Evolution in Electrical and Electronic Engineering Vol. 2 No. 2 (2021) 378-384

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Noise Cancellation Studies in Vectoring DSL Technologies

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DOI: https://doi.org/10.30880/eeee.2021.02.02.045
Received 04 July 2021; Accepted 23 July 2021; Available online 30 October 2021

Abstract: Vectoring is one of the extensions of Digital Subscriber Line (DSL) technologies that utilize the concept of noise cancellation in its system where the technology analyses noise on copper lines and creates inverted noise so that they would be cancelling each other. This concept is proved to be effective and cost-friendly. In this thesis, noise cancellation in vectoring DSL technologies is studied by acquiring the data through laboratory setup. The cable length of 100 m to 1000 m is used, to indicate the real situation for the customer premises where their location varies. We also compare the results when 3 modems are used and when 6 modems are used. Different traffic conditions from low, medium to high is also being considered in the measurement as we use Ixia Ixchariot to indicate user activities. The performance of the network is compared and discussed through the attainable data rate, line data rate, line attenuation and FEC error. Each data is correlated and discussed with each other in different configurations. Noise cancellation effectiveness is studied from the relationship of FEC error and line rate. From the results, we managed to observe the attainable rate, line rate, attenuation and FEC error performances over distance. We also could see the effectiveness of noise cancellation as it helps the modem to maintain its speed even when the FEC error is high.

Keywords: Noise Cancellation, DSL Technologies, Vectoring

1. Introduction

Digital Subscriber Line (DSL) is a technology where the modem uses the existing telephone lines to transport high-bandwidth data. This technology is normally used for multimedia and video, and it will be transported to the service subscribers. The connection is typically between a network service provider (NSP) central office and the customer site, or on local loops created either within buildings or campuses [1]. There are many types of DSL technologies that already exist up until this day including the term xDSL. The x in the context is the variable, but the discussion is still about DSL in general.

Vectoring is an extension of DSL technologies that employs the coordination of line signals to reduce crosstalk levels in order to improve the performance [2]. This method mainly revolves around

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the concept of noise cancellation where it analyses the noise conditions on copper lines and creates a cancelling anti-noise signal.

Phone lines that carry Very high-rate Digital Subscriber Line (VDSL2) signals are part of cables that contain from 10 to few hundred lines positioned very closely together [3]. This situation results in undesired effect of signal transmitted on one circuit to another one or cross- talk such as far-end crosstalk (FEXT). The more the number of cables positioned together, the more cross-talk will occur. This method is one of the best ways to deliver good VDSL2 performance. With no interference, every VDSL2 line can operate as if it were the only line in the cable, and as consequence, deliver higher bit rate [3]. Basically, vectoring does not increase the speed directly, it just decreases the gap between the theoretical upper limit of performance and the speeds can be delivered in variable field conditions. Moreover, vectoring works by 'listening' to unwanted noise and producing sound that exactly like it but in inverted phase so that the two sounds can cancel each other out.

Vectored VDSL2 line can reach downstream speed of 70 Mbps at distances up to 900 meters, with the attenuation of the cable exceeding 0.4 dB while 50 Mbps can be supported with loops as long as 1200 meters [4].

2. Materials and Methods

2.1 Laboratory Setup

In order to obtain precise results, the laboratory setup is assembled mimicking the actual DSL network that are being used by Telekom Malaysia (TM). Figure 1 shows the laboratory setup in UTHM. As for the real system, mini Multi-Service Access Node (mini MSAN) is located in the street cabinet as a connection of the customer premises to the core network. There are two tag blocks being used in this setup. The first tag block is located near to the mini MSAN and also in the cabinet. The second tag block works as reference to the distribution point in TM networks which connects to the customer premises.

Modem is a hardware device that can convert the data into suitable format from the access network system. 6 modems that are connected to 6 binder copper cables act as an indicator of customer premises. Ixia network and switch are not provided in the actual TM networks, but it is added in the lab setup that helps to emulate a real traffic network with necessary parameter.

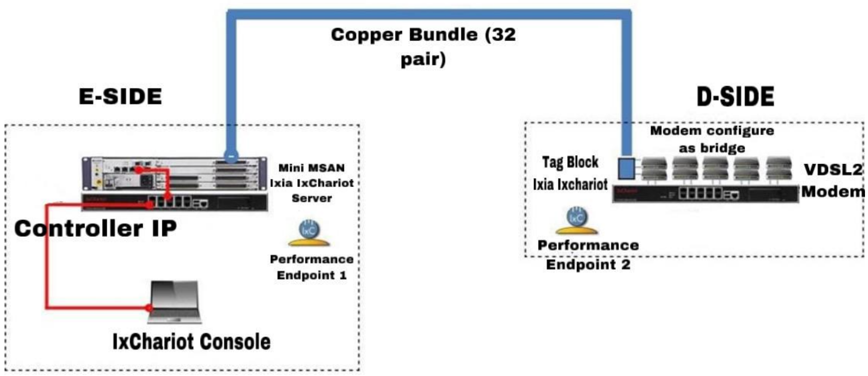

Figure 1: Schematic diagram of UTHM laboratory setup

2.2 DSL Parameters Categorization

This project mainly depends on the measurement data, which is the Line Operation Parameters (LOP) to be analyzed in order to satisfy the objectives of the project. This information is significant as an indication to the overall performance of the DSL technology. As for the LOP data, it is divided into two parts which is the upstream rate and downstream rate. Upstream refers to the data sent through a device. For example, a computer to a network as it involves outgoing data. As for the downstream rate, it refers to the data received by the device or a network, such as downloading videos or messages. Table 1 shows the LOP data identifies that is very important to measure the output data of this project.

Table 1: Line Operation Parameter

Upstream	Downstream
Line Rate (kbps)	
Average Attainable Rate (kbps)	
Line Attenuation (dB)	
FEC error	

2.3 LOP Data Collection

In this project, the LOP is the most important data that has to be analyzed in order to fulfil the objectives. The LOP will be extracted from Multi-Service Access Node (MSAN) and Customer Premises Equipment (CPE). The data collection is run through experimental hardware setup that is already being explained in the previous section. The cable length for this setup is from 100 to 1000 meters that indicate the real situation for the customer premises where their location varies but still in the core network point radius. Cable fault conditions in the transmission line between the MSAN and CPE exist according to the actual environment of the network access infrastructure. The cable conditions that are considered are open, partial open, short, partial short, uneven, bridge tap, and much more. However, in this project, only the ideal line transmission condition will be observed and analyzed. Traffic condition of low, medium and high is also considered in the measurement to indicate users activity.

The data from MSAN is collected by using Xshell software which is a remote connectivity program. The data used from this software's extraction is only LOP even though this software also collected the LLT and Hlog data. After the data collection takes place, the data will be classified based on their respective types by using Phyton programming language, as the language is the primary programming language used in TM Research and Development system. Classification of the data is based on the port used and available in the MSAN setting.

However, the data collected from Xshell software will be in the raw form. At this point, Phyton programming language get involved to transform the data into (.csv) format. The process will be repeated for CPE data extraction.

2.4 Analyzing LOP Data

From the ideal condition of LOP data that is collected from MSAN and CPE, attainable rate, actual line rate, line attenuation, and FEC error is analyzed and studied. Each of the parameter is studied for both upstream and downstream. The evaluation of the data is based on the performance of the CPE. Therefore, only data from CPE will be analyzed. The data is also used to correlate the noise cancellation method that is used in the vectoring DSL technologies.

3. Results and Discussion

3.1 Heatmap

Line Operation Parameter such as attainable rate, actual line rate, line attenuation and FEC error are vital as it will be used to observe the difference in the performance of both condition, which are the performance when 3 modems are used and the performance when 6 modems are used. Data is also collected for MSAN but the result from CPE is more important to be analyzed as it will determine the performance of each setup.

In order to see the overall relationship of the parameters, heatmap is being used to determine the correlation of each parameter and to determine which parameter to focused more on. The correlation data includes distance, attainable rate (downstream/upstream), SNR margin (downstream/upstream), line attenuation (upstream/downstream), output power (upstream/downstream), line rate (upstream/downstream), CRC error (upstream/downstream), FEC error (upstream/downstream), HEC error (upstream/downstream), send byte, receive byte, send packet and receive packet.

From the correlation heatmap in Figure 2 we could see various of colours that determine the strength of the correlated parameter. The colour that is closer to -1 will be darker while the colour that is closer to white indicated the vale to be closer to +1. Correlation ranges from -1 to +1 that indicated when the values closer to zero means there is no linear trend between the two variables. The closer the variable to +1, the more positively correlated the data. Similarly, with the data set that closer to -1, but it differs in terms of when one variable increase, the other will decrease.

However, not all data will be analyzed as we have to stick to the objectives of the project. Some data is insignificant to the findings of the project. The data that will be analyzed in details are attainable rate (kbps), line rate (kbps), line attenuation (dB) and FEC error. The other parameters are not highly correlated to the findings of this project. As for upstream CRC and upstream HEC error, the data are missing from the heatmap, this is because both of errors are not present for upstream line.

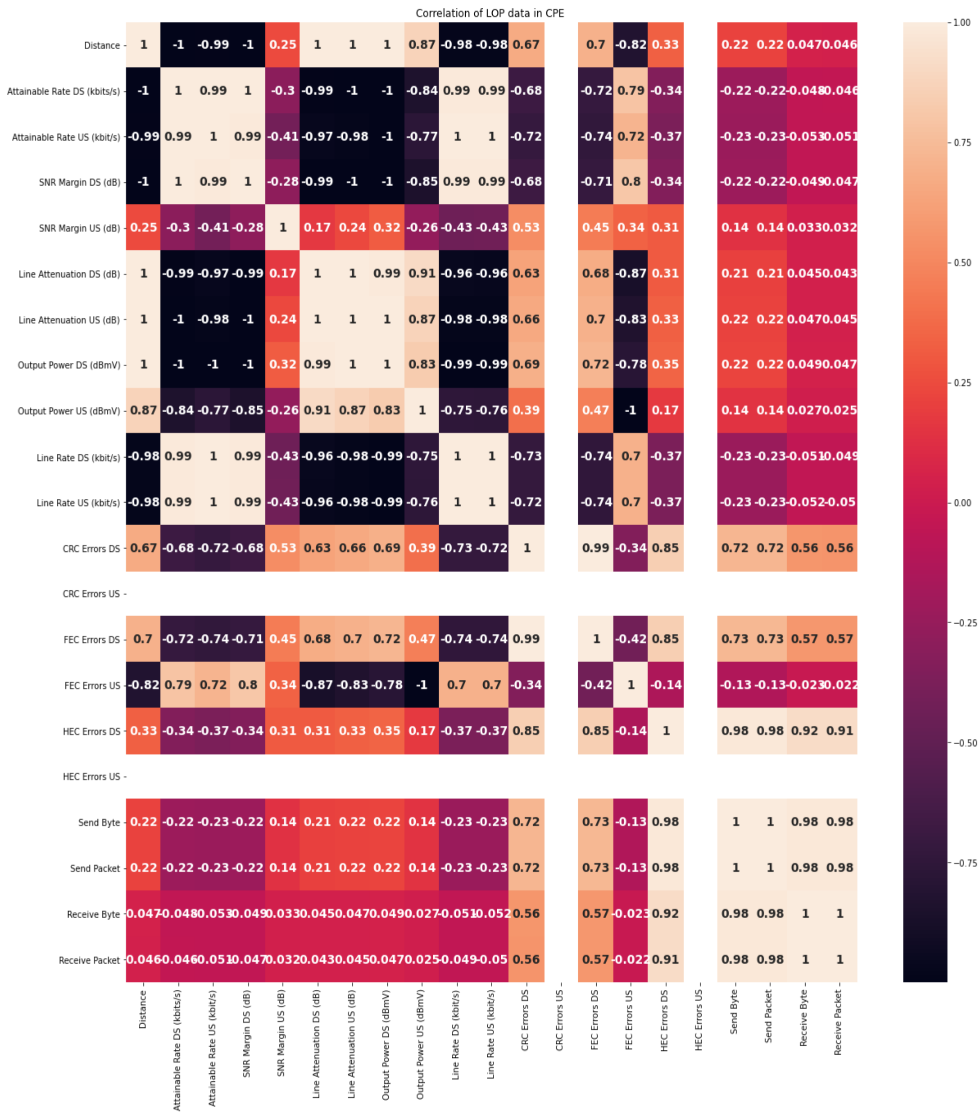

Figure 2: The correlation of LOP data in CPE

3.2 Noise Cancellation Study

Forward Error Correction (FEC) is an indicator of error during data transmission. We could see the mechanism of noise cancellation through the correlation between FEC error and attainable rate. The data is also collected from 3 different distance which is from 100 m to 1000 m. The discussion will be more focused on downstream data as the upstream data is zero for every configuration. The same case scenario also happened to CRC and HEC error.

From Figure 3 and Figure 4, we could see the relationship between FEC error and downstream attainable rate for 3 modems. The result from both scatter plots satisfies the correlation between the two parameters which is -0.74 that shows the strength of its correlation.

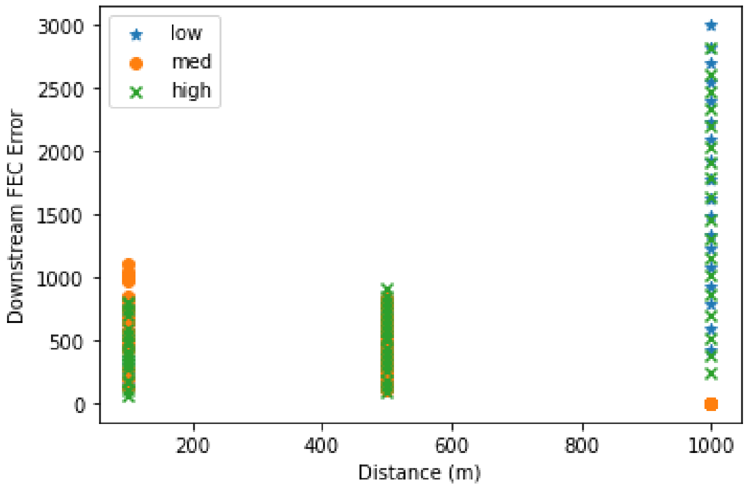

Figure 3: Downstream FEC error for 3 modems

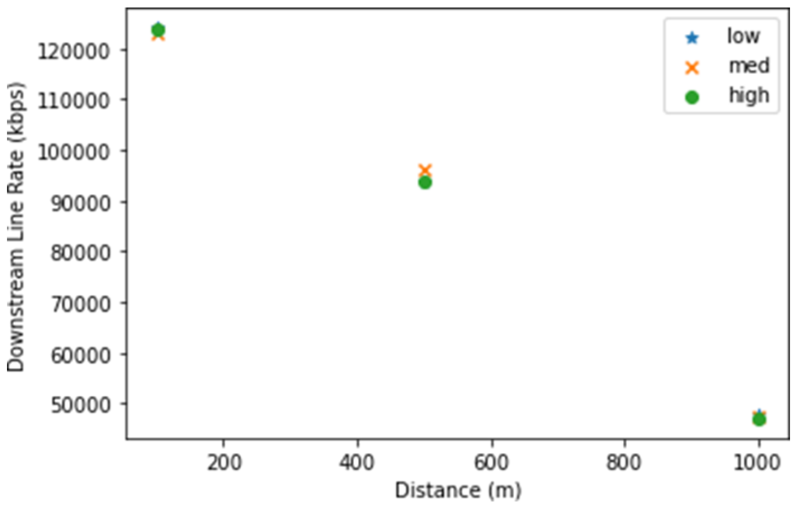

Figure 4: Downstream line rate for 3 modems

We could see the FEC error increase as the distance increase which followed the correlation heatmap which recorded to be +0.7. This is because the longer the distance, the higher the attenuation of the data, which resulting the line rate to be degraded. The scatter plots for the line rate are built from 18 time slots. However, we could see from Figure 4 that the line rate data are very close together according to the respective distance. This shows the data to be very stable even though with the presence of high FEC error in the cable.

This proved the mechanism of noise cancellation in the system as noise cancellation is about coping in noisy copper cable but still be able to maintain the performance. Without noise cancellation, the data will not be able to maintain its stability.

As for the FEC error for upstream, no significant FEC error is recorded except for the low traffic configuration at 100 m of distance as shown in Figure 5. However, the line rate is still high despite the presence of FEC error which once again proved the effectiveness of noise cancellation in the system as shown in Figure 6.

Next, for the data of FEC error for 6 modems, there were no data recorded as the value is zero at every configuration of distance and traffic condition. Therefore, we can conclude that there is no error recorded for data, hence there will be no noise cancellation mechanism happened in the system.

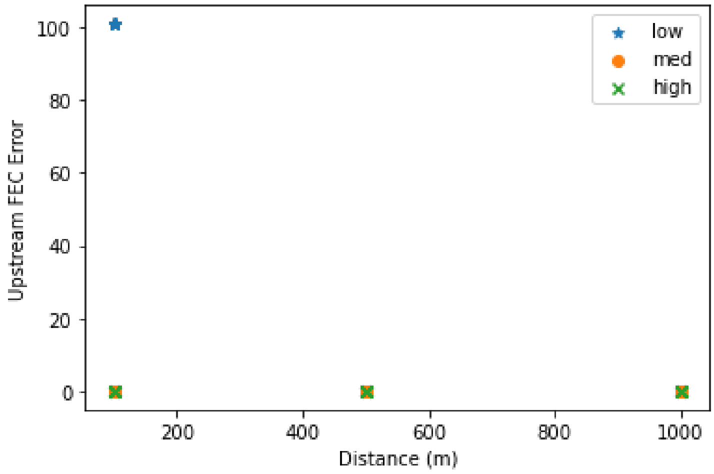

Figure 5: Upstream FEC error for 3 modems

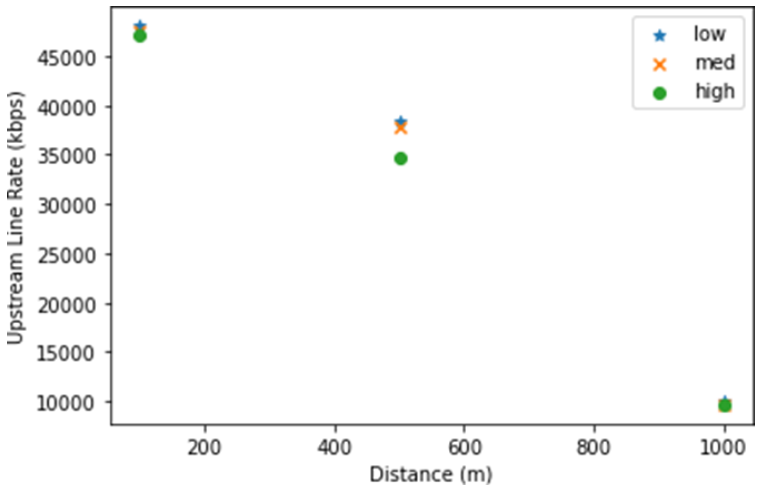

Figure 6: Upstream line rate for 3 modems

4. Conclusion

The development of Digital Subscriber Line technologies has enabled us to taste the steady speed of internet in order for us to do our daily routine especially during this pandemic where most of people stay at home. Students or workers need fast internet more than anything these days. But, high speed of internet usually comes with a higher price which not everyone can afford. Therefore, the development of this technology is very important in order to satisfy everyone's need.

From the result that already being shown in the previous chapter, we could see the performance of the attainable rate for both upstream and downstream rate over distance and number of modems used.

We could see clearly how the attainable rate decrease when the distance increase because the line attenuation increase. The result that we produced is theoretically aligned as that is what we already expected even before the simulation is made.

The result of the line rate data is considered reliable because from theory, it is expected the actual line rate to be less than the attainable rate. The data also degraded as the distance increase as the amount of loss increase alongside with it. The result also can relate to how internet speed actually works in real life. When your service provider claim that they provide 100 Mbps to your internet, most of the time your internet speed will be less than that. This concept is similar to attainable rate and line rate.

As for noise cancellation study, we could see its performance through the result of FEC error and line rate. When 3 modems were switched on, we could see clearly how FEC error increase as the distance increase. However, the line rate remains stable for 18 time slots as shown in Figure 4 where the data of downstream line rate for 3 modems is still located at the same spot even when the FEC error increase in Figure 3 This shows the effectiveness of noise cancellation in the system. However, we could not prove the effectiveness of noise cancellation when 6 modems were switched on because there were no FEC error recorded for the configuration.

In conclusion, we managed to satisfy the objectives of this project. Firstly, to simulate data acquisition platform in order to observe the performance of the DSL technologies and to correlate related parameters to prove the effectiveness of the noise cancellation in the system.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

Appendix A

CORRELATION HEATMAP CODING

```
import pandas as pd

import seaborn as sns

import matplotlib.pyplot as plt

import numpy as np

dt = pd.read_excel('overall.xlsx')

sns.heatmap(dt.corr(), annot=True)

fig= plt.figure(figsize = (9,9))
```

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