ITR-4 4th Infocomm Technology Roadmap Seminar

iDA INFOCOMM DEVELOPMENT AUTHORITY OF SINGAPORE

Trial-based Study of Free Space Optics Systems in Singapore

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Overview

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2. Trial Objectives
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4. Test Methodology
    - (a) Physical Network Layer Tests
    - (b) Network Layer Tests
    - (c) Application Layer Tests
5. Deployment Considerations
6. Conclusion

Introduction

FSO – Optical Transmission Through Free Space

Concerns about the Effects of S'pore Environment
On Performance of FSO Systems

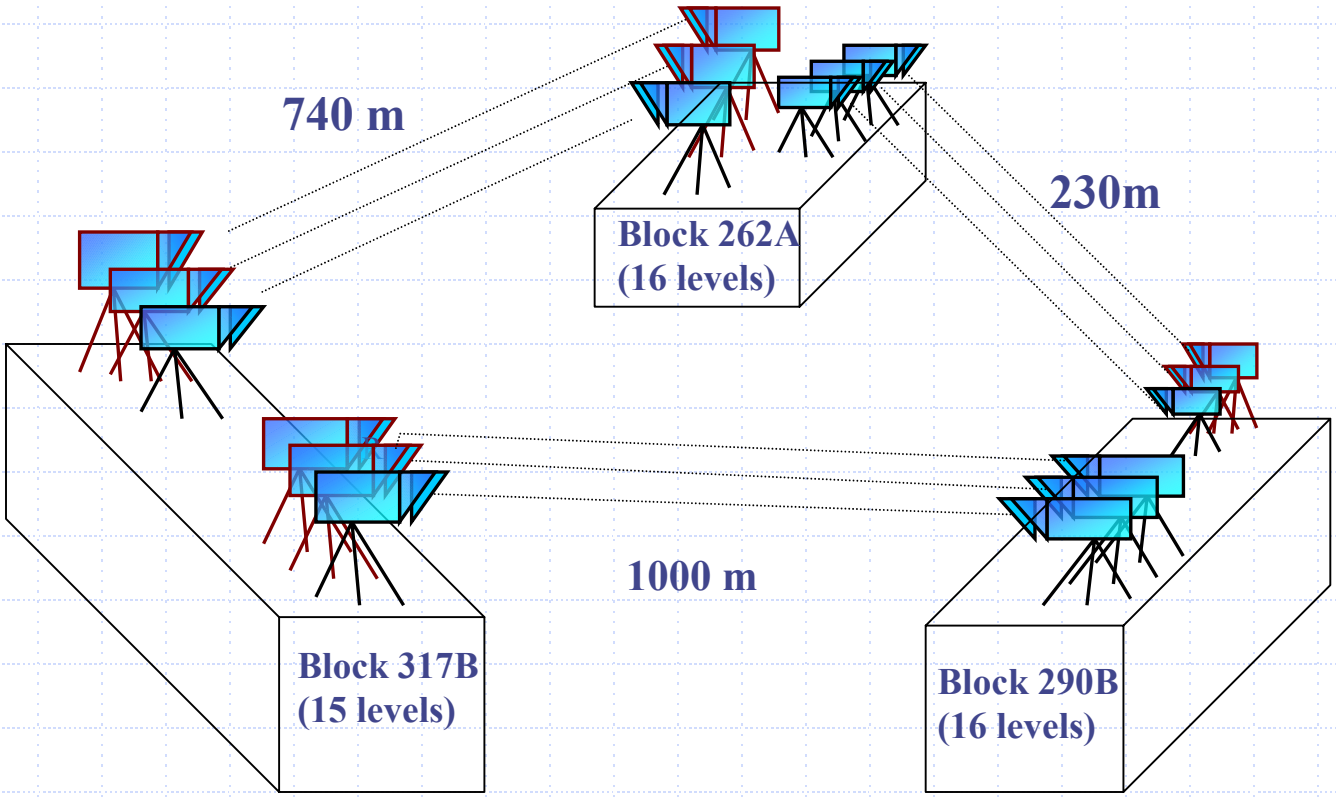
- Heavy Rain
- Haze
- Others

What % of the Year Would FSO Work Effectively?
(Link Availability 99.9%, 99.99% or 99.999%?)

Trial Objectives

- Independent Assessment by NTU of Performances & Availability of FSO Systems in the Local Environment.
- Deployment Considerations for Implementing FSO Systems in Singapore

Trial Site & Systems Configuration



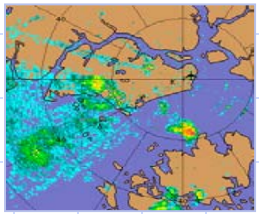
Participating Vendors' FSO Systems

- **Canobeam**
  - Feature: Automatic Beam Tracking
- **LightPointe**
  - Feature: 4 Tx & 4 Rx Diversity
- **LaserBit**
  - Feature: 4 Tx & 1 Rx Diversity

NOTE: Laser Beam ~ few mrad

Trial Methodology

- Test Results Collected over a Period of **3 months**
- Specific Tests for the **Physical**, **Network** and **Application** Layers
- **Concurrent Assessment** of all Three Vendors' Systems as far as possible
- Trial Results are Correlated to Prevailing **Weather Conditions**
  - Weather Monitoring System Installed at Two Blocks
  - Complemented by Data from Meteorological Service



Test Methodology

(a) Physical layer:
- Monitor Signal Power
- Rainfall Rate
- BER
- Other Tests

(b) Network Layer
- ATM Loop-back Tests
- Network Redundancy
- Automatic Failover Tests

(c) Application Layer
- Real Time and Non-real Time Traffic Tests Using Chariot Software

Physical Layer

Bit Error Rate (BER) Tests Over 5 Weeks
When 155 Mbps Data Sent through 1000m FSO Link

- No Significant Bit Errors Recorded
- 4 Rain Events with Rainfall Rate >60mm/hr

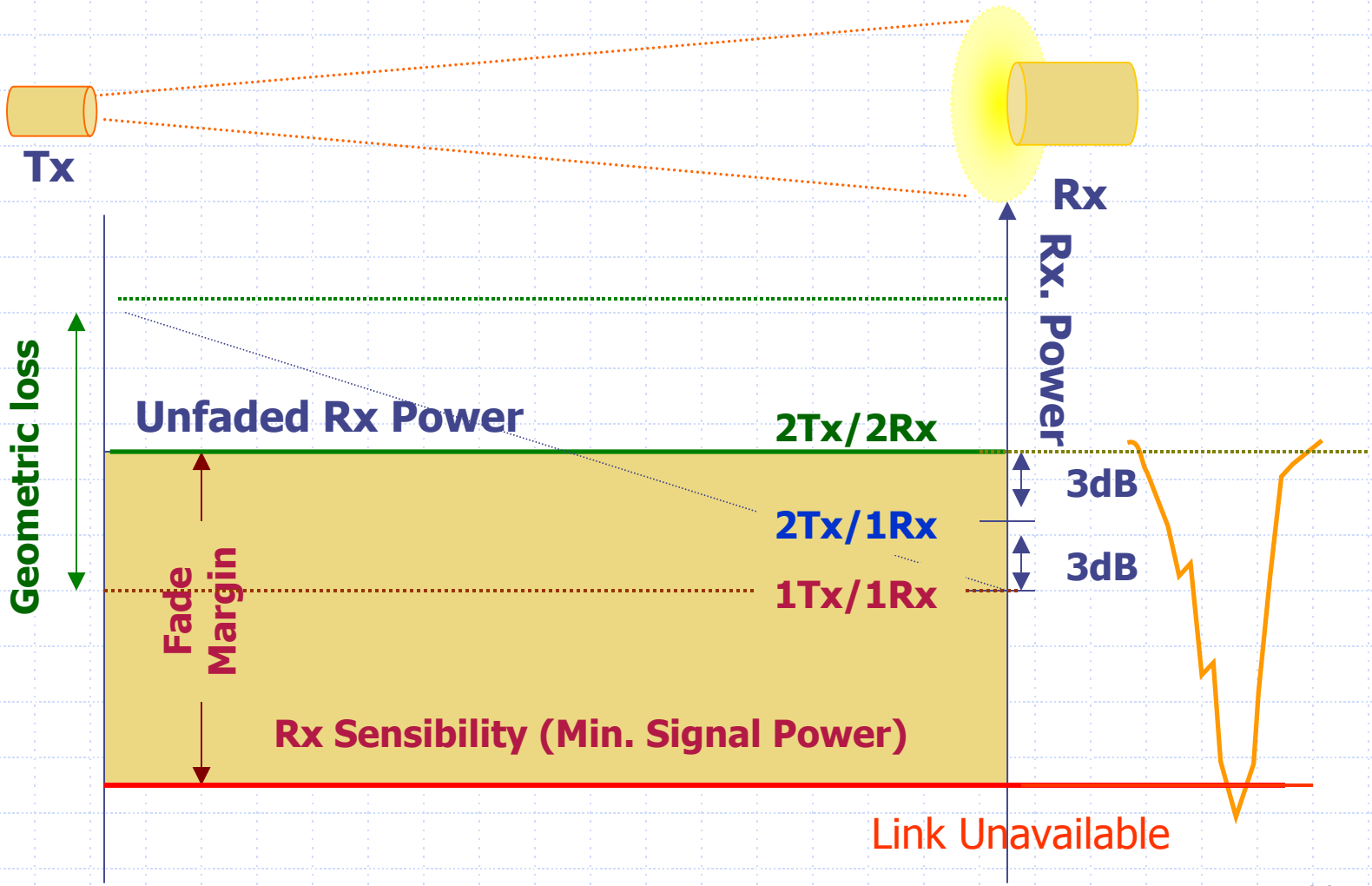
  2 Rain Event > 96mm/hr (Attenuation< Fade Margin)
- Odd Errors During Clear Weather (Due to Receiver momentary overload When Scintillation is Higher)

Physical Layer Considerations

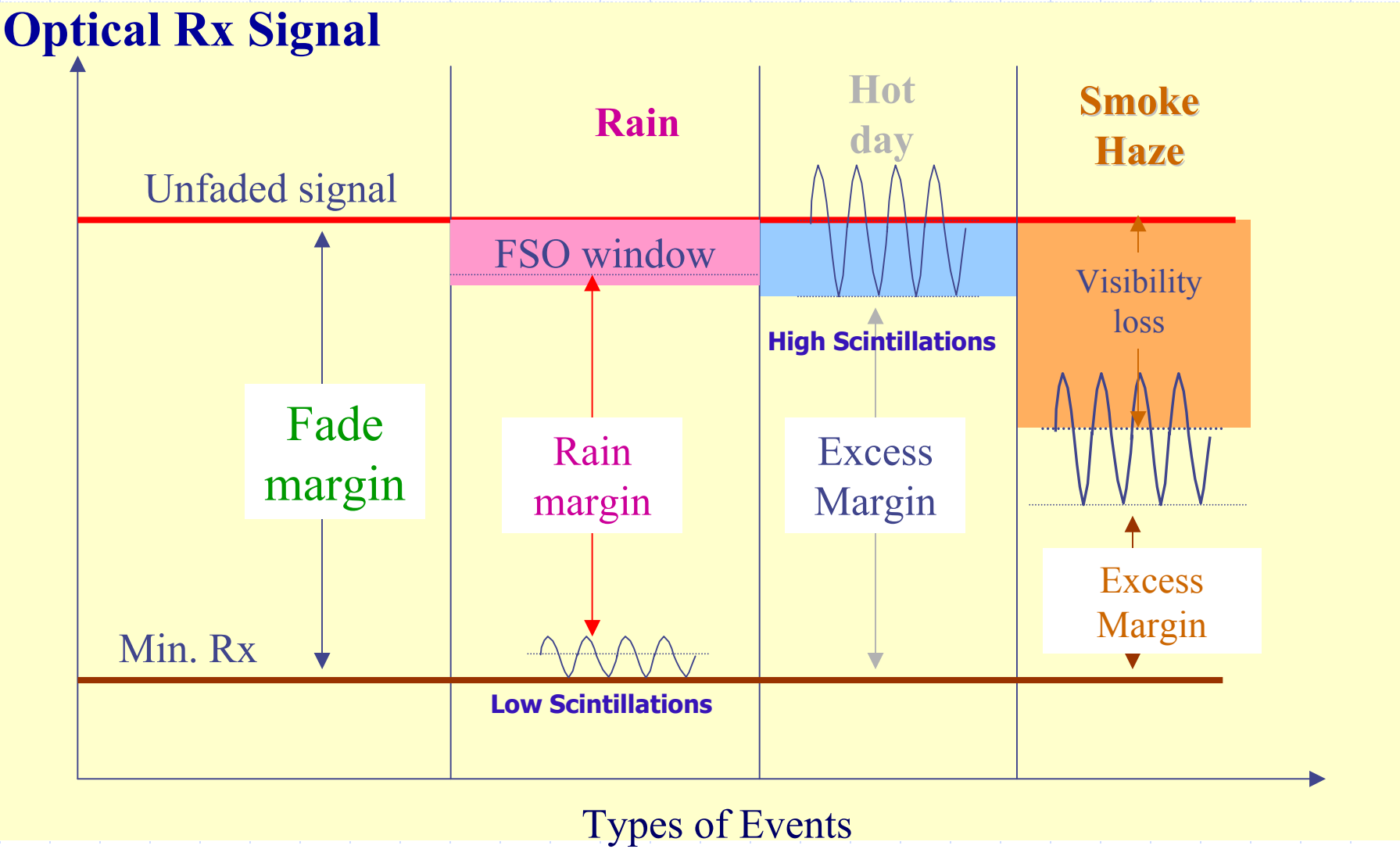
Different Attenuation Mechanisms

- Geometrical Path Loss
- Rain Attenuation along Path
- Atmospheric Scintillation
- Smoke Haze
- Water on FSO Transceiver Window or Window Pane
- Window Pane Losses

Physical Layer – Link Budget
(FSO Rx Power/Fade Margin/Link Availability

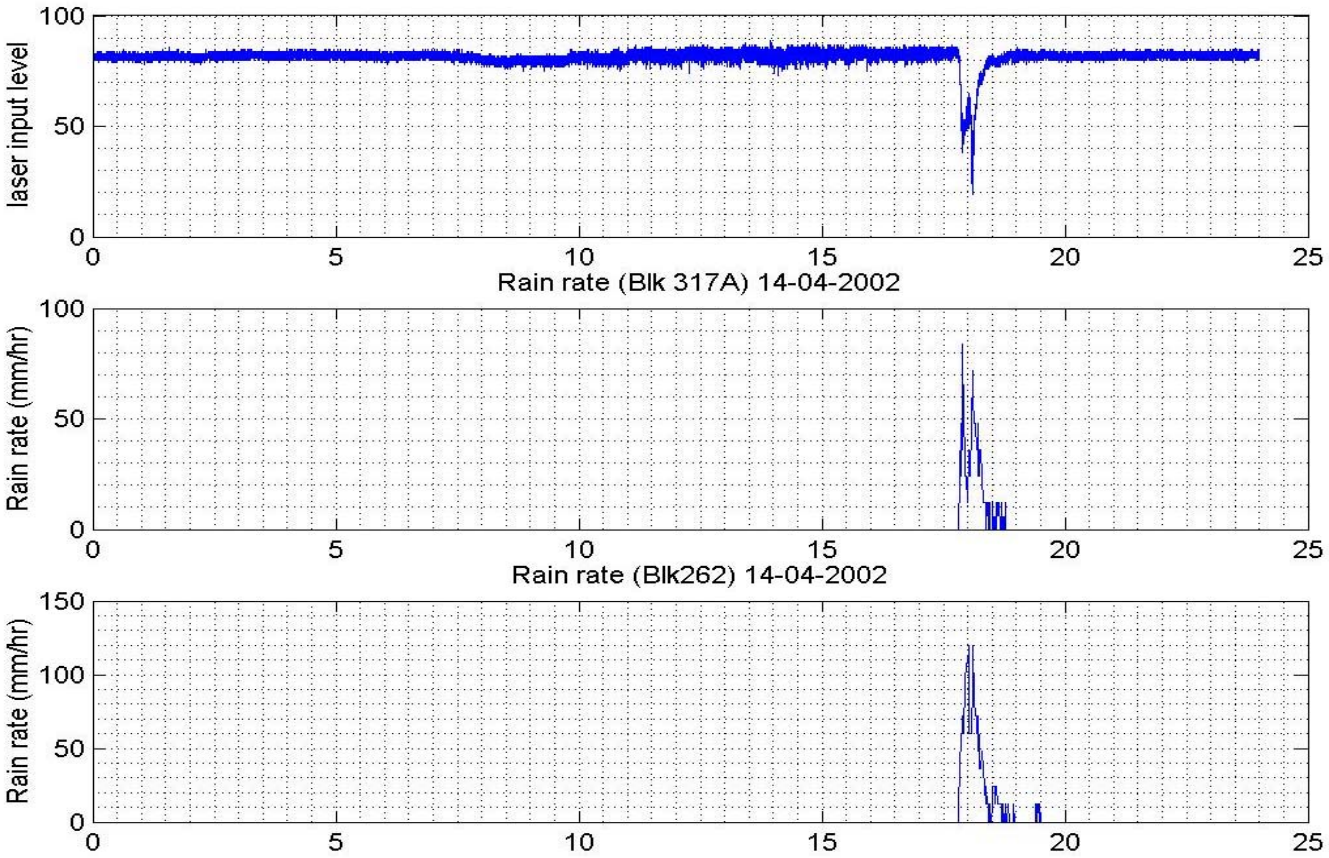


Physical Layer Considerations
(Environmental Effects – Rain, Scintillations & Haze)



Physical Layer - Effects of Rain

A Rain Event: 14 April 2002



RX power & the Two Rainfall rates Not Correlated

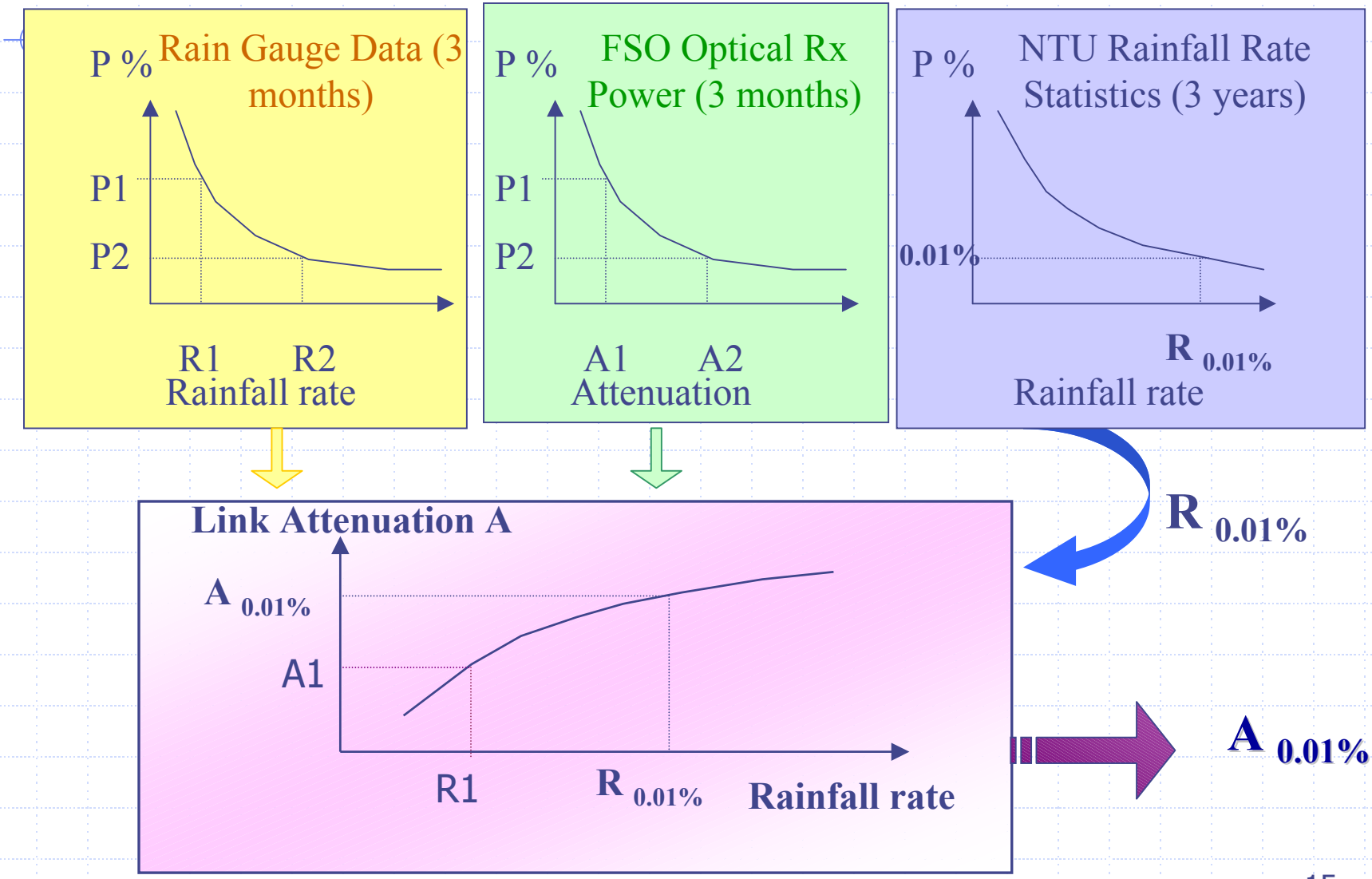
Physical Layer - Effects of Heavy Rain on Optical Rx Power

- Cumulative Distribution (CDF) of Rainfall Rate
- CDF of Optical Received (Rx) Power (Signal Strength) - *Only 3 Months*
- Correlation between Rx Power and Rainfall Rate

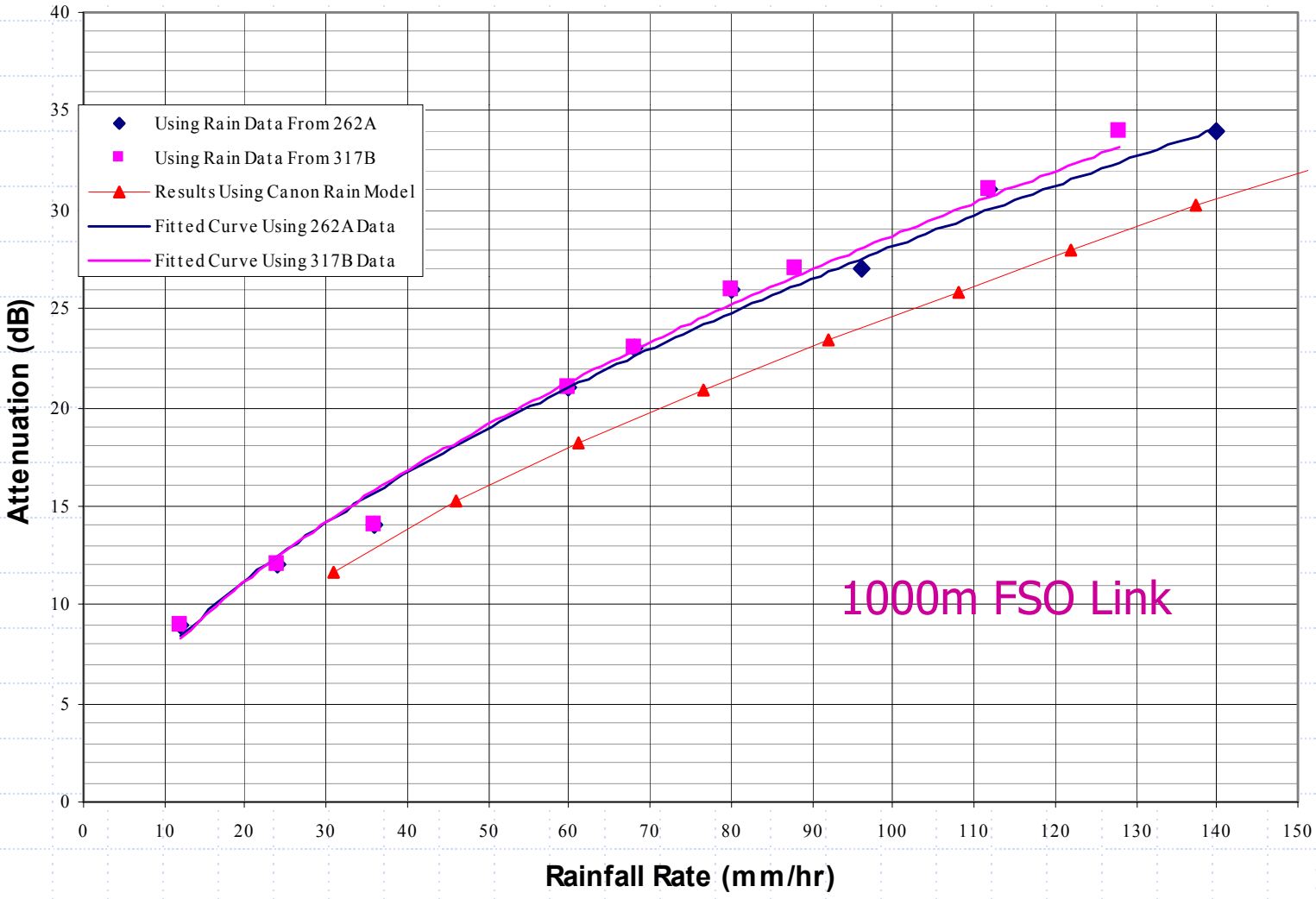
Fade Margin Extrapolated Using NTU's

3 Years Rainfall Rate Statistics

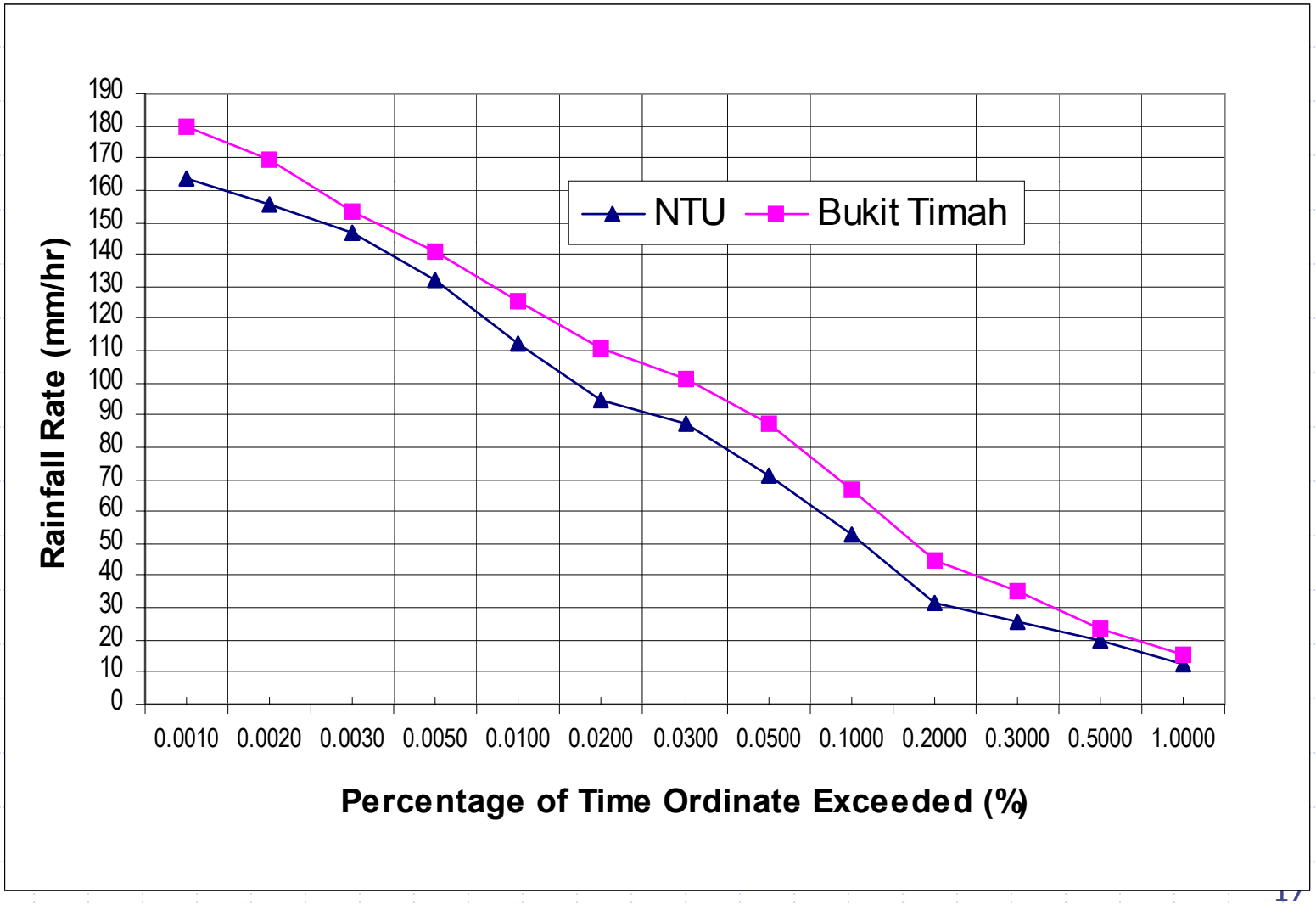
Physical Layer – Extrapolation of Long Term FSO Link Attenuation from 3-months Data



Physical Layer - FSO Link (Rain) Attenuation vs. Rainfall Rate Obtained from Trials (3-Months)



Physical Layer – 3 Year Rain Rate Statistics at Bukit Timah and NTU



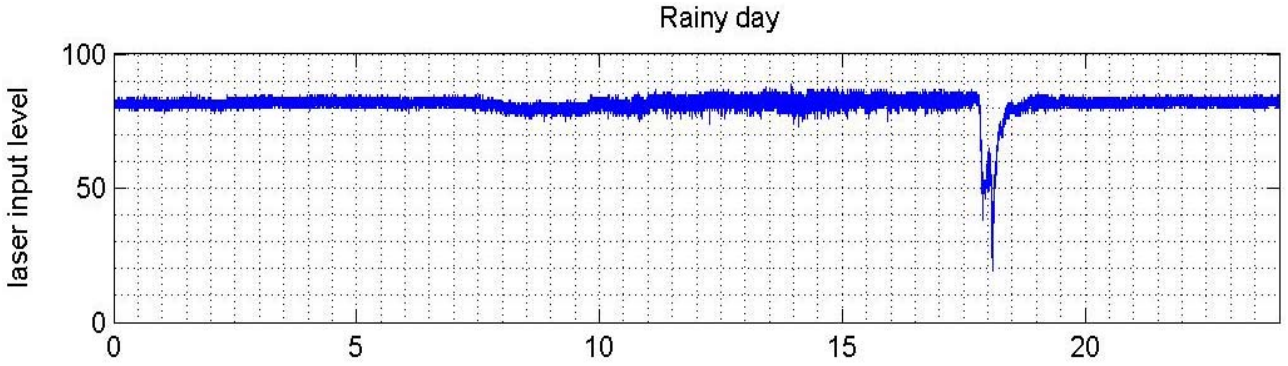
Physical Layer - Scintillation

Fluctuations in Beam Intensity due to Small-Scale Variation of Refractive Index of the Atmosphere

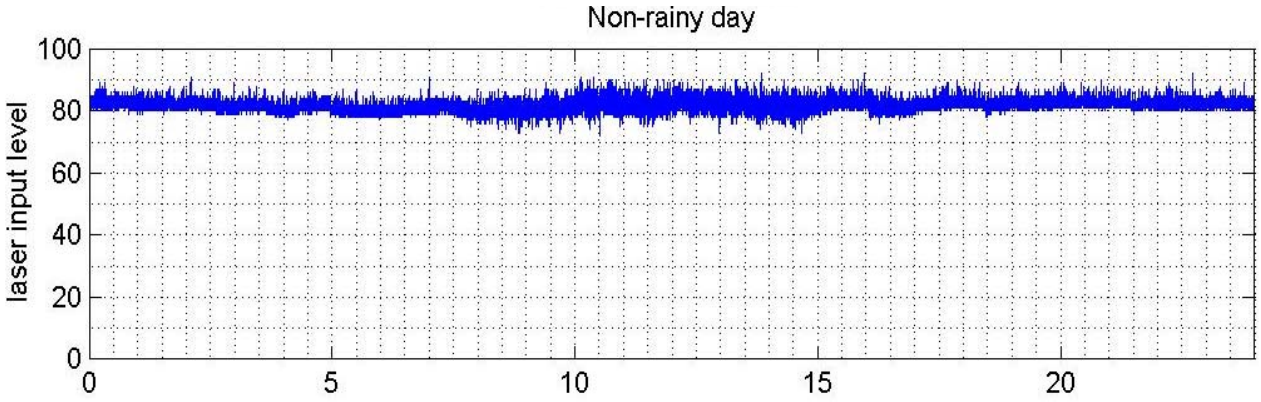
- More Serious in Tropical Compared with Temperate Environments
- Diurnal Variations - Peak-to-Peak (P/P) for Each Hour of Day Averaged over the Month
- Monthly Seasonal Variations
- Peak-to-Peak Could be Higher for Any Hour

Physical Layer - Scintillation

Received Optical Power Measured Throughout a Day



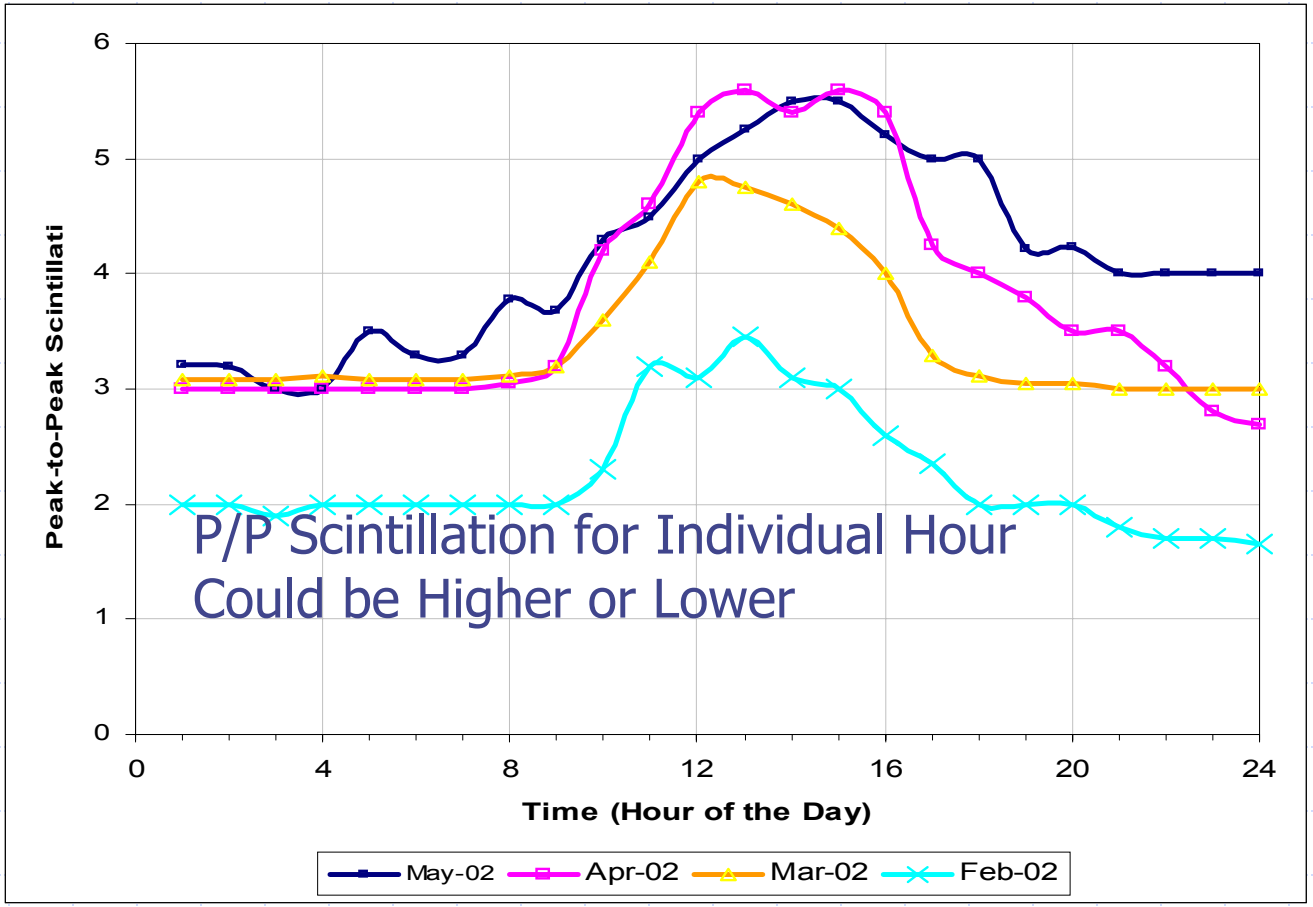
Received optical power in rainy day



Received optical power in non-rainy day

Physical Layer - Scintillation

Diurnal & Seasonal Variations of Average Hourly Peak-to-Peak Scintillation



Physical Layer - Haze

Low Visibility due to Forest Fires & Other Conditions 1997 – an El Nino Year

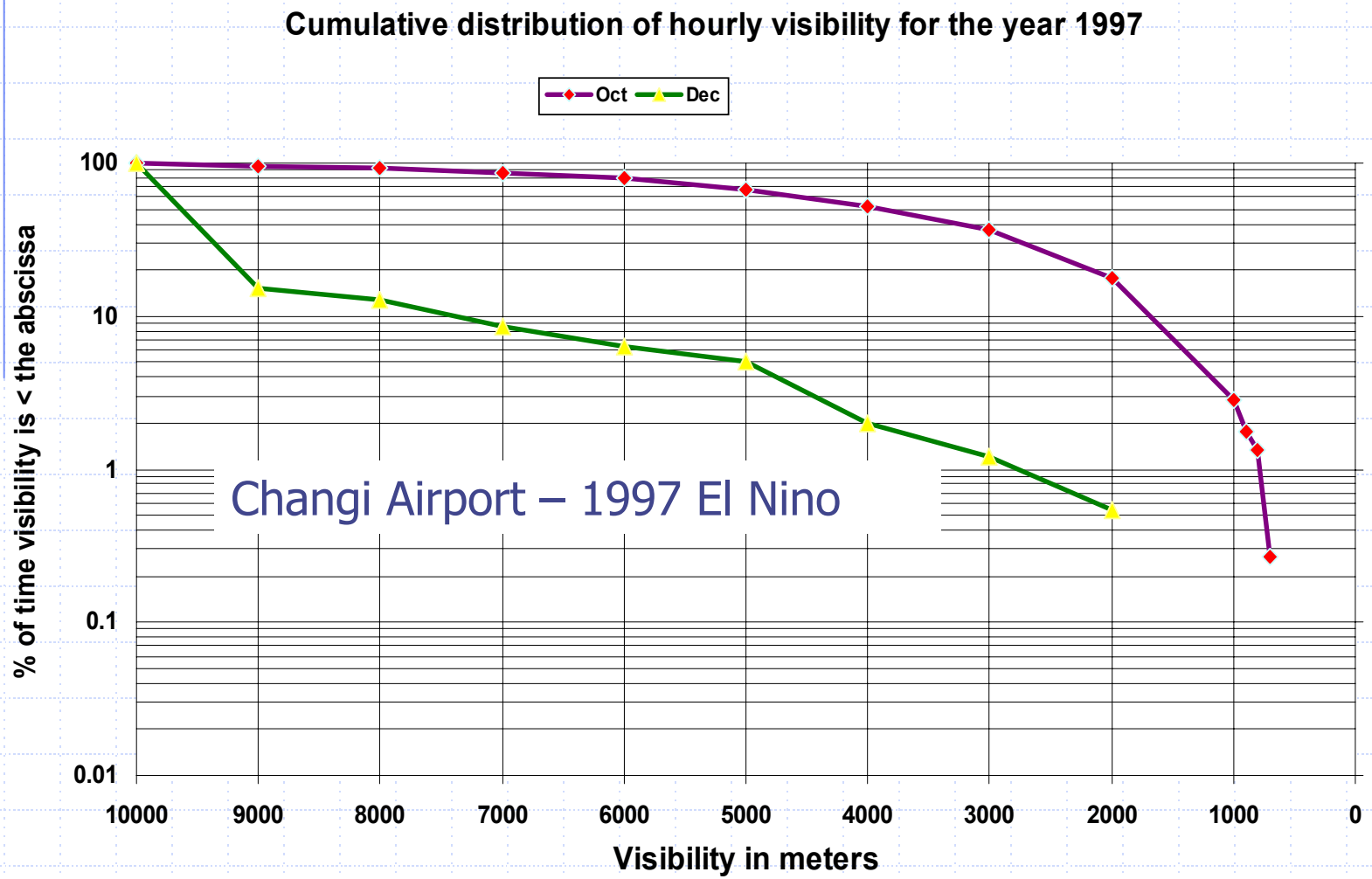
Analyses of Hourly Visibility Data from MSS

- Low Visibility due to:
  - Smoke Haze (Oct 1997)
  - Heavy Rain (Dec 1997)

- Important to Separate the Low Visibilities due to Haze from that Due to Rain When Processing Visibility Data

Physical Layer - Haze

Haze and Other Low Visibility Conditions



Physical Layer - Haze

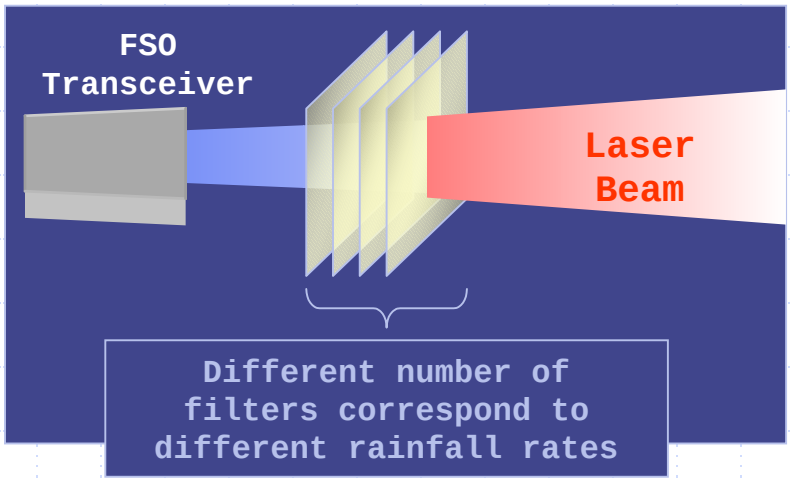
- For Worst Month - Oct'97, 13 Observations <1000m
- 2 for 700m, 8 for 800m & 3 for 900m
- Estimated Attenuation for Lowest Visibility: 16 to 26 dB/km

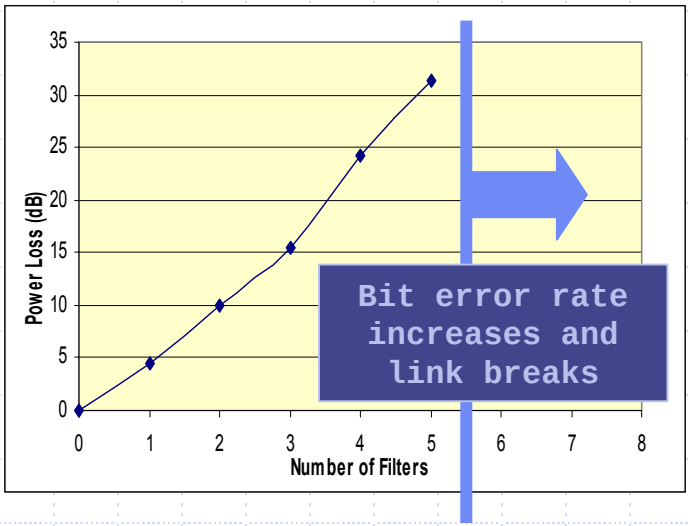
  In Worst Case, Haze Attenuation is still Less Than Rain Attenuation

Physical Layer – Poor Weather Simulation

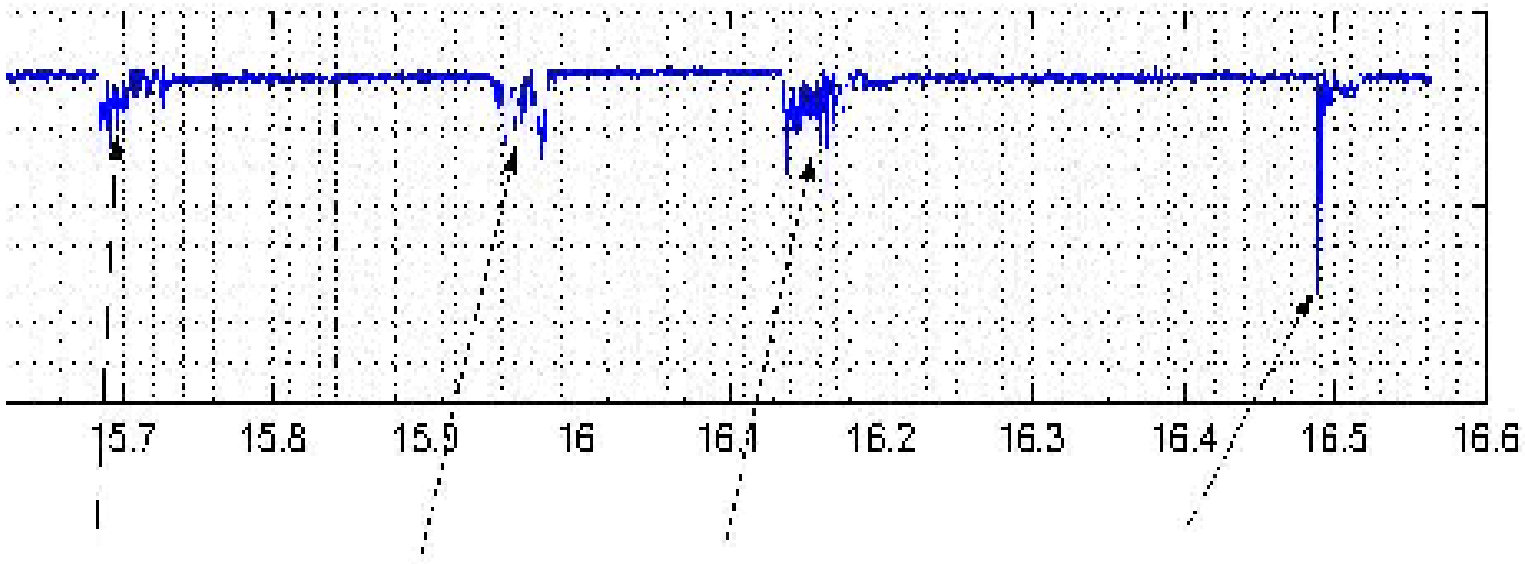
To Obtain Data Corresponding to Weather Conditions Worse than That Encountered during Trial

- **Light-Absorbing Filters** Placed in Path of the Beam



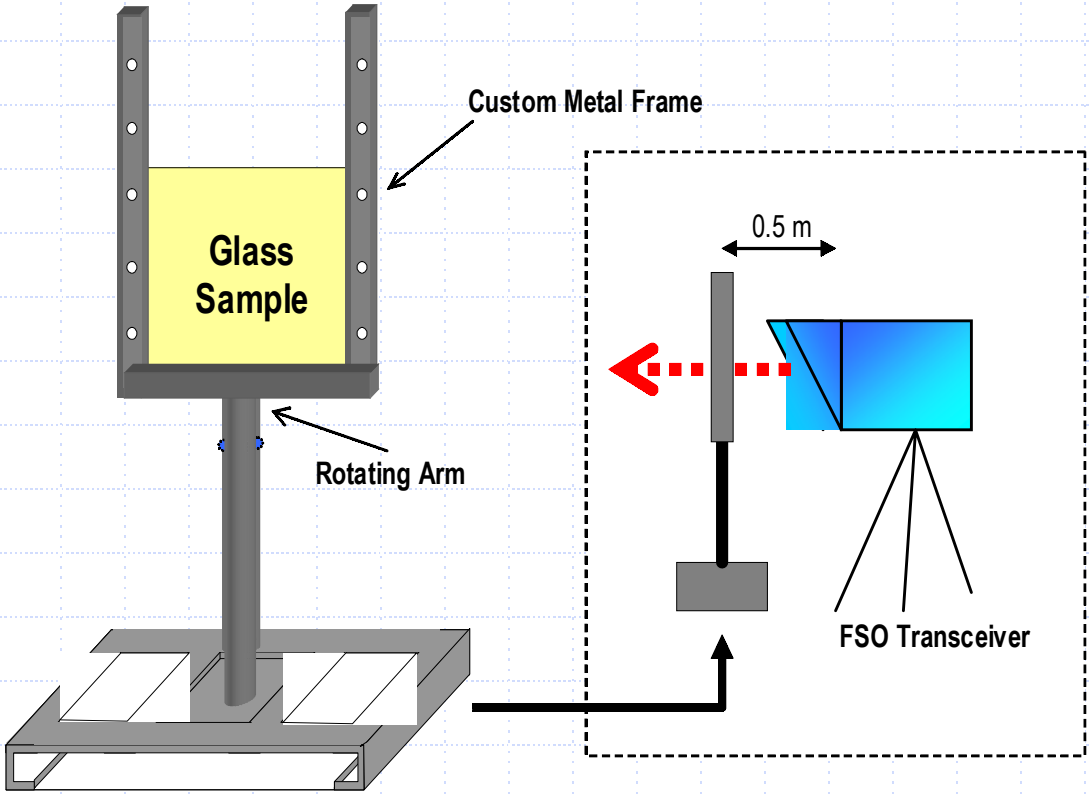


Physical Layer – Water on FSO Transceiver or Window Pane



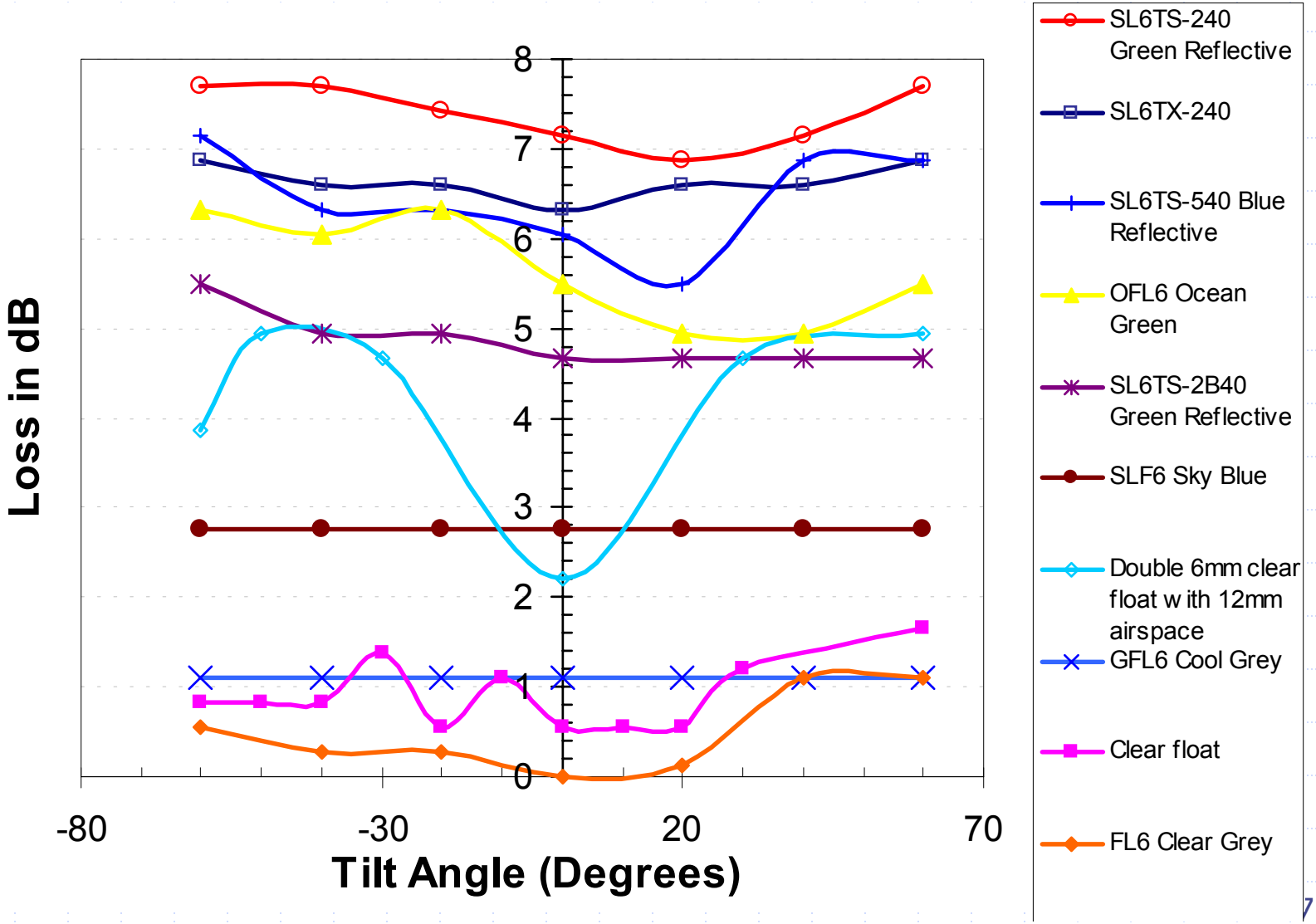
Loss of 8 dB is a More Realistic for a Practical Link

Physical Layer – Optical Power Loss through Window Pane



- **10 Types of Glass Commonly Used In S'pore**
- **Varying Incidence Angle θ = -60° to +60°**

Physical Layer – Transmission Through Window Panes

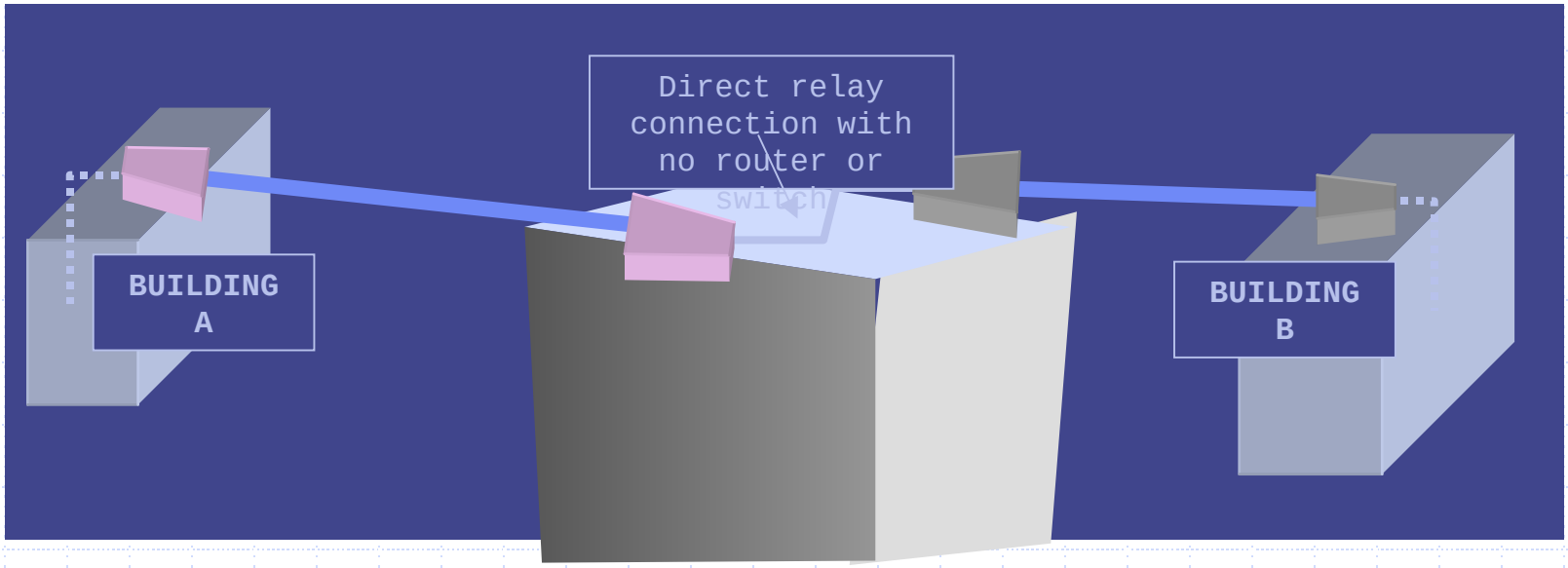


Physical Layer – Relay Link

- **Relay Link**

  Investigate Feasibility of Connecting FSO Links Back-to-Back to Extend the Reach of the Network Without Additional Network Hardware or if Direct Path Blocked

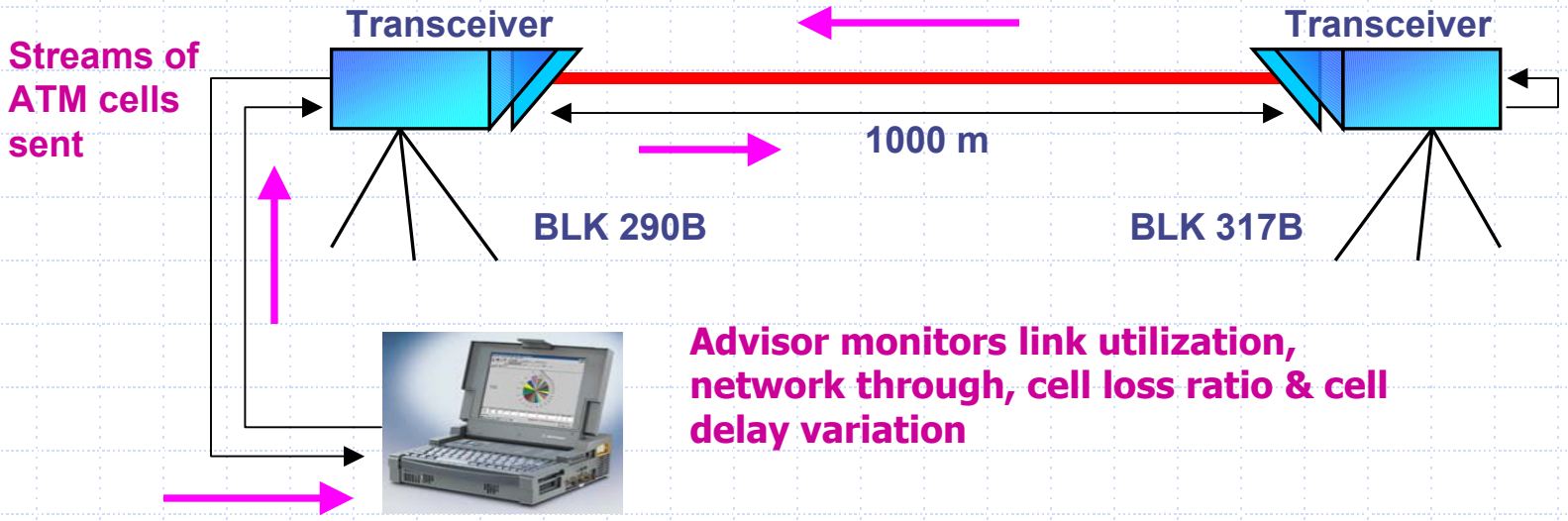
  ➔FSO Transceivers can be Connected Back-to-Back Directly Without Additional Network Equipment



Network Layer

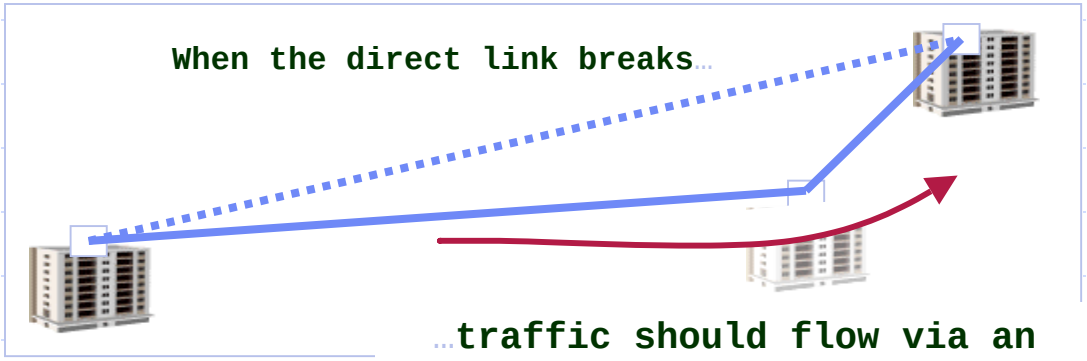
- To Study the **Network Behaviour** of FSO
  - Tests Carried out in Clear Weather
    - Important that Test Results are Independent of Physical Transmission Impairments Caused by Bad Weather
    - Time did not Permit Further Testing under Poor Weather Conditions
- Measurement of **ATM parameters**

➔ **No Cell Loss** Observed during Tests



Network Layer

- Failover Performance
  - To Study Means of Building a Robust FSO Network Employing Redundant Paths Using Additional Network Equipment



- Automatic Failover is not an intrinsic feature of point-to-point FSO Links
- Restoration time is about 3 seconds
- Faster restoration times may be needed for telco networks, different network hardware will be necessary

Application Layer

- To Study the Behaviour of Application Traffic Over an FSO Link
- Non-Real-Time Traffic
  - E-mail, FTP Files & Lotus Notes
- Real-Time Traffic
  - VoIP &
  - Video Streaming

- Performance of FSO Link Indistinguishable from that of Wire
  - Applications Behave as they would if Infrastructure was Wireline
  - FSO Links exhibit very Low Latency and Jitter
    - Ideal for VOIP, Video Conferencing Applications

Recommendations for Deployment

- FSO Equipment Features
  Auto-tracking/Narrower Laser Beam, Tx/Rx Diversity
- Account for Path Rain Attenuation
- Careful Design of FSO Links (Fade Margin/Link Availability/Path Length Trade-off)
- Specify Hoods to Shield FSO Window from Heavy Rain
- Specify Heater on FSO Window to Prevent Condensation
- Account for Loss Through Windowpane

Further Recommendations for Deployment

- Line-of-Sight Between FSO Terminals
- Transmission Security
- Avoid High Temperature Sources

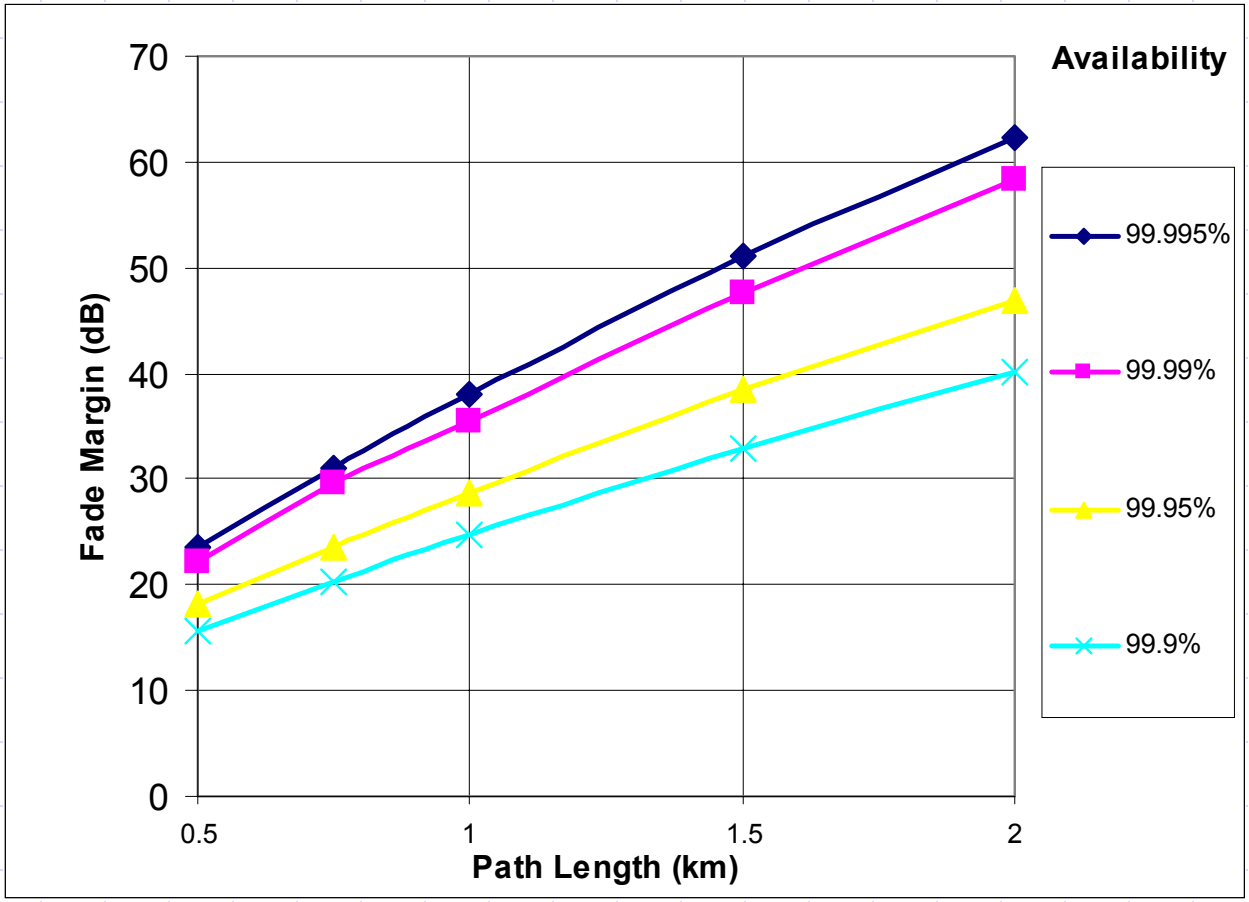
- Equipment Stability
- Building Stability

- Interference from Sun
- Laser Safety
- Network Redundancy

FSO Link Design Considerations

- Data Collected & Analysed was for 1 km FSO Link; Availability <99.99%
- Availability Increased by Reducing Path Length OR by Increasing Fade Margin
- Hence Trade-off between Availability, Fade Margin & Path Length
- Model Proposed to Extrapolated Measured Data from 1 km to Other Path Lengths

Fade Margin vs. Path Length for Various Link Availabilities



Conclusions

- FSO Can be Used for High Speed Communications in Singapore Provided They are Carefully Designed
- Heavy Rain is the Limiting Factor in Design of FSO Systems in Singapore
- Smoke Haze and Scintillation may not be a problem
- Link Availability of 99.99% Not Possible for 30dB Fade Margin if Link is 1000m Long
  - Availability of 99.95-99.99% if Link Reduced to ~800m
  - Availability of 99.9% if Link Extended to ~1200m
- Precautions Discussed Earlier To Be Taken to Maximise Link Availability

Assumptions and Uncertainties

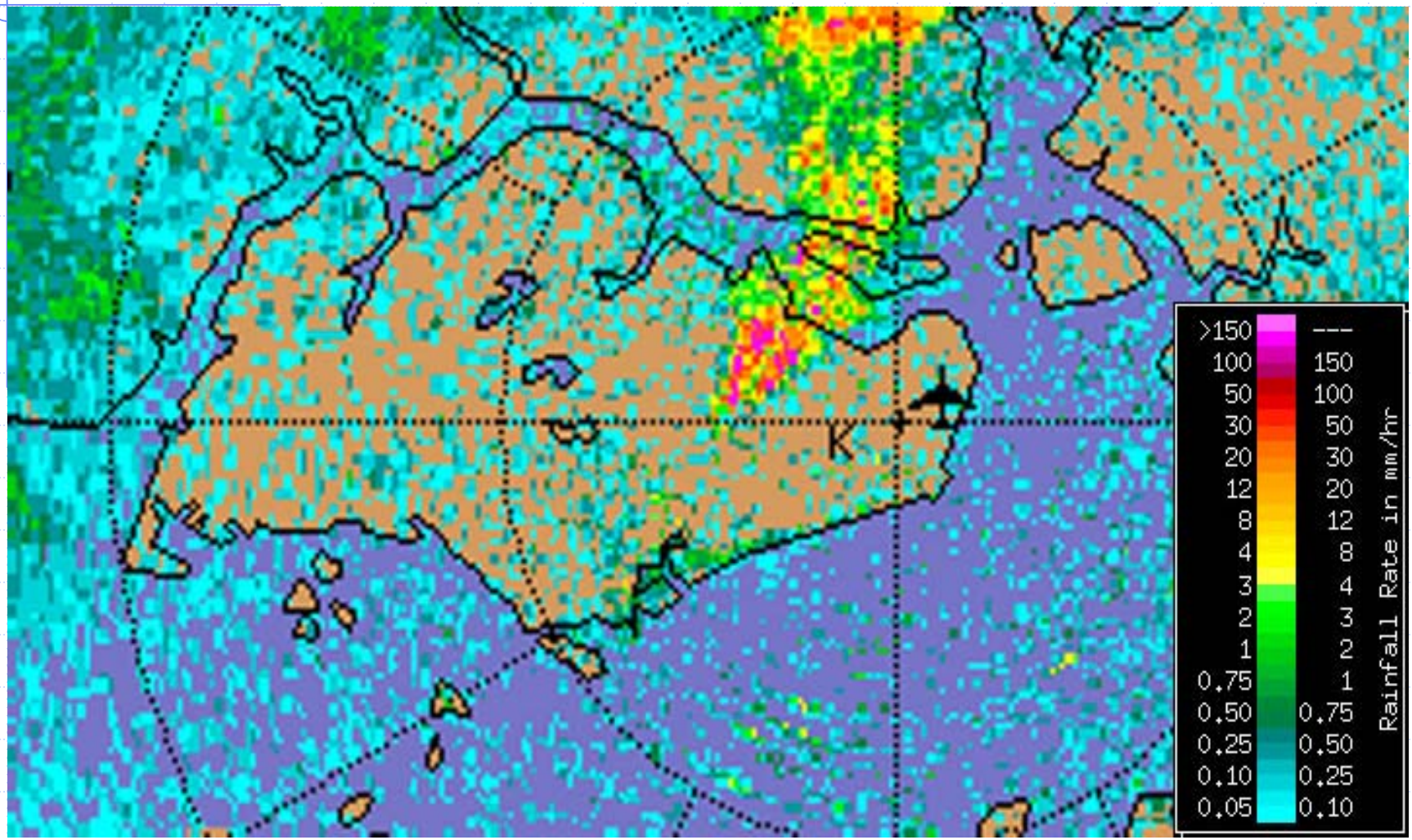
There are several limitations and uncertainties in such a trial. There were also engineering judgements made in arriving at the findings of this trial. Details are given in the full report available in the IDA.

Thank You

7. Future Work

Explore Higher End-to-End Availability Over Longer Distances By Employing Path Diversity or Mesh Network With Extended Individual FSO Path Lengths

MSS Doppler Rain Radar of Rain 2101L 8-May-02



MSS S-Band Doppler Radar 18:07:01L