Performance Analysis of ADSL

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Abstract: This study will present a deep research regarding the characteristics of ADSL in term of its advantages and disadvantages. The performance analysis concentrates on the impact of the services. Tests are being carried out to prove that the performance is affected by loop length and also noise issue as well as their impairment issues especially crosstalk. Crosstalk modeling is performed to discuss the performance of ADSL with the supports of a proposed statistical methodology. At the end of the study, a comparison of ADSL with other copper using fixed line broadband communication system, Cable Modem is discussed.

Keywords: ADSL, Bridge tap, Copper broadband, Crosstalk, Loop length.

1. INTRODUCTION

According to Committee on Broadband Last Mile Technology, definition of broadband is: ‘the access link performance should not be the limiting factor in a user’s capability for running today’s applications’. In general, any connection to the customer of 256 kbps (0.256 Mbit/s) or more is considered broadband Internet [1]. Nevertheless, there is no specific bitrate defined by the industry until now.

Basically, broadband implementations are characterized into two types that consist of fixed line implementation and wireless broadband implementation. Components in the fixed line broadband implementations are:

- Digital Subscriber Line (DSL): digital data transmission over the wires used in the local loop of a telephone network
- Cable modem: designed to modulate a data signal over cable television infrastructure
- Power line communication: wireline technology using the current electricity networks
- Satellite Internet access
- Fiber to the premises: based on fiber-optic cables and associated optical electronics

On the other hand wireless broadband implementations consists of:
- Local Multipoint Distribution Service: broadband wireless access technology that uses microwave signals operating between the 26GHz and 29GHz bands.
- WiMAX: a standards-based wireless technology that provides high-throughput broadband connections over long distances [2].

Even though wireless broadband implementations are being emphasized strongly in this competitive world, but the role of fixed line broadband still cannot be neglected especially DSL and cable modem. They are still widely deployed all over the world.

The objective of this project is to evaluate the characteristics of DSL [2, 3] and identity deficiencies of the existing implementations and to determine methods to improve the performance of these technologies. Statistical modeling tool is also developed in order to monitor the performance analysis of telecommunication networks.

There are many types of parameters that can be taken into account when dialing with performance analysis, but this study will only concentrate on the impairment of the technologies. For xDSL technologies, ADSL become the main topic which will be discussed and evaluated in terms of the modulation technique, FEC and thereof. Crosstalk issue is highlighted.

The outline of the report is as below:
Section 1 performs the background and basic concept of this project. It includes the objectives and scope for this project. Section 2 is the literature review for these two fixed-lined broadband implementations. It is divided into two parts. First part is for xDSL technologies [4] while second part is for cable modem technology. This paragraph will give an insight into the characteristics of these technologies. Section 3 presents the methodology for this project. It describes how the project is to be implemented and the methodology methods for the tasks. Section 4 describes about the performance analysis of ADSL technology. The test configuration, procedures and simulation result as well as some comments regarding the physical layer test for ADSL are presented in this paragraph. Finally, crosstalk issue is discussed. Section 5 summarizes the comparison between xDSL technologies and cable modem technology.
2. LITERATURE REVIEW

2.1 ADSL

Asymmetric digital subscriber line (ADSL) technology is one of the most well established technologies for high-speed communication access capability for various services over the twisted-pair cable infrastructure [5,6,7,8,9,10,11].

The performance of xDSL technology is affected adversely by two main factors, which are loop condition [5,12] and transmission environment. Other factors include attenuation, return loss, longitudinal balance, split pairs, wire gauges and interruption. Longitudinal balance refers to the balance between the flow of current in a circuit and the earth of each conductance. An unbalanced circuit caused by unbalanced longitudinal currents or power-line harmonics can cause crosstalk noise, causing bit errors that result in slower xDSL transmissions and thus reduce the efficiency of xDSL services. Using mixed wire gauges in one cable can also result impedance mismatch which can defiance the efficiency of delivery [13].

The factors stated above are only related to the characteristics of physical layer. In fact, the modulation scheme, forward error scheme in upper layer for the system will also affect the performance.

2.1.1 Loop Length

Loop length refers to distance between Customer Premise Equipment (CPE) and exchange/Centre Office (CO). DSL technologies are distance sensitive. It is found out, that the longer loop length, the lower data rates this technology can deliver and support. This is because the magnitude of resistance is higher for longer loop which leads to higher power dissipation and signal attenuation.

2.1.2 Loading Coils

Loading coils (amplifier) is used by telephone companies to boost the voice signal in far distance, mostly at local loop longer than 18 kft. Thus, it is a severe deterrent for transmission over loop length more than 18 ft. When dealing with xDSL technology, it is noticed that it is incompatible with the loading coils. Hence, using loading coils will disqualify the telephone users from receiving xDSL signal. It can additionally cause serious distortion at high frequency.

2.1.3 Bridge Taps

A bridge tap is a branch of two-wire cable that is connected to the two-wire loop at one end, and is an open (un-terminated) at the other end (Figure 1). Existence of bridge tap will cause impedance discontinuity at the point where the cable is attached to the two-wire loop thus bring a signal loss. The impedance mismatch presented by the un-terminated end of the bridge tap can produce reflected signals that interfere with the original signal. It will depend on the length of the lateral bridge tap and the quantity of bridge taps that determine how much signal rejoins the two-wire loop. It is found out, that the reflected signal will suffer small attenuation for the shorter bridge taps and thus will severely distort the receive signal if compare to the longer bridge taps. This phenomenon can be seen from Figure 2.

2.2 Transmission Environment

Transmission environment for xDSL technologies decides the throughput, latency as well as the reliability of the transmission. Thus, it is important to discuss about the issue related to transmission environment including crosstalk, impulse noise and also EMI.

2.2.1 Crosstalk

In ADSL technology, telephone wires are bundled together in multi-pair binders containing 25 or more twisted wire pairs. As a result, electrical signals from one pair can electromagnetically couple onto adjacent pairs in the binder. This issue is called crosstalk. Due to the ability of ADSL to coexist with other types of DSL services in the same binder, it is found out, that the crosstalk issues became prevalent nowadays. ADSL suffered serious alien crosstalk especially from ISDN and HDSL services. This scenario should not be neglected as it will adversely effect the penetration of data through ADSL service. Thus, it is essential to evaluate the performance of ADSL in the environment with crosstalk and find solution to suppress crosstalk noise from other DSL services.

2.2.2 ADSL Crosstalk Statistical Modelling

The level of crosstalk is greatly affected by the specific loop topology and implementation. Important factors are for example the length and location of the overlap between the interfering and interfered loops, the specific pairs of the bundle and the wire cross-section used in each segment of the line, the length of the segments and connections between them, the presence of bridge taps.
The type of crosstalk whether it is NEXT or FEXT crosstalk [14] should be taken into account when calculating the magnitude of crosstalk model. Generally, crosstalk is modeled in the frequency domain by means of the crosstalk power transfer function as shown in Equation (1). It relates the power spectral density of the crosstalk interference to the spectral density of the disturbing signal.

\[ S_{xt}(f) = |H_{xt}(f, l)| \cdot S_{src}(f) \]  

where \( S_{xt}(f) \) is spectral density of crosstalk interference, \( S_{src}(f) \) is spectral density of disturbing signal, and \( H_{xt}(f, l) \) is transfer function of the transmission line. The crosstalk transfer function depends on the electromagnetic coupling and the attenuation in the line which depends on the variables frequency and length of the loop.

### 2.2.3 NEXT (SELF-NEXT)

The transfer function of NEXT is given by Equation (2)

\[ |H_{next}(f, l)|^2 \approx k_{next}^1.5 \cdot (1 - e^{-\alpha \sqrt{f}}) \approx k_{next}^1.5 \]  

where \( k_{next} \) is coupling coefficient of between the crosstalk pairs and \( \alpha \) is an attenuation of the transmission line.

### 2.2.4 FEXT (SELF-FEXT)

The transfer function of FEXT is given by Equation (3)

\[ |H_{fext}(f, l)|^2 = k_{fext}^1 \cdot |H_{line}(f, l)|^2 \cdot f^2 \]  

where \( k_{fext} \) is a coupling coefficient of between the crosstalk pairs and \( H_{line}(f, l) \) is a transfer function of the transmission line, as defined in Equation (4)

\[ H_{sso}(f, l) = \frac{Z_s \cdot \sec h(\gamma t)}{Z_s \cdot \cosh(\gamma t) + Z_r \cdot \sec h(\gamma t)} \]  

where \( Z_s \) is a characteristic impedance of the load, \( Z_r \) is an impedance of the source and \( \gamma \) is a propagation constant of twisted pair that can be expressed as:

\[ \gamma = \sqrt{(R + j \omega L)(G + j \omega C)} = \sqrt{Z} \cdot \gamma \]  

\[ \gamma \]  

\[ (5) \]

\( R, L, G \) and \( C \) are the lumped components in transmission line as can be seen in the Figure 4. The actual value of \( R, L, G \) and \( C \) also depend on the length between receivers and transmitters, \( \Delta x \). The approximated value for these inputs impedance is shown as below:

\[ R = R_0 \Delta x f \]  

(6)

\[ C = C_0 \Delta x \]  

(7)

\[ L = L_0 \Delta x \]  

(8)

The magnitude of crosstalk can be calculated using the Equation (1).

### 2.2.5 Crosstalk from Mixed Signal Sources

When there are mixed signal sources in the same binder group, alien crosstalk becomes inevitable. The mathematical model for the magnitude of FEXT and NEXT is different with the self crosstalk model. There are several summing methods to calculate the crosstalk from mixed signal including direct summation method, meaning PSD summation method, Annulus summation method, FSAN summation method and thereof. FSAN summation method gives good estimates of the mixed-signal crosstalk, is widely accepted and has become the ANSI standard for summing crosstalk from mixed sources.

\[ S_{crosst}(f, n_1, n_2) = \sum_{i=1}^{N} S_{m}(f) \cdot 0.6 \cdot i^{0.8} \cdot k_{crosst}^{1.5} \]  

\[ (12) \]

where \( R_{in}, C_0 \) and \( L_0 \) are decided by the specific cable type used (Figure 3). From here, we can also explain the phenomenon that if \( \Delta x \) (loop length) is longer, the data rates will be slower because of larger attenuation brought by the input impedance.

![Figure 3. Lumped Model of Transmission Line](image)

The coupling coefficients \( k_{next} \) and \( k_{fext} \) depend on the electrical parameters of the cable, the cable structure, and are also influenced by aging and imperfections in the cable, bridge taps, wire connections and other factors. Therefore, these coefficients are different for any pair of cable pairs and for any cable. They can be considered random variables. Nevertheless, to guarantee the reliability of transmission, 1% worst case crosstalk model was developed. Unger proposed an expression for the 1% worst-case NEXT and FEXT transfer function, with coupling coefficient expressed in formula below:

\[ k_{next} = 10^{-13} \cdot (\frac{n}{49})^{0.6} \]  

(10)

\[ k_{fext} = 9 \cdot 10^{-20} \cdot (\frac{n}{49})^{0.6} \]  

(11)

2.2.6 Impulse Noise

Impulse noise is another severe impairment in xDSL technologies. It is a non-stationary stochastic electromagnetic interference which consists of random occurrences of energy spikes with random amplitude and spectral content [15]. It is typically caused by power switching equipment that discharges electrical.
2.2.7 Electromagnetic Interference (EMI) or Radio Frequency Interference (RFI)

Electromagnetic Interference that is also known as radio frequency interference is an electromagnetic radiation that is emitted by electrical circuits carrying rapidly changing signals [15]. There are two phenomenon of EMI that are ingress and egress. Ingress happens when external source of RF coupled unequally into DSL receivers. RF ingestion interrupts, obstructs, or otherwise degrades or limits the effective performance DSL. The source of interruption may come from AM or FM radio [6].

2.3 Cable Modem

Cable modem is a broadband fixed line service that gives users high-speed Internet access through a traditional cable television network at a rate 500 times faster if compared to voice-band modems [16]. Cable modem is used widely in United Stated, Canada and Europe as a mode of high-speed data access. In contrast with xDSL technologies, ISDN and voice-band modems which operate through the telephone line, it utilizes coaxial cables entering subscribers' premises to simultaneously deliver cable TV programs, access the Internet, and also provide voice telephony [17]. Theoretically, the maximum bandwidth that is supported is as high as 36Mbps [16]. Nevertheless, due to the impairments of noise, the practical speed is typically lower than 36 Mbps. Table 1 depicts the comparison of data speed for different access methods by testing the download time frame for 10 Mbytes file. This result was taken from reference [17].

Table 1. Comparison download time for 1 Mbytes data between different access methods [17]

<table>
<thead>
<tr>
<th>Access Method</th>
<th>Maximum Speed</th>
<th>Download time for a 10 Mbytes file</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dialup Modem (28.8 kb/s)</td>
<td>28.8 kb/s</td>
<td>46 min</td>
</tr>
<tr>
<td>Dialup Modem (33.6 kb/s)</td>
<td>33.6 kb/s</td>
<td>40 min</td>
</tr>
<tr>
<td>Dialup Modem (56.6 kb/s)</td>
<td>56.6 kb/s</td>
<td>30 min</td>
</tr>
<tr>
<td>ISDN Basic Rate Interface</td>
<td>64 kb/s</td>
<td>21 min</td>
</tr>
<tr>
<td></td>
<td>128 kb/s (2 lines)</td>
<td>10 min</td>
</tr>
<tr>
<td>Satellite (Direct PC)</td>
<td>400 kb/s</td>
<td>3.3 min</td>
</tr>
<tr>
<td>LMDS</td>
<td>500 kb/s</td>
<td>2.7 min</td>
</tr>
<tr>
<td>ADSL Modem 1.5- 9.0 Mbps</td>
<td>8.9 – 53 s</td>
<td></td>
</tr>
<tr>
<td>Cable Modem 10 – 30 Mbps</td>
<td>2.7 – 8.0 s</td>
<td></td>
</tr>
</tbody>
</table>

Further information regarding operation, standards and operating system of the cable modem can be found in [3,4,5,21,22].

3. METHOD OF ANALYSIS

Among xDSL standards and data rates [8], we focus on the performance analysis for ADSL technologies. Hence, we evaluate its characteristics which embody the performance test (physical layer etc) by carrying out the test at a network operator which took around 1 (one) week time. The performances of these modems are compared and evaluated according to their results. Finally, we discuss about crosstalk and EMI issue which defyance the performance of ADSL and the comparison between ADSL, ADSL 2 and ADSL 2 plus. In the process of carrying out this analysis, we had deeper discussion with the researchers from the network operator to improve the results of the analysis.

After collecting the required information and data, the next step is analyzing the data by plotting graph and comparing the performance. On the other hand, MATLAB was used for modeling and developing an algorithm for DSL technologies to improve the network performance. There are two methods of analysis we utilized during this project:

a) Measurement and comparison of result: This is as shown in paragraph 4, TR0-67 Interoperability Test Plan.

b) Statistical modeling: Modeling is essential in order to facilitate us with references in the future.

4. TEST PLAN

4.1 Conformance, Performance and Functionality Interoperability Tests

There are three aspects of testing that usually are carried out to test the reliability of ADSL technology. They include conformance, performance and functionality test. Conformance test is also known as compliance test, which is defined as the ability of a product to meet established criteria of an implemented specification. It consists of physical layer electrical conformance and protocol conformance tests. It sets the parametric limits on the physical layer of all associated elements of the network [18].

Functional interoperability is another important test that is used to validate the operation of ADSL modem over a commonly implemented set of features. Interoperability also implies cross-vendor interoperability to measure the ability of ADSL to adapt with different vendor DSLAM. This test also measures interoperability at different levels, i.e. interoperability at layer-I, 2 or higher layer to end-to-end interoperability. For instance, according to the Interoperability test plan TR-067, the tests cover ATM connectivity tests, Layer 3 Ethernet throughput test, RFC 2156 PPPoE end to end connectivity test, RFC 2364 PPPoA end to end connectivity test, RFC 2684 end to end connectivity test and usability test. Interoperability can also be measured as static or dynamic. Static interoperability is the ability of two products to inter-operate over all implementation features in a benign environment, i.e. 10 foot loop for ADSL without noise intrusion. Dynamic interoperability is the ability of a product to inter-operate at all implemented features over all aspects of loop lengths and noise conditions such as effect of RFI, DSL noise spikes, stress test, electrical compatibility test [18].

On the other hand, performance testing is defined as the behavior of a system with respect to time, physical and external resources (such as noise). The parameter is usually measured in the form of bit error rate (BER). The ADSL performance matrix also covers line attenuation, ADSL line status, transmit blocks, corrected blocks, disconnect-able Blocks, bits/caller (DMT only),
equalizer settings (CAP only), interleave delay, rate adaptation, noise margin counters for current and previous loss of signal, loss of frame, loss of Power. The performance test also checks the ability of ADSL to emulate a real world environment with all possible performance test also checks the ability of ADSL to emulate a real world environment with all possible condition that could affect the performance of an ADSL link. The Performance test conditions include the following:

- Loop Conditions: Length, Wire Gauge, Bridge Taps, etc.
- PSTN Conditions: Ringing, Ring-Trip, Battery Feed, signaling.
- Co-Channel Noise Interference's: BR-ISDN, HDSL, ADSL, etc.
- Other Interference's: Impulse Noise, RFI, etc.
- Customer Premise Wiring effect

When comparing the performance of different data communication system, the capability and reliability of system to transmit data become hot issues. It draws more interest for us to discuss about the performance of ADSL link under different condition such as the maximum data rates at different loop conditions. Conversely, conformance and interoperability test will not be discussed in this project because the tests are usually implemented by cable operators.

4.2 TRO – 67 Interoperability Test Plan

TRO-67 interoperability test plan was proposed during DSL forum 2006 to replace the original test plan TR0-48. The objective of the test plan is to improve the interoperability between ADSL and DSLAM at different circumstances. The tests below refer to the test plan ANNEX A that involves the physical layer test cases using G992.1 Annex A. ANNEX A defines those parameters of ADSL system that have been left undefined in the body of this recommendation because they are unique to an ADSL service that is frequency-division duplexed with POTS. According to [19], there are two sets of tests that cover tests at North America, A.1 and tests at European, A.2. The test sets at North America, A.1 consists of:

- A.1.1 CPE Margin verification tests
- A.1.1.7. CO Margin Verification (Optional)
- A.1.2 ANSI T1-413 Operation
- A.1.3 Operation in the Presence of Impulse Noise Events (G.996.1, Test Impulse 1)
- A.1.4 Verification of downstream fine gain values
- A.1.5 Loop Tests with Ports Set for Adaptive Rate
- A.1.6 Loop Tests with Ports Set For Fixed Rate
- A.1.7 CSA #4 Standard Loop
- A.1.8 ANSI 13 Standard Loop
- A.1.9 Bridged Tap Tests

4.2.1 Scope of the Test

In this project, tests are carried out based on A.1.5 and A.1.9 with some modifications at the loop length. A.1.5 describes the performance of ADSL at straight loop with and without the existences of some undesired noises. Meanwhile, A.1.9 refers to bridge tap loop tests. The parameters under testing are the sync speed for upstream and downstream speed.

4.2.2 Test Equipment and Configuration

Test equipment used is:

- a) Noise generator: DLS 5200 Series allow users to apply standard-based noise shaped (DLS 5Bxx Noise Libraries) or custom generated noise shape to the test circuit. The noises that are supported include white noise and crosstalk.
- b) Loop simulator (Wireline Simulator): DLS 410A is the loop simulator that is used to perform straight loop and bridge tap loops tests.

On the other hand, devices under test (DUT) are:

- a) CPE
- b) ADSL termination unit at customers’ site, usually named ATU-R. The ATU-R should compliance with G992.1 ANNEX A.
- c) DSLAM
- d) ADSL termination unit at CO, usually called ATU-C.

The ATU-C under test is ZXDSL 8220 ZTE Broadband Universal Access System, developed by ZTE, based on ADSL and SHDSL technologies. It can transmit high-speed digital signals over a pair of common twisted telephone lines, greatly improving the line utilization of the PSTN. It implements the “last kilometer” ADSL broadband data access on the existing telephone lines and is an ideal solution for the access of a small-sized office, SOHO, telecom VOD and high-speed Internet. The ZXDSL 8220 (V2.1) is a kind of office-end DSLAM equipment.

In the experiment, DSLAM is connected to CPE modem through loop simulator that provides different loop condition. When implementing the noiseless straight loop test and bridge taps tests, the noise source will be set close. But, in noise environment, various noise sources will inject loop simulator through the high impedance network.

![Figure 4. Physical Layer Loop Test Configuration](image_url)

Test requirements are fast mode and AWG 26. Moreover, the DSLAM port setting is as below:

- Latency setting fast path or 16 ms interleaved path
- Target noise margin 6 dB
- Minimum noise margin 0 dB
- Maximum noise margin 16 dB for all rate reach tests, including fixed rate tests.
- Maximum noise margin 31dB for all other tests, e.g., margin verification tests, CRC verification tests.
- Rate negotiation, rate adaptive mode
- Trellis coding allowed
Loop simulators used to fulfill the requirements below:

- Attenuation
- Noise Floor of the simulator should lower than -150 dBm/Hz within the ADSL band.
- Impedance shall have less than 10% variation from the theoretical amplitude and phase measured with the appropriate termination impedance. For North American noises this is 100 ohms.
- Phase shall have a total phase with less than 10% variation from the total theoretical phase.
- Noise Sources

4.2.3 Test Procedures

Test procedures conducted in this study are as below:

a) Firstly, the loop simulators shall be calibrated relative to the nominal attenuation as defined in test requirements.

b) Secondly, the noise injection is calibrated as defined in test requirements above.

c) After calibration, the test configuration is set up as shown in Figure 3. Noise shall be injected through a high impedance network as specified in G.996.1, with simultaneous noise injection at both ends of the loop.

d) Then the loop simulator is set with the appropriate noise impairments and loop length as desired.

e) The modem must operate within a total of 60 seconds, starting from the time that the ATU-C was placed in service (IS).

f) After being operated to the desired loop condition, the modem will attempt to synchronize with the DSLAM.

g) When DSLAM and the modem are synchronized (operating session), data will start to be transmitted to the computer. We will be notified by the indicators (LED) labeled “DSL”, or “LINK” on modem when it is synchronized. At this moment, records are under the bi-direction sync rate and the noise margin.

h) After step VII, we repeat sequence V to VII by incrementing the loop simulator loop length.

5. RESULTS

5.1 Loop Condition Tests:

These tests are carried out to prove the relationship between loop length and the sync data rates for the upstream and downstream. There are totally five tests in this task, including the noiseless environment and the noisy environment with crosstalk.

5.1.1 No noise, different loop length

The test is implemented in noiseless environment to prove their maximum synchronous speed for upstream and downstream. However, this test is not practical because in reality, noise occurs anywhere and any time. The collected data is shown in Figure 5.

At the loop length from the range 0-10 kft, the upstream and downstream record the maximum speed around 1024 kbps and 8000 kbps. It shows that at this length, the ATU-R can synchronize very well with DSLAM to reach the maximum data rates. The speed starts to decrease as the loop length increases after the loop length is more than 10 kft. The maximum length that the modem can be synchronized is only 16 kft. Practically, the maximum length that can be supported by ADSL is 18 kft. This may be due to some external unknown interference that makes the data inaccurate.

5.1.2 White Noise Impairment, Different Loop Length

During this test, the white noise will be injected into the wireline simulator at different loop length. The frequency spectrum of white noise is as shown in Figure 6 as a straight line that maintains the same frequency spectrum level at -140dB/Hz. The sampling rate set is 32MHz with impedance loss 17.5 dB, whereas the impedance during calibration is 100 ohm. Figure 6 shows the measured data.

As can be seen from Figure 7, the sync rates for bi-directional transmission are about the same if compared...
to the case of free of noise. This may be due to the reason that the impact of white noise is not so obvious.

tremendously when impairment caused by 24 bundle HDSL crosstalk exists.

5.1.3 24 HDSL Impairment, Different Loop Length
24 HDSL noise is injected to wireline, thus crosstalk issue will emerge due to the interference of HDSL transmission in the same wireline. The crosstalk issue will defiance the speed of transmission thus reduces the maximum length reached. The frequency spectrum for HDSL is as shown in Figure 8 below.

5.1.4 24 DSL Impairment, different loop length
24 DSL impairment refers to the case when ADSL transmits data, which coexists with 24 bundles of Integrated Services Digital Network (ISDN). The frequency spectrum in Figure 10 indicates that the signal strength is reduced abruptly at higher frequency.
The effect of loop length towards speed rates can be viewed by comparing the upstream/downstream data rates at different loop condition with different noise source in Figures 12 & 13. Figure 12 obviously shows that the upstream speed start to decrease as the loop length increase. Thus, data rate is inversely proportional with the loop length. It is also found out, that the upstream data rates with and without white noise is about the same, thus we can say that the effect of white noise is not severe.

Both figures prove that the intrusion of noise will definitely limit the maximum data rates as well as the maximum length reached. It is also seen that the negative impact from HDSL is more severe if compared to ISDN impairment towards the performance of ADSL. Thus, in conclusion, the performance of transmission of ADSL will drop at the existence of noise. But the magnitude of degradation will depend on the characteristic of crosstalk source as well as the location of the source.

5.2 Bridged Tap Test
Based on A.1.9 Bridged Tap tests in TR0-67 ADSL Interoperability test plan, this test is carried out with the existence of white noise disturbance at both the ends of the loop, at -140 dBm/Hz in fast mode (Figure 13). The data rate of ATU-R is monitored when bridge tap is located at the distances 9 kft, 12 kft and 15 kft from ATU-C. The length of bridge tap is also varied from range 0 to 1500 ft to observe the impact to the speed of ATU-R. The results are shown in Figures 15 and 16. Nevertheless, only comparison of downstream/upstream data rates between different bridge tap lengths will be plotted and evaluated.

As seen in Figures 15 and 16, the data rates for both upstream and downstream are remarkably lower for bridge tap loop that is far from ATU-C. The length of bridge taps will give some impact to the speed too. Nevertheless, it is found out that the downstream data rates are not in straight line but data rates seem not to be stable.
phase-shifted noise. It should be noted that, if the distance between bridge tap with ATU-C is longer, the impact from the reflected signal can be neglected. Thus, theoretically, the bridge tap should be located farther from ATU-C to mitigate this reflection problem. But, the result from bridge tap tests shows that, the overall speed for longer distance between ATU-C and bridge tap is slower. We may explain this phenomenon by using the attenuation factor due to longer loop length. We can conclude that, the attenuation issue for transmission line severely hampers the speed of transmission.

5.3 Impact of crosstalk in an unbundled environment on ADSL Performance

Development of various DSL technologies and the effort to unbundle the existing access network has prompted different DSL technology to work in same binder. Nevertheless, this issue has brought severe alien-crosstalk phenomenon. Hence, we should research the impact of crosstalk in an unbundled environment. The data presented in this session is referring to the thesis titled “Analysis of the Impact of Impulse Noise in Digital Subscriber Line Systems” done by Nedko H. Nedev [22]. During the analysis, it is assumed that the line under consideration is placed in a bundle of 50 pairs, where all 49 additional pairs carry a DSL service (i.e. the worst case). Four crosstalk scenarios have been considered:

a) Kindred-only: 49 ADSL pairs
b) Mixture: 24 ADSL + 25 HDSL pairs
c) Mixture: 24 ADSL + 25 ISDN pairs
d) Mixture: 19 ADSL + 15 HDSL + 15 ISDN

The metrics under test include ADSL mux frames and ATM cell/header error rates. Comparing Figures 17 and 18, it can be observed that the frame error probability is higher when the transmission data rates is higher. It is known that, when the data rates is higher, the number of bits in subchannel will also be increased. Thus, it will be more susceptible to noise. Ultimately, the noise will introduce higher frame error probability.

Both figures show that the impact of the mixture of ADSL, HDSL and ISDN is significant. This may be due to the incompatibility among these three signals that deteriorates the SNR value in the DMT tones of ADSL. However, if only 25 ISDN pairs bundle with 25 ADSL, the impact is not so noticeable. This is because the noise based loading algorithm in ADSL enables the ADSL to monitor the performance the each tone and adapt the data rate accordingly that may reduce the probability of errors.

Figure 19 shows the impact of crosstalk to the downstream of ADSL transmitted on a 15 kft 26 AWG with two type of crosstalk: self-FEXT from other ADSL and alien-NEXT from HDSL. Figure 19(a) shows the transmitted PSD of ADSL downstream and also HDSL. It can be seen that PSD of downstream stays at level -40 dBm/Hz at the range of 180 kHz to 1100 kHz. On the other hand, the transmitted spectrum HDSL is not stable.

From Figure 19(c), it is noticed that the coupling coefficient for FEXT is decreasing as frequency increases. This is in contrary with coupling coefficient for NEXT. Adding up the power coupling transfer function of FEXT and NEXT from Figure 19(b) gives us the value of received PSD in Figure 19(c). In Figure 19(d), it is observed that the SNR value for self-FEXT is higher compared to alien-NEXT, thus we can conclude from here that, the data rates that are affected by SNR in channel are greatly decreasing in alien-NEXT environment compared to self-FEXT environment.
5.4 Impact of system parameters towards SNR of ADSL

Signal to Noise Ratio (SNR) is an important parameter in determining the performances of ADSL. Higher value of SNR leads to higher yield and accuracy. However, there are many factors that influence the SNR of this system. As mentioned above, crosstalk will deteriorate SNR of the channel. Besides this, according to [23], system parameters such as loop length, transmission power and QAM constellation size also will affect SNR.

Bit error rate and noise margin are primary factors in achieving subscriber-designated parameters. ADSL transceivers can work well with bit error rate (BER) not exceeding $1 \times 10^{-7}$. Line noise is a function of length and noise. As length or noise in the loop increases, upstream and downstream payload rates decrease. Also, the thinner the copper wire, the more susceptible it is to noise. Line noise fluctuation is known as the noise margin.

![Figure 20. Maximum SNR margin as function of loop length using different constellation size](image)

As can be seen from Figure 20, it is found out, that noise margin is decreasing as loop length increases and also with increasing QAM modulation constellation size. It means that, with smaller constellation size, ADSL is less susceptible to noise and thus more stable. This is due to the fact that with smaller constellation sizes, the probability of error in the channel is low.

5.5 ADSL and Cable Modem

Recently, the unprecedented growth of Internet has opened up a vast market for high-speed data services to home usages. The demand has motivated the deployment of broadband access technologies such as xDSL technologies and hybrid fiber coaxial (HFC) technology. Presently, ADSL technology is adopted extensively in Malaysia by Telecom to provide unlimited access to internet that is known as tmnet streamyx. With the high-speed connectivity, the service is ideal to support most broadband applications such as, web hosting, video streaming, e-commerce, distance learning and others. Cable modem still doesn’t receive much population among Malaysian. However, with the standard DOCSYS [23,24], cable modem is popular in the Malaysia’s neighbor countries like Thailand, in the Philippines, Indonesia etc.

In this study, it can be concluded that both of these technologies have their similarities and dissimilarities. They share the same similarities as shown below:

- Provide “Always on” services to internet without dial up process
- Able to send voice and data concurrently
- Utilize copper wire in transmission
- Connectivity is fast and reliable. Offer up to 100x more network performance than a standard modem.

Nevertheless, these technologies are differing from each others in a few terms, including bandwidth supported, security, pricing and thereof. The network topology utilized in cable modem hybrid fiber-coaxial (HFC) provides much bigger bandwidth if compared to DSL technologies. The speed of transmission through cable modem doesn’t depend on the length of cable as in DSL technologies. But, they are sharing the same bandwidth thus less secured. This raises the specter of packet sniffing. DSL technology is protected from this problem because they have dedicated bandwidth for data transmission. Besides, the congestion in the network will degrade the performance of cable modem severely [25].

The differences are summarized into Table 2 below.

<table>
<thead>
<tr>
<th>No</th>
<th>Comparison</th>
<th>Cable Modem</th>
<th>DSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bandwidth supported</td>
<td>Supports approximately 30 Mbps</td>
<td>Below 10 Mbps (VDSL can support 30 Mbps)</td>
</tr>
<tr>
<td>2</td>
<td>Bandwidth for uploads</td>
<td>128 Kbps – 768 Kbps (mostly providers)</td>
<td>128 Kbps</td>
</tr>
<tr>
<td>3</td>
<td>Bandwidth for downloads</td>
<td>1 Mbps – 6 Mbps (mostly providers)</td>
<td>1.5 Mbps</td>
</tr>
<tr>
<td>4</td>
<td>Transmission Medium</td>
<td>HFC Coaxial cable (copper)</td>
<td>Twisted pairs cable (copper)</td>
</tr>
<tr>
<td>5</td>
<td>Modulation method</td>
<td>64-QAM/256-QAM/ QPSK</td>
<td>4PAM/ 16PAM/CAP/ DMT</td>
</tr>
<tr>
<td>6</td>
<td>Protocols and configuration</td>
<td>MPEC-2</td>
<td>ATM, PPP, PPPoE, PPPoA</td>
</tr>
<tr>
<td>7</td>
<td>Popularity</td>
<td>Greater popularity in U.S</td>
<td>Europe, North America</td>
</tr>
<tr>
<td>8</td>
<td>Reliability</td>
<td>Lower</td>
<td>Higher (circuit oriented, consistent transmission rate)</td>
</tr>
<tr>
<td>9</td>
<td>Weakness</td>
<td>Shared bandwidth, inconstant transmission rate</td>
<td>Crosstalk, distance sensitive technology, insulation resistance</td>
</tr>
<tr>
<td>10</td>
<td>Bandwidth supported</td>
<td>Supports approximately 30Mbps</td>
<td>Below 10Mbps (VDSL can support 30Mbps)</td>
</tr>
</tbody>
</table>
6. CONCLUSION

xDSL technologies is the most popular broadband fixed line implementation nowadays. Each type of DSL is differentiated from the others by its maximum speed and reach loop. Though, they share common characteristic which means they use copper technology. Among these technologies, ADSL is the most widely deployed technology because of its asymmetry characteristics.

Evaluation on the performance of ADSL based on TR0-67 Test Plan has proven the effect of loop length, noise and also bridge taps to the synchronous speed of ADSL. In section 4, the performance of ADSL downstream is evaluated in terms of errors in ADSL frames within crosstalk environment. An investigation of the impact of crosstalk demonstrates how alien crosstalk in combination with impulse noise may worsen the error performance in ADSL, which shows the importance of spectral compatibility in a multi-operators environment. These results are performed by the TR0-67 Test Plan under the condition of the telecommunication network in Malaysia. Similar thoroughly done results by network operators or ADSL vendors are not publicly known.

There are many factors that deteriorate the performance of the fixed line broadband communication services, such as the physical layers’ conditions, environmental issues (noise), natural effects, network architectures and thereof. The higher layer protocol that is deployed by the technology also should be taken into account. These include FEC techniques, modulation schemes etc that affect the robustness of the technologies. Researches in these areas could benefit the improvement of ADSL as well as Cable Modem systems further.

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REFERENCES