

# Broadband Wireless Trial for 1-Net / StarHub

*LMDS Test Report  
29<sup>th</sup> December 2000*



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# 1 INTRODUCTION

## 1.1 Purpose

The intent of this Wireless Test Plan is to demonstrate to 1-Net and StarHub, Vendor A's Local Multipoint Distribution System (LMDS) solution and its capabilities. The document covers the following functionality:

- Voice Services
- Data Services
- Ethernet Services
- NMS support

These tests will be performed once the Trial Network has been successfully installed and commissioned.

## 1.2 Project Information

<b>Site Name:</b>	<b>1-Net/Starhub</b>
Customer Name	1-Net/StarHub
Site location	Singapore BTS : Suntec City Tower 1 CPE : Haw Par Center CPE : Six Battery Road

**Table 1-1 - Project Information**

1.3 Site information

<b>Type of Site</b>	<b>Base Station</b>	<b>Qty 1 radio cards</b>
<b>Site Name</b>	<b>Suntec City Twr 1</b>	
Location	Singapore	
Coordinates	Latitude:N01°17'-43.4	Longitude: E103°51'-30.4
Telephone No	434 9639 / 434 9649	
Direction to Site		
Notes		

<b>Type of Site</b>	<b>CPE</b>	<b>Qty 1 NIU</b>
<b>Site Name</b>	<b>Haw Par Centre</b>	
BTS Site Name	Suntec City Twr 1	
Location	Singapore	
Coordinates	Latitude:N01°17'-86.2	Longitude: E103°50'-58.2
Telephone No	337 3320	
Direction to Site		
Notes:	building height 30 meters; distance from BTS 1.8km	

<b>Type of Site</b>	<b>CPE</b>	<b>Qty 1 NIU</b>
<b>Site Name</b>	<b>Six Battery Road</b>	
BTS Site Name	Suntec City Twr 1	
Location	Singapore	
Coordinates	Latitude:N01°17'-07.1	Longitude: E103°50'-07.6
Telephone No		
Direction to Site		
Notes:	building height 176 meters; distance from BTS 1.9km	

## 2 EQUIPMENT

### 2.1 Network Configuration

#### 2.1.1 Frequency Spectrum

The following tables provide details on the frequency spectrum and radios that are used in this T&E.

	<b>IF Start (MHz)</b>	<b>IF End (MHz)</b>	<b>RF Start (MHz)</b>	<b>RF End (MHz)</b>	<b>L.O. (MHz)</b>
<b>BTS OUT</b>	1250	2050	28190	28226	100
<b>BTS ORU</b>	550	950	27350	27368	100

**Table 2-1 Summary of Radio Frequency Specifications**

Channel width (MHz)		Channel Guardband				
36		0				
Downstream Channel	RF Start (MHz)	RF Center (MHz)	RF End (MHz)	IF Start (MHz)	IF Center (MHz)	IF End (MHz)
1	28190	28208	28226	1590	1608	1626
2	28226	28244	28262	1626	1644	1662
3	28262	28280	28298	1662	1680	1698
4	28298	28316	28334	1698	1716	1734
5	28334	28352	28370	1734	1752	1770
6	28370	28388	28406	1770	1788	1806
7	28406	28424	28442	1806	1824	1842
8	28442	28460	28478	1842	1860	1878
9	28478	28496	28514	1878	1896	1914
10	28514	28532	28550	1914	1932	1950

**Table 2-2 - Downstream Spectrum Channelization**

Upstream Channel	Uplink 1						Uplink 2					
	RF Start (MHz)	RF Center (MHz)	RF End (MHz)	IF Start (MHz)	IF Center (MHz)	IF End (MHz)	RF Start (MHz)	RF Center (MHz)	RF End (MHz)	IF Start (MHz)	IF Center (MHz)	IF End (MHz)
1	27350.0	27355	27359.0	550.0	555	559.0	27359.0	27364	27368.0	559.0	564	568.0
2	27368.0	27373	27377.0	568.0	573	577.0	27377.0	27382	27386.0	577.0	582	586.0
3	27386.0	27391	27395.0	586.0	591	595.0	27395.0	27400	27404.0	595.0	600	604.0
4	27404.0	27409	27413.0	604.0	609	613.0	27413.0	27418	27422.0	613.0	618	622.0
5	27422.0	27427	27431.0	622.0	627	631.0	27431.0	27436	27440.0	631.0	636	640.0
6	27440.0	27445	27449.0	640.0	645	649.0	27449.0	27454	27458.0	649.0	654	658.0
7	27458.0	27463	27467.0	658.0	663	667.0	27467.0	27472	27476.0	667.0	672	676.0
8	27476.0	27481	27485.0	676.0	681	685.0	27485.0	27490	27494.0	685.0	690	694.0
9	27494.0	27499	27503.0	694.0	699	703.0	27503.0	27508	27512.0	703.0	708	712.0
10	27512.0	27517	27521.0	712.0	717	721.0	27521.0	27526	27530.0	721.0	726	730.0

Table 2-3 - Upstream Frequency Channelization

2.1.2 *BTS Frequency Allocation*

<b>BTS 1 – Suntec</b>				
<b>Sector ID</b> 1	<b>Name:</b> Suntec_Sector1		<b>Tx Polarization:</b> V	<b>Angle:</b> 0°
<b>Downlink</b>	<b>RF Start Frequency (MHz)</b> 28190		<b>RF End Frequency (MHz)</b> 28226	
<b>Uplink</b>	<b>RF Start Frequency (MHz)</b> 27350		<b>RF End Frequency (MHz)</b> 27368	
<b>Radio-Card Group ID 1</b>				
<b>Downlink</b>	<b>RF Start (MHz)</b> 28190	<b>RF End (MHz)</b> 28226	<b>IF Start (MHz)</b> 1050	
<b>Uplink</b>	<b>RF Start (MHz)</b> 27350	<b>RF End (MHz)</b> 27359	<b>IF Start (MHz)</b> 550	<b>Offset (MHz)</b> -150
RadioCard	Downlink Ctr Freq.	Downlink Ch. width	Uplink 1 Ctr Freq.	Uplink 2 Ctr Freq.
	28208	36 MHz	27355	27364

**Table 2-4 - BTS System Configuration Parameters**

2.1.3 *NIU Commissioning Information*

Each Network Interface Unit has been given a NIU ID and assigned to an Uplink. The BTS has been assigned to a sector and given its RF start and end frequency for both the downlink and uplink.

<b>CPE Site Name</b>	<b>NIU Id</b>	<b>Serial Number</b>	<b>Data VPI</b>	<b>BTS Name</b>	<b>ARIC Port</b>	<b>Uplink #</b>
Haw Par Center	NIU107	18000100007	2	Suntec	1	1
6, Battery Road	NIU715	03000119615	2	Suntec	1	2

**Table 2-5 - NIU Commissioning Information**

### 3 BTS COMMISSIONING

#### 3.1 BTS System Configuration

##### 3.1.1 Objectives

Configure the BTS, activate radios and verify that transmitters are powered up.

##### 3.1.2 Test Results

**Comments:** The ARIC card (ATM Radio Interface Card) has been programmed with the appropriate downstream and upstream channel frequency and bandwidth.

## 4 CPE COMMISSIONING

### 4.1 NIU configuration

#### 4.1.1 Objectives

To configure the NIU and see it “enter” the network. The “Network” LED at the NIU will turn to green after it “enter” the network.

#### 4.1.2 Test Description

Configure the NIU with the appropriate frequency parameters. The Air ATM link should then come up and the NIU should enter the network.

#### 4.1.3 Test Results

Downstream	RF Rx Start	RF RX Ctr	RF Rx End	IF Rx Start	IF Rx Ctr	IF Rx End
CPE Site Name						
Haw Par Center	28190	28208	28226	1590	1608	1626
6, Battery Road	28190	28208	28226	1590	1608	1626

**Table 4-1 - Downstream Frequency Configuration**

Upstream	RF Tx Start	RF Tx Ctr	RF Tx End	IF Tx Start	IF Tx Ctr	IF Tx End
CPE Site Name						
Haw Par Center	27350	27355	27359	550	555	559
6, Battery Road	27359	27364	27368	559	564	568

**Table 4-2 - NIU Upstream Frequency Allocation**

**Comments:** Each CPE has one NIU associated with it. Each NIU has been programmed with the appropriate downstream and upstream frequency. Refer to Table 2-3 and 2-4 for Spectrum Channelization. After configuring the NIU, the AIR interface was established and both BTS and CPEs, i.e. the network management workstation was able to detect the NIU.

## 4.2 Link Budget Verification

### 4.2.1 Objectives

To verify that the measured link power levels are as expected, hence that the desired link availability is achieved.

### 4.2.2 Test Result

Downstream 28 GHz											
Radio Tx (dBm)	Combiner Loss	Cable Loss	OTU Gain	BTS Ant Gain	BTS Misalign. Loss	Range(km) FSL (dB)	CPE Misalign Loss	CPE Ant Gain	OTRU Gain	CPE Cable Loss	NIU Rx (dBm)
4	-17	-10	40	21	0	1.8	0	36	35	-12	
	-13	-23	17	38	38	-126.4	-88.4	-52.4	-17.4	-29.4	<b>-29.4</b>
End to End delta = -33.4						Actual Measured = <b><u>-36.5</u></b>					
Upstream 27 GHz											
NIU Tx (dBm)	Cable Complex Loss	OTRU Gain	CPE Ant Gain	CPE Misalign Loss	Range (km) FSL (dB)	BTS Misalign. Loss	ORU Ant Gain	ORU Gain	Cable Complex Loss	Combiner Loss	Radio Rx (dBm)
	-6	35	36	0	1.8	0	21	40	-9	-15	-56
<b>-31.9</b>	-37.9	-2.9	33.1	33.1	-126.1	-93	-72	-32	-41	-56	
<b><u>-10</u></b> = Actual Measured						End to End delta = -18.1					

Table 4-3 – Haw Par Centre Link Budget Verification

Downstream		28 GHz									
Radio Tx (dBm)	Combiner Loss	Cable Loss	OTU Gain	BTS Ant Gain	BTS Misalign. Loss	Range(km) FSL (dB)	CPE Misalign Loss	CPE Ant Gain	OTRU Gain	CPE Cable Loss	NIU Rx (dBm)
4	-17	-10	40	21	0	1.9	0	36	40	-16	
						-126.9					
	-13	-23	17	38	38	-88.9	-88.9	-52.9	-12.9	-28.9	<b>-28.9</b>
End to End delta = -32.9										Actual Measured = <b>-40</b>	
Upstream		27 GHz									
NIU Tx (dBm)	Cable Complex Loss	OTRU Gain	CPE Ant Gain	CPE Misalign Loss	Range (km) FSL (dB)	BTS Misalign. Loss	ORU Ant Gain	ORU Gain	Cable Complex Loss	Combiner Loss	Radio Rx (dBm)
	-8	35	36	0	1.9	0	21	40	-9	-15	-56
					-126.6						
<b>-29.4</b>	-37.4	-2.4	33.6	33.6	-93	-93	-72	-32	-41	-56	
<b>-20</b> = Actual Measured						End to End delta = -18.6					

**Table 4-4 – Six Battery Road Link Budget Verification**

**Comments:** Both antenna heights of the BTS and of the CPE at Six Battery Road are similar. As the heights are 178 m and 179 m respectively, the ideal antenna tilt angle should be at 0 degrees. However, this could not be achieved. The antenna of the other CPE, Haw Par Center, was at a height of 33m. In order to include these two CPEs into the network, the BTS antenna was down tilted to the angle in which both CPEs could be reached. The down tilting of the antenna will introduce misalignment loss to the downstream receive signal and upstream receive at CPE and BTS respectively. The misalignment loss should be taken into account when completing a link budget calculation. However, these losses are considered to be zero in Table 4-3 and 4-4 of link budgets. Therefore, the calculated link budget and measured downlink signal at the CPEs were recorded at different strengths. The recorded signal strengths at Haw Par Center and Six Battery Road were measured with misalignment losses considered.

## 5 LMDS NETWORK TESTS

### 5.1 Fade Margin Test

#### 5.1.1 Objectives

The purpose of this test is to see by how much the signal can degrade before errors are introduced.

#### 5.1.2 Test Description

This test should be done at the same time as the Primary Rate Circuit Emulation test (see Primary rate Circuit Emulation Test) so that one can verify when errors begin to occur. Insert an inline attenuator on the receive side. Increase attenuation until errors are seen on the tester or loss of synchronization occurs. Note attenuator setting. Decrease attenuator setting until the tester is running error free. Note attenuator setting. The reading on the attenuator is the amount of fade margin for this particular link.

#### 5.1.3 Test Results

### 6 Battery Road

Downstream frequency: IF: 1790 MHz  
RF: 28190 MHz  
Tx power after Radio Card + 4 dBm

Upstream frequency: IF: 414 MHz  
RF: 27364 MHz  
Tx power for Upstream: - 20 dBm

Attenuation	Rx signal strength	NIU status (Network Entry)	BER	Remarks
Without attenuator	- 40 dBm	OK	0	Normal Rx level
Add attenuator with 0 dB	- 45 dBm	OK	0	Attenuator loss is 5 dB
9 dB	--	OK	2 e-7	Spectrum reached the noise floor
10 dB	--	OK	2 e-6	
11 dB	--	OK	2 e-4	
12 dB	---	Failed	2 e-3	AIS

**Table 5-1 – Six Battery Road Fade Margin Test**

#### Conclusion:

- a) NIU A behaves as expected.
- b) Low BER (e-6) is at – 55 dBm and High BER is at – 57 dBm.

**Haw Par Center**

Downstream frequency: IF: 1790 MHz  
 RF: 28190 MHz  
 Tx power after Radio Card: + 4 dBm

Upstream frequency: IF: 405 MHz  
 RF: 27355 MHz  
 Tx power after NIU: - 10 dBm

Attenuation	Rx signal strength	NIU status (Network Entry)	BER	Remarks
Without attenuator	- 36.5 dBm	OK	0	Normal Rx level
Add attenuator with 0 dB	- 40.8 dBm	OK	0	Attenuator loss is approx. 4 dB
5 dB	- 44.6 dBm	OK	0	
7 dB	- 46.1 dBm	OK	0	
10 dB	--	OK	0	Spectrum reached noise floor
12 dB	--	OK	0	
13 dB	--	OK	8.5e-7	Errors occurred after 104 seconds of test
16 dB	--	OK	1.7e-6	
17 dB	--	OK	1.5e-4	AIS alarm was intermittent
18 dB	---	Failed	2 e-3	AIS

**Table 5-2 – Haw Par Center Fade Margin Test**

**Conclusion:**

- a) NIU B behaves as expected.
- b) Low BER (e-6) is at - 56 dBm and High BER is at - 58 dBm.

**Comment:**

The fade margins for both CPEs are slightly lower, 22 dB for Haw Par Center and 17 dB for Six Battery Road. This is due to the lower receiving signal. The fade margin could be increase by improving the signal strength for each CPE. In this case however, the signal strength could be improve by having a lower BTS antenna height, this will reduce the misalignment loss.

On the other hand, the threshold levels for both NIUs are at - 57 dBm and - 58 dBm. The results are better than compared to - 60 dBm of the NIU specifications.

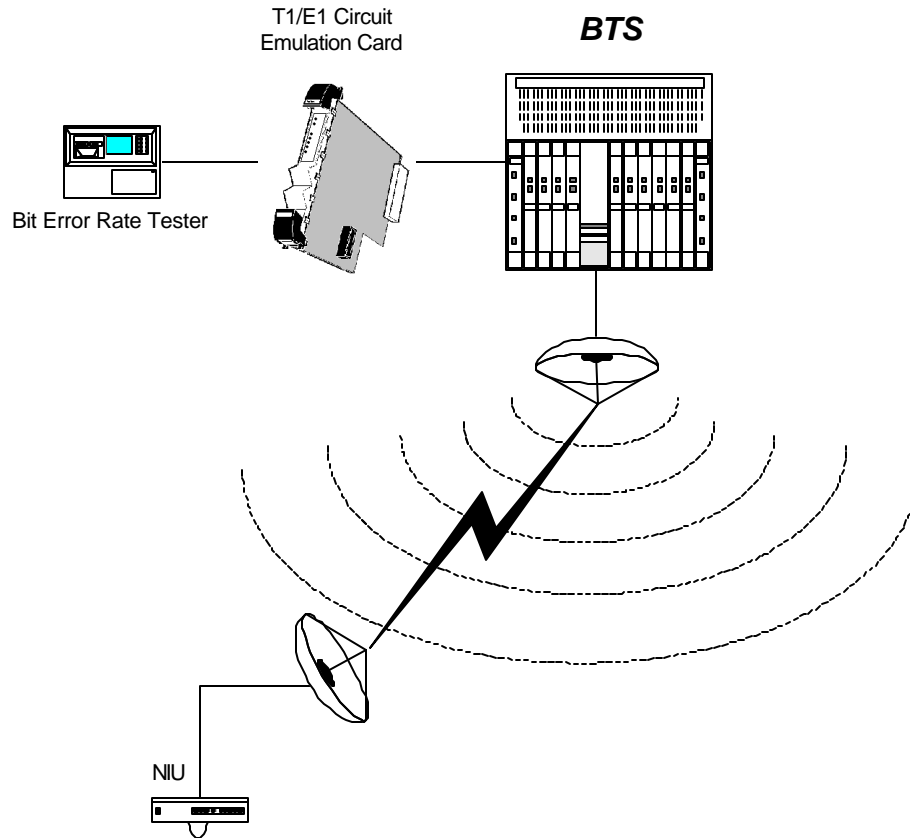
**5.2 Primary rate Circuit Emulation Test**

**5.2.1 Objectives**

The air ATM link is tested to confirm that it is error free and thus suitable to carry end user applications on the NIU Primary Rate port.

**5.2.2 BTS to CPE Test Description**

The air ATM link will be tested between each BTS and each NIU. The test pattern is generated and injected at the local BTS site, which serves the NIU under test. The generated test pattern is injected into the ATM switch via a port on a T1/E1 Circuit Emulation card. An ATM VCC path is created between the Circuit Emulation port and the remote NIU port. Figure 5-1 illustrates the topology of the test configuration. The T1/E1 port on the NIU is physically looped back.



**Figure 5-1 - BTS to CPE PRI CE test**

### 5.2.3 Test Results

**Comments:** Please refer to Application Test 6.4 – N x E1 Leased Line.

5.2.4 CPE to CPE Test Description

The air ATM link can optionally be tested between selected CPE sites as shown in the next figure. The CPEs may be located on the same sector, in different sectors or on a different BTS. Record the results obtained by indicating how well the test performed (bit error rate achieved and elapsed time), and where the CPEs were located (e.g. same sector, different sector, different BTS).

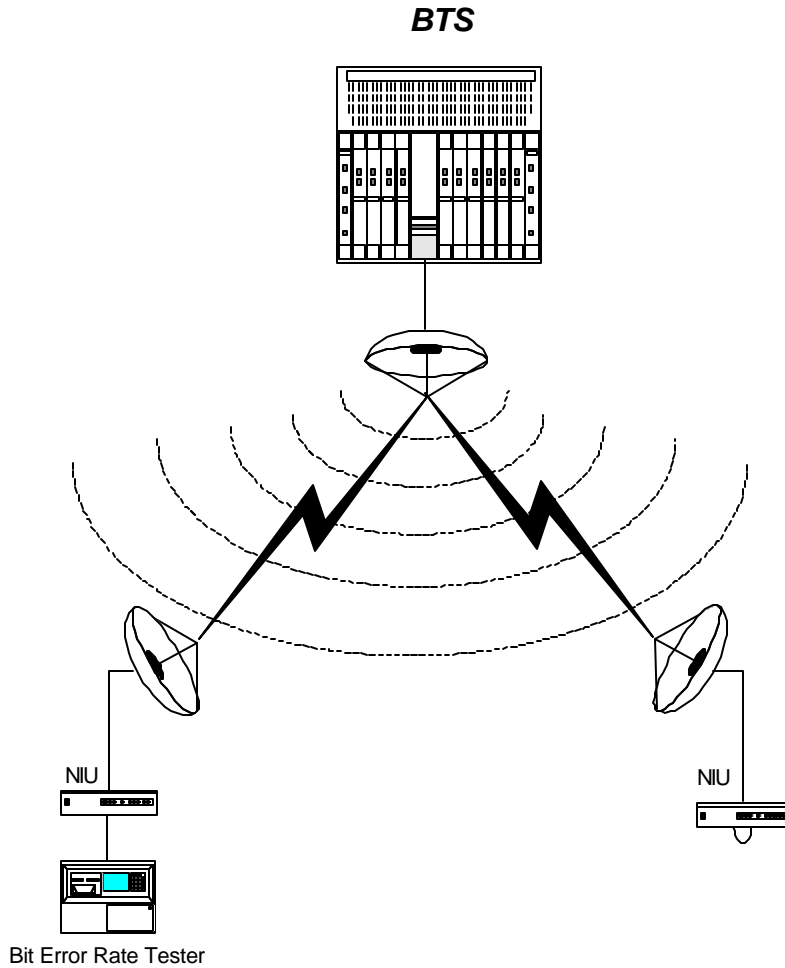


Figure 5-2 - CPE to CPE PRI CE test

### 5.2.5 Test Results

**Comments:** Please refer to Application Test 6.4 – N x E1 Leased Line.

## 6 APPLICATIONS TESTING

### 6.1 N x 64 Lease Line

#### 6.1.1 Test Objectives

To verify that N x 64K-lease line traffic can be carried over Wireless ATM successfully.

#### 6.1.2 Test Description

An N x 64K-lease line circuit was created from Haw Par Centre to Suntec City and via a lease line to StarHub's Central Office. A loopback was made at the CO. N X 64K-lease line traffic was generated from a tester at Haw Par Centre and results were collected as per below.

#### 6.1.3 Test Results

**Expected Results:**

- BER :1 E-07
- %EFS :>99.7%
- SES :<5 secs per 15 minutes block

#### Extract from Result Obtained

<b>NIU A</b>	Bit Error Rate	: 0.0
	% Errored Second	: 0
	% Error Free Second	: 100
	% Available Second	: 100
	SES	: 2
<b>NIU B</b> (Loopback at Tai Seng)	Bit Error Rate	: 1.3E-07
	% Errored Second	: 0.14
	% Error Free Second	: 99.86
	% Available Second	: 100
	SES	: 2

**Comments:** Tests were run for two types of NIU's. One that supports CBR(time sensitive application), NIU A, and one that supports UBR(non-time sensitive applications like ADSL, Frame). NIU A had error free performance over a 5 day period. The Nx64k tests exceeded the standard and were excellent. The NIU B results are stated even though NIU B doesn't support CBR type of connections.

## 6.2 Simple Voice Applications

### 6.2.1 Test Objectives

To verify that Voice services can be carried over wireless ATM

### 6.2.2 Test Description

A voice circuit was created from Haw Par Centre to Suntec City and back to Haw Par Centre. Two separate phones were connected at Haw Par Centre to each end of the voice circuit. Voice quality was discerned for clarity and delay.

### 6.2.3 Test Results

**Comments:** Users were able to place phone calls from Haw Par to BTS and back without any noticeable delay. Voice quality was average.

### 6.3 Frame Relay Internetworking with StarHub FR Network

#### 6.3.1 Test Objectives

To verify that N x 64K Frame Relay traffic can be carried over wireless ATM and the interoperability of the Frame Relay service to StarHub's existing FR switch.

#### 6.3.2 Test Description

A Frame Relay circuit was created from Haw Par Centre to Suntec City and via a leased line to StarHub's Frame Relay Switch at StarHub's Central Office. A loopback was made at the Frame Relay Switch. FR traffic was generated from a tester at Haw Par Centre and results were collected as per below.

#### 6.3.3 Test Results

**Expected Results:** No loss or bad Frames

#### Extract from Result Obtained

<b>NIU A</b>	Transmit Frames	: 50996878
	Received Frames	: 50996880
	Loss Frames	: 0
<b>NIU B</b>	Transmit Frames	: 26770705
	Received Frames	: 26770406
	Loss Frames	: 299

**Comments:** Both NIUs A and B were tested. The tests were conducted on three different days and there was only one occurrence where there was a bad frame. The NIU A result was good. There were no loss or bad frames encountered.

## 6.4 N x E1 Lease Line Application

### 6.4.1 Test Objectives

To verify that N x E1 lease line traffic can be carried over Wireless ATM successfully.

### 6.4.2 Test Description

A N x E1 lease line circuit was created from Haw Par Centre to Suntec City and loopbacked to Ha w Par Centre. N X E1 traffic was generated from a tester at Haw Par Centre and results were collected as per below.

A separate test was also conducted where the circuit was extended via Suntec City to Six Battery Road and loopbacked.

### 6.4.3 Test Results

**Expected Results:**

BER	: 1 E-09
%EFS	: >99.4%
%SES	: 0.015%

#### Extract from Result Obtained

<b>NIU A</b>	Bit Error Rate	: 0.0
	% Errored Second	: 0
	% Error Free Second	: 100
	% SES	: 0
	% Available Second	: 100
<b>NIU B</b>	Bit Error Rate	: 1.05E-06
	% Errored Second	: 0.11
	% Error Free Second	: 99.12
	% SES	: 0.11
	% Available Second	: 87.38
<b>NIU B</b> (Loopback: Six Battery Rd, SunTec City, Haw Par Centre)	Bit Error Rate	: 1.58E-07
	% Errored Second	: 0.29
	% Error Free Second	: 99.71
	% SES	: 0.19
	% Available Second	: 99.80

**Comments:** Since NIU A can support only 1 x E1 CE port, the type B NIUs were used for multiple E1s over the Air. The results are stated even though type B NIU doesn't support CBR.

## 6.5 High Speed Internet Access

### 6.5.1 Test Objectives

To verify that high speed internet access via ADSL can be carried over wireless ATM equipment.

### 6.5.2 Test Description

Various PVCs were created to access Internet services from both 1-Net and StarHub's existing connection to their respective ISP. Separate Web Browsing and Video Streaming application tests were conducted from 6 Battery Road and Haw Par Centre.

### 6.5.3 Test Results

**Comments:** Internet access using the Ethernet port of the NIU A (RFC1483 Bridged) at Six Battery Road, and Internet access using ADSL with NIU B via 1-Net's broadband network was demonstrated to work without interruption.

i) Using RFC1483 Bridged via 1-Net's broadband network (from Haw Par Center)

This capability has been demonstrated to work. The video and audio streaming through Internet was smooth.

ii) Using PPPoA via StarHub (from Haw Par Center)

This has not been successful during the early stages of the trial and it was suspected to be due to an interoperability issue between StarHub and Vendor A's equipment. Symptoms observed were that the workstation was only able to "PING" to Internet addresses but Web-surfing was not possible.

The above **was resolved** after adjusting the QoS parameters of the ADSL PVC at StarHub's ATM Switch. After employing various bandwidth settings, it was concluded that for optimum High Speed Internet Access, the PVC QoS at the ATM Switch has to be set to **UBR – Best Effort**. (UBR with bandwidth limitations will lead to unsatisfactory surfing and video streaming) Hence, future customer PVC bandwidth limitations will have to be set at the Basestation(s) instead.

The video and audio streaming through Internet was also demonstrated to be smooth after the QoS issues were resolved.

## 6.6 ISDN BRI Lease Line Application

### 6.6.1 Test Objectives

To verify that ISDN BRI lease line traffic can be carried over Wireless ATM successfully.

### 6.6.2 Test Description

An ISDN BRI lease line circuit was created from Haw Par Centre to Suntec City and via a lease line to StarHub's Central Office. A loopback was made at the CO. ISDN BRI lease line traffic was generated from a tester at Haw Par Centre and results were collected as per below.

### 6.6.3 Test Results

**Expected Results:** BER :1 E-07  
 %EFS :>99.7%  
 SES :<5 secs per 15 minutes block

#### Extract from Result Obtained

<b>NIU A</b>	% Errored Second	: 0
	% Error Free Second	: 100
	% SES	: 0
	% Available Second	: 100
<b>NIU B</b>	% Errored Second	: 0.138
	% Error Free Second	: 99.861
	% SES	: 0
	% Available Second	: 99.999

**Comments:** Tests were conducted for the two types of NIU at 128K. One that supports CBR (time sensitive applications), the NIU A, and the other that supports UBR (non-time sensitive applications like ADSL, Frame Relay).  
NIU A had error free performance over a 5 day period. NIU B achieved a BER of 10<sup>-7</sup>. Since ISDN is a time sensitive application NIU B had difficulty.

## 6.7 Wireless ATM Cell Loss Test

### 6.7.1 Wireless ATM Cell Loss Test (Normal Condition)

#### 6.7.1.1 Test Objectives

To verify the stability of the Wireless ATM link to carry ATM cells with minimal discarded or lost cells.

#### 6.7.1.2 Test Description

An ATM PVC will be created over the wireless ATM link, with a loopback on the ATM switch. An ATM tester, is setup to generate ATM cells of a fixed bandwidth for a pre-determined duration. The ATM tester, on receiving the looped back cells, determines the number of cells lost and subsequently calculates the cell loss ratio.

A benchmark test is also carried out to determine the number of cells lost through the wired ATM link, before reaching the wireless link. For this, the loopback is configured at the ATM switch at the BTS.

#### 6.7.1.3 Test Results

##### Benchmark Test

Test	ATM Bandwidth (Mbps)	Test Duration (Hrs)	Cells Transmitted	Cells Received	Cell Loss Count	Cell Loss Ratio	Cell Misinsertion Count	Cell Misinsertion Rate
1.	10	12	1018696789	1018696788	0	0	1799	0.0416

##### Wireless ATM Test (Haw Par Center)

Test	ATM Bandwidth (Mbps)	Test Duration (Hrs)	Cells Transmitted	Cells Received	Cell Loss Count	Cell Loss Ratio
1.	8	12	814957489	814957489	0	0
2.	8.5	12	865890520	865890343	177	2.04e-7
3.	9	12	916820885	914290144	2531216	0.00276
4.	9.5	12	961464718	921924337	39540381	0.0411
5.	10	12	1018694822	927160912	91533910	0.0899

##### Wireless ATM Test (6 Battery Road)

Test	ATM Bandwidth (Mbps)	Test Duration (Hrs)	Cells Transmitted	Cells Received	Cell Loss Count	Cell Loss Ratio
1.	8	12	814954485	814954485	0	0
2.	8.5	12	865890254	865890254	0	0
3.	9	12	916824383	916824380	3	3.27e-9
4.	9.5	12	967759819	944482981	23276838	0.02405
5.	10	12	1018694822	927160912	91533910	0.0899

#### 6.7.1.4 Comments

From the benchmark test above we can conclude that other than the misinsertion count, no cell were lost up to the ATM switch at the BTS. The lost cells were a result of the wireless ATM link.

From the wireless ATM test, we can observe that the number of lost cells were minimal at bandwidths of 8Mbps to 8.5Mbps. If the bandwidth were to be increased, it would result in undesirable high losses in the ATM cells.

6.7.2 Wireless ATM Cell Loss Test (Wet Weather Conditions)

6.7.2.1 Test Objectives

To verify stability of the Wireless ATM link to carry ATM cells with minimal discarded or lost cells, under rainy conditions.

6.7.2.2 Test Description

An ATM PVC will be created over the wireless ATM link, with a loopback on the ATM switch. An ATM tester, is setup to generate ATM cells of a fixed bandwidth for a pre-determined duration. The ATM tester, on receiving the looped back cells, determines the number of cells lost and subsequently calculates the cell loss ratio.

6.7.2.3 Test Results

Wireless ATM Test

Test	ATM Bandwidth (Mbps)	Test Duration (mins)	Cells Transmitted	Cells Received	Cell Loss Count	Cell Loss Ratio	Weather
1.	9	5	6299024	6299022	2	3.18e-7	Clear
2.	8.5	5	5949380	5949380	0	-	Clear
3.	8.5	10	11954809	11954804	5	4.18e-7	Mod Rain
4.	8	10	11253177	11253172	5	4.44e-7	Mod Rain
5.	8	5	5600466	5600466	0	-	Clear
6.	6	5	4322801	4322801	0	-	Clear

6.7.2.4 Comments

From the above test results we can conclude that under clear weather conditions, the Wireless ATM link could sustain a bandwidth of 8.5 Mbps without any cells lost. However, when the bandwidth was increased to 9 Mbps, minimal cell loss was observed.

Under moderate rain conditions, minimal cell loss was also observed for ATM bandwidths of 8 Mbps and 8.5 Mbps.

## 6.8 Ethernet Throughput Test

### 6.8.1 Test Objectives

To verify the throughput of internet packets over the Wireless ATM link.

### 6.8.2 Test Description

A host FTP server is configured on the workstation at the CPE site, while a client workstation, setup at the BTS, FTPGETs files of varying sizes on the FTP server. During the FTP sessions, the average throughput is recorded at various elapsed time intervals.

Various test scenarios of different connection types are set up below. In scenario 1, the FTP server is connected to the wireless network via an ADSL connection, while at the remote end, the client is connected to the wireless network via a FastEthernet 100BaseT connection. A similar setup is applied to the other scenarios.

Test Scenario	CPE Site	Host Type	Client Type
1	Haw Par Center	ADSL	100BaseT
2	Haw Par Center	ADSL	ADSL
3	Haw Par Center	10BaseT	100BaseT
4	Haw Par Center	10BaseT	ADSL
5	No. 6 Battery Rd	10BaseT	100BaseT
6	No. 6 Battery Rd	10BaseT	ADSL

### 6.8.3 Test Results

#### Scenario 1

Test	File Size (Mb)	Ave. Transfer Rate (kbps)				Download Time (mins)
		0 mins	5mins	10 mins	15 mins	
1.	220	725	716	715	715	~ 49
2.	134	730	720	718	716	~ 30
3.	56	710	714	714	-	~ 12.5
4.	4	711	-	-	-	~ 0.9

#### Scenario 2

Test	File Size (Mb)	Ave. Transfer Rate (kbps)				Download Time (mins)
		0 mins	5mins	10 mins	15 mins	
1.	220	680	685	685	686	~ 52
2.	134	692	685	685	682	~ 33
3.	56	690	682	685	-	~ 13
4.	4	686	-	-	-	~ 1

Scenario 3

Test	File Size (Mb)	Ave. Transfer Rate (Mbps)				Download Time (mins)
		0 mins	5mins	10 mins	15 mins	
1.	220	2.12	2.08	2.04	2.00	~ 17
2.	134	2.05	1.98	2.01	-	~ 10
3.	56	2.13	2.08	-	-	~ 4.5
4.	4	2.05	-	-	-	~ 15 secs

Scenario 4

Test	File Size (Mb)	Ave. Transfer Rate (Mbps)				Download Time (mins)
		0 mins	5mins	10 mins	15 mins	
1.	220	1.65	1.68	1.67	1.66	~ 20.5
2.	134	1.66	1.68	1.68	-	~ 12.5
3.	56	1.60	1.65	-	-	~ 5.5
4.	4	1.66	-	-	-	~ 20 secs

Scenario 5

Test	File Size (Mb)	Ave. Transfer Rate (Mbps)				Download Time (mins)
		0 mins	5mins	10 mins	15 mins	
1.	220	2.3	2.12	2.10	2.10	~ 17
2.	134	2.3	2.0	1.8	-	~ 10
3.	56	2.3	1.5	-	-	~ 7
4.	4	2.5	-	-	-	~ 10 secs

Scenario 6

Test	File Size (Mb)	Ave. Transfer Rate (Mbps)				Download Time (mins)
		0 mins	5mins	10 mins	15 mins	
1.	220	1.96	1.8	1.5	1.6	~ 20
2.	134	1.94	1.5	1.6	-	~ 11
3.	56	1.9	1.83	-	-	~ 5
4.	4	1.9	-	-	-	~ 10 secs

#### 6.8.4 Comments

From the results above, in Scenarios 3 to 6, where the host FTP server was connected via Ethernet 10BaseT, showed higher FTP throughput than compared to Scenarios 1 and 2, where the FTP server was connected via ADSL. This was the case regardless of the client FTPGET workstation's connection. This lower throughput was due to the limitations on the ADSL modem at the host FTP Server-end.

Considering the client FTPGET workstation-end, across Scenarios 1 to 6, it can be observed that higher performance was obtained when the client-end was a FastEthernet 100BaseT connection as compared to an ADSL connection. The lower throughput was again due to the limitations on the ADSL modem.

## 6.9 Rain Effect on Bit Error Rate Test (BERT)

### 6.9.1 Test Objectives

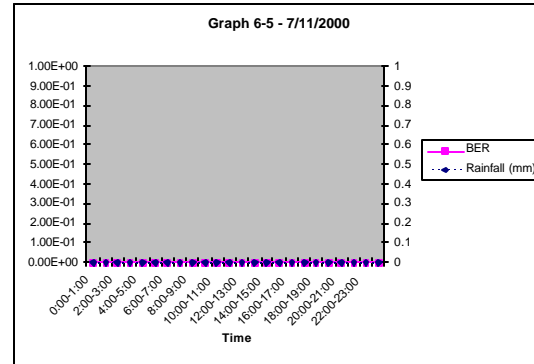
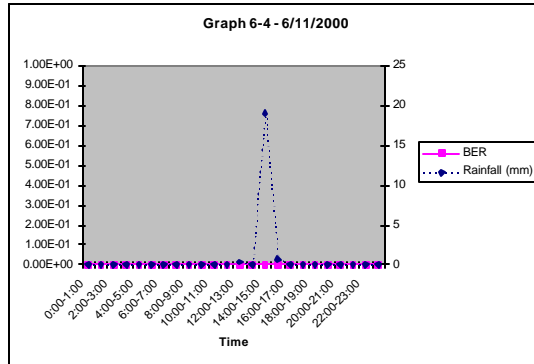
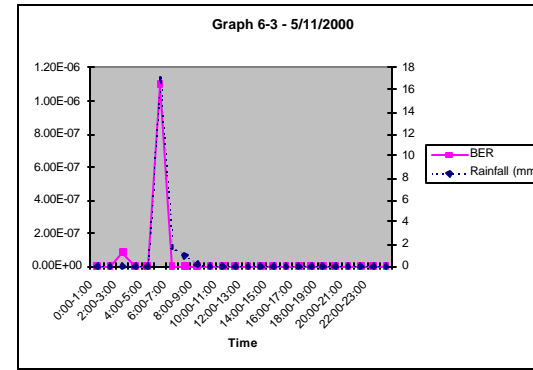
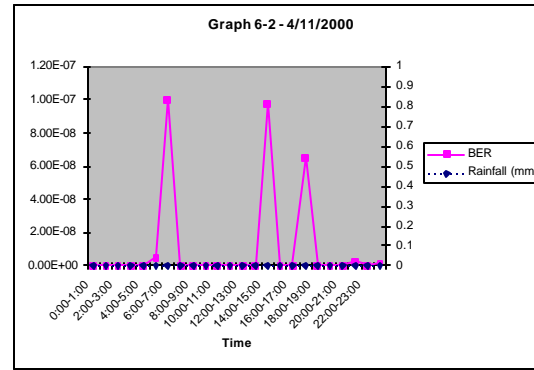
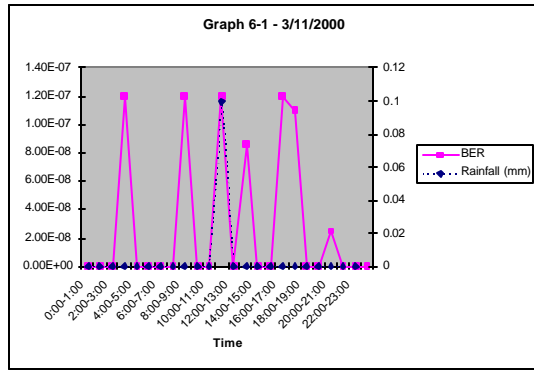
To verify the effect of Rainfall on the transmission of wireless TDM packets over free space

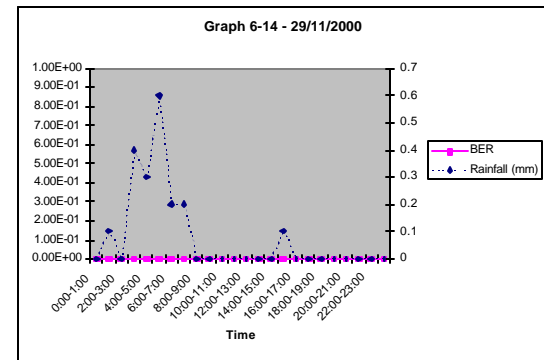
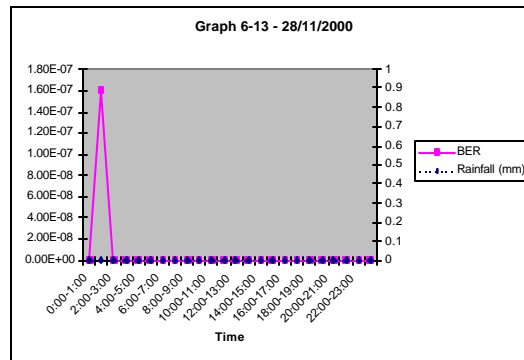
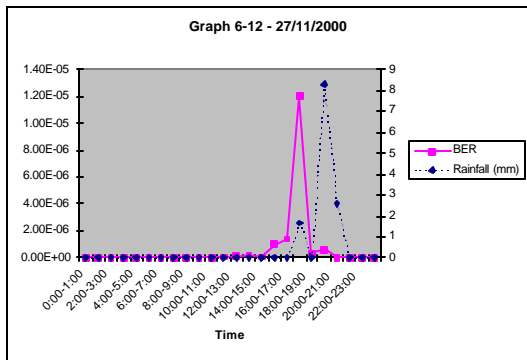
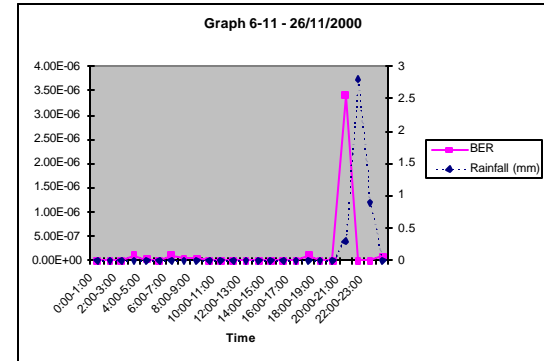
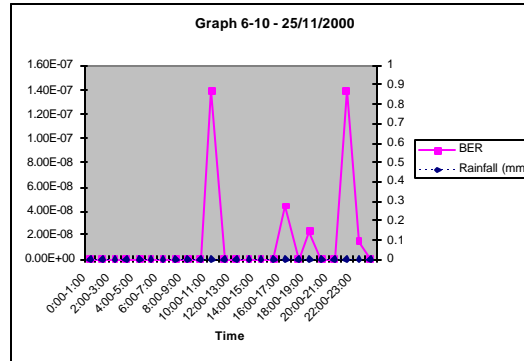
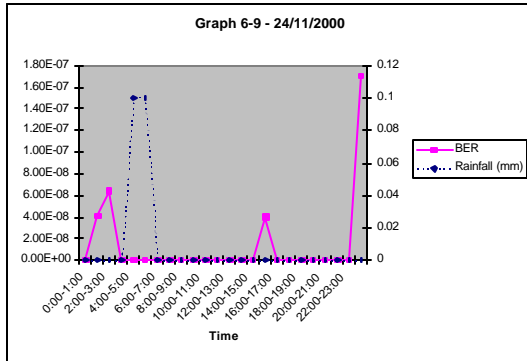
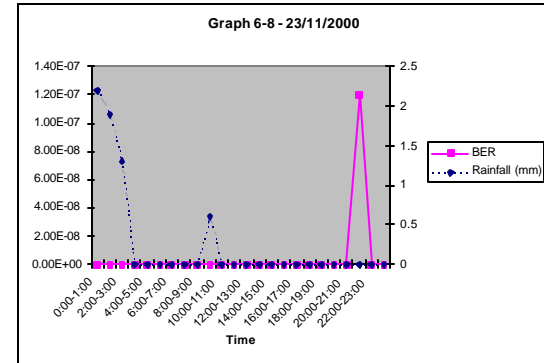
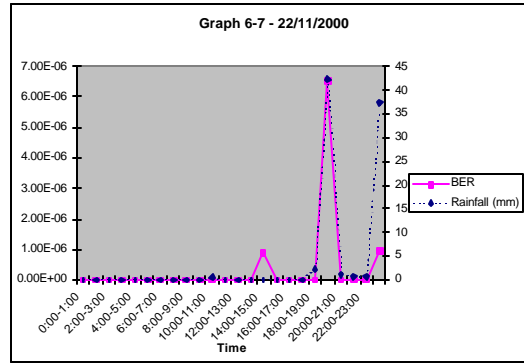
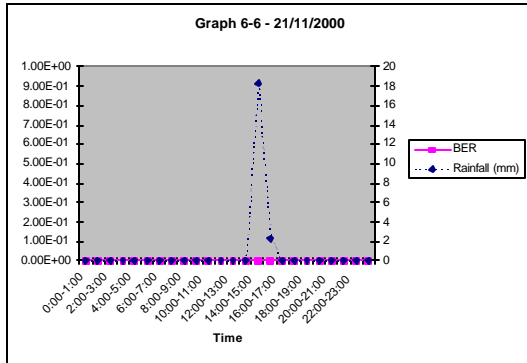
### 6.9.2 Test Results

The test was run for two separate periods: 3/11–7/11 & 21/11-29/11. Results for hourly BER and instantaneous high **BER** were gathered and **plotted against hourly absolute rainfall amounts (mm)** obtained from The Meteorological Service Singapore (MSS).

(Note: The results are based on those gathered from the nearest rain measurement device of MSS situated at the top of Singapore Power building at Somerset Road, hence, it is observed that there is a offset of 1-2 hours between occurrences of rainfall measured and corresponding BERs)

The results are as per the following pages:

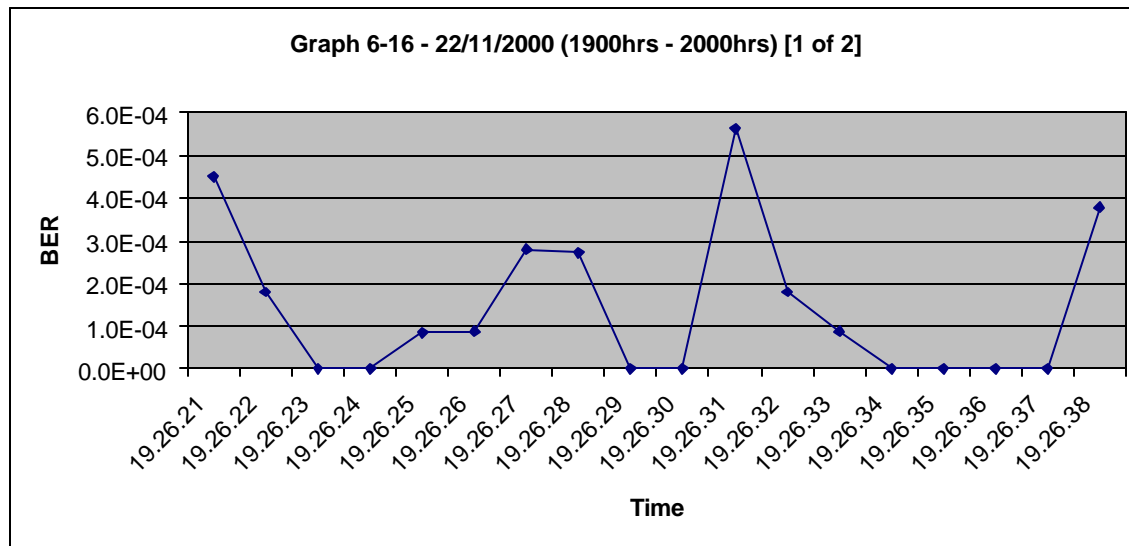
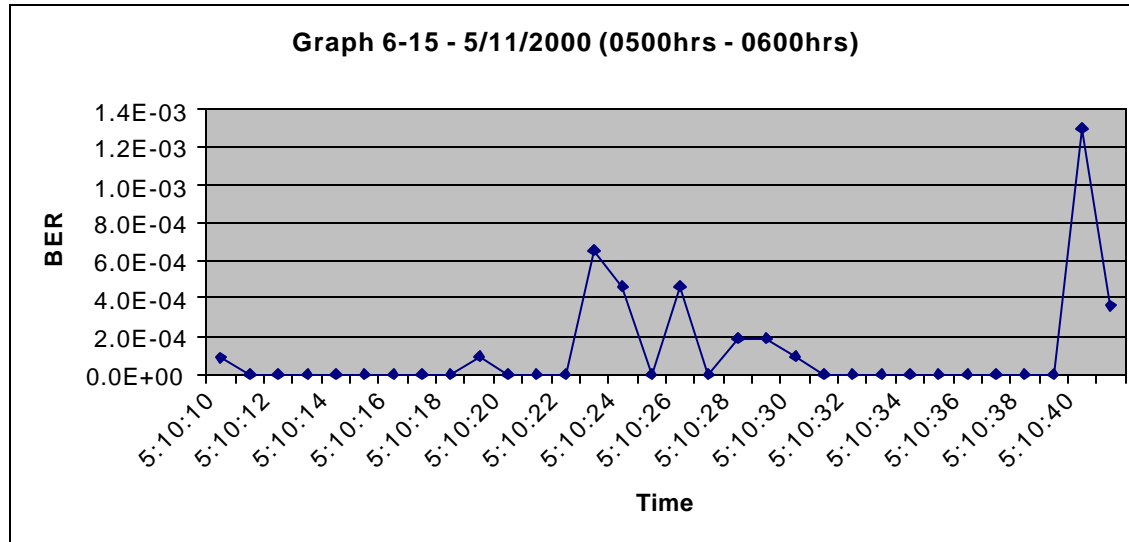


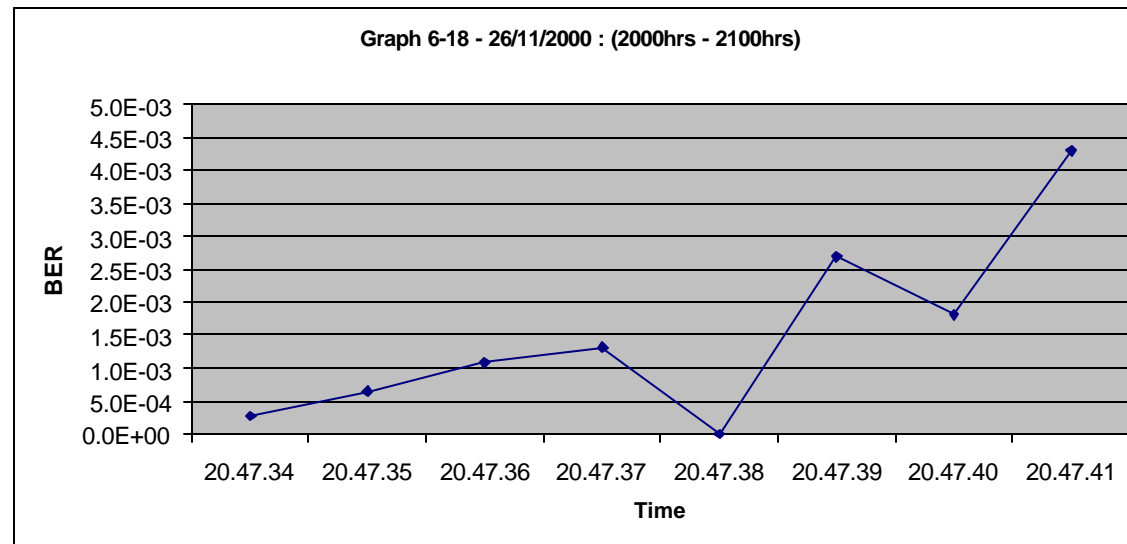
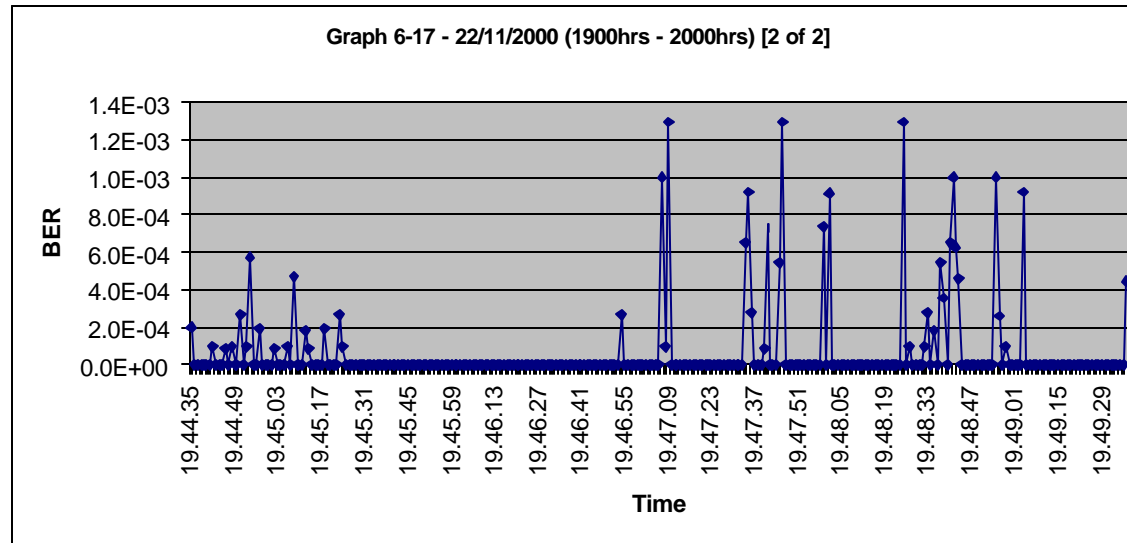


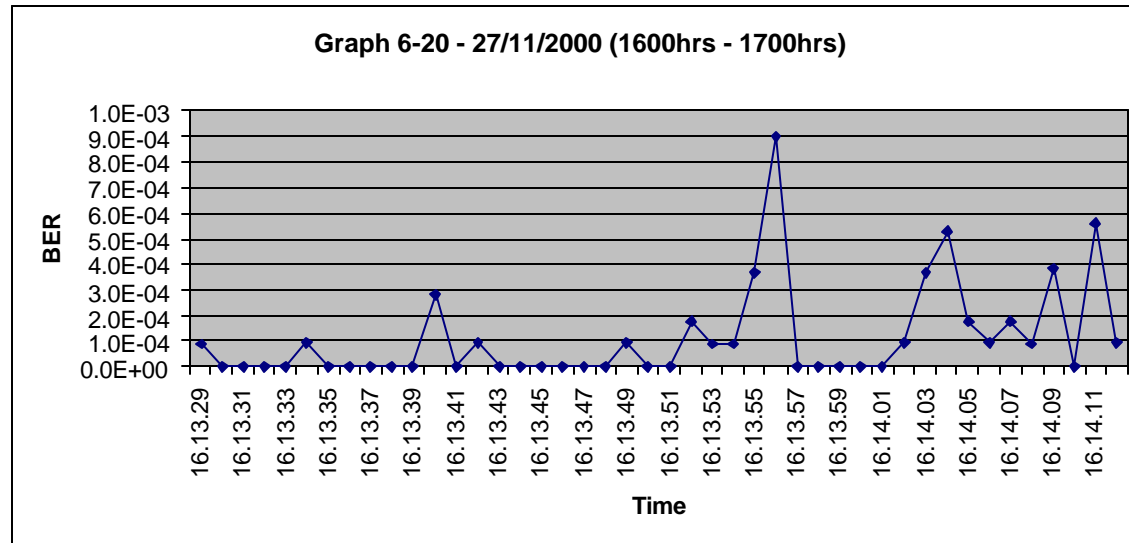
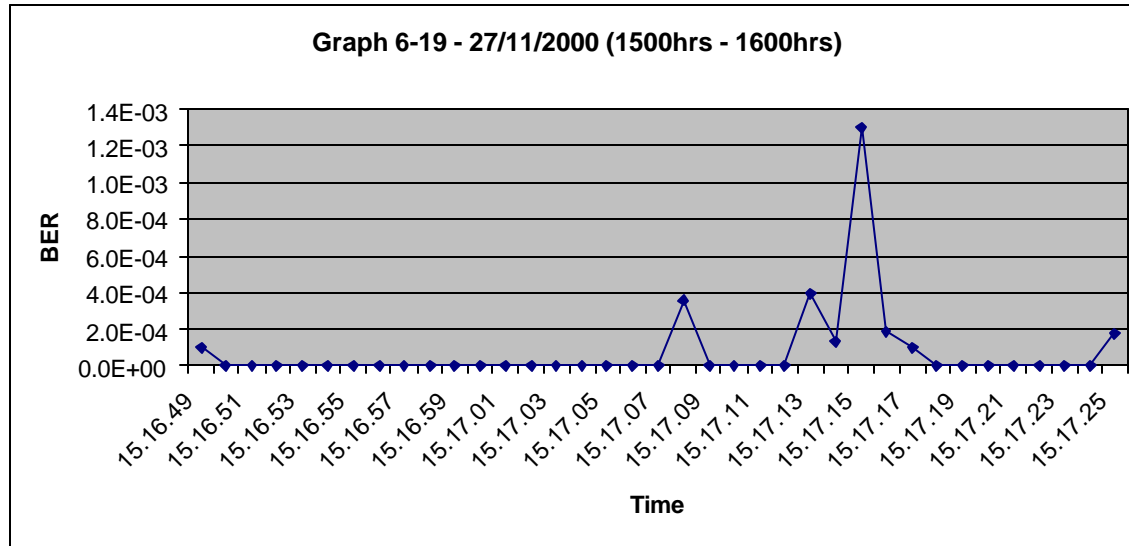
### 6.9.3 Comments

It can be observed that different levels of BER were generated during various rainfall amounts. Below are the key observations on the relevant graphs/days with the corresponding comments of what attributed to those BERs.

Key Observation	Relevant Graphs/Days	Comments
Acceptable BER without Rain	Graph 6-2 – 4/11/2000; Graph 6-8 – 23/11/2000; Graph 6-9 – 24/11/2000; Graph 6-10 – 25/11/2000; Graph 6-13 – 28/11/2000	These short BERs that are within the acceptable limits of 1E-6 are attributed to maintenance activities.
Acceptable BER during low rainfall	Graph 6-1 – 3/11/2000	This proves that LMDS links can work well during low rainfall periods.
No BER during low or no rainfall	Graph 6-4 – 6/11/2000; Graph 6-5 – 7/11/2000; Graph 6-6 – 21/11/2000; Graph 6-14 – 29/11/2000	This result proves that LMDS links are capable of providing highly reliable links.
Unacceptable BER during high rainfall	Graph 6-3 – 5/11/2000; Graph 6-7 – 22/11/2000; Graph 6-11 – 26/11/2000; Graph 6-12 – 29/11/2000	There were 6 of such occurrences during the days of 5/11, 22/11 (2 consecutive hours), 26/11 and 27/11 (2 consecutive hours).  Signals that are degraded beyond 1E-3 are considered to be unacceptable. This has been experienced on 5 out of 6 of the above occasions. The instantaneous BER for these high outage periods were recorded and plotted below for further analysis.







It can be further observed that high BERs usually occur in an instantaneous bursty fashion, and that the system recovers immediately without any outage time. Such BERs are attributed to sudden bursts of intense rainfall that are measured in the units of seconds. However, these occurrences were expected for this trial as the link length was more than 500m longer than the recommended link length of a 99.995% availability link length for Singapore, which is 1.0km.

It must also be noted that such adverse situations can be avoided by using shorter link lengths that leads to higher fade margins, thus compensating for higher amounts of rainfall attenuation.

Thus, it is hereby recommended that future initial commercial deployments of LMDS in Singapore employ shorter link lengths (smaller cell sizes) that are about 1.0km in cell radius. The optimal link length will be highly dependent on the desired link availability and technical capability of the radio component of the equipment to be used.

## REFERENCES

*Vendor A's internal technical references, hardware installation and maintenance guides were used throughout the trial.*