15.4 in terms of throughput in the network with respect to the nodes number. With the help of Riverbed OPNET simulator the present network model was analyzed.

The simulation was started to study and analyze the consequence of altering the number of nodes in wireless network in terms of the system throughput and delay in by considering various network load conditions. From the results, it is observed that the throughput of the wireless network has a largest impact and with the increase of nodes to some extent, network could attain the state of congestion state and could lead to the weakening of the performance of the network. Hence from the results, it is observed that the load on the network in terms of number of nodes, the performance of the network was affected and should take some precautions in considering the nodes number such that to yield good performance from a network.

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