Performance Evaluation of 802.11 Networks Using OPNET

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***Abstract*— IEEE 802.11 standard allows different electronic devices to wirelessly exchange data over the computer network. Wireless networks have become a norm with the growing technology and play a very important role in our lives. Different wireless standards have their own advantages and disadvantages. Hence it becomes important to compare and evaluate them to determine the standard suitable for the network environment. In this paper, we demonstrate a way of simulating different 802.11 standards using Riverbed OPNET modeler. This study experimentally examines the network performance of 802.11 b/n networks. Each network is simulated using OPNET with varying 802.11 network standards b/n, number of nodes and traffic sources. The study is focused towards parameters like end-to-end delay, throughput, retransmission attempts, packet loss. Also, network response towards node failures and handling traffic congestion is simulated to determine the better network for the environment.**

Keywords—IEEE 802.11, OPNET, Performance and Simulation.

1. Introduction

Wireless LAN technology is now becoming a viable alternative to traditional wired solutions. There are several advantages to a wireless network. Since wireless networks require no physical connection between the end user and a network server, they are generally less expensive to install. They require less infrastructure and are an easier solution for hard to reach places. The WLAN (Wireless Local Area Network) protocol, IEEE 802.11, allows wireless and mobile network access to a network infrastructure. Before the 802.11b protocol (which was coined Wi-Fi) was widely adopted in the early 2000s, to get high speed network access to your LAN you had to be physically connected via a cable. The family of 802.11 protocols are made up of an arrangement of over-the-air modulation techniques that use the same basic principles.

The 802.11 wireless standards can differ in terms of speed, transmission ranges, and frequency used. The most widely used protocols are the 802.11b, 802.11g and 802.11n for 2.4GHz networks and the 802.11a, 802.11n and 802.11ac for 5GHz networks.

- **IEEE 802.11 Original**: There were two variations on the initial 802.11 wireless standard. Both offered 1 or 2Mbps transmission speeds and the same RF of 2.4GHz. The difference between the two was in how data traveled through the RF media. One used FHSS, and the other used DSSS. The original 802.11 standards are far too slow for modern networking needs and are now no longer deployed.

- **IEEE 802.11a:** The 802.11a standard was far ahead of the original 802.11 standards in terms of speed. 802.11a supports bandwidth up to 54Mbps and signals in a regulated frequency spectrum around 5 GHz, but most commonly, communication takes place at 6Mbps, 12Mbps, or 24Mbps. This higher frequency compared to 802.11b shortens the range of 802.11a networks. The higher frequency also means 802.11a signals have more difficulty penetrating walls and other obstructions. 802.11a is incompatible with the 802.11b and 802.11g wireless standards. 802.11a is also referred to as *Wi-Fi 2*.

- **IEEE 802.11b:** The 802.11b standard provides for a maximum transmission speed of 11Mbps. However, devices are designed to be backward-compatible with previous 802.11 standards that provided for speeds of 1, 2, and 5.5Mbps. 802.11b uses a 2.4GHz RF range and is compatible with 802.11g. Being unregulated, 802.11b gear can incur interference from microwave ovens, cordless phones, and other appliances using the same 2.4 GHz range. 802.11b is also referred to as *Wi-Fi 1*.

- **IEEE 802.11g:** 802.11g is a popular wireless standard today. 802.11g attempts to combine the best of both 802.11a and 802.11b. 802.11g offers wireless transmission over distances of 150 feet and speeds up to 54Mbps compared with the 11Mbps of the 802.11b standard. Like 802.11b, 802.11g operates in the 2.4GHz range and therefore is compatible with it. 802.11g is also referred to as Wi-Fi 3. Pros of 802.11g is that it is supported by essentially all wireless devices and network equipment in use today and is thus less expensive. The problems is that entire network is slow to match any 802.11b devices on the network which is the slowest/oldest standard still in use.

- **IEEE 802.11n:** The newest of the wireless standards listed in the Network+ objectives is 802.11n. The goal of the 802.11n standard is to significantly increase throughput in both the 2.4GHz and the 5GHz frequency range. *802.11n* was designed to improve on 802.11g in the amount of bandwidth supported by utilizing multiple wireless signals and antennas (called *MIMO* technology) instead of one. The baseline goal of the standard was to reach speeds of 100Mbps, but given the right conditions, it is estimated that the 802.11n speeds might reach a staggering 600Mbps. In practical operation, 802.11n speeds will be much slower. 802.11n also offers somewhat better range over earlier Wi-Fi standards due to its increased signal intensity, and it is backward-compatible with 802.11b/g gear. 802.11n is also referred to as *Wi-Fi 4*.

- **IEEE 802.11ac:** 802.11ac utilizes dual-band wireless technology, supporting simultaneous connections on both the 2.4 GHz and 5 GHz Wi-Fi bands. 802.11ac offers backward compatibility to 802.11b/g/n and bandwidth rated up to 1300Mbps on the 5 GHz band plus up to 450Mbps on 2.4 GHz. Most home wireless routers are compliant with this standard. 802.11ac is also referred to as *Wi-Fi 5*.

With different standards for wireless communication, it is important to find out which is suited for the network environment. Thus, the goal of the paper is to evaluate the performance of the standards under different scenarios. Section 2 describes the related work. **Section 3 talks about the methodology used to evaluate the networks. Section 4 lists the performance metrics used for evaluation.**

2. RELATED WORK

There is a growing literature on wireless traffic measurement and Internet protocol performance over wireless networks. Network simulators provide an easier method to construct networks, evaluate them before deploying them in the real environment. So, the use of network simulators is common technique to evaluate the quality of the network.

V Kulgachev and H Jasani[1], 2010, compared the performance of 802.11b and 802.11g by simulating and evaluating using OPNET. Standalone networks and hybrid networks were evaluated by the means of network delay, network load, throughput and media access delay. Number of nodes were varied for different scenarios.

Idris Babiker, Dr. Amin Babiker [5], 2016, presented a study on voice over wifi performance for 802.11b, a, g, n releases based on throughput, delay and packet drop key performance indicators.

Vithika Singh, Shahiruddin, D.K Singh, Priya Jayaswal [2], 2014, performed a simulation study of an IEEE802.11b WLANs used to model a WLAN sub network deployed within an enterprise WAN framework based on parameters like WLAN load data, Packet Delay and Medium Access Delay, and the overall throughput of the WLAN by varying data rate and physical characteristics.

Seema, Vikram Nandal, Kuldeep Vats, Sonia [4], 2014, proposes a solution for performance enhancement of Ad-hoc WLANs. Also compares the performance of Small size and large network over different IEEE 802.11a and IEEE 802.11b standards based on performance of the network over different QoS parameters like delay, network load, throughput, routing traffic sent and received, and hello traffic sent.

Evizal Abdul Kadir, Apri Siswanto, Abdul Syukur [3], 2016, performed a study simulation to estimate the number of web user clients and other network applications that could be supported by the Wireless LAN 802.11n to provide certain network load.

3. METHODOLOGY

A network simulator is a software program that simulates the working of network modeled with devices, traffic, etc. while supporting most of the modern network protocols. Nowadays, there are numerous network simulation tools available on the market such as ns2/ns3, OMNET+++, GloMoSim, NetSim, OPNET. This paper uses OPNET Modeler 17.5 to evaluate the performance of the 802.11 networks and evaluate the performance of each for different scenarios. OPNET provides a comprehensive development environment supporting the modeling of communication networks and distributed systems. Both behavior and performance of modeled systems can be analyzed by performing discrete event simulations. The OPNET environment incorporates tools for all phases of a study, including model design, simulation, data collection, and data analysis.

3.1 SIMULATION MODEL

OPNET Modeler 17.5 to evaluate the performance of the 802.11 b/n networks and evaluate their performance during node failures and traffic congestion. For the network setup to build up the network, we use office network scale spanning across 100 meters x 100 meters area. Ethernet and wireless_lan_adv were used to rig up the network connections and devices. Following are the components used to build up the network.

WLAN_WKSTN_ADV: Used to set up nodes that are connected to the router.

WLAN_ETHERNET_ROUTER_ADV: Routers providing wireless network to the nodes and are connected to the switch.

ETHERNET16_SWITCH: Used to connect the server and the router to receive, process, and forward data.

ETHERNET_SERVER: Used to provide internet to the network.

100BaseT was used to physically connect the server, switch and the router.

APPLICATION CONFIG: Specifies standard and custom applications used in the simulation including traffic and QoS parameters.

PROFILE CONFIG: Specifies the activity patterns of a user or group of users in terms of applications used over a period of time.

3.2 SIMULATION PROCEDURE

Following procedure is used to create the network using OPNET:

- Wireless network with 8 nodes (workstation) is created in OPNET project editor. Two routers are used to provide wireless network to the 8 nodes with 4 of the assigned to each router. Circuit is completed with switch and the server. Assign IP address to all the network components.
- Create a test profile in the profile config with HTTP heavy browsing as the application.

- Configure all the nodes for to use the created profile. Now set the server to provide the same traffic source as used by the profile config.
- Set the network to either 802.11 g/n protocol so that all the network components are configured to one of the standard.
- Parameters for simulation statistics is chosen for all the nodes and the network is simulated for a duration of 2 hours.
- Simulation is then performed to obtain results for throughput, retransmission attempts, packets loss and network delay.

The process is repeated by varying the number of nodes to 16 and 24. Network for 24 nodes is shown in Figure 1. Failure scenario is simulated by failing one of the router and network parameters are analyzed. Similar analysis is also done for network congestion for both 802.11 g/n standards. Network congestion is simulated by reducing the buffer size and the RTS threshold values for both the router nodes. (More detail will be added in the final report).

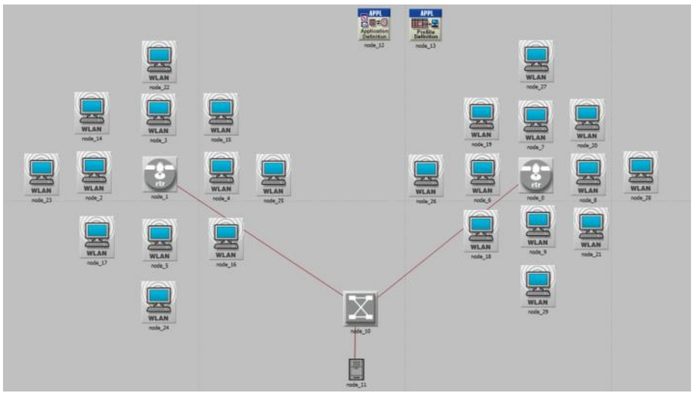

Figure 1: 24 node configuration using OPNET

4. PERFORMANCE METRICS

Network Delay - Represents the end to end delay of all the packets received by the wireless LAN MACs of all WLAN nodes in the network and forwarded to the higher layer.
Wireless LAN Data dropped - The total size of higher layer data packets (in bits/sec) dropped by all the WLAN MACs in the network due to:
a) full higher layer data buffer, or
b) the size of the higher layer packet, which is greater than the maximum allowed data size defined in the IEEE 802.11 standard.
Throughput - Represents the total number of bits (in bits/sec) forwarded from wireless LAN layers to higher layers in all WLAN nodes of the network.
Retransmission attempts - Total number of retransmission attempts by all WLAN MACs in the network until either packet is successfully transmitted or it is discarded because of reaching short or long retry limit.

5. RESULTS

Performance analysis of 802.11 g/n networks are measured based on the network delay, wireless LAN data dropped, throughput and number of retransmission attempts.

Scenario 1:
Comparison between 802.11 g/n standards for 16 node configuration is done. Figure 2 shows how the throughput varies with time for the 802.11 n network and figure 3 shows the throughput variation for 802.11 g network.

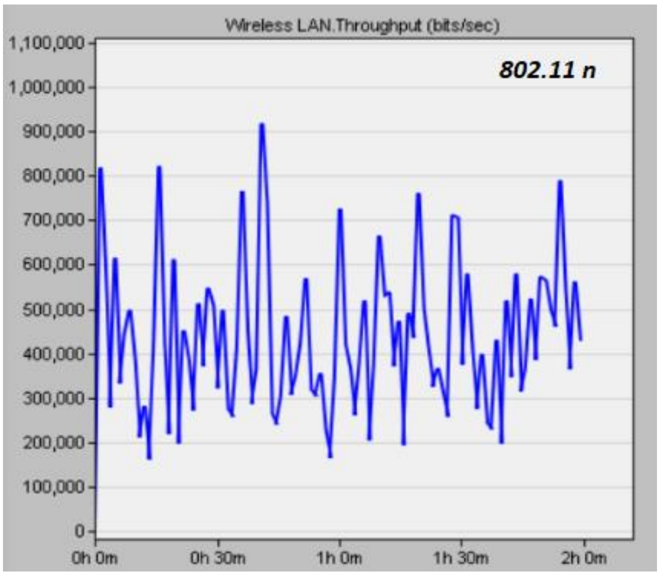

Figure 2: Throughput for 802.11 n for 16 nodes

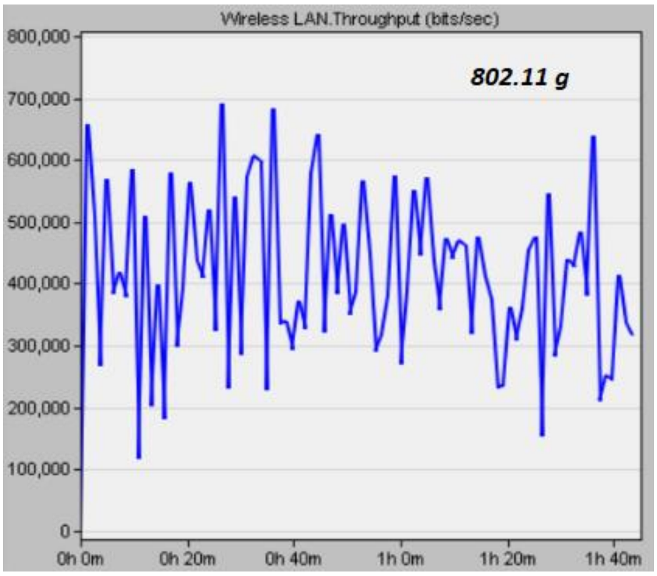

Figure 3: Throughput for 802.11 g for 16 nodes

From the above figures, we can see that the throughput for a 16 node 802.11 n network has a peak value around 900k bits/sec while 802.11 g has a peak value around 700k bits/sec. Reason for such a behavior is due to frame aggregation in 802.11 n standard. Similar pattern is observed with the throughput of n standard being greater than g for 24 nodes. However, for 8 nodes network g standard had a peak throughput value around 900k while n standard had 820k. As the number of nodes increases, throughput of the network decreases for both g and n standards.

Scenario 2:

Comparison between 802.11 g/n standards for 24 node configurations is done. Figure 4 shows how the delay varies with time for the 802.11 n network and figure 5 shows the delay variation for 802.11 g network.

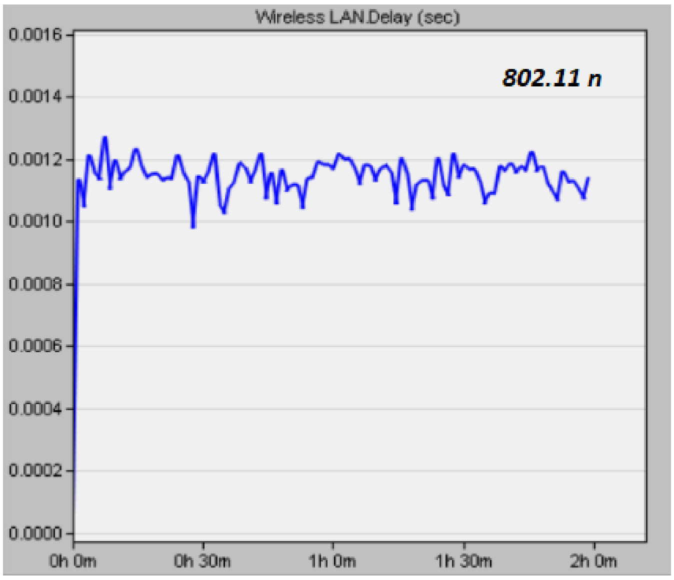

Figure 4: Delay for 802.11 n for 24 nodes

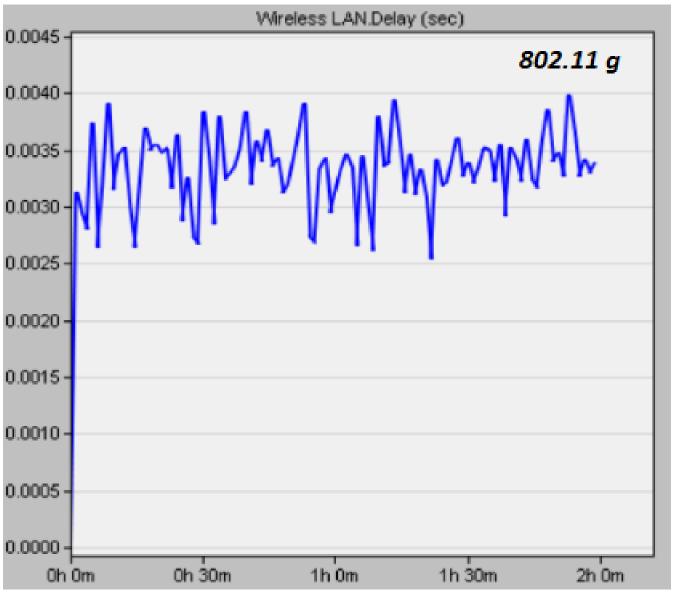

Figure 5: Delay for 802.11 g for 24 nodes

From the above figures, we can see that the 802.11 n network has a minimum delay around 9 msec and a maximum of around 13 msec. Whereas 802.11 g has a minimum delay around 26 msec and a maximum of around 40 msec. This behavior can be due to frame aggregation where once a station requests a channel and has the authority to transmit, it can transmit a series of frames without having to release the channel. Varying the number of nodes, we can see 802.11 n having lower latency compared to 802.11 g.

Scenario 3:

Comparison between 802.11 g/n standards for 24 node configurations is done. Figure 6 shows how the retransmission attempts varies with time for the 802.11 n network and figure 7 shows the retransmission attempts variation for 802.11 g network.

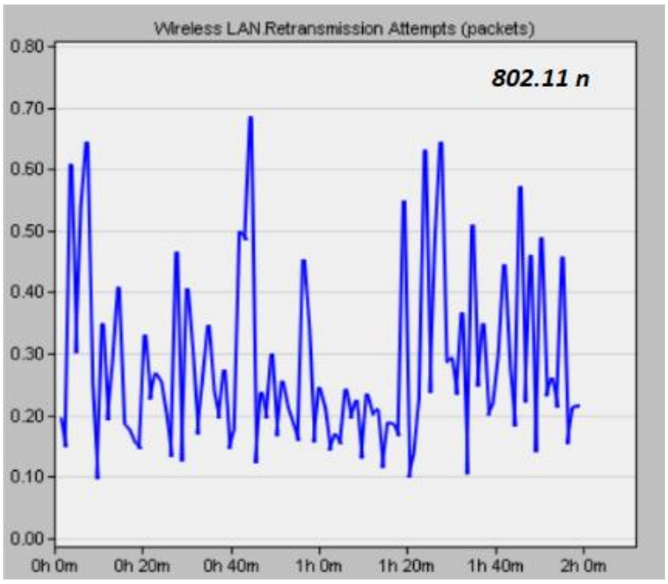

Figure 6: Retransmission attempts for 802.11 n for 24 nodes

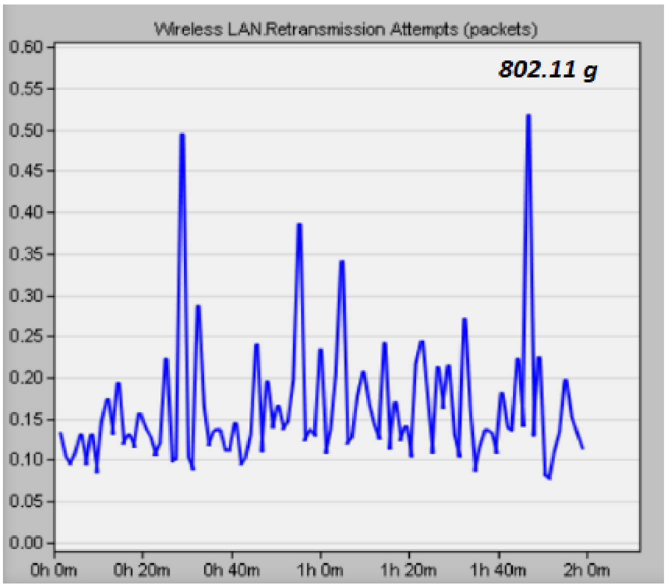

Figure 7: Retransmission attempts for 802.11 g for 24 nodes

From the above figures, we can see that the 802.11 n has a retransmission rate at around 70% whereas 802.11 g has a rate around 53%. Retransmission rate for both the standards are similar for smaller network sizes and become significant as the network grows. The retransmission rate in n network is contributed by high packet loss that occurs in the network.

Scenario 4:

Comparison between 802.11 g/n standards for 16 node configurations is done. Figure 8 shows how the data dropped varies with time for the 802.11 n network and figure 9 shows the delay variation for 802.11 g network.

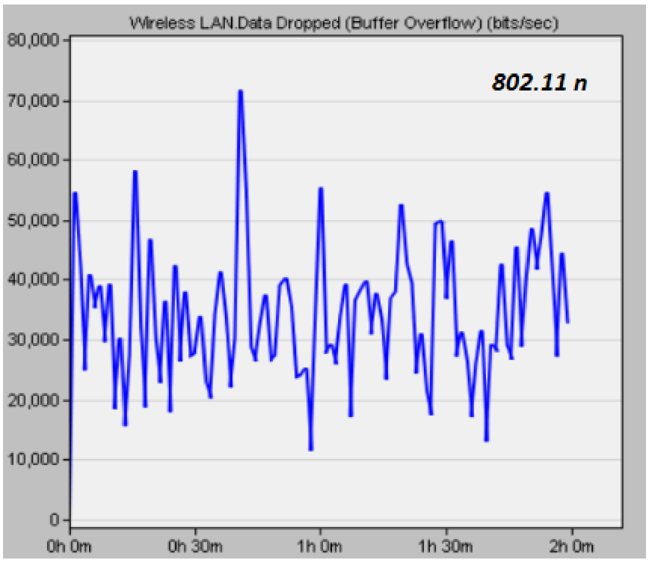

Figure 8: Wireless LAN Data dropped for 802.11 n for 16 nodes

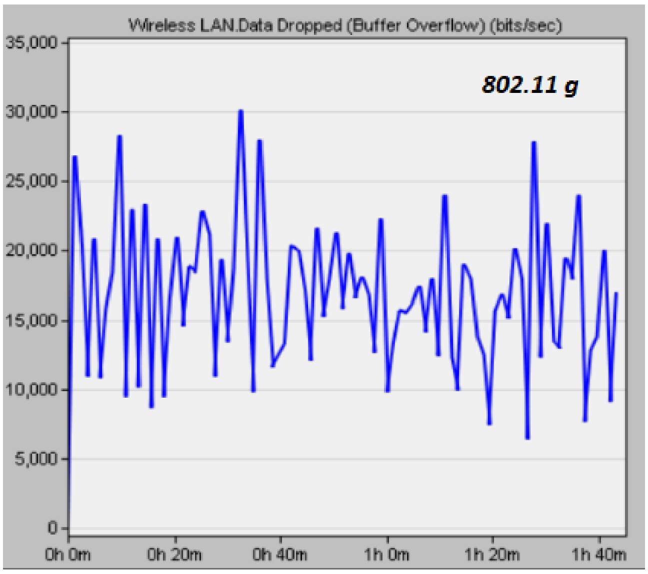

Figure 9: Wireless LAN Data dropped for 802.11 g for 16 nodes

From the above figures, we can see that the 802.11 n has dropped around 70k bits/sec at 45 min mark whereas 802.11g drops only 30k bits/sec. 802.11 g proves to be perform better than n in terms of the packet loss and this behavior is consistent while testing with other node configurations.

Scenario 5:
Comparison between 802.11 g/n standards with and without node failure for 24 node configurations is done. Table 1 shows the performance metrics

From the table we can see the following:
a) Throughput for 802.11 n configuration dropped from 550k to 300k with node failure while g dropped from 450k to 250k. This is mainly due to the reduced number of nodes as a result of failure contributing to the network throughput.

b) Data dropped for 802.11 n decreased from 40k to 16k while for g configuration it decreased from 18k to 9k. As the router failure occurred, all the work stations connected to that BSS also failed and no packets were transmitted to them resulting in decrease in the data being dropped.

c) We can see a huge increase in the retransmission attempts for both 802.11 configurations with node failure. As the node failed, large number of packets were attempted to be retransmitted repeatedly to the failed nodes hence resulting in the increase of the retransmission rate.

d) Increase in delay is observed because of node failure from 9msec to 16msec for 802.11 n and 24msec to 45msec for g configuration.

Table 1: Performance metrics with node failure

Standard	Throughput (bits/sec)	Delay (sec)	Retransmission attempts (packets)	Data dropped (bits/sec)
802.11 n	300k	16m	2.2	16k
802.11 g	250k	45m	3	9k

Table 2: Performance metrics without node failure

Standard	Throughput (bits/sec)	Delay (sec)	Retransmission attempts (packets)	Data dropped (bits/sec)
802.11 n	550k	9m	0.7	40k
802.11 g	450k	24m	0.5	18k

Scenario 6:
From the simulation results of the 2 wireless standards for 24 nodes with congestion buffer is reduced by a factor of 4, n performs better than g considering the packet loss and retransmission attempts. The packet loss of n standard was 16k bits/sec and 180% of packets getting re-transmitted while for g standard it was 17k bits/sec packet loss and 300% packet re-transmission rate. A similar behavior can be seen for different nodes.

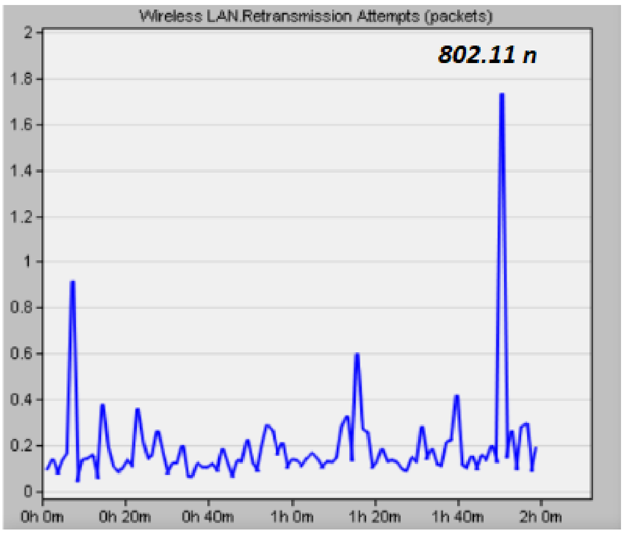

Figure 10: Retransmission attempts for 802.11 n for 24 nodes with congestion

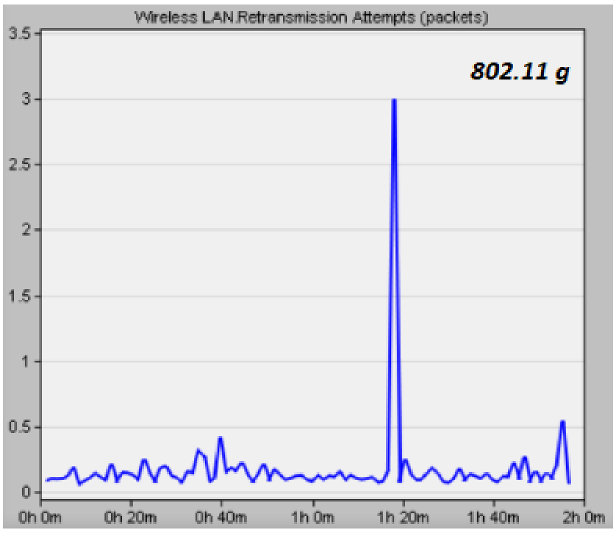

Figure 11: Retransmission attempts for 802.11 g for 24 nodes with congestion

6. CONCLUSION

In this paper, a detailed analysis on the performance of wireless network standards was performed in a real-world scenario by using OPNET network simulation tool. Performance was measured with dedicated active measurements of the metrics and comparing them to decide the better standard for the environment. Performance analysis for both the standards was done by varying the number of nodes from 8 to 24 and measuring their effect on the quality of the network. Results show that throughput for a n standard network is better that the g counterpart in most of the cases due to frame aggregation by the n standard. However, n standard has a high packet loss and it significantly affects the retransmission rates. During node failures n was able to perform better than the g network and handled congestion better too.

7. REFERENCES

[1] Kulgachev, V., & Jasani, H. (2010, October). 802.11 networks performance evaluation using Opnet. In Proceedings of the 2010 ACM conference on Information technology education (pp. 149-152). ACM.

[2]. Singh, V., Shahiruddin, D. K., & Jayaswal, P. Performance Evaluation of IEEE 802.11 b WLANs.

[3]. Kadir, E. A., Siswanto, A., & Syukur, A. (2016, May). Performance analysis of wireless LAN 802.11 n standard for e-Learning. In Information and Communication Technology (ICoICT), 2016 4th International Conference on (pp. 1-6). IEEE.

[4]. Seema, Vikram Nandal, Kuldeep Vats, Sonia (2014 June). OPNET based Performance Evaluation of MANET using IEEE 802.11a/b in International Journal of Computer Science and Mobile Computing.

[5]. Idris Babiker, Dr. Amin Babiker (2016 Mar-Apr). Voice Over Wifi Performance Evaluation and Comparisons of IEEE.802.11 B, A, G, N Releases at IOSR Journal of Computer Engineering.

[7] Gawanmeh, S. H. (2006). Wireless network performance optimization using Opnet Modeler. Information Technology Journal, 5(1), 18-24.

[8] Kaur, A. (2010). Congestion Analysis of IEEE 802.11 Wireless Infrastructure Local Area Networks. Global Journal of Computer Science and Technology.

[9] Bai, G., & Williamson, C. (2003, October). Simulation evaluation of wireless web performance in an IEEE 802.11 b classroom area network. In Local Computer Networks, 2003. LCN'03. Proceedings. 28th Annual IEEE International Conference on (pp. 663-672). IEEE.