TCP Throughput Drop Prediction Model in IEEE802.11n WLAN for Indoor-To-Outdoor Scenario

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Abstract
The IEEE 802.11n is one of the most common WLAN Wi-Fi, operating at either 2.4GHz and 5GHz bands. Wi-Fi Access Point (AP) could be specifically made for indoor or outdoor signal wireless coverages. Indoor setting consists of many partitioned spaces while outdoor environment is characterized with the presence of trees, other foliage, building exterior and other structures. Indoor-to-outdoor wireless signal coverage is common whereby indoor AP is required to also provide coverage in adjacent outdoor setting. The purpose of this project is to characterize and model RSSI and TCP throughput changes in the abovementioned setting for AP with and without corner reflector. The setting emulates a case of obstruction presence in between AP and user equipment (UE) and subsequent correlation of RSSI and TCP throughput changes for investigated scenario was modelled. The design and placement of 90° corner reflector to indoor AP, the measurements of RSSI and TCP throughput for outdoor environment of Wireless Communication Centre Universiti Teknologi Malaysia (WCC UTM) and other findings are reported in this paper.

Keywords: TCP throughput, IEEE802.11n Corner Reflector; Access Point.

1. Introduction

The communication system is a model of communication exchange between transmitter and receiver. It reflects the signal's utilisation of it to travel from a source to its destination. Currently, wireless communication systems are among the most rapidly evolving and dynamic technology fields in the realm of communication. Wireless communication is a way of sending data from one location to another without the need of wires, cables, or other physical media [1]. Wi-Fi is one type of most commonly used technology in wireless communication systems or wireless local area network (WLAN). WLAN allows various devices like laptops and smartphones, to connect to an access point such as Wi-Fi router and access the internet.

WLAN is based on IEEE 802.11 serial protocol, or commonly known as Wi-Fi [2]. The standard is set by the IEEE for WLAN communication. Therefore, each device with a wireless network interface card (NIC) can connect the internet resources as well as roam within areas protected by WLAN signals [3]. The IEEE 802.11n or Wi-Fi generation 4 is the most commonly used Wi-Fi. The operating frequency bands of IEEE 802.11n are 2.4GHz and 5GHz [4]. Depending on the administrator's settings, the supported data rate exceeds 500Mbps maximum. Wi-Fi Access Point (AP) could be specifically made for indoor or outdoor signal wireless coverage. IEEE 802.11n standard Access Point (AP) have different channels for the 2.4 GHz band, with each channel has a bandwidth of 20 MHz [5].

The internet protocol (IP) family contains a set of network protocols. These may include higher-level protocols namely file transfer protocol (FTP), hypertext transfer protocol (HTTP), transmission control protocol (TCP) and user datagram protocol (UDP). There are also lower-level IPs that include address resolution protocol (ARP) and internet control message protocol (ICMP) that co-exist with IP. Lower-level protocols interact with hardware while higher level protocols interact more closely with web browser applications. TCP is an excellent measure of network connection as the TCP occupied for more than 80% of all Internet's traffic. Analyzing TCP throughput is critical to understand Wi-Fi-network connection capacity to the internet [6].

To provide a Wi-Fi connection in outdoor environment, one of the most typical installation approaches is relying on installed indoor AP to allow users in vicinity outdoor environment to be connected. Outdoor environment is characterized with the presence of trees, other foliage, building exterior and other structures may cause signal interference. The existence of such obstructions may result in signal transmission to be affected severely as they can attenuate received signal power, hence degrading communication. Obstructions regardless of being in motion or motionless would nonetheless affect the propagating signals [7]. Obstruction presence between transmitter and receiver ends would result in undesired interference that could spell out reduction of data throughput in the network. Thus, there is a need to quantify such cases in order to better predict level of severity in terms of throughput pertaining to reduction of received signal.

Corner reflector structure is an easy and low-cost add-on that could be easily integrated to Wi-Fi's AP. The reflector could also change the AP's wireless signal coverage by moving its position relative to AP antennas' position [8]. Characterizing the change of Received Signal Strength Indicator (RSSI) as well as inspection of throughput when corner reflector is applied to AP could imitate scenario where obstruction is presence between AP and user equipment (UE). TCP throughput investigation of such scenario could model throughput-drop correlation to the RSSI change.. Literature suggests that more RSSI-TCP throughput analysis is required to establish reliable prediction modelling specifically for different environment where Wi-Fi WLAN are expected to operate [6].

This paper is arranged as follows; Section 2 presents on related studies. This is followed by Section 3 that describes the methodology of this study. Subsequently section 4 presents on results as well as findings. Finally, the conclusion is made in section 5.

2. Related Works

2.1 Received Signal Strength Indicator

RSSI is known as Receive Signal Strength Indicator. It's a measurement of the strength of the received radio signal and commonly used as a wireless network's performance indicator. RSSI performance is usually classified into four categories: excellent, good, fair, and weak [5]. RSSI can be measured using a variety of computer software. The WLAN performance also impacted by the Signal-to-Noise Ratio (SNR). RSSI and SNR have a mathematical relationship, which is SNR is equal to RSSI minus the RF background noise. The noise is the signal interference by other device likes phones, radar, microwaves or others. Good SNR and great signal strength could result better WLAN performance.

2.2 Wi-Fi Throughput

Throughput is one of the important parameters to determine a WLAN's performance. Throughput is the rate at which data is successfully transmitted over a given period of time. In a wireless network system, the client sends a message to another client are determined by throughput in unit bits per second. It means that the messages are delivered faster if a larger throughput existed. TCP throughput has two types which are uplink, speed of client delivered data to server and downlink, that is the speed of server delivered data to client. According to I. Oghogho, et al, upload and download throughputs exhibit a substantial difference [9]. The throughput may be affected by factor including environment, transmission medium limitation, protocol operation or others. The throughput could be anticipated directly from signal to noise ratio (SNR). For example, a greater SNR number indicates that the signal strength is greater in comparison to the noise levels, allowing for faster data rates and lower retransmissions, resulting in improved throughput.

2.3 Outdoor Propagation

The outdoor signal propagation may be affected by many factors such as tree, building exterior, sculptures and others. In this condition, an outdoor propagation model might be utilized to create a WLAN network structure and increase communication services to users in a strategic way [7]. To predict outdoor wireless signal coverage, different types of outdoor propagation model have been developed. By determining the path loss or the ratio between transmit and received power from transmitter and receiver, these outdoor propagation models can predict the signal strength at outdoor environment [10]. Outdoor propagation models are in handy when constructing a network and conducting interference tests as the deployment progresses. Empirical, stochastic, and deterministic models are the three types of propagation models available. In addition, the signal strength also can be obtained by measurements without propagation predictions to observe the outdoor signal propagation. Propagation is commonly characterized based on path loss (PL) in dB calculated from

$$PL = Pt + Gt + Gr - Pr \qquad (1)$$

where Pt is transmitted power, Pr is received power, Gt is antenna gain at transmitter end and Gr is antenna gain at receiver end.

2.4 Regulating Signal Wave Propagation

Certain scenarios may necessitate that operating signal waves coverage do not exceed a certain area of interest [11]. In addition to limiting coverage of private wireless signal, such an approach also prevents electronic eavesdropper or unwanted transceiver to establish wireless link with proprietary wireless communication systems. Among the approaches to materialize the control of signal wave propagation is through the modification of building structure materials such as concrete blocks. Through addition of steel fibres, carbon powder and taconite, conductive concrete was introduced to act as Electromagnetic (EM) shield [12]. It can be used to block or reduce the electromagnetic field in a space. By using band-stop filter designs on the surface of composite substrate, frequency selective attribute that attenuate unwanted signals while permitting signal wave of desired channels to pass through are achievable. These composite surfaces can be then placed on walls, partitions, doors and windows [13].

2.5 Corner Reflector

The V-shape or sphenoidal corner reflector is known as a directional antenna. John D. Kraus invented this type of antenna which made up of a driven dipole or radiator and a reflector made up of two planar conducting sheets, or their electrical counterparts, that meet at an angle to form a corner. The corner reflector easy to design. The angle of corner reflector is commonly made to be 90° for easy design. Other angles can nevertheless be used as well. The gain is greater when the angle of reflector is smaller [14]. The aim of using a corner reflector in antenna is to improve the directivity so that the signal strength will increase. The emitted energy is contained within the metallic plate thanks to the corner reflectors. The directivity is improved since the incoming energy is reflected in the desired direction. On the other hand, corner reflector also could attenuate signals and regulate wireless signal coverage.

3. Methodology

3.1 Corner Reflector Design

To design a corner reflector, the wavelength (λ) of operating frequency is calculated by using the formula $\lambda = c/f$ where c is speed of the light and f is operating frequency. The corner reflector is designed according to parameters based on Figure 1. The angle of corner reflector used is 90°. The feed to vertex distance (s) is commonly made between $\lambda/3 < s < 2\lambda/3$ [15].

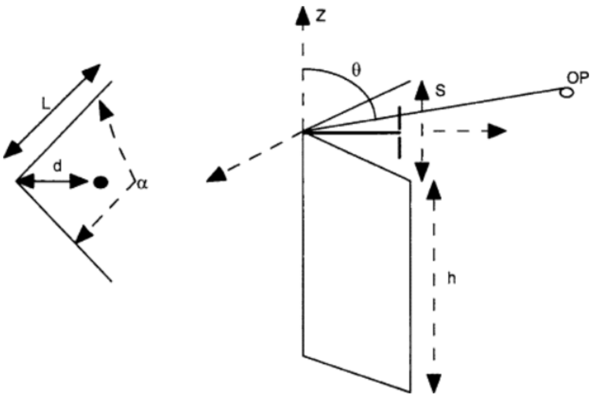


Figure 1: Corner Reflector antenna dimension specifications

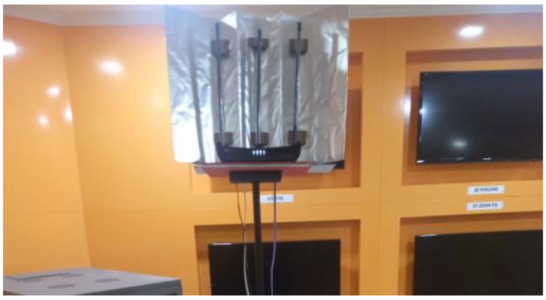
For this project, the feed to vertex distance is chosen at 1/2 λ. The length of reflector (L) is usually equal to 2s for 90° corner reflector. The height of reflector (h) is set to be about 1.2 higher than the length of feed element [16]. An aluminum film is used to coat a hardboard to develop the corner reflector. The parameters of corner reflector are shown in the Table 1 and Figure 2 demonstrated the placement of designed corner reflector to AP.

Table 1: Parameter For Corner Reflector

Design	90° corner reflector
Frequency	2.4GHz
Wavelength (λ)	12.5cm
Feed to vertex distance	6.25cm
Length of reflector(L)	12.5cm

Figure 2: (a) AP without corner reflector (b) Corner reflector placed near to AP

(a)

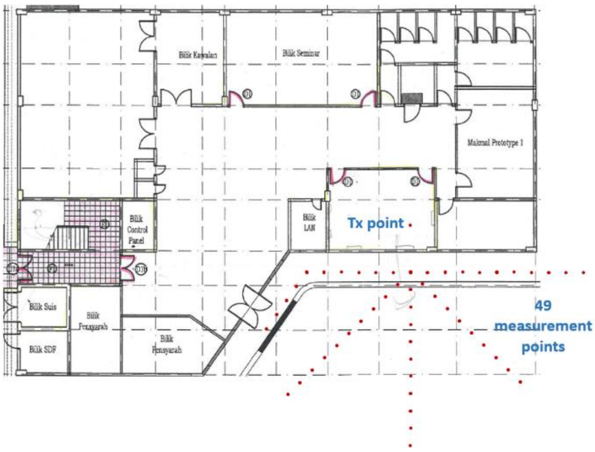


(b)

3.2 Measurement Site

The data of signal strength and Wi-Fi throughput were obtained as part of this experiment's measurement. The analysis and measurement data collection has been done at various distances between the transmitter and receiver, as well as with and without the use of a corner reflector. Experiment was conducted at outdoor environment of Wireless Communication Centre (WCC) in UTM. The Wi-Fi's AP (Tx) was setup at indoor of WCC. All measurement points were setup in non-line of sight (non-LOS) region separated by wood panel and brick wall. Cumulatively, there were 49 measurement points, represented by red circle dots in Figure 3. All measurement of RSSI and TCP throughput were recorded in two sets to ensure robustness of recorded data.

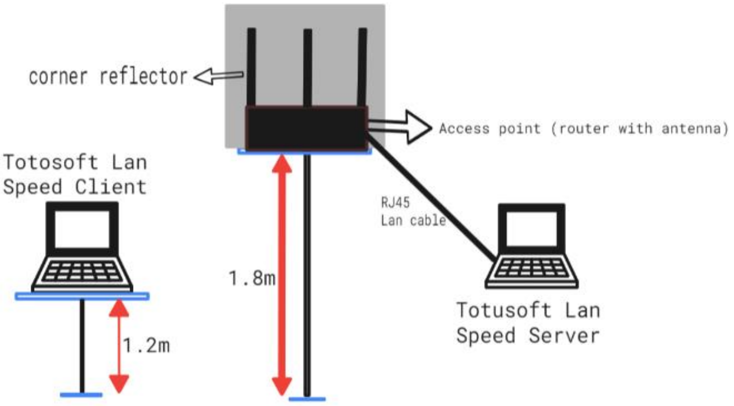
Figure 3: Layout of measurement site



3.3 Measurement Setup

A TP-Link TL-WR941HP Wi-Fi modem router with 20 dBm transmission power and three 9 dBi antennas was used as AP in this measurement campaign. The corner reflector was place behind the AP's antennas with configuration on Figure 1 for case with corner reflector measurement setting. Two long RJ45 LAN cables were used to connect the Wi-Fi AP router to the server laptop and LAN port while another laptop was functioning as client (UE) for the measurement works. An EDUP Wireless 11AC USB adapter with 2dBi antenna was used at UE. The UE was positioned at all measurement points. Figure 4 shows the setup. The AP was positioned 1.8m from the ground, whereas the client laptop as UE was positioned 1.2m from the ground.

Figure 4: Access point and corner reflector setup



3.4 Software Setup

Two main software tools used in this measurement campaign of RSSI and Wi-Fi TCP throughput are Totusoft LAN Speed Test (LST) and Acrylic Wi-Fi software. The Totusoft LAN Speed Test tool is used accompanying Totusoft LST Server to measure the Wi-Fi TCP throughput. By using this configuration, the client connects right away to the server through the network with no hard drive limitations for precise actual network performance [17]. The packet size was setup in 1MB. The results of throughput were shown on the Totusoft's interface in terms of writing and reading which represent the upload and download TCP throughput. The Acrylic Wi-Fi Home software is used to measure the RSSI of the Wi-Fi's AP. The RSSI by the client is measured in decibels (dBm), which normally varies from 0 to 100. This tool displayed the Wi-Fi networks information (SSID/BSSID) and connected users, signal quality charts for Wi-Fi channels and discovered devices [18]. It has a Wi-Fi channel scanner and can connect to Wi-Fi networks on 2.4 GHz and 5 GHz channels.

4. Results and Analysis

Cumulatively, 392 throughput data were recorded for the case of upload as well as download scenarios. Figure 5 shows radio frequency (RF) heatmap of recorded RSSI for the scenario of Wi-Fi AP without and with corner reflector. The heatmap show the impact of corner reflector to AP where AP's outdoor signal coverage is distinctively attenuated.

Figure 5 : Heat map result of RSSI (a) without corner reflector (b) with corner reflector

(a)

(b)

Figure 6 shows the PL on a logarithmic distance, d scale. From the recorded data, it was observed that the average signal attenuation is 7.6 dB when the corner reflector is applied. The signal strength logarithmically decreased with distance. Based on log-distance model considering NLOS links and random shadowing effects [18], the path loss exponent, n, and standard deviations, χ, for with and without corner reflector are described in Table 2.

Table 2: PL Parameter for Log-Distance Model

PL Parameter	Without reflector	With reflector
n	5.8	6.3
χ (dB)	6.8	6.5

Figure 7 presents recorded upload and download throughput in Mbps for the investigated scenarios. The plots demonstrate that upload and download scenarios may experience different attenuation effects when corner reflector is applied to AP. It is shown that upload scenario experience larger drop of TCP throughput with decreasing RSSI based on the investigated setting.

Figure 7: TCP Throughput (Mbps) versus RSSI (dBm)

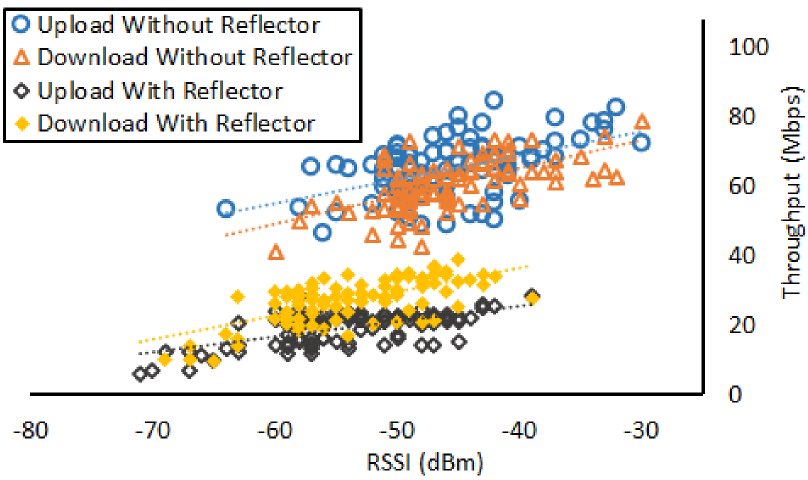


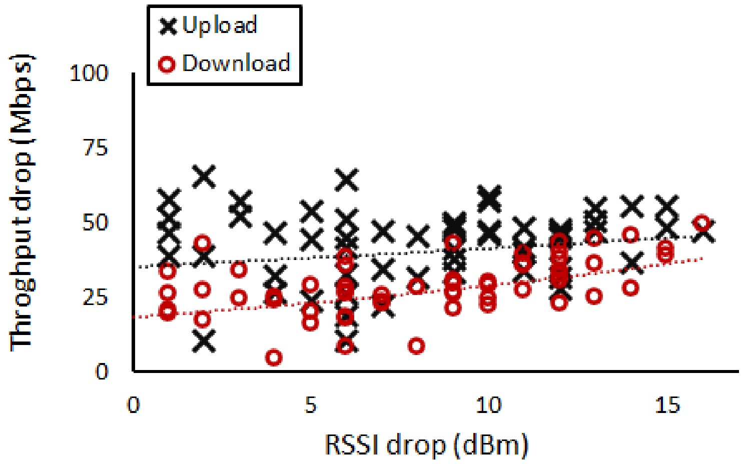
Figure 8 shows the plots of TCP throughput changes for both upload and download scenarios. From analysis of the plotted data, it was found that TCP throughput drop, Td, for both upload and download scenarios could be best modelled against RSSI drop, Rd, based on exponential equation (2) where values of α and β are as per Table 3.

$$Td = \alpha e^{\beta (Rd)} \quad (2)$$

Table 3: Exponential Model For Td Against Rd

Model Parameters	Upload	Download
α	35.2	18.4
β	0.02	0.05

Figure 8: TCP Throughput drops (Mbps) versus RSSI drops (dBm)



5. Conclusion

This research work has characterize RSSI and TCP throughput changes for inddor-to-outdoor environment for an indoor Wi-Fi's AP with and without corner reflector. The corner reflector was applied to imitate signal attenuation due to obstruction presence between the AP and UE. The implementation of corner reflector is able to reduce the signal strength and TCP throughput as intended. This study also has modelled correlation of RSSI and TCP throughput changes for investigated scenario.

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