



Evaluation of Impact of Signal-to-Noise Ratio on Communication Channel Capacity of a Wifi Network

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Abstract

WIFI is a wireless communication facility that allows computers, smartphones, or other devices to connect to the internet or communicate with one another within a particular coverage area or range. It has become an integral part of our fast-paced everyday lives. We no longer have to be tethered to the Internet with cables. It uses radio waves to transmit data from its wireless router to a Wi-Fi enabled devices. Since the devices communicate with each other over airwaves, devices and personal information are prone to noise and other security threats. These challenges are of great concern when accessing a public Wi-Fi network at places like shopping mole, airport to mention but few. Introduction of unwanted signal can affect the signal to noise ratio of the channel leading to unreliable performance of wireless communication network in terms of its capacity resulting to network congestion, interference and accuracy of the information. In this study, Least mean square constant modulus was employed in noise reduction as in equation 2.21 to optimize the channel capacity and was compared with the conventional constant modulus. It showed a significant reduction in noise which lead to increase in signal to noise ratio and channel capacity. This technique was implemented in development of the proposed model using Shannon channel capacity model. The developed Model was simulated and the result analyzed. The result showed that reduction in noise increases signal to noise ratio thus increases the channel capacity of the WiFi network used for the study.

KEYWORDS: Wifi, Least Square Constant Modulus Algorithm, Signal to noise ratio, Channel capacity

1. INTRODUCTION

Wi-Fi is a wireless technology that uses radio waves to transmit data from its wireless router to a Wi-Fi enabled devices like computers, tablets, smartphones and other devices to the internet. Cisco(n.d). It is the radio signal sent from a wireless router to a nearby device, which translates the signal into data that can be seen and used. The WiFi device transmits a radio signal back to the router, which connects to the internet by wire or cable. Wi-Fi uses radio waves to transmit information between user's device and a router through frequencies. Two radio-wave frequencies (2.4 gigahertz and 5 gigahertz) can be used, depending on the amount of data being sent. The two Wi-Fi frequencies are split into multiple channels so as to prevent high traffic and interference. Frequencies used by Wi-Fi networks are typically split into 14 channels in the 2.4 GHz band, 34 channels in the 5 GHz band, and up to 59 channels in the 6 GHz band. Channels are what the GHz can transmit on. Connection of Wi-Fi can be of the following settings; Wireline/router, Mobile hotspot or jetpack, LTE Home Internet and 5G Home Internet.

When it comes to sharing the data across these channels, the first step in the process is initiated by the user. Access to the Internet requires using an internet friendly device, it converts the information requested into binary code, the language of computers. Everything computers do is based in binary code, a series of 1s and 0s. If using Wi-Fi, these 1s and 0s are translated into wave frequencies by the Wi-Fi chip embedded in the user's device. The frequencies travel across the radio channels mentioned earlier and are received by the Wi-Fi router in which the user's device is

connected to. The router then converts the frequencies back into binary code and translates the code into the Internet traffic requested, and the router receives that data through a hardwired Internet cable. The process repeats itself until a command is loaded or anything that requires the Internet services. All of this happens at an unbelievably fast rate and requires a reliable and optimal network capacity; most routers operate at 54 Mbps (megabits per second), meaning that when such routers translate and transmit binary data, 54 million 1s and 0s are taken in or sent out in a single second. Furthermore, information are prone to noise and other security threats as that transmitted through a channel. These network challenging factors causes interference in the channel, poor signal to noise ratio thus affecting the rate at which information can be reliably transmitted over a communication channel. Hence the motivation of this work was based on delay encountered while accessing the internet services using WiFi facility.

However, this study focused on the impact of signal to noise ratio on the channel capacity. The channel capacity C (measured in bits per second or binary digits per second) is the maximum rate at which symbols can be transmitted reliably between the source and destination over a channel subject to additive, white, Gaussian noise. It is essential to minimize Noise in order to maximize the capacity of the network. Hence, noise reduction Least mean squared constant modulus based technique was proposed for this study and was compared with the conventional constant modulus technique. Shannon's Capacity model was adopted and the technique was implemented for the observation. It started that the maximum rate at which information can be transmitted over a communication channel of a specified bandwidth in the presence of noise. In order to maximum the rate at which information can be transmitted through a channel, it is important to minimize the probability of noise/error occurring in the channel thereby improving its signal to noise ratio and the capacity. This model was modified to suite the proposed model of the technique and used to observed the behaviour of the system. The noise reduction least mean constant modulus based technique was substituted in signal to noise ratio of the Shannon capacity model to form the new model used in observing the behaviour of the proposed channel.

2. MATERIALS AND METHODS

2.1 Materials Used

Wifi enabled devices, smart phones, computers, WiFi Analyzer, GPS device and stop watch.

2.2.0 Methods Implemented

2.2.1 Characterization of the WiFi Network under Study

Having identified a study gap (need to improve on signal to noise ratio in order to improve the channel capacity of a WiFi communication network through thorough review of some related works on channel capacity of a WiFi communication using Wi-Fi established network connection, a replica of such system was established and used in this work for the purpose of studying the behaviour of the network when the constituents' parameters are varied. In characterizing the system, the physical model of the communication network was established using smart phones, Hotspot-Wi-Fi ad-hoc connection as shown in plate I. This was done to determine the parameters that made up the network under study and ascertain the behaviour of the system with variation in the constituent parameter values. Some of the equipment used in the experimental setup were mobile phones of different manufacturers and model such as Techno Pop4, Techno Pova, Gionee m12, and Gionee m5, and techno with Wi-Fi analyser installed on the phones, GPS (geographical positioning system) devices and stop watches. A free space environment (Shoprite Enugu) was selected, with the proposed network established and observed for the purpose of actualizing the objective of this work. The environment was selected based on the aim of this research, accessibility, for better understanding and implementation of the proposed technique. This experiment was done three times for three hours each day for days during raining (August, 2024) and dry season (January, 2025). The behaviour of the system was also observed by simulation method using mathematical equation as discussed in section 2.2.2. The results of both experiments were taken at the same period. The simulation was repeated 15 times each for each of the seasons. The reason for carrying out the experiments for the two seasons was to determine if weather will affect the results.





Plate I: Experimental Setup for Measurement of the Parameters Used in Characterizing the Network under Study.

2.2.2 Evaluation of the Proposed Noise Reduction Model for the Study

Least square constant modulus was chosen over the conventional CM because it has the capability of converges faster when compared with the conventional CM.

Let signal transmitted = $s(t)$ and signal impinged on receiver antenna element = $X_i(t)$ using single antenna system in this work.

Then, the signal incident on the element is expressed as

$$X_1(t) = s(t) \exp\left(j \frac{2\pi}{\lambda} (i-1) d \cos \theta\right) + n(t), i = 1, 2, 3, \dots \quad 2.1$$

Assuming the signal arriving on the element i are of same frequency (f_c) with incident angle θ , $i=1,2,3, \dots, N$, signal transmitted be $s_1(t), s_2(t), \dots, s_N(t)$ and the received signal $X_i(t)$ being equal to the sum of the incident signal and noise.

Then the total signal incident on the receiver is represented as;

$$\therefore X(t) = \sum_{i=1}^n h(\theta_i) s_i(t) + n(t) \quad 2.2$$

(Zeeshan A, (2021))

Where $n(t)$ is considered as a matrix $N \times 1$ vector of the noise at antenna element. In this study, $N=1$

$$h(\theta_i) = \begin{bmatrix} 1 \\ e^{-jkr_1} \\ e^{-jkr_2} \\ \vdots \\ e^{-jkr_N} \\ 1 \\ e^{-j\frac{2\pi}{\lambda} d \cos \theta_i} \\ \vdots \\ e^{-j\frac{2\pi}{\lambda} (i-1) d \cos \theta_i} \end{bmatrix} \quad 2.3$$

$$h(\theta_i) = \begin{bmatrix} 1 \\ e^{-jkr_1} \\ e^{-jkr_2} \\ \vdots \\ e^{-jkr_N} \\ 1 \\ e^{-j\frac{2\pi}{\lambda} d \cos \theta_i} \\ \vdots \\ e^{-j\frac{2\pi}{\lambda} (i-1) d \cos \theta_i} \end{bmatrix} \quad 2.4$$

Where $h(\theta_i)$ is the steering vector.

Representing equation 2.2 in matrix form, $X(t) = h(\theta_i)x(t) + n(t)$

$\therefore h$ is $M \times N$ matrix of the steering vectors.

$$h(\theta_i) = [h\theta_1 \quad h\theta_2 \quad \dots \quad h\theta_N] \quad 2.5$$

$$s(t) = \begin{bmatrix} s_1(t) \\ s_2(t) \\ \vdots \\ s_N(t) \end{bmatrix} \quad 2.6$$



Expressing equation in vector form;

$$X_i(t) = [h\theta_1 \ h\theta_2 \ \dots \ h\theta_N] X \begin{bmatrix} s_1 & (t) \\ s_2 & (t) \\ \vdots & \vdots \\ s_N & (t) \end{bmatrix} \quad 2.7$$

$$X_i(t) = h(\theta)x_i(t) \quad 2.8$$

$s_i(t)$ = input of the data vector.

In determining the error signal, output signal and the desired output from the decision feedback unit were used. The weight was determined using the current weight, signal input from the antenna, step function and the error signal. To determine the weight, let the received signal be equal to X_i and transmitted signal be equal to $s(t)$.

Then,

$$X_i = hS_i + n_i \quad (\text{with interference inclusive}) \quad 2.9$$

With $h|S_i| = 1$

constant modulus for all i and the source being unknown., in this study $I=1$

To determine the weight vector of the receiver(W),

At the initial stage, the weight vector is defined such that the output of the receiver system is represented as;

$$y_i = W^H X_i \quad 2.10$$

System is desired in such a way that the desired output from the feedback unit will be;

$$\widehat{S}_i = y_i * \frac{\bar{y}_i}{|y_i|}$$

Identifying w for $\bar{y}_i = 1$ for all i

Zhang *et al.* (2018)

For optimization using CMA,

$$\min_w J(w) = E[(|y_i|^2 - 1)^2] \quad 2.11$$

To determine the current weight,

Update the weight using stochastic gradient,

$$\Rightarrow W_{\text{new}} = W_{\text{current}} + \Delta W_{\text{current}}$$

$$\therefore W_{\text{new}} = W_{\text{current}} + (\text{StepSize}) u e^*$$

$$W_{i+1} = W_i + \mu X_i (|y_i|^2 - 1) \bar{y}_i \quad 2.12$$

Where w is a vector of all weights W_i , X is a vector of all inputs X_i and the $*$ operator denotes the complex conjugate

$$W_{i+1} = W_i - \mu \nabla J(w_i), \quad 2.13$$

where μ = step size

To compute for gradient;

$$|y_i|^2 = y_i \bar{y}_i \quad 2.14$$

$$|y_i|^2 = W^H X_i X^H W \quad 2.15$$

Then,

$$\nabla J(w) = 2E[(|y_i|^2 - 1) - \nabla (W^H X_i X^H W)] \quad 2.16$$

$$= 2E[(|y_i|^2 - 1) - X_i X^H W] \quad 2.17$$

Implementing the conventional CMA in weight update,

$$J(w) = E[(|y_i|^2 - 1)^2] \quad 2.18$$

$$J(w) = E[(|W^H X_i|^2 - 1)^2]$$

$$y_i = W^{(i)H} X_i$$

$$W^{(i+1)} = W^{(i)} - \mu X_i (|y_i|^2 - 1) \quad 2.19$$

Estimating error using the least square constant modulus algorithm,

$$y_i = W^{(i)H} X_i \quad 2.20$$

$$\therefore \text{Error update}(e) = \widehat{S}_i - W^H X \quad 2.21$$

And the estimated desired output will be

$$\widehat{S}_i^{(k)} = \frac{\bar{y}_1}{|y_1|}, \frac{\bar{y}_2}{|y_2|}, \frac{\bar{y}_3}{|y_3|}, \dots, \frac{\bar{y}_N}{|y_N|} \quad 2.22$$

$$W^{(i+1)} = W^{(i)} - \mu (\widehat{S}_i^{(i)} - y(i)) x(i) \quad 2.23$$

Osita.A (2023).

Note: The step size used is specified as a positive scalar. Increasing the step size reduces the equalizer convergence time. Noise of equation 2.21 substituted into equation 2.23 to ascertain the new weight that was used in equation 2.20 to observe the impact of the noise on the output signal. This was compared with that of the conventional constant



module(CM) using Matlab R2015a tools. The result of the simulation was represented in Fig.3.2 in section 3.2. used observed the impact of noise on the system.

2.2.3 Development of the Model for Estimating the Channel Capacity of the Network under Study

In development of the desired model of the proposed technique, Implementation of the noise reduction model proposed and stated in equation 2.21 was substituted into Shannon channel capacity model of equation 2.24. where noise is represented as error(e).

Shannon model was chosen because it provides a straightforward way of communication and easy understanding by any new scholar or practitioner. It can be applied in high speed data transfer and simple voice communication. Shannon capacity allows the use of noisy channels which are more cost effective as compared to noiseless channel. Shannon greatly increased understanding of how data communication works.

Therefore Shannon's channel capacity is represented

$$C = B \log_2 (1 + S/N) \quad 2.24$$

(Shannon Capacity,2024)

C is the channel capacity in bits per second.

B is the bandwidth of the channel.

S is the average received signal.

N is the average power or noise.

S/N is the signal to noise ratio

To develop the desired model of the technique, equation 2.21 was substituted into equation 2.24. where noise is represented as error(e).

This implies that

$$C = B \log_2 (1 + S/(S_i - W^H X_i)) \quad 2.25$$

substituting e in equation in Equation 2.21 into equation 2.25, channel capacity(C) becomes;

$$C = B \log_2 (1 + S/(S_i - W^H X_i)) \quad 2.26$$

Where W^i represents $W^{(i+1)}$ of equation 2.19.

Equation 2.26 is the proposed model developed. This model was simulated in Matlab R2016a platform and the result of the simulation was taken. The result was compared with that of a conventional constant modulus and the analysis of the results was done using Fig. 3.3

3. RESULTS AND DISCUSSION

3.1 Results

3.1 Presentation of Results from the Characterization of the WiFi Network under Study.

Table 3.1 below showed the parameters used for the study and the values estimated from measurement, derived and assumptions.

Table 3.1: Results from the Characterization of the WiFi Network Used for the Study

Parameters of the Characterized Network	
Operating frequency	2.4 and 5.0GHZ
Bandwidth	25mbps
Radius of the footprint of each node	100m(measured)
Height of the receiver	1.83 Meters (measured)
Height of the transmitter	2.08metres (measured)
Coverage Area of a node(circular)	31,420

For this study, Wi-Fi system was adopted and characterised. Wi-Fi frequencies observed with wavelength of 0.125meters and 0.06meters respectively. The coverage area of the node represented in this work using Wi-Fi system was chosen to be circular assuming that the system radiates in all direction. The result of the calculation of area of the circle was gotten to be 31,420m² as recorded in Table 3.1 with other parameters used for the characterisation of the Wi-Fi system under study

3.2 Presentation of Result from Simulation of Signal to Noise Ratio Versus Output Signal of the WiFi



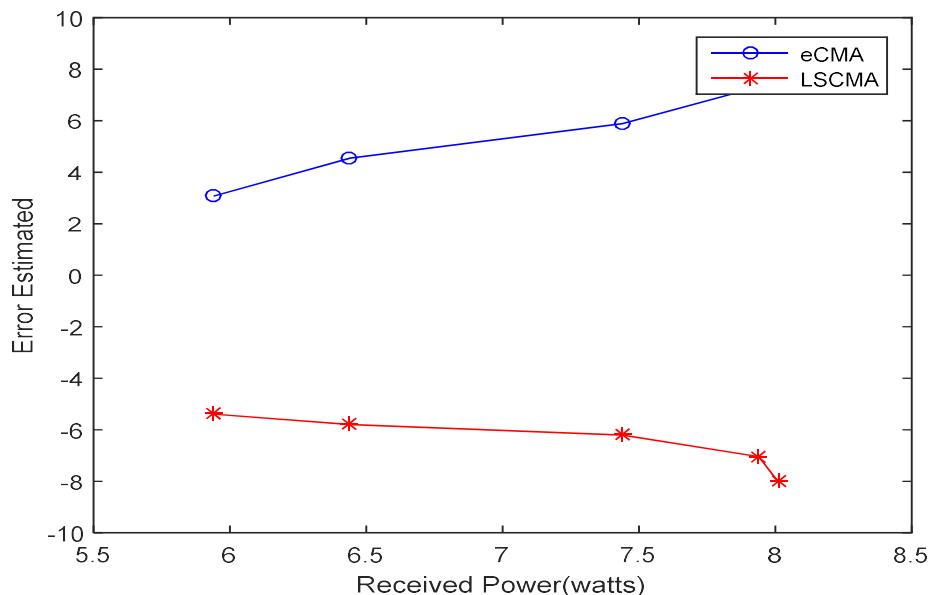
Network**Fig. 3.1: Noise Versus Signal output**

Fig.3.1 showed the results gotten from simulation of the mathematical models of conventional constant modulus and least square constant modulus equation respectively. From the Fig.3.1, the conventional CMA error is high and it increases with increase in received power. High error showed that the difference between the output of the combiner and desired signal is high, this affects the signal output negatively. The graph of Fig. 3.1 showed that LSCMA minimized error better than conventional CMA.

Increase in CMA error increases with increase in signal power received while with LSCMA, error decreases with increase in signal power received thus this affects the signal power output. From the analysis, Least Square Constant Modulus had better error minimizing capability when compared with conventional constant modulus. Desired better performance requires minimized error signal; thus Least Square Constant Modulus was preferred to conventional constant modulus scheme in error estimation. The error and weights are variables employed in estimating the desired output (received signal strength of the network).

3.3 Presentation of Result from the Simulation of the Developed Model (Equation 2.26) by Implementing of the Proposed Technique as Used in this Study

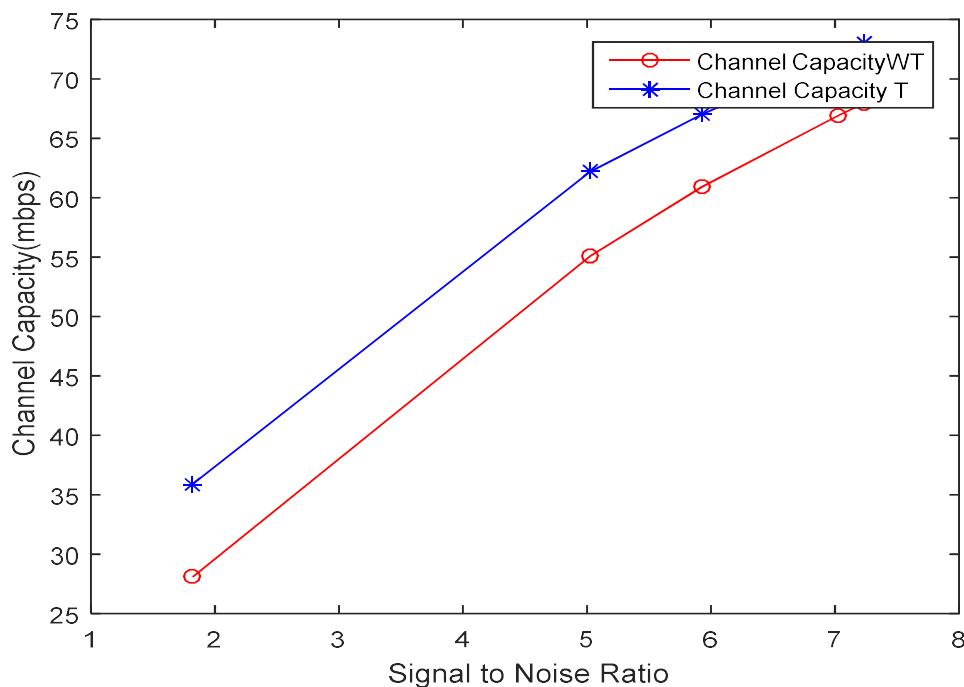


Fig. 3.2 : Channel Capacity Versus Signal-to-Noise Ratio

Channel capacity T= when the technique was implemented

Channel capacity WT= when the technique was not implemented

The result of the performance of channel capacity of the network under study with the technique implemented was represented in Fig.3.2 Noise reduction technique implemented in the Shannon capacity model showed increase in channel capacity in a positive direction as signal to noise ratio increases. The results when the technique was implemented showed better performance when compared with the conventional constant modulus technique was implemented in noise reduction.

4. CONCLUSION

Comparing the result shown in Fig. 3.2 above, the channel capacity with the noise reduction conventional CM based technique implemented proved to have lower impact in the improvement of channel capacity unlike when the technique was implemented.

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