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IMPACT OF INTERFERENCE ON WIRELESS MESH NETWORK PERFORMANCE

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ABSTRACT

To date, wireless access network is deemed essential in many domains of the industry and the academic. The wireless access technology allows a user to be mobile within the local coverage and remain connected to the network. In a highly-dense residential area, each resident unit may be associated with a single wireless network. Multiple wireless network in proximity can lead to interference, due to the limited availability of wireless channel to be selected. Therefore, the accumulation of wireless network in a severely contained area may lead to suboptimal performance. In addition, a particular wireless technology, which is Wireless Mesh Networks (WMN) is extremely dependent on the mesh topology to provide complete redundancy and reliability to the network connection. Despite such provision, the inherent issue with such arrangement is the radio interference impacted on the wireless communication. This research study aims to quantify the performance of mesh network when exposed to extremely high interference in grid wireless network. In addition, the paper also discusses about the fundamental model of WMN and the simulation tool used in the experiment. The design of experiment is also presented, including the performance metrics to evaluate the wireless performance.

Keywords: wireless mesh network, network simulation, interference, performance evaluation.

INTRODUCTION

Access to the Internet and online medium is one of the essential components of our daily lives. As a matter of fact, much of the business matters and financial transaction are operated online and mobile, where consumers can instantly access the content while mobile. Indeed, some of the cities have deployed a complete wireless connectivity to the citizens. In big cities, most café shops are equipped with free WiFi access to the customers. In future, the introduction of Industry Revolution 4.0, the wireless connectivity may become an integral part of the system. Machines have the ability to interactively communicate with another machine and also human. The emerging interest of such technology will lead to the high dependency of wireless connectivity and along with the expectation of reliable connection and redundancy. To create a resilient network, multiple access point (AP) is placed at various location within the predetermined network area. Several gateways are also needed to enable traffic from within the network to be propagated to the Internet. Nonetheless, in such network topology i.e. WMN, the absence of a central server to manage accounting, authorization and authentication is quite a challenge. On the contrary, a properly structured wireless system is able to monitor bandwidth utilization and rapidly adapt to changes leading to optimal network performance.

In light of the issue, this research work investigates via simulation experiment the performance of WMN when subjected to severe interference by proximity wireless nodes. The experiment is conducted by using a credible simulation tool i.e. Network Simulator 3 (NS3). Typical WMN can be classified into two types. First, sensor networks comprising of devoted devices that offers the ability for users to monitor and estimation information about the environment. Secondly, the sensor network is a set of specially appointed systems, formed on-demand with minimum intervention by human.

To quantify the simulated grid wireless network, the NS3 is employed. The tool is modular and specific features of WMN can be investigated. In addition, a specific routing protocol is adopted to be used as the basis for routing communication between the nodes. Data packets is generated randomly and transmitted using the standard 802.11 protocol and transported using user datagram protocol (UDP). Figure-1 shows the classic wireless topology based on 802.11 Local Area Network (LAN). The choice of UDP for the experiment is to remove the additional overhead of packet retransmission offered by Transport Control Protocol (TCP). It is deemed sufficient to minimize the bandwidth utilization, which otherwise may impact the network performance evaluation. Therefore, by using UDP, results obtained from the simulation experiment will be more credible and genuinely reflects the effect of radio interference to the wireless communication. Two performance metrics are used to quantify the wireless network i.e. throughput and average packet delay.

LITERATURE REVIEW

As previously stated, Figure-1 shows a typical IEEE802.11 LAN topology. Standards of IEEE802.11 in wireless networks have important features that is diverse from classic wired system. In IEEE802.11 protocol stack, the physical (PHY) layer employed a carrier sense multiple access/collision avoidance (CSMA/CA) approach as compared to collision detection in the wired system. The basic service set (BSS) is a set of stations (STA) competing for usage of shared wireless medium. BSS is typically isolated or linked to the backbone distribution system (DS) via an AP. Figure-1 illustrates two BSS, where all of them has two stations (STA). Both stations in BSS connect to one another via AP which functions as relay and AP also become a bridge to the DS. Independent BSS (IBSS) occurred when all stations in the BSS will be the mobile station and no connection to additional BSS. Typically, an ad hoc network, all stations can directly communicate to each other. Although extended service set may be the most generic topology of a wireless network, the system may still rely on several BSS connected to DS.

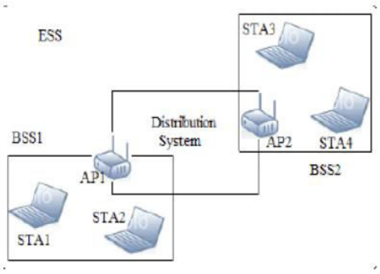

Figure-1. IEEE 802.11 LAN topology.

There are several research works, which discuss about the impact of noise interference on 802.11 technology [1] [2] [3] [4] [5] [6]. Many of the papers are quite recent and therefore, it is deemed that the research on such issue is quite relevant and essential for investigation.

Jaejin *et al.* [1] in the paper discussed about out-of-channel Radio Frequency Interference (RFI) noise. The research work identified that WiFi throughput is affected i.e. decreased when impacted by out-of-channel noise. The author also determines that it may be possible that WiFi radio to be immune to RFI noise when frequency spacing is increased. In addition, the WiFI radio can further sustain noise higher than -80 dBm when RFI is located on the edge of the channel. The study provides insights on the design of RFI-risk platforms. Nonetheless, the research work does not account for the cross interference due to proximity nodes on parallel WiFi channel.

The co-existence of WiFi and ZigBee network in a scenario is investigated by a research work [2]. It is shown by modeling and simulation experiment that a mesh topology offers the worst performance. The throughput of both network i.e. WiFi and Zigbee are severely degraded due to co-channel interference.

In other research work [3], the radio frequency interference is measured empirically in a campus network. It is determined based on the experiment that packets are dropped due to poor signal strength during transmission. Network management tools such as Cisco Prime Infrastructure and Wireless LAN Controller are employed to quantify the network performance. A two months period of data collection are required to generate a satisfactory report. The results confirmed that there is an excessive amount of co-channel and co-adjacent inference due to inapt placement of Access Points (AP) and the severe congestion of large number of users, which operates on the same frequency bands i.e. 2.4 GHz.

The existence of WiFi interference and the effect on the network performance is also verified by Jiun-Ren Lin [4]. The research work reports that based on a comprehensive experimental study of Intra-Vehicular Wireless Sensor Network (IVWSN), the Bluetooth Low Energy Technology is more feasible choice to be used in a high density WiFi communication networks.

The research works by the authors in [5] [6] also confirmed that the existence of WiFi interference, which particularly affect the Zigbee devices transmission. The main reason such technology is susceptible to interference is due to the fact that WiFi-equipped devices have higher transmission power. As such, the research works implicitly confirms that in a highly congested network such as in a grid topology (and nodes are placed in proximity), the existence of WiFi interference is highly likely.

IEEE Standards

Since the released of the IEEE80.211 in 1997, the protocol stack specifies the Physical (PHY) layer and Media Access Control (MAC) layer separately. It includes the bandwidth speed of 1-2 Mbps and three choices of PHY technologies, which are infrared i.e.1Mbps, the regular hopping spread spectrum operating at 1 or 2 Mbps and the immediate sequence spread spectrum operating 1 or 2 Mbps. Later, many amendments were introduced, attempting to compensate for the drawbacks.

Wireless Mesh Networks (WMN)

In WMN, mesh nodes can be categorized into two types, which are mesh router and the second type is mesh clients. Usually, the mesh router is equipped with a minimal network interfaces and highly complex software essential to support different wireless technologies, including mesh routers that are fixed at the appointed locations.

The main function of mesh router is to form the ad hoc ‘backbone’ network. However, mesh routers also can be deployed as a gateway to connect the backbone network with the external networks. The mesh client is an end-user for the network that connects to the network through the mesh router. The mesh client is usually mobile and equipped with only a single wireless interface [7].

The architecture of the mesh networks contains three types of networks:

- Backbone network - this type of network is formed by the mesh routers that are connected to each other by using existing radio technologies and mostly IEEE 802.11 technologies are the popular standard used in this network. This type of network also is capable to enabling Internet access for the mesh network through the gateway functionality.
- Client network - usually this type of network are the conventional ad hoc networks with the self-configuration and self-healing attributes of the mesh network.
- Hybrid mesh network - backbone and client types are combined to form this hybrid type of network. Mesh client can communicate with other mesh clients as well as can access the network through the mesh routers.

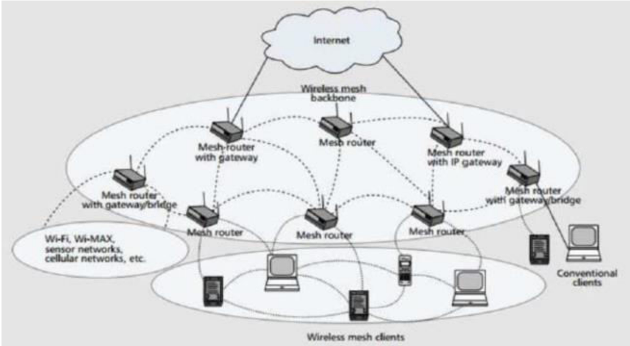

Figure-2. Wireless Mesh Network.

In Figure-2, the dotted and solid lines represent the wireless and wired links, respectively. A hybrid mesh network (type 3) is a combination of wireless mesh backbone or backbone network (type 1) and wireless mesh clients or client network (type 2).

Network simulator

There are several types of network simulators available to be employed for experimental analysis. It is also imperative that the choice of tool for the simulation must be able to replicate the as accurate as possible to real system i.e. WMN. As such, to select the best and suitable environment for evaluating and analyzing the performance of WMN, a brief comparison of two choices of simulator is presented.

Network Simulator 2 (NS2) is a discrete event simulator focused for research in computer networking. The simulator provides a layered approach to build nodes, topology, routing protocol, radio propagation model and other pertinent components in WMN. It also supports various protocol for unicast, broadcast and multicast over wireless communication. The features enable the WMN to be thoroughly measured in various network scenarios and traffic load [8]. To support communication between nodes, the NS2 supports large number of routing protocols and modules, developed by researchers over the years. The simulation supports several routing protocols such as ad-hoc on-demand distance vector routing (AODV) [9] and dynamic distance-sequenced distance-vector routing (DSDV). Nonetheless, when used in WMN environment, high overhead is incurred due to frequent broadcast packet disseminate in the network. Therefore, the choice of routing communication for the research work is Optimized Link State Routing Protocol (OLSR). Subsequent section discusses the OLSR.

In general, much of the modules in NS2 are contributed by the research community. The NS2 is formed by two components. The core of the simulation is based on C programming language, while the variables definition and topology configuration is done by TCL script. The binding of both programming languages is complex and may not be as efficient and less intuitive for extensive simulation work.

An improved version of Network Simulator is NS3, is recently introduced. There are several advantages of NS3 compared to NS2. The main advantages are NS3 is that is employed a single language, i.e. C++, which allows for efficient simulation and support extensive experiment iteration with less resource utilization [10]. The below are the points considered when choosing NS3 as the main simulation tool for this work.

- Extensible software core: written in C++ with optional Python interface and an extensively documented API (doxygen)
- Attention to realism: model node more like a real computer and support key interface such as sockets API and IP/device driver interface (in Linux)
- Software integration: conforms to standard input/output formats (pcap trace output, NS2 mobility scripts, etc) and adds support for running implementation code
- Support for virtualization and testbeds: develops two modes of integration with real systems.

  - Virtual machine run on top of NS3 devices and channels
  - NS3 stacks run in emulation mode and emit/consume packets over real devices

- Flexible tracing and statistics: decouple trace sources from trace sinks so we have customizable trace sinks
- Attribute system: controls all simulation parameters for static objects, so you can dump and read them all in configuration files.
- New models: includes a mix of new and ported models.

Optimised link state routing protocol

As previously stated, the choice of routing protocol for this research work is OLSR. The routing protocol is an IP routing protocol, optimized for mobile ad-hoc networks, which may also be used on other types of wireless ad-hoc networks [11], including WMN. The OLSR protocol is a proactive routing protocol, which accumulates a path for data transmitting by keeping a routing table inside every node of the network. OLSR apply the HELLO packets to identify its one hop neighbors and its two hop neighbors through their responses. This protocol does not need a reliable transmission because of its control message, each node transmits its control messaged periodically and may occasionally sustain the lack of packets. OLSR protocol performs hop by hop routing with each node uses its latest information to path a packet [12].

PERFORMANCE EVALUATION METHOD

The performance of the WMN is simulated with using nodes arranged in grid. Such topology enables the network to be quantified with respect to high radio interference between the neighboring nodes.

Topology patterns

Figure-3 shows the distribution of nodes in a grid network. The separation distance between each node horizontally and vertically is 125 meters. The nodes

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around the area are located exactly on the border of the network area. The wireless nodes are set to be within other nodes radio coverage to see the impact of multiple radio interference to the network performance.

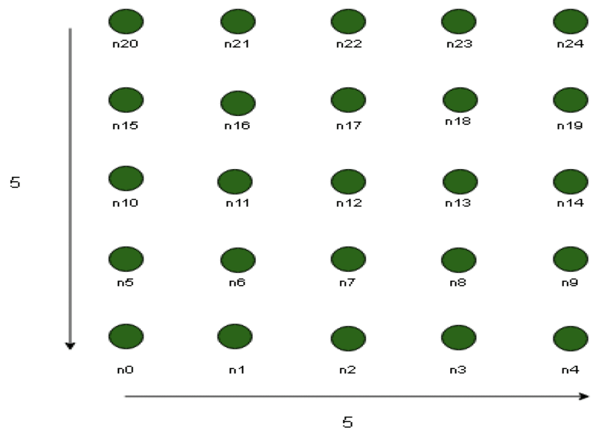

Figure-3. Mesh nodes 5 by 5.

The radio signal strength of each node is set to default i.e. 250 meters. Therefore, in the topology shown by Figure-3, each wireless node will be within other node's radio range. In the worst-case scenario, for node 12 i.e. n12, the node will be receiving radio interference from all 24 nodes. Such condition may impact the ability of the node to send and receive packets. Subsequently, the network performance will be affected.

Grid topology and routing decision

The traffic in the network topology utilizes UDP. The routing decision process is performed by the source node when it has data packets to transmit or when it receives packet that needs to be forwarded to the destination. In Figure-4, n0 intends to transmit a data packet to n24. Therefore, n0 refers to its neighbor table, which is constructed during the neighbor discovery process. Based on Figure-4, the source node i.e. n0 identifies that it has three neighbor nodes, which are n5, n6 and n1. After n0 ensure that the nodes are in the same quadrant, the node will forward the data packet to node n24.

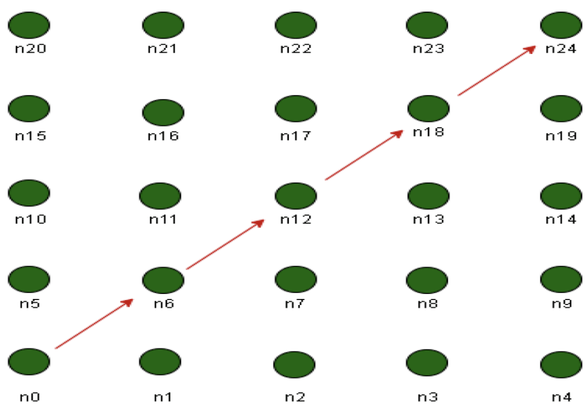

Figure-4. Route taken by a packet from n0 to n24.

Such mechanism as previously described is the feature of OLSR, where packets are sent only as needed. In Figure-4, n0 attempts to send a data packet to n24. Therefore, before packet is transmitted, n0 refers to its neighbor table, which was constructed during the neighbor discovery process.

Simulation tool

To test and verify the topology design, NS3 is used as the simulation tool. As previously discussed, Network Simulator provides an efficient method to simulate complex network. In addition, NS3 is the more advance version, which addresses the weaknesses in NS2. Therefore, the tool is chosen as the simulation tool for this work.

Simulation experiment

In principal, the process flow to create and run a simulation in NS3 is shown by Figure-5. The nodes must be created prior to setting the position of the node. Next, the topology of the network is created by assigning the x and y value to locate the nodes on the network area. In the research experiment, each node is set to be stationary and therefore, the mobility model is not required. In the next step, the net device is bound to the nodes before connection between nodes can be made.

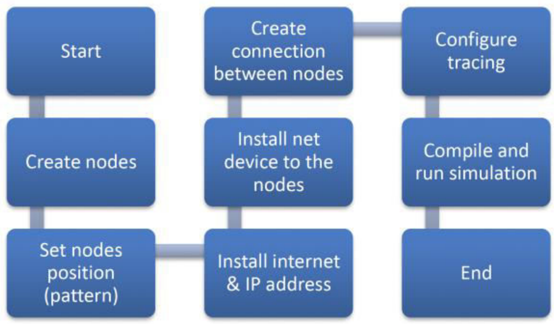

Figure-5. Flowchart to create and run simulation in NS3

In the actual node, the net device can be regarded as the network card. Subsequent to the binding of net device, the location of the node and the routing protocol is configured. At the application layer, a user needs to configure the connection of the nodes. In other words, users must define the data connection pattern on the network. Tracing generates all the relevant information of simulation such as time stamp, the flow of packets according to packet identification number and the status of the packets. After every setting and configuration is set, the simulation calls the run function and the simulation will begin to execute.

RESULTS AND ANALYSIS

Effect of the number of nodes within fixed area size

To investigate the effect of the number of nodes in the network, N numbers of mesh nodes are located within 5 x 5 area and the value of N is increased with the

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sequence of 25, 50, 75 and 100. The throughput [13] and the packet delay are presented in Figure-6 and Figure-7 [14].

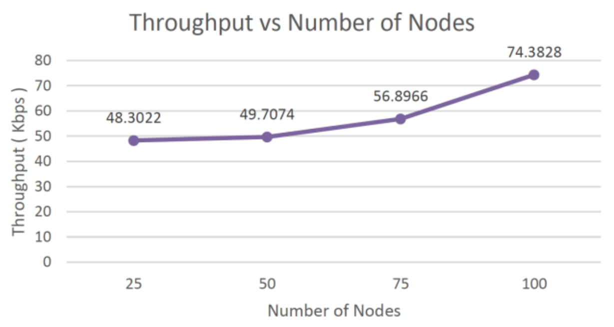

Figure-6. Throughput performance results with different number of nodes.

Figure-6 shows when there are 100 nodes in the area, the throughput for wireless network is better compared when the number of nodes is 25, 50 and 75. Since the number of data connection between nodes is according to the number of nodes in the network, the congestion problem arises when there were 100 nodes with 5 x 5 gird area. With 100 connections, the path for every node to forward the packet according to the destination of the sink node. Nodes that were not in the specified quadrant for the connection were not involved in the forwarding process. As a result, the congestion in the network decreases and more packets are successfully delivered to the destination.

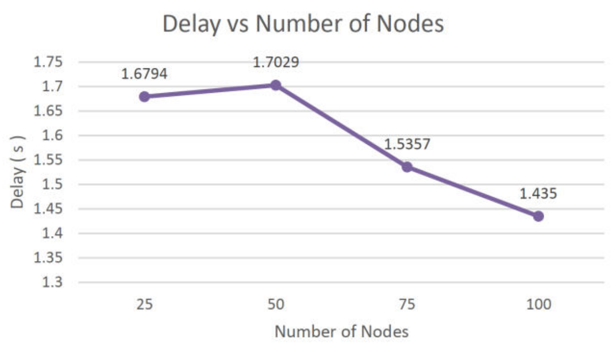

Figure-7. Delay performance results with different number of nodes.

Figure-7 shows the average packet delay to deliver data packet from source to destination decreases as the number of nodes is increased. It is because when the number of connections is increased, the traffic is high and causes congestion to the network. Some collisions may happen, and node need to wait for the available path to route the data. It seems that the time delay for number of nodes 25 and 50 is 1.65s as compared to time delay when the number of nodes is set to 75 and 100. For greater number of nodes, which corresponds to high-density network, packet propagation time is the longest, and therefore the time to deliver the data packet is much significant than 25 and 50 of nodes.

Effect of the size of network with fixed number of nodes

For this experiment 25 nodes are created and located randomly in the size of network of 100-meter, 200-meter, 300-meter, 400-meter and 500-meter. The throughput from this simulation is shown in Figure-8 and the average packet delay is depicted in Figure-9.

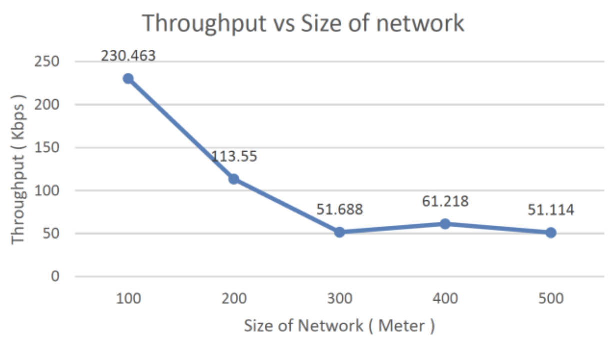

Figure-8. Throughput performance result size of network.

Figure-8 shows throughput decreased as the size of network is increased. This is because as the network becomes scarce, there are probabilities that nodes are located far away from each other since the distribution of nodes in the network is random. If the distance between two nodes is higher than the transmission range, both nodes cannot be connected to each other. As a result, not all packets can be sent because no path to the destination can be found. This explains why throughput for the 500-meter is the lowest compared to others.

In terms of average packet delay, 100-meter the lowest time delay for the network in all simulated size as shown in Figure-9. It shown that, the highest packet delay in network is with 500-meter. The increasing of packet delay for size of network is because the total received packet is increase.

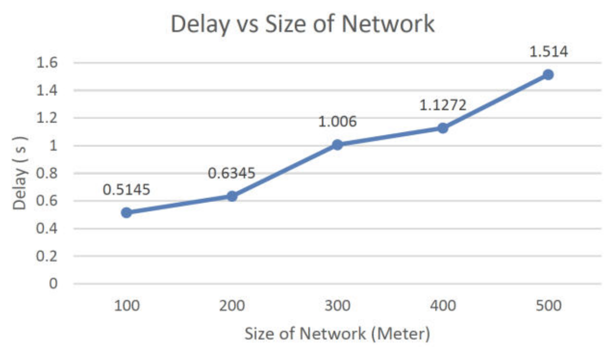

Figure-9. Delay performance result size of network.

Effect of the packet size with fixed number of nodes

In this experiment, the number of nodes is fixed. Nodes are created in the packet size of 200, 400, 600, 800

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and 1000. The throughput from this simulation shown in Figure-10 and the packet delay is illustrated by Figure-11.

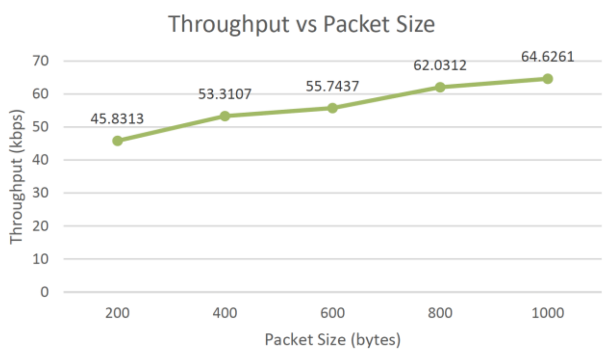

Figure-10. Throughput performance result of packet size.

Figure-10 shows the throughput performance result of packet size. For each packet size, the throughput of network traffic increases. It can be observed that the throughput increases as the packet size is getting bigger. The increment is because the connections between nodes are according to the number of nodes, hence more data transmitted and delivered.

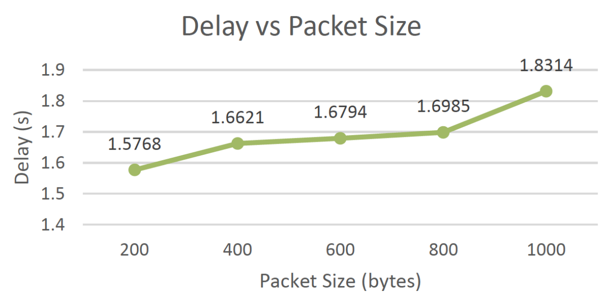

Figure-11. Delay performance result of packet size.

The results for average packet delay in the simulation are plotted against the packet size in Figure-11. For each packet size, the delay increases with the increase in packet size. As such, the packet received may be delayed and queued as compared to a transmission with a smaller packet size. Large size packets can be more easily fill the buffer than small packets and will cause packet drop.

CONCLUSIONS

In conclusion, the research work investigates the impact of severe interference of proximity nodes in WMN with using Network Simulator 3. The choice of NS3 is due to the credibility of the simulation tool and the ability of the tool to provide modular layer of the TCP/IP protocol stack. The analysis of network performance is done based on various performance metric. The type of packet is kept consistent i.e. UDP. It is deemed that the increasing the number of nodes and packet size causes the increase in the throughput of network. However, the increasing size of network may decrease the throughput of network. The observation on packet delay is done by varying the value of size of network and packet size. When both values i.e. size of network and packet size is increased, the delay is increased because the packet requires a longer path to propagate from source to destination. However, delay from source to destination decreases as the number of nodes is increased. It is clear that multiple packet transmission may affect the wireless network performance.

REFERENCES

[1] J. Lee, H. Hsu, P. Davuluri, Y. Ho and J. Chen. 2017. Impact of broadband and out-of-band radio frequency interference (RFI) noise on WiFi performance. 2017 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI), Washington, DC. pp. 456-457.

[2] S. Arif and S. H. Supangkat. 2014. Simulation and analysis of ZigBee - WiFi interference. 2014 International Conference on ICT for Smart Society (ICISS), Bandung. pp. 206-210.

[3] T. S. Andjamba, G. L. Zodi and D. S. Jat. 2016. Interference analysis of IEEE 802.11 wireless networks: A case study of Namibia University of Science and Technology. 2016 International Conference on ICT in Business Industry & Government (ICTBIG), Indore. pp. 1-5.

[4] J. Lin, T. Talty and O. K. Tonguz. 2013. An empirical performance study of Intra-vehicular Wireless Sensor Networks under WiFi and Bluetooth interference. 2013 IEEE Global Communications Conference (GLOBECOM), Atlanta, GA. pp. 581-586.

[5] H. Jiang, B. Liu and C. W. Chen. 2017. Performance analysis for ZigBee under WiFi interference in smart home. 2017 IEEE International Conference on Communications (ICC), Paris. pp. 1-6.

[6] D. Croce, D. Garlisi, F. Giuliano and I. Tinnirello. 2014. Learning from errors: Detecting ZigBee interference in WiFi networks. 2014 13th Annual Mediterranean Ad Hoc Networking Workshop (MED-HOC-NET), Piran. pp. 158-163.

[7] Akyildiz I. F., Wang X. & Wang W. 2005. Wireless mesh networks: A survey. Computer Networks. 47(4): 445-487.

[8] Issariyakul T. & Hossain E. 2012. Introduction to network simulator NS2. Introduction to Network Simulator NS2. 2012, https://doi.org/10.1007/978-1-4614-1406-3.Alotaibi, E., & Mukherjee B. 2012. A

survey on routing algorithms for wireless Ad-Hoc and mesh networks. Computer Networks. https://doi.org/10.1016/j.comnet.2011.10.011.

[10] Chaudhary R., Sethi S., Keshari R. & Goel S. 2012. A study of comparison of Network Simulator -3 and Network Simulator-2. International Journal of Computer Science and Information Technologies. 3(1): 3085-3092.

[11] Clausen T. & Jacquet P. 2003. Optimized Link State Routing Protocol (OLSR). IETF RFC3626, 75, https://doi.org/10.1.1.11.620.

[12] Liang S. (Lynn). 2010. Performance evaluation of multihop wireless network. Masters Degree dissertation, Massey University.

[13] Ng P. C. & Liew S. C. 2007. Throughput Analysis of IEEE802.11 Multi-Hop Ad Hoc Networks. Ad Hoc Networks. 15(2): 309-322.

[14] Woon W. T. H. & Wan, T.-C. 2008. Performance evaluation of IEEE 802.15.4 wireless multi-hop networks: simulation and testbed approach. International Journal of Ad Hoc and Ubiquitous Computing. (1): 57-66.