Nigerian Journal of Technology (NIJOTECH)
Vol. 34 No. 1, January 2015, pp. 177 – 183

University of Nigeria, Nsukka, ISSN: 1115-8443
www.nijotech.com
http://dx.doi.org/10.4314/njt.v34i1.22

INTERFERENCE EFFECTS OF BLUETOOTH ON WLAN PERFORMANCE

J. E. Okhaifoh[1], J. O. Emagbetere[2] and F. O. Edeko[3]
[1]DEPT. OF ELECTRICAL/ELECTRONIC ENGINEERING, FEDERAL UNIV. OF PETROLEUM RESOURCES EFFURUN, NIGERIA
[2,3] DEPARTMENT OF ELECTRICAL/ELECTRONIC ENGINEERING, UNIVERSITY OF BENIN, NIGERIA
E-mail Addresses: *[1] jokhaifoh@yahoo.com, [2] joyokumo@yahoo.com, [3] frededeko@yahoo.co.uk*

ABSTRACT
In this paper, Network stumbler version 0.4.0 was used to estimate the impact of impulsive interference on Wireless Local Area Network (WLAN) when Bluetooth coexist by measuring radiation from a WiFi Access Point (AP) in a homogeneous and heterogeneous scenarios. The parameters measured include Received Signal Strength (RSS) and Signal-to-Noise ratio (SNR) while Bit Error Rate (BER) performance was theoretically deduced from the measured data. Results obtained from the measurements of both scenarios were compared and used in describing the interference problem. The study revealed that Bluetooth impact on performance was minimally significant with mean degradation of 4.74% in RSS and 0.77% in SNR despite the fact that its signal are weak and are designed to accommodate WiFi devices by AFH technology.

Keywords: *Impulsive interference, Received Signal Strength, ISM devices, Access Point, Interference, Performance*

1. Introduction

Recent years have witnessed the increasing popularity and attractiveness of the 2.4 GHz Industrial, Scientific and Medical (ISM) unlicensed band in wireless communications for most manufacturers of wireless products because of its global availability and the ease with which new products can be deployed to it [1]. Among the technologies that employ the use of the 2.4 GHz ISM unlicensed band are two wireless technologies: Bluetooth wireless personal-area network (WPAN) and IEEE 802.11 wireless local-area network (WLAN), both of which support operation in the crowded 2.4-GHz Industrial, Scientific and Medical (ISM) band [2, 14].

Although WLAN (also known as WiFi) and Bluetooth (BT) are different technologies and are designed for different uses, they often complement each other in personal computers as well as mobile devices such as phones and personal digital assistants. It is anticipated that some interference which are impulsive in nature will result in the same environment when both are operating at the same time and within range of each other. Impulsive interference (or noise) is usually described as a process characterized by bursts of one or more short pulses whose amplitude, duration and time of occurrence are random. It is also characterized by transient short-duration disturbances distributed essentially uniformly over the useful passband of a transmission system[3]. The interference between WLAN and WPAN networks can be divided into two classes: (1) Internal: Both IEEE 802.11 and Bluetooth devices are co-located (which is defined as a distance < 2m) and can be physically connected to each other. (2) External: In this case, IEEE 802.11 and Bluetooth devices are within range of each other (i.e. the interfering device are physically separated by > 2m), but in separate, autonomous devices. The second case is the most common and will be our primary consideration in this work. The mutual interference between WLAN and other ISM devices like Bluetooth primarily depends on the physical distance between the two technologies, actual physical environment, operating data rates, the frequency with which they transmit, the type of data that is being transmitted and transmit power levels [2][4][6]. The end result of interference can be degraded data throughput, reduced voice quality, or even link disconnection [2].

2. RELATED WORKS

Efforts to study interference in the 2.4 GHz band are not new. For example, interference caused by

Corresponding Author, Tel: +234-805-414-5506

Bluetooth operating in the vicinity of a WLAN network has been investigated in [5][2]. Their attempt to quantify the interference effects was based on simple geometric models of Bluetooth deployment rather than actual usage models. The work found out that if Bluetooth and Wi-Fi are operating at the same time in the same place, they will interfere (collide) with each other. Specifically, these systems transmit on overlapping frequencies, creating in-band coloured noise for one another. The outcome of their work showed that even Wi-Fi stations with less than 5–7m of free space from their access point suffer greater than 25% degradation in throughput. This degradation exceeds 50% by the 30-m mark. In an office environment with cubicles, the range associated with each throughput level would be reduced significantly. When cubicles must be penetrated, Wi-Fi loses nearly one-third of its expected throughput within the first couple of meters. Erosion of performance exceeds 50% with stations <8m from their access point. [6] in their work reported the effect of interference on the throughput between a WLAN AP and a WLAN client device in a typical office environment, placing the interferer in two different locations. Of the devices tested, only the Bluetooth device had minimal impact on WLAN throughput. All of the other devices significantly degraded the WLAN throughput, with some up to 100% for specific WLAN channels.

The paper [7] presented a simulation environment for modelling interference based on detailed Medium Access Control (MAC) and Physical layer (PHY) models. Measurement performance in terms of packet loss, residual number of errors, and access delay was used to evaluate the impact of interference on the performance of Bluetooth and IEEE 802.11 in several simulation scenarios. Results of the effect of the Bluetooth on the IEEE 802.11 system indicate that scenarios using Bluetooth voice traffic may be the worst of all interference cases (65% of packet loss for the WLAN 1 Mbits/s system). Moreover, the results suggested that the data rate in the WLAN system may be a factor in the performance, and, the recommended rate for WLAN depends on the topology and the parameters used.

Reports in [8] discussed solutions to the interference problem caused by the proximity and simultaneous operation of Bluetooth and WLAN networks. Different techniques that attempt to avoid time and frequency collisions of WLAN and Bluetooth transmissions were considered. Also, comparative analysis of their respective performance, the trends and trade-offs they bring for different applications and interference levels were discussed. Performance was measured in terms of packet loss, TCP goodput, delay, and delay jitter. Results showed the impact of the Bluetooth interference is not as significant since the WLAN node only receives short ACK packets. When no interference mitigation algorithm is implemented for Bluetooth, the packet loss is 17% and 10% at a distance of 1 and 3 meters respectively. The packet loss when AFH is implemented drops to 7% and 5% at d=1 and 3 m respectively. The packet loss is less than 1% with BIAS.

The paper [9] dealt with the coexistence simulation of IEEE 802.11b/g and Bluetooth 2.1 EDR (non AFH) physical layer model in Mathworks Matlab Simulink. Result from simulations showed that IEEE 802.11g standard provides the best performance when mandatory data rates (non-punctured convolutional codes) are used. Also Bluetooth EDR 3 Mbit/s causes smaller interference to the IEEE 802.11b signal than Bluetooth 1 Mbit/s data rate. [10][11] evaluated the effects of interference on general WLAN traffic by various interferers at short and long ranges. Results showed that Bluetooth devices caused more degradation than expected, by reducing throughput at short range by about 20%. This is significant although still much less than the other sources.

A measurement study of interference from six common devices that use the same 2.4GHz ISM band as the IEEE 802.11 protocol was presented in [12]. Using both controlled experiments and production environments measurements, they quantified the impact of these devices on the performance of IEEE 802.11 Wi-Fi networks. In the controlled experiments, they characterized the interference properties of these devices, as well as measured and discussed implications of interference on data, video and voice traffic. Results showed that for data traffic, Bluetooth headset reduced the throughput by 20% at close distances despite having low duty cycle and designed to accommodate WiFi devices. Although Bluetooth had some impact on data traffic, there was minimal impact on video traffic. Lastly, for voice traffic, Bluetooth had minor impact at short distance and no impact at longer distances.

The main goal of this paper is to present findings on the performance of WLAN when operating in close proximity to Bluetooth technology. The results are based on interference experiments conducted on a Wi-Fi network in which Received Signal Strength (RSS) and Signal-to-Noise ratio (SNR) are measured. From the data, Bit Error Rates (BER) are theoretically calculated for the system and the impact of interference quantified.

3. RESEARCH METHODOLOGY

This research work employed software tools like Netstumbler version 0.4.0, MATLAB® and Excel. Field measurements of Received Signal Strength Indicator (RSS) and Signal-to-Noise ratio (SNR) were performed around the first floor of a 3-storey Administrative building. Figure 1 shows the measurement environment which has a dimension of 30m by 25m, an area of 750sqm. This floor has 10 rooms which consist primarily of cubicles, a few closed offices and conference rooms.

NetStumbler version 0.4.0 which is a tool for Windows that allows detection of Wireless Local Area Networks (WLANs) using IEEE 802.11b, IEEE 802.11a and IEEE 802.11g was installed in a laptop (WLAN Client or Mobile Station). For the AP, the software displays the medium access control (MAC) address, service set identifier (SSID), wired equivalent privacy (WEP) status, signal strength, signal to noise radio (SNR), speed. It was used to monitor the radio channels [15], measure the level of energy (Received Signal Strength Indicator) and the Signal-to-Noise ratio (SNR) in the 2.4 GHz Wi-Fi channels and to visually monitor the level of interference as the tests were run (Figure 2)

For the series of measurements, performance results for IEEE 802.11 are obtained at varying distances away from AP to MS at an interval of Im for a total path length of 25m under two scenarios [10]:

(a) Homogeneous set-up (i.e. a relatively unimpaired radio environment) where IEEE 802.11 device is considered separately to obtain a baseline performance.
(b) Heterogeneous (Interference) set-up i.e. an arrangement of Wi-Fi and Bluetooth devices coexistence.

The configuration was intended to be representative of a mobile station i.e. laptop (a device which needs simultaneous operation and collocation) equipped with collocated Wi-Fi and Bluetooth (BT1) interacting simultaneously with a Wi-Fi access point and another Bluetooth node (BT2) which is the interferer. The distance between the collocated Wi-Fi and Bluetooth was fixed approximately 10cm. The second Bluetooth node (BT2) was located initially at 8m from AP2 for NEAR position and later moved to 15m for FAR position. The two Bluetooth nodes were laptops that ran data transfers from BT1 to BT2 at an RF power output of 1mW [16]. Measurements were carried out using MS (WLAN client) at intervals of 1m from AP2 covering a total path length of 25m.

.

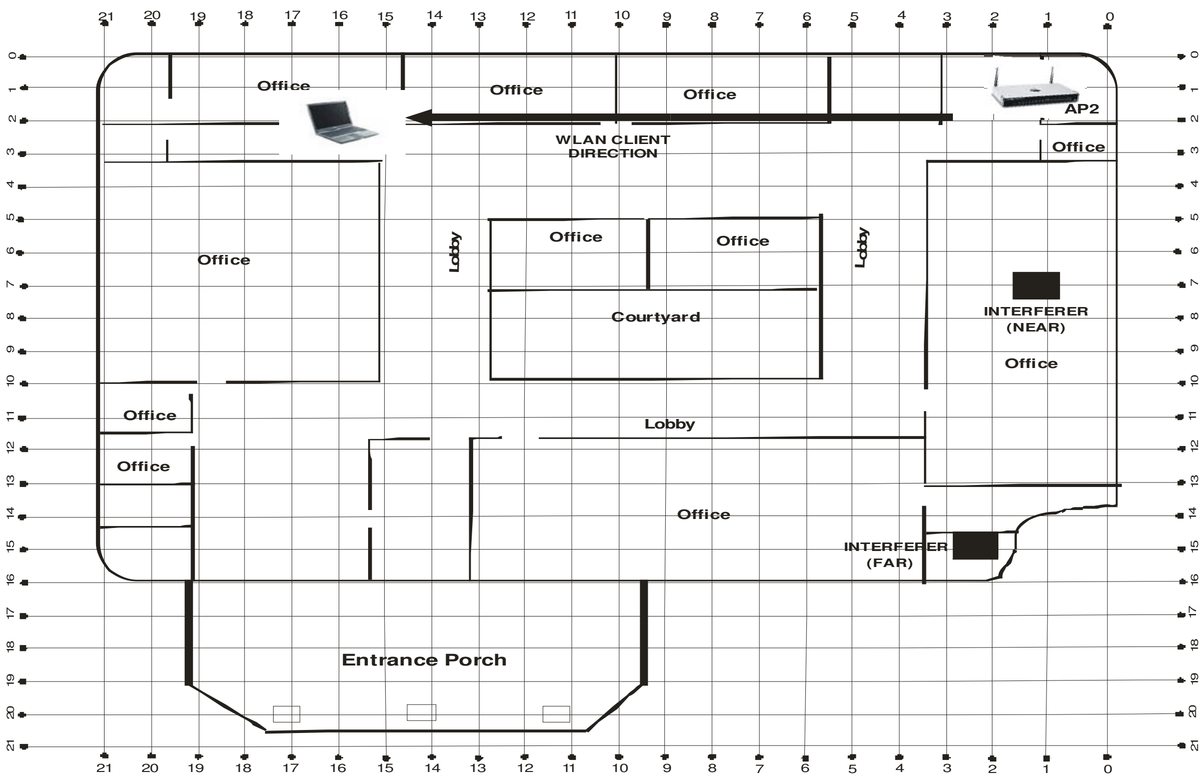

Figure 1: Administrative Building

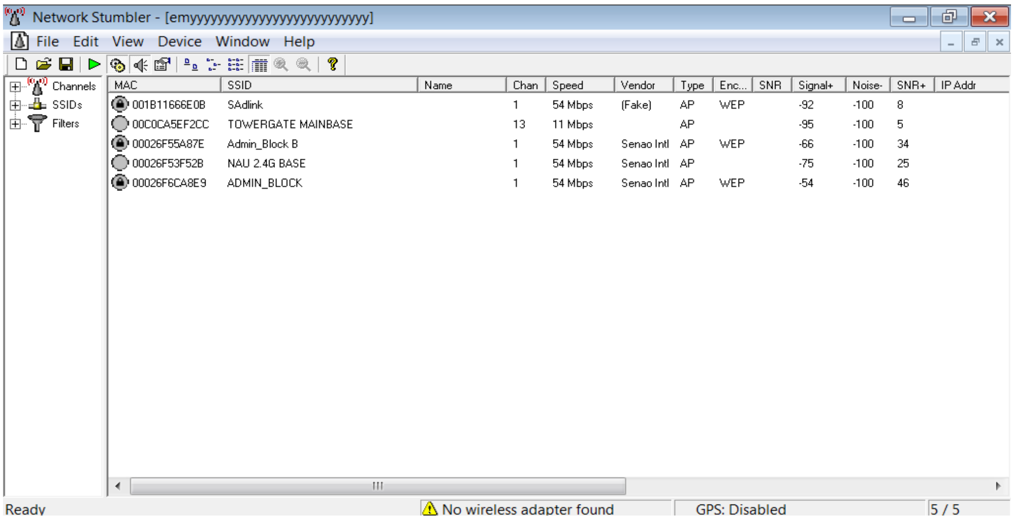

Figure 2: NetStumbler Tools Window

Table 1: Mean RSS and SNR for Homogeneous and Heterogeneous Scenarios

Baseline		Mean RSS for WiFi-BT (dBm)		Mean SNR forWiFi – BT(dB)	
Mean RSS (dBm)	Mean SNR (dB)	Near	Far	Near	Far
-55.11	41.91	-57.72	-55.11	41.59	41.91

AP2 which is a WLAN Access Point for IEEE 802.11(b/g) was used for the investigation. The equipment specification is given as:
Model: GS-CPE3014
Operatingfrequency: 2.4GHz
Gainofantenna: 14dBi
Type: Panelantenna
PowerOutput: 500mW

The Mobile Station equipment specification is given as:
Model: Dell Inspiron E1505
Network Adapter: Dell Wireless 1701 802.11b/g
Bluetooth Radio: Dell Wireless 1701 Bluetooth v3.0+HS
Network Sniffer: Network Stumber version 0.4.0

4. DATA PRESENTATION AND ANALYSIS

The resulting RSS and SNR measured as a function of distance for the total path length of 25m were recorded and the mean computed for homogeneous and heterogeneous scenarios. This is presented in Table 1.

In order to estimate the performance of WiFi devices in the presence of Bluetooth, data obtained for this investigation were analyzed. It involved the following:

(i) Comparing the baseline performance with interference results for NEAR and FAR positions of interferer for RSS and SNR, calculation of degradation (percent change) using [12]

$$Degradation\ (\%) = \frac{AI - ABP}{ABP} \times 100 \qquad (1)$$

In (1), AI is the average interference and ABP is the average baseline performance. These values are then plotted and compared graphically as shown in Figures 3 – 6.

(ii) Estimating the link error rate: In this section, the possible mechanisms used in estimating the bit error rate p_b of its incoming links using radio signal-to-noise ratio is discussed. In a real implementation, this measure is based on a theoretical calculation using the signal to noise ratio measured and the receiver a priori performance [13].

From the RSS and SNR values measured, the noise (N) was calculated using eqn. (2):

$$SNR = 10 \log \frac{P_r}{N} \qquad (2)$$

In (2), SNR is the Signal-to-Noise ratio, P_r is the Received power level (RSS) and N is the Noise. The relation between the bit error rate (p_b) over a wireless channel and the received power level P_r is a function of the modulation scheme. However, in general, several modulation schemes exhibit the following generic relationship between p_b and P_r [17]:

$$p_b \propto \left(\sqrt{\frac{constant \times P_r}{N \times f}} \right) \qquad (3)$$

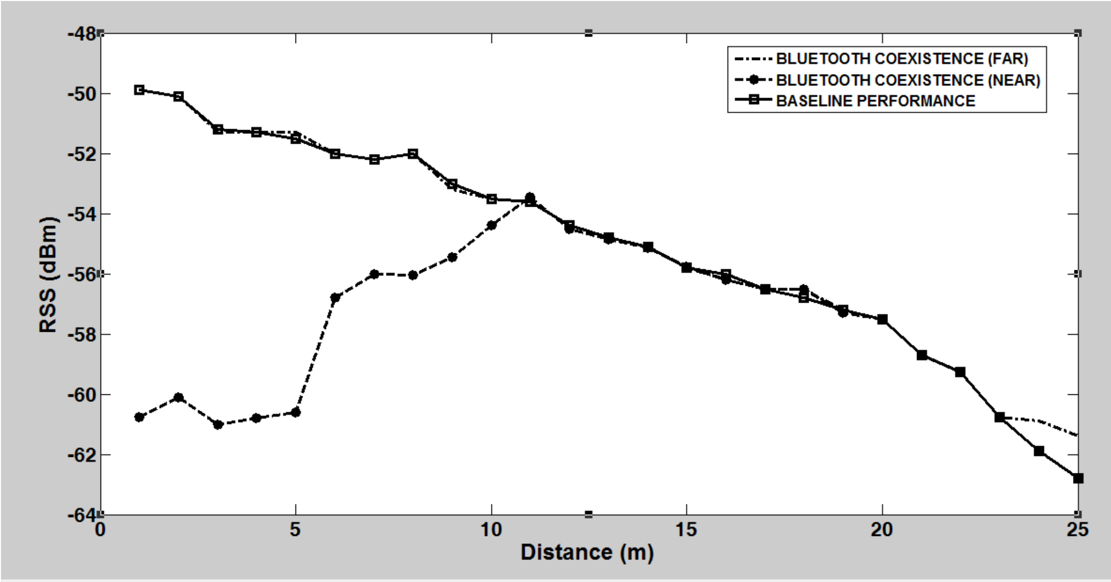

Figure 3: Comparison of Baseline Performance with Bluetooth Coexistence (RSS vs. Distance)

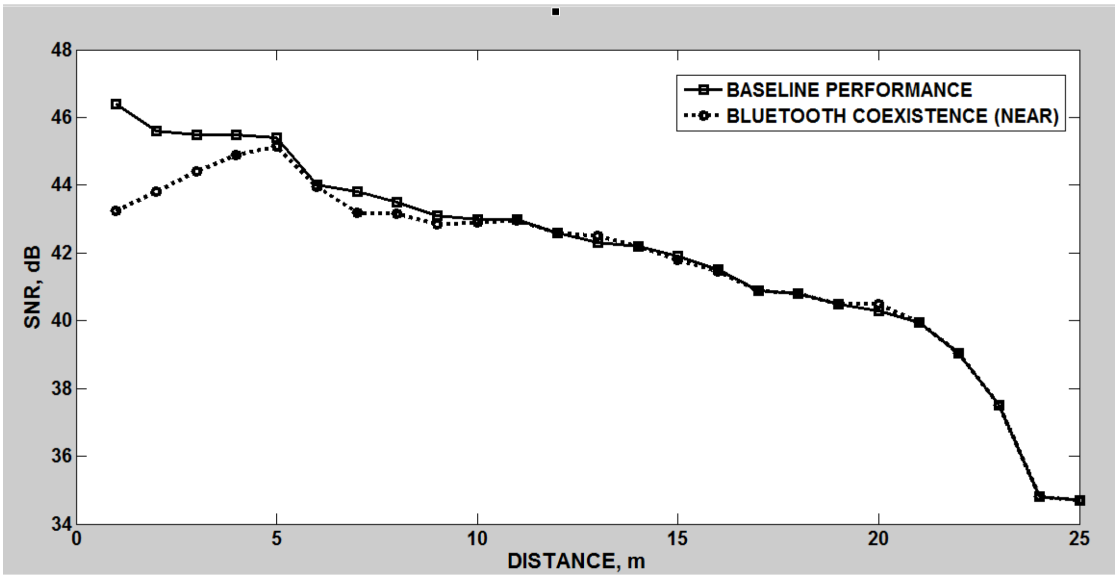

Figure 4: Comparison of Baseline Performance with Bluetooth Interference (SNR vs Distance

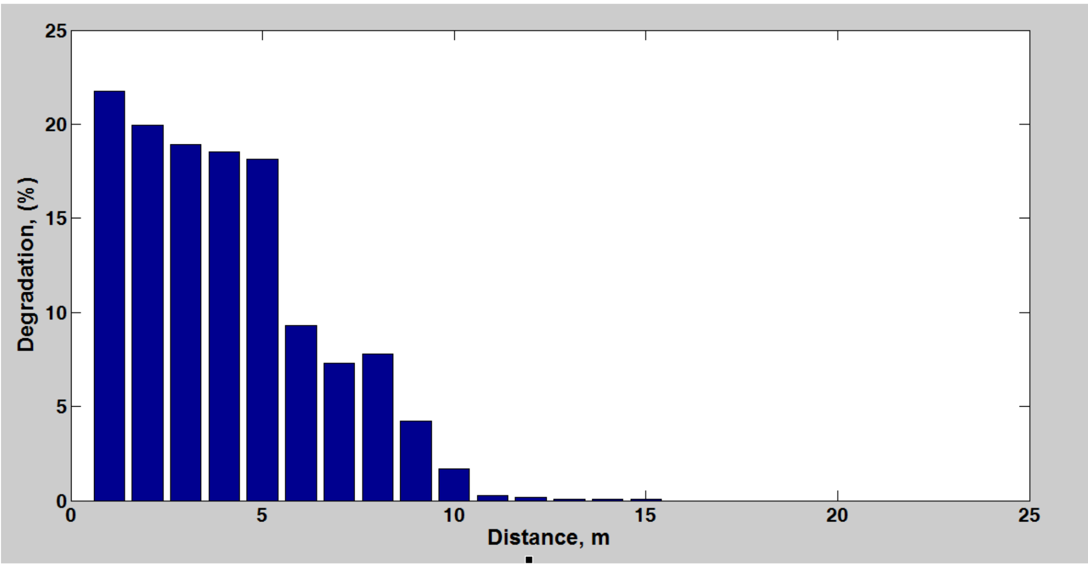

Figure 5: Comparison of RSS Degradation for Bluetooth Interference (Near and Far Positions)

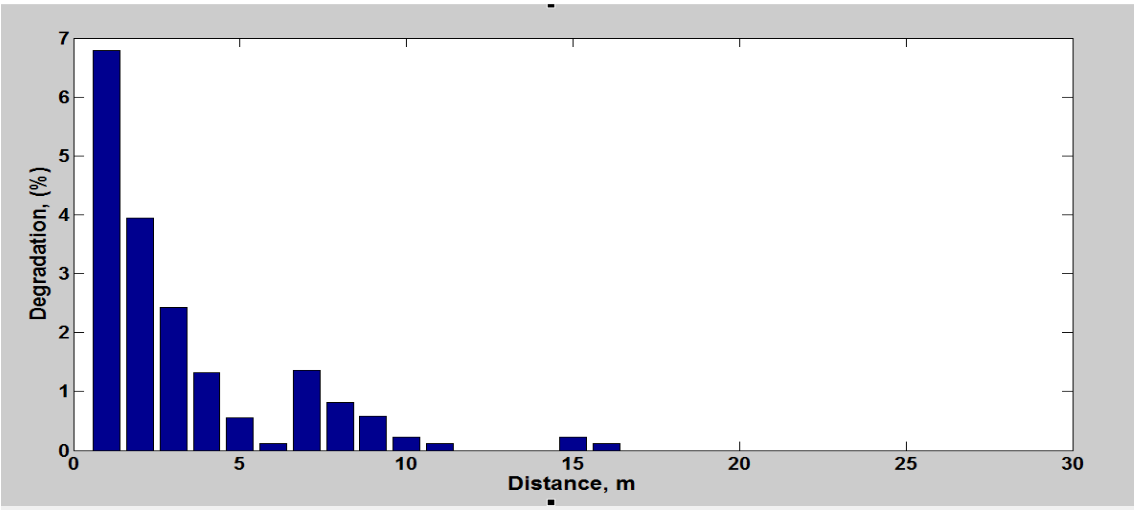

Figure 6: Comparison of SNR Degradation for Bluetooth Interference (Near and Far positions)

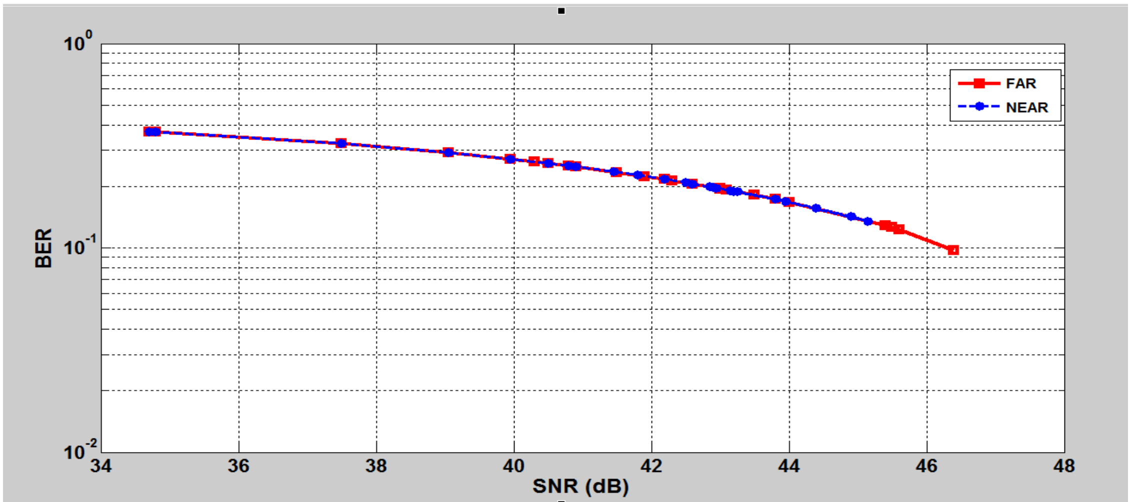

Figure 7: Comparison of BER Performance for Bluetooth Interference (Near and Far)

In (3), N is the the noise spectral density and f is the the raw channel bit rate. The error function is given as

$$erf(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} dt \qquad (4)$$

and erfc(x) is defined as the complementary function of erf(x) and is given by

$$erfc(x) = 1 - \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \qquad (5)$$

The bit error rate is then given as

$$p_b = 0.5 \times erfc\sqrt{\frac{P_r}{N\,f}} \qquad (6)$$

In (6),p_b is the Bit Error Rate (BER) while f = 54mbps (for IEEE 802.11g)

Substituting the values in eqn. (6), the bit error rate experienced was estimated for the interference situation. The BER performance is plotted in Figure 7.

5. DISCUSSION AND FINDINGS

From Table 1, the mean RSS for NEAR and FAR positions for Bluetooth coexistence were -57.72 dBm and -55.11 dBm respectively while that of the baseline performance was -55.11 dBm. The impact of interference between Wi-Fi and Bluetooth systems is such that the mean RSS degradation for NEAR position is 4.74% and 0% for FAR positions. It was also observed that WiFi client less than 8m away from the access point suffered more than 7.78% and 0% degradation in Received Signal Strength (RSS) in NEAR and FAR positions respectively. It can be inferred from Figure 3 where comparison of Bluetooth coexistence and baseline was done that Bluetooth devices whose signal is weak caused interference with WiFi signal in NEAR position only but when moved away as little as 10 meters, it had negligible impact. In FAR position, the presence of Bluetooth device had no impact whatsoever on the signal received from the access point. In the case of mean SNR, Table 1 also compared the mean SNR of NEAR and FAR positions for Bluetooth interference (41.59 dB and 41.91 dB respectively) to that of the baseline (41.91 dB). The impact of interference is such that the mean SNR degradation for NEAR position is 0.77% and 0.0% for FAR positions. It was observed that WiFi client with less than 8m away from the access point suffered more than 0.8% and 0% degradation in NEAR and FAR positions respectively. Lastly, Figure 7 compared the BER performance for NEAR and FAR position. It was observed that there was no significant difference between them. This implies that in these particular conditions, both systems (Bluetooth and Wi-Fi) were able to coexist without any bit errors. It also shows that Bluetooth devices at very far distances from AP do not interfere with the system performance.

6. CONCLUSION

The impact of impulsive interference by Bluetooth on the reception of WiFi in the 2.4GHz ISM band has been the crux of this work. From the physical measurements and analysis, it was observed that when the Bluetooth device is very close (NEAR position) to the Wi-Fi access point its impact on WLAN performance due to interference is 4.74% and 0.77% for RSS and SNR respectively. Also, Bluetooth devices when moved way as little as 10 meters from AP had no impact whatsoever on the optimum reception of Wi-Fi. The interference problem is only significant in NEAR position of interference.

7. REFERENCES

[1] Lansford, J., Nevo, R. and Monello, B. "Wi-Fi and Bluetooth: Enabling Coexistence" www.ce.mag.com. Accessed on March 22, 2010.

[2] Broadcom "BCM4325 Bluetooth and WLAN Coexistence", Broadcom White Paper- 4325-WP100-R, Broadcom Corporation, Irvine, California, 2008, pp. 2 – 7.

[3] Eionet "Gemet Thesaurus" http:// www. eionet. europa. eu/ gemet/ concept ?ns= 1&cp=4178. Accessed on June 20, 2013.

[4] Nick, H. "Bluetooth and 802.11 Coexistence" www.ezurio.com. Accessed on March 23, 2010.

[5] Lansford, J., Stephens, A., Nevo, R. and Mobilian Corporation "Wi-Fi (802.11b) and Bluetooth: Enabling coexistence", http:// home.deib. polimi. it/ capone/ rmd/ readings/ Lansford01.pdf. Accessed on March 22, 2010.

[6] Bandspeed "Understanding the Effects of Radio Frequency (RF) Interference on WLAN Performance and Security", www.bandspeed.com/ technology/ docs/BSP_RF+WLAN_WP.pdf. Accessed on November 22, 2011.

[7] Golmie, N., Van Dyck, R.E. and Soltanian, A. "Interference of Bluetooth and IEEE 802.11: Simulation Modeling and Performance Evaluation." Proceedings of the Fourth ACM International Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems, Rome Italy. http://w3.antd.nist.gov/pubs/Golmiemswim01.pdf. Accessed on March 02, 2014.

[8] Golmie, N., Chevrollier, N. and Rebala, O. "Bluetooth and WLAN Coexistence: Challenges and Solutions" *Wireless Communications, IEEE*, Vol. 10, Issue 6, 2003, pp. 2 -5.

[9] Mikulka, J. and Stanislav, H. "Bluetooth and IEEE 802.11b/g Coexistence Simulation" http://www.radioeng.cz/fulltexts/2008/08_03_066_073.pdf. Accessed on March 03, 2010.

[10] Farpoint Group "The Effects of Interference on General WLAN traffic" Document FPG 2006-328.3, http://www.cisco.com/c/dam/en/us/solutions/collateral/borderless-networks/rf-solutions/net_implementation_white_paper0900aecd805eb8a5.pdf. Accessed on February 22, 2012.

[11] Farpoint Group "Evaluating Interference in Wireless LANs: Recommended Practice", Document FPG 2006-307.1, http://www.cisco.com/c/dam/en/us/solutions /collateral/ borderless-networks/rf-solutions /net_implementation_white_paper0900aecd80554f8b.pdf. Accessed on February 22, 2012.

[12] Aniket, M., Niklas, C., Carey, W. and Martin, A. "Ambient Interference Effects in Wi-Fi Network", 9th International IFIP TC 6 Networking Conference, Chennai India, May 2010, pp. 160 – 173.

[13] Golmie, N. "Coexistence in Unlicensed Bands: Challenges and Solutions" http://www.ieee802.org/802 tutorials/04-July/802 Coexistence Tutorial July04a.pdf. Accessed 07/04/2010.

[14] Nwabueze, C.A. and Akaneme, S.A. "Wireless Fidelity (Wi-Fi) Broadband Network Technology: An Overview with Other Broadband Wireless Networks" *Nigerian Journal of Technology*, Vol. 28, No.1, March 2009, pp. 71 – 78.

[15] Obot, A., Simeon, O., and Afolayan J. "Comparative Analysis of Path Loss Prediction Models for Urban Macrocellular Environments" *Nigerian Journal of Technology*, Vol. 30, No.3, October 2011, pp. 50 – 59.

[16] Edwards, E.O. and Orukpe, P.E. "Development of a RFID Based Library Management System and User Access Control" *Nigerian Journal of Technology*, Vol. 33 No.4, October 2014, pp. 574 – 584.

[17] Ananda, A., Mun, C.C. and Wei, T.O. *"Mobile, Wireless and Sensor Networks*", John Wiley and Sons Inc., 2006.