Error Distribution in Optical Links

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Introduction

One of the topics discussed in the Seoul HSSG meeting was how the various proposals for striping data across multiple lanes might affect parameters such as the Mean Time To False Packet Acceptance (MTTFPA) see law_01_0907.pdf.

One of the factors that affects this issue is the extent to which errors in the received data occur with a random distribution or in bursts.

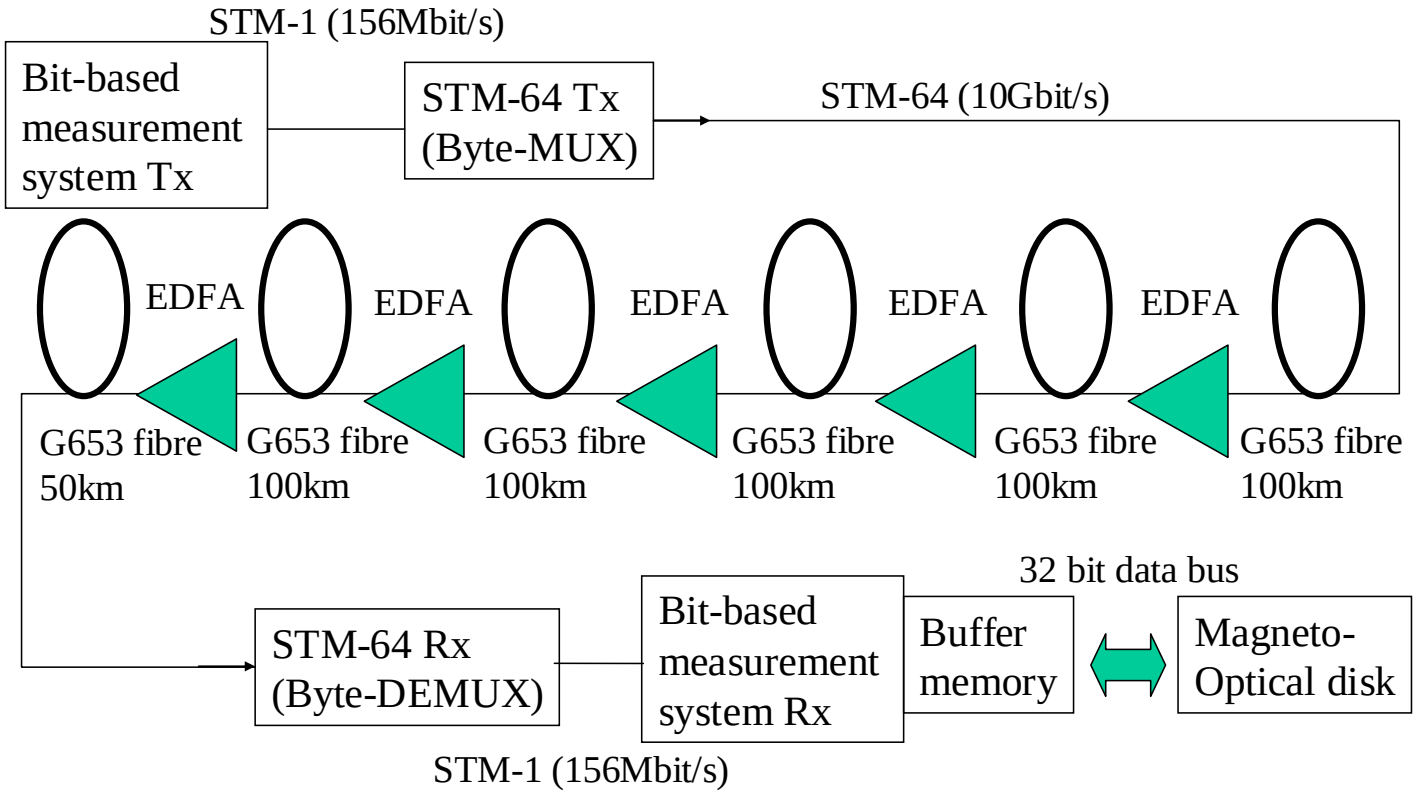
This contribution reports on some measurements in this area and identifies some factors that might affect burst error occurrence.

Measurements

NTT performed a series of measurements on the error distribution in optical links in 1999 – 2000 and reported the results in three ITU-T contributions [1-3]

- The first measurement was for a noise and chromatic dispersion limited setup (including some SPM due to +7 dBm launch) [1]
- The second was for a link containing sufficient PMD (Polarisation Mode Dispersion) to cause significant numbers of errors [2]
- The third was for a WDM system on G.653 fibre which was limited by Four Wave Mixing (FWM) [3]

NTT noise and CD limited measurement setup

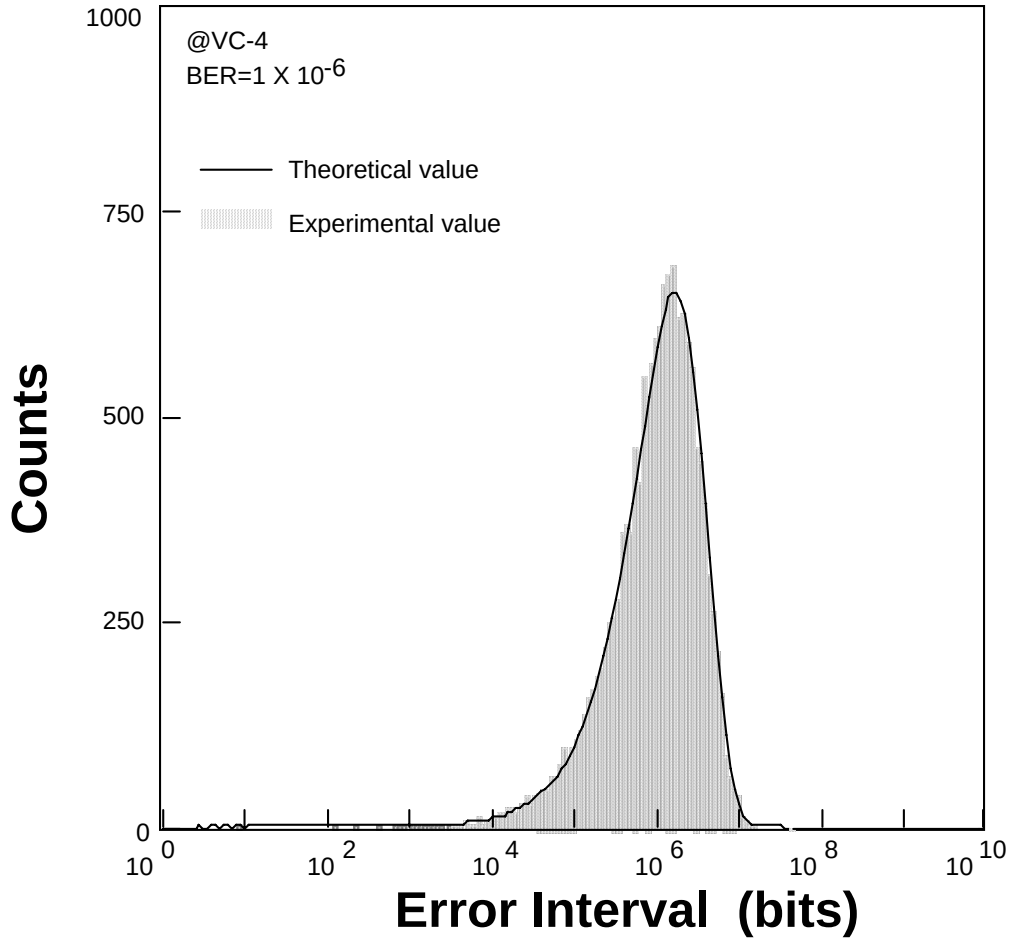


+7 dBm launch, -462 ps/nm residual dispersion

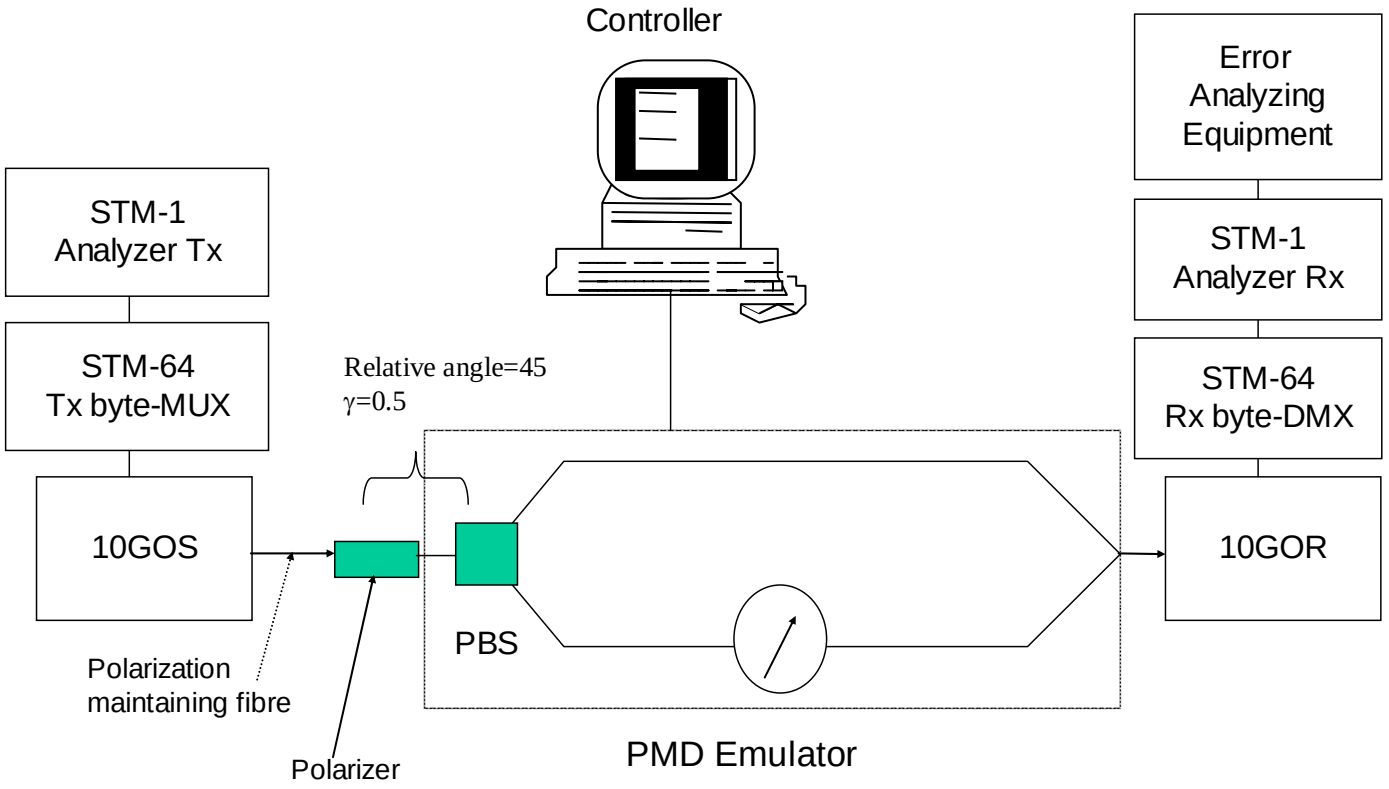
NTT noise and CD limited results

Measurement result is almost exactly Poisson (random) statistics.

Ratio of σ^2/μ is 1.0014 compared to 1.0000 for Poisson distribution.

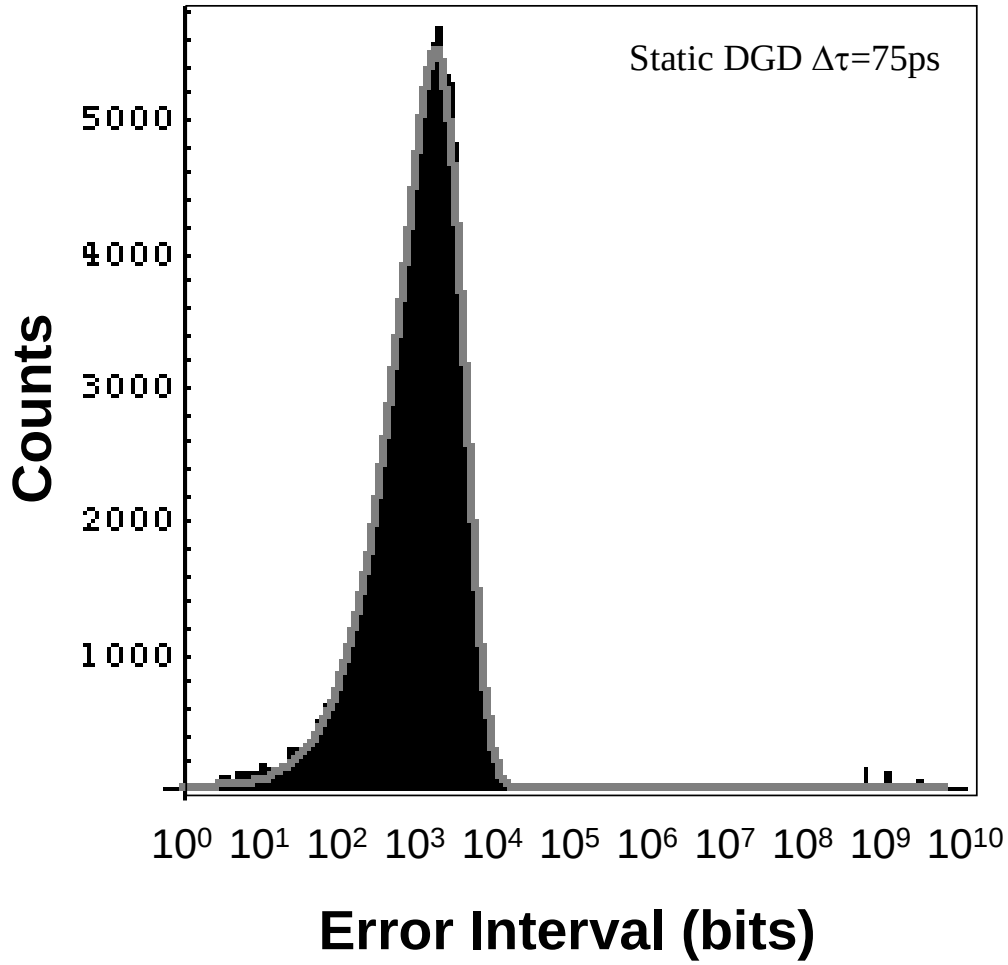


NTT PMD limited measurement setup



NTT PMD limited results - static DGD

Measurement result for static DGD is also almost exactly Poisson (random) statistics.

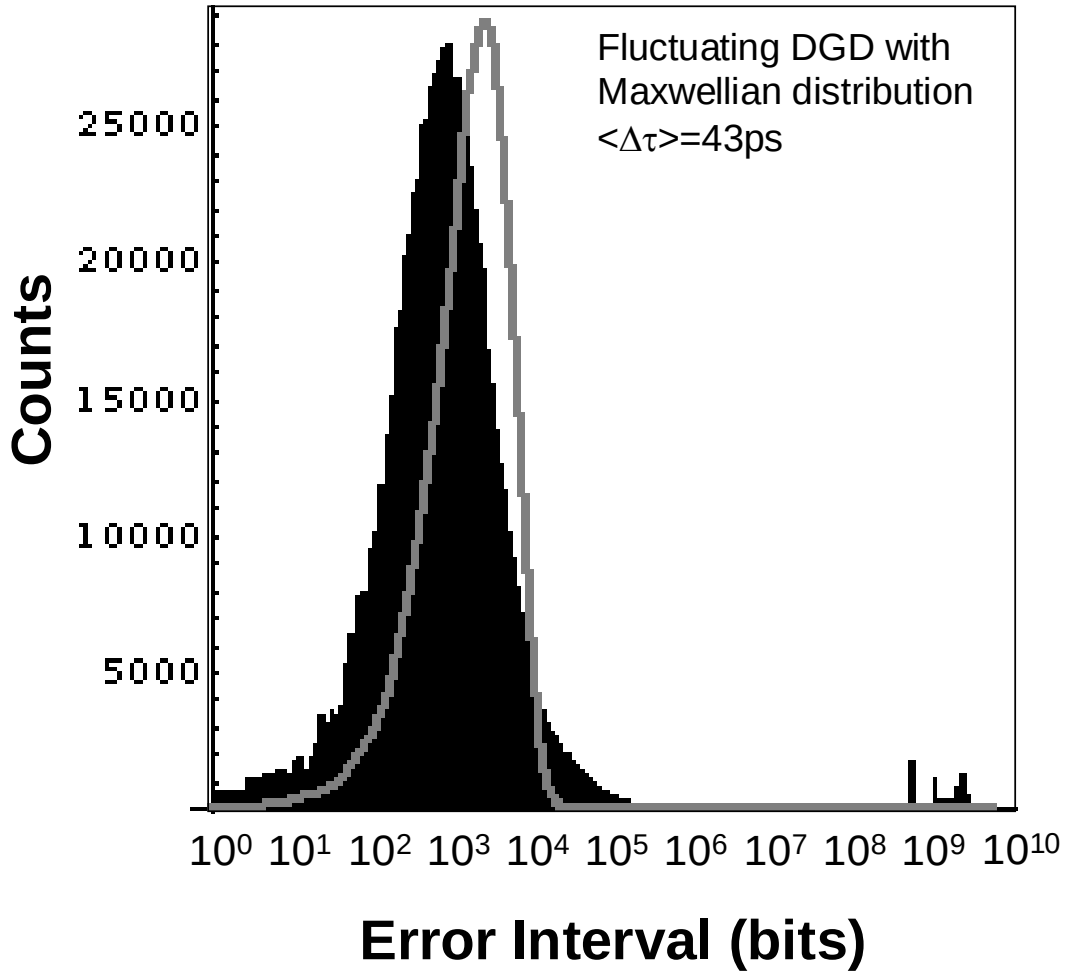


NTT PMD limited results - changing DGD

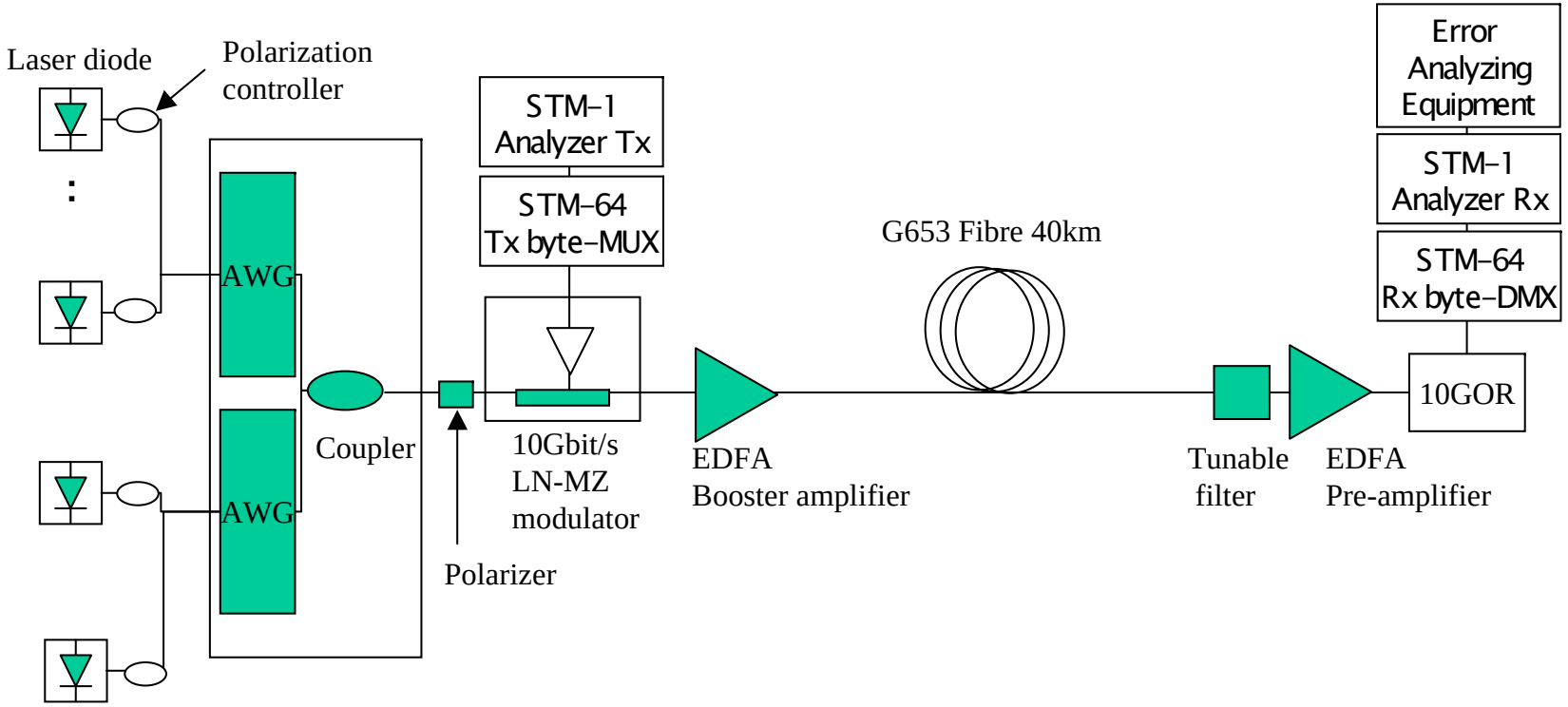
Measurement result for changing DGD.

This shows some departure from Poisson statistics, probably because it is the superposition of multiple Poisson distributions with different mean values (BERs).

Consequence – need to take account of highest BER in short time period if there is a significant penalty due to PMD



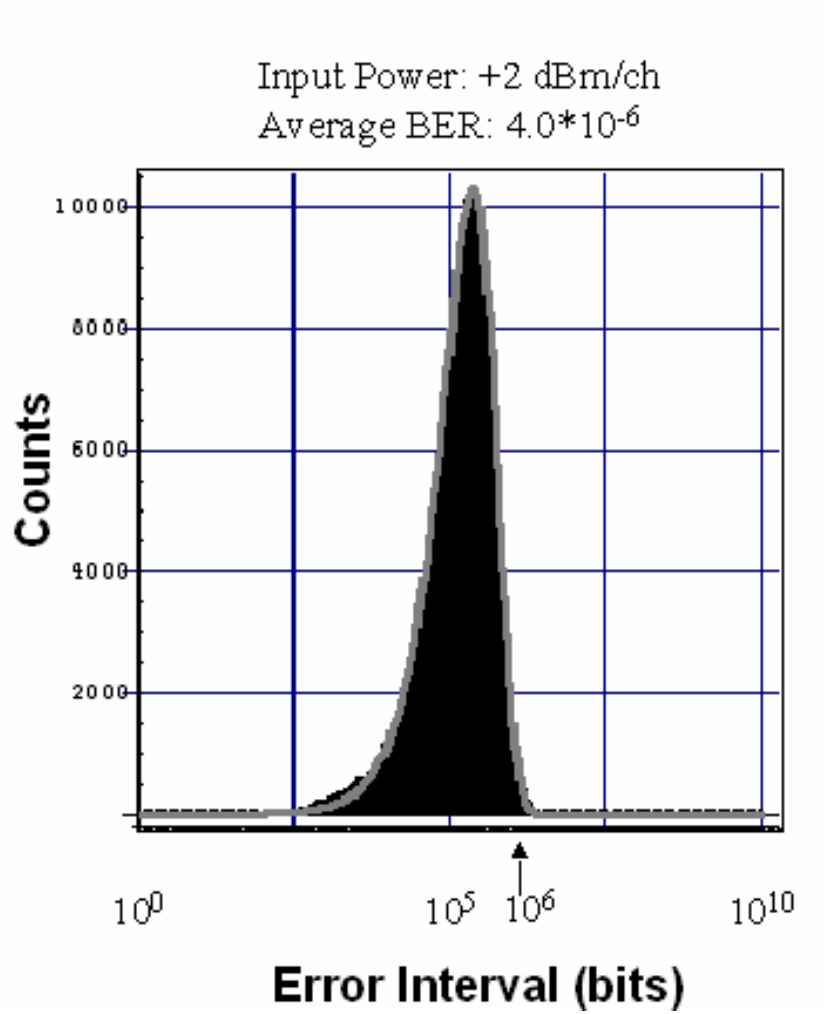
NTT FWM limited measurement setup



16 channels with 200GHz spacing

NTT FWM limited results BER 4 x 10^{-6}

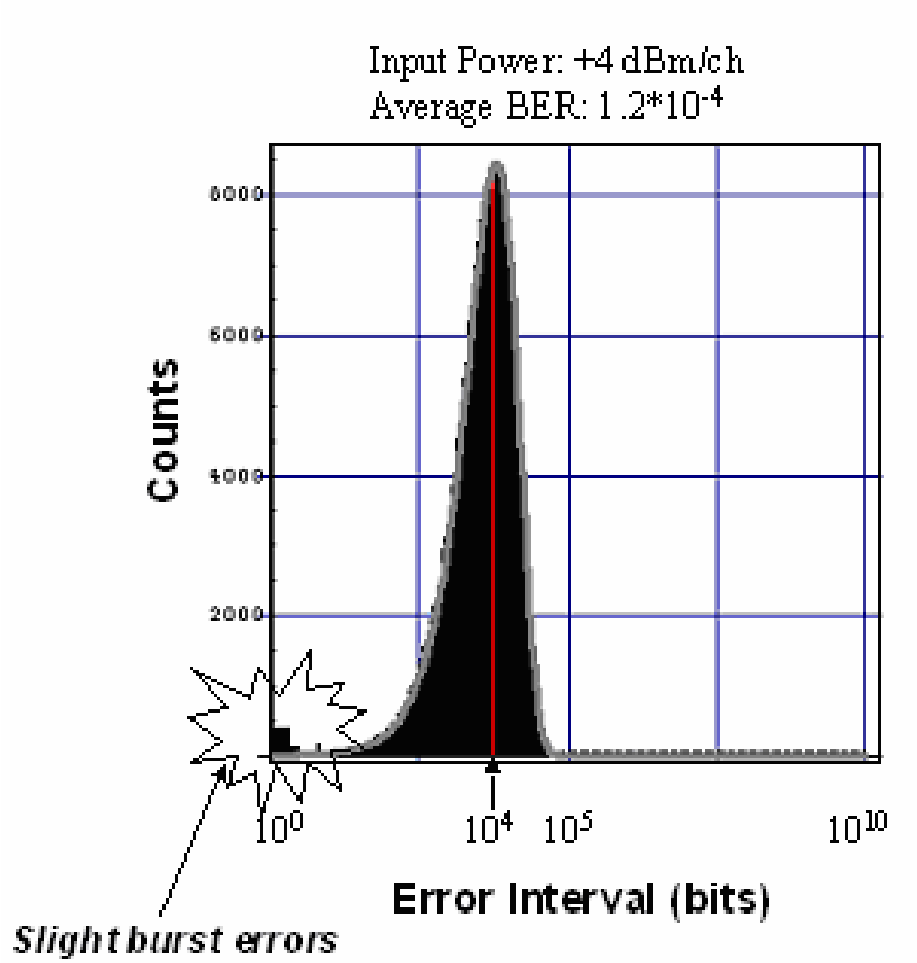
Measurement result for a BER of 4 x 10^{-6} and below is almost exactly Poisson (random) statistics.



NTT FWM limited results BER 1.2 x 10^{-4}

Measurement result for very strong FWM (a BER of 1.2 x 10^{-4}) shows some burst errors.

Unless 40 or 100 GbE are specified such that large penalties due to FWM are possible, this is not an issue.



The good news

From these results it is expected that optical links where the BER is dominated by:

- Noise
- Chromatic dispersion
- Modest Self Phase Modulation (SPM)
- Polarisation Mode Dispersion (PMD)
- All except extreme amounts of Four Wave Mixing (FWM)

Will show error distribution statistics that are approximately random.

For effects that can vary rapidly with time (e.g. PMD) care should be taken to consider the worst short term BER rather than the average.

Things that could cause non-random errors

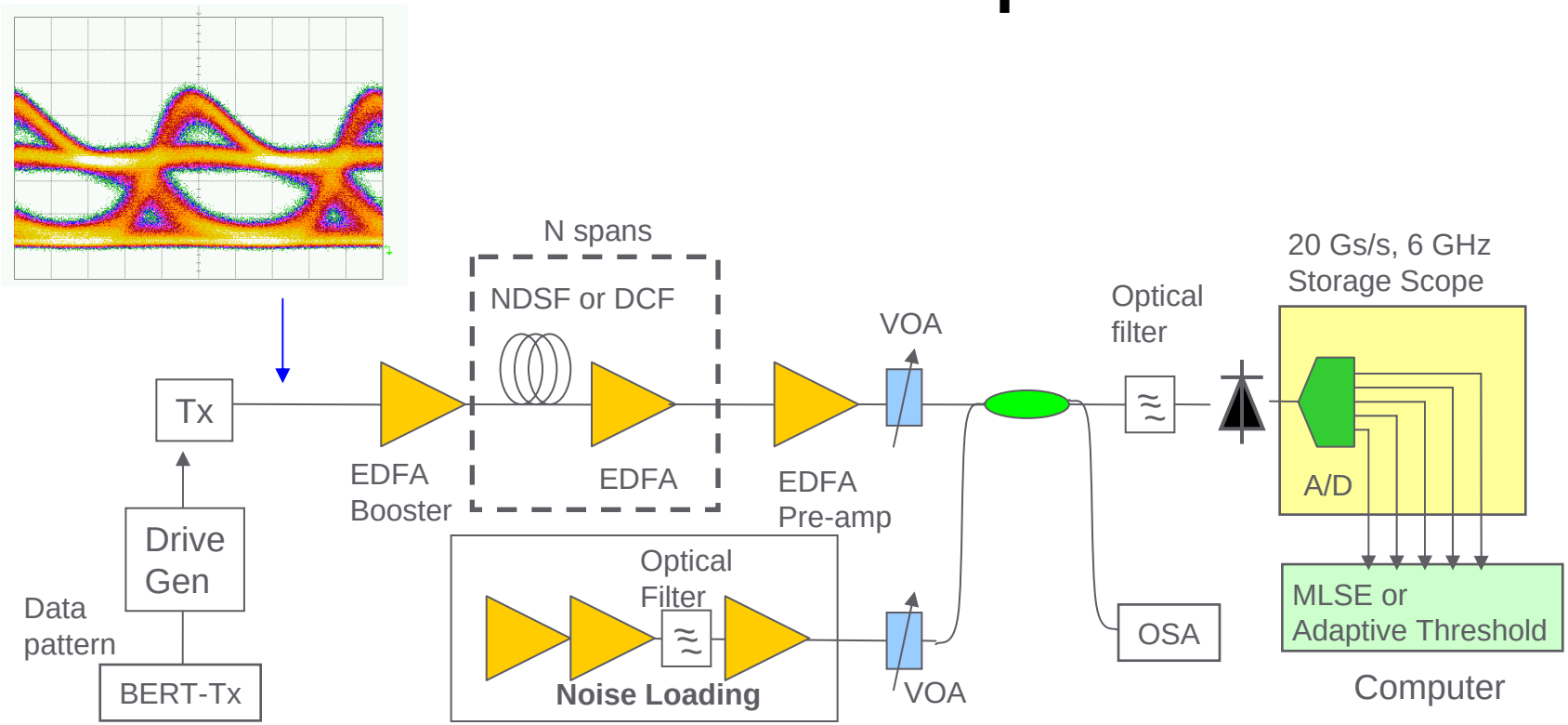
Some factors that can cause the error distribution to be non-random are:

- If FEC were used to improve the power budget then small numbers of errors in any block would be corrected. When a FEC based system does make errors, this is because there are too many errors in a block for the correction algorithm so they tend to occur with multiple errors per block. The FEC decoder, however, can generally detect uncorrectable errors and mark the block as bad.

- If the BER is limited by some form of interference (e.g. spikes getting through the power supply filtering) then this could cause bursts of errors. This is very hard to quantify.

- If EDC were part of the solution, Decision Feedback Equalisation (DFE) or MLSE may cause error bursts. (See next slides for some MLSE based EDC results).

Nortel MLSE measurement setup

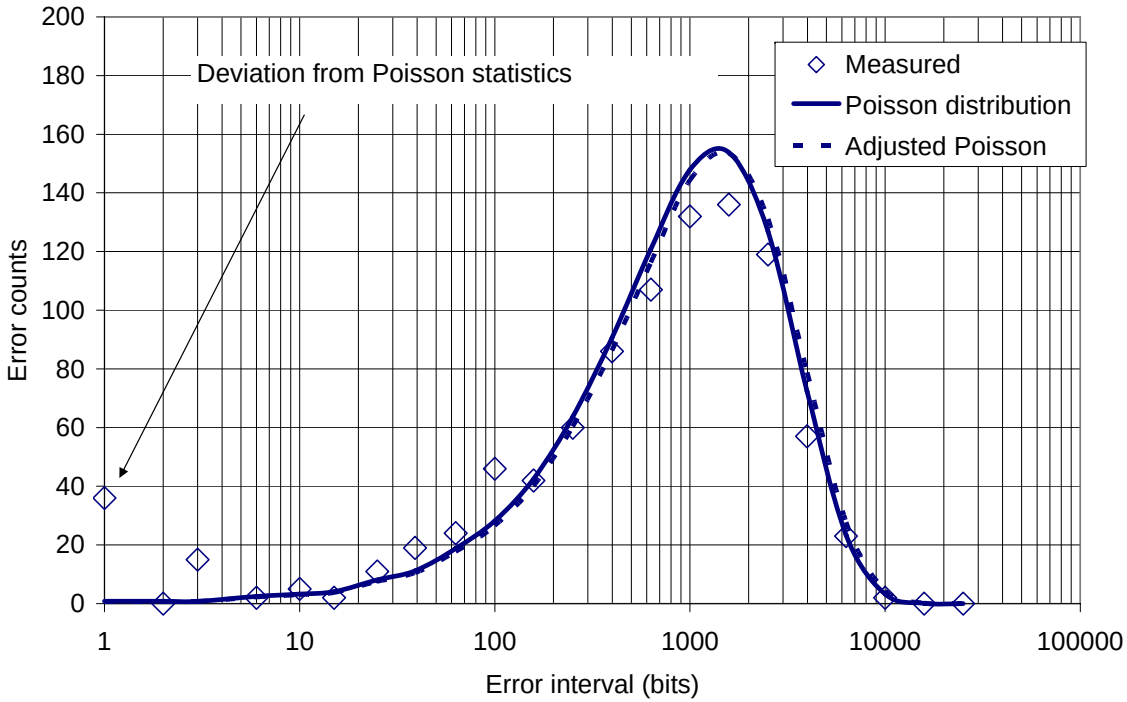


Dispersed and noise loaded 10 Gbit/s signal captured with a 20 Gs/s oscilloscope and MLSE algorithm applied via a computer [4]

Nortel MLSE results

Because MLSE looks at sequences, when an error occurs, adjacent bits have a higher error probability.

The same is true for DFE based EDC.



Conclusions

It is expected that error distribution statistics will be approximately random for optical links where the BER is dominated by:

- Noise
- Chromatic dispersion
- Modest Self Phase Modulation (SPM)
- Polarisation Mode Dispersion (PMD)
- All except extreme amounts of Four Wave Mixing (FWM)

Some factors that can cause the error distribution to be non-random are:

- FEC
- Interference
- EDC involving DFE or MLSE

References

[1] ITU-T COM15-D.485, “Error Occurrence Statistics in GVD-ASE Limited Transmission Systems”, NTT, June 1999, Geneva

[2] ITU-T COM15-D.684, “Error Occurrence Statistics In PMD Limited Optical Transmission Systems”, NTT, April 2000, Geneva

[3] ITU-T COM15-D.685, “Error Occurrence Statistics In WDM Transmission Systems Limited By Four Wave Mixing Induced Cross-talk”, NTT, April 2000, Geneva

[4] C.R.S. Fludger, J.E.A. Whiteaway, P.J. Anslow, “Electronic Equalisation for Low Cost 10 Gbit/s Directly Modulated Systems”, OFC 2004, Los Angeles, paper WM7

Thanks!

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