Ethernet in the First Mile - Power Budgets and Optics Considerations

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Topology considerations

- Point to Point - Dual Fiber
  - Reference case
  - Budget increased for 10 km link
  - Extended temperature considerations
- Point to Point - Single Fiber
  - Budget increased for 10 km link
  - Extended temperature considerations
  - Various wavelength configurations

Topology considerations (continued)

- Point to Multipoint (PON)
  - Budget increased for 10 km link
  - Extended temperature considerations
  - Various wavelength configurations

Specifications Sources

- Based on Clauses 38, 36, 52
- PMA per 36
- Signal Detect per 38 and new
- OAM (MDIO) per 52 and new
- Jitter Specifications per 38
- Jitter Methodology - best practice 38,52
- Fiber Plant Specifications - 52.12 and 52.13
- Budget Calculations and Estimates
    - Enhanced Gigabit Ethernet model
    - Interferometric losses (see Bhatt_2_0701.pdf)
    - Crosstalk penalty (see Bhatt_2_0701.pdf)
    - Optical Mux/Demux and splitter loss

Assumptions

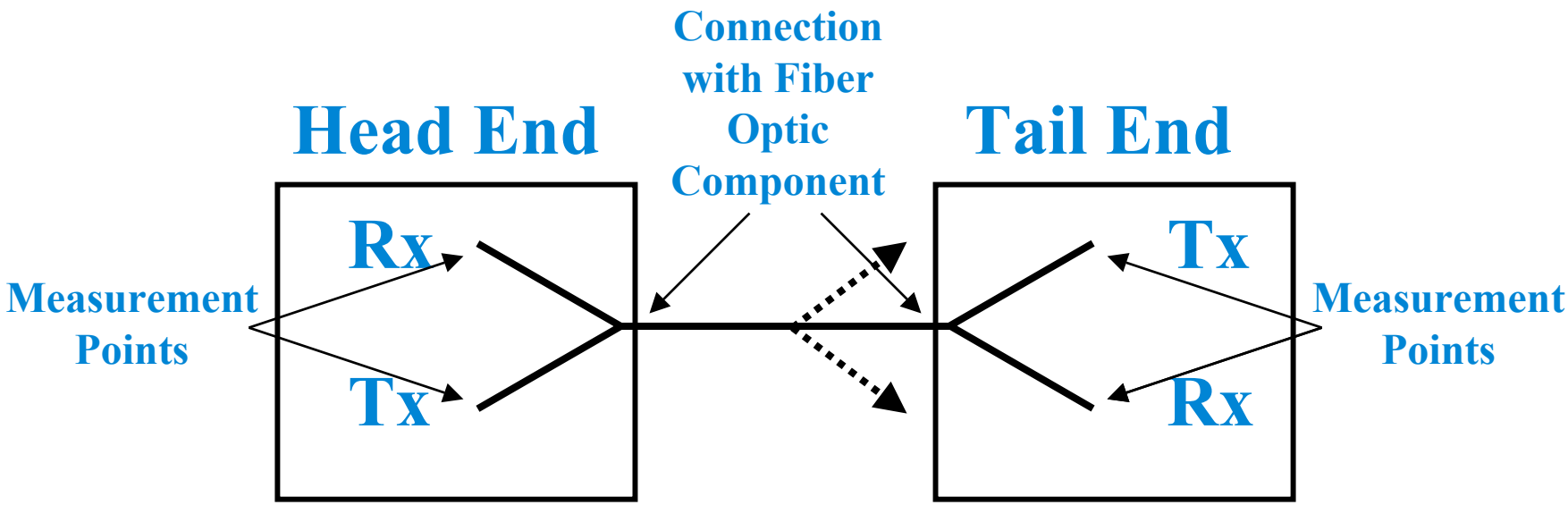
- Fiber attenuation at 1310 nm - 0.5 dB/km
- Fiber attenuation at 1550 nm - 0.3 dB/km
- Interferometric noise (needs more investigation)
  - Two wavelength windows = 0 dB
  - One wavelength window = 1.5 dB
- Crosstalk penalty (needs more investigation)
  - Two wavelength windows = 0 dB
  - One wavelength window = 1.6 dB
- Operating temperature - -40 deg C to 85 deg C
  - Component case temperature

Assumptions (con't)

- 1310 FP laser
  - k = 0.5
  - Borderline operation at extended temperature
    - Can substitute DFB or VCSEL
- 1550 nm or 1310 nm DFB
  - Spectral width = 0.2nm
- Splitter for PON
  - Star topology
  - 1:16 split - 14.3 dB loss
  - For other star topologies adjust power budgets
    - 1:32 add 3.5 dB
    - 1:8 subtract 3.2 dB

Assumptions (con't)

- Optical Mux/Demux
  - Single wavelength windows
    - 7 dB per link
  - Two wavelength windows
    - 1.5 dB per link
  - Treated as "external" components and losses for comparison



Dual Fiber, Point to Point, 1310nm - Reference Case

Dual Fiber, Point to Point, 1310 nm

- Provided as basis for comparison

Differences from Gigabit Ethernet LX

	1000 Base – LX (Clause 38)	10 km Extended Temp (–40 to 85 deg C)
Center Wavelength	1270 nm – 1360 nm	1280 nm – 1350 nm
Spectral Width	4.0 nm	2.8 nm
Power Budget	8 dB	9.6 dB
Min Launch	-11 dBm	-10.4 dBm
Sensitivity	-19 dBm	-20 dBm

Single Fiber, Point to Point

Single Fiber, Point to Point

- 10 km
- Extended temperature at subscriber
- Wavelength configurations
  - 1310 band - One Wavelength Window
  - 1310+,1310- band - Two Wavelength Windows
  - 1550 nm / 1310 nm
  - 1550 nm - One Wavelength Window
  - 1550+, 1550- nm - Two Wavelength Windows

Assumptions

- 1310 nm
  - Center wavelength - 1280 nm to 1350 nm
  - Spectral width, k
    - FP - 2.8 nm, k = 0.5
    - DFB - 0.2 nm, k = 0
  - Attenuation - 0.5 dB/km
- 1550 nm
  - Center wavelength 1550 nm
  - Spectral width - DFB - 0.2 nm
  - Attenuation - 0.3 dB/km

Determining the Power Budget

- Existing Gigabit Ethernet Optical Budget
  - ISI (Intersymbol Interference)
  - Attenuation
  - MPN (Mode Partition Noise)
  - RIN
  - Extinction Ratio
  - Connectors - 2 dB
- Budget Model Enhancements for Single Fiber
  - IN (Interferometric Noise)
  - Crosstalk Penalty
  - Passive Optical Mux/Demux

Single Fiber, Point to Point, 1310 nm, One Wavelength Window

- Downstream and Upstream
- 1310 nm FP
  - Losses from model (calculated)
    - 9.6 dB
  - Additional Losses (estimated)
    - 1.5 dB IN
    - 1.6 Crosstalk Penalty from 12 dB return loss
    - 7 dB Optical Mux/Demux
  - Power Budget - 19.7 dB

Single Fiber, Point to Point, 1310 nm, One Wavelength Window

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1310 nm
Downstream Laser Type	FP
Upstream Wavelength	1310 nm
Upstream Laser Type	FP
Downstream Power Budget	19.7 dB
Upstream Power Budget	19.7 dB
Head End Tx	-1.3 to +3.7 dBm
Head End Rx	-21 dBm
Tail End Tx	-1.3 to +3.7 dBm
Tail End Rx	-21 dBm

Single Fiber, Point to Point, 1310+ nm, 1310- nm, Two Wavelength Windows

- Downstream and Upstream
- 1310+ nm DFB, 1310- nm DFB
  - Separation greater than 1 GHz
    - IN and Crosstalk approximated as zero
  - Losses from model (calculated)
    - 8.1 dB
  - Additional Losses (estimated)
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 9.6 dB

Single Fiber, Point to Point, 1310+ nm, 1310- nm, Two Wavelength Windows

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1310+ nm
Downstream Laser Type	DFB
Upstream Wavelength	1310- nm
Upstream Laser Type	DFB
Downstream Power Budget	9.6 dB
Upstream Power Budget	9.6 dB
Head End Tx	-10.4 to -5.4 dBm
Head End Rx	-20 dBm
Tail End Tx	-10.4 to -5.4 dBm
Tail End Rx	-20 dBm

Single Fiber, Point to Point, 1550 nm, 1310 nm, Two Wavelength Windows

- Downstream
- 1550 nm DFB
  - Losses from model (calculated)
    - 6.1 dB
  - Additional Losses (estimated)
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 7.6 dB

- Upstream
- 1310 nm FP
  - Losses from model (calculated)
    - 9.6 dB
  - Additional Losses (estimated)
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 11.1 dB

Single Fiber, Point to Point, 1550 nm, 1310 nm, Two Wavelength Windows

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1550 nm
Downstream Laser Type	DFB
Upstream Wavelength	1310 nm
Upstream Laser Type	FP
Downstream Power Budget	7.6 dB
Upstream Power Budget	11.1 dB
Head End Tx	-12.4 to –7.4 dBm
Head End Rx	-21 dBm
Tail End Tx	-9.9 to –4.9 dBm
Tail End Rx	-20 dBm

Single Fiber, Point to Point, 1550 nm, One Wavelength Window

- Downstream and Upstream
- 1550 nm DFB
  - Losses from model (calculated)
    - 6.1 dB
  - Additional Losses (estimated)
    - 1.5 dB IN
    - 1.6 Crosstalk
    - 7 dB Optical Mux/Demux
  - Power Budget - 16.2 dB

Single Fiber, Point to Point, 1550 nm, One Wavelength Window

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1550 nm
Downstream Laser Type	DFB
Upstream Wavelength	1550 nm
Upstream Laser Type	DFB
Downstream Power Budget	16.2 dB
Upstream Power Budget	16.2 dB
Head End Tx	-5 dBm to 0 dBm
Head End Rx	-21.2 dBm
Tail End Tx	-5 dBm to 0 dBm
Tail End Rx	-21.2 dBm

Single Fiber, Point to Point, 1550+ nm, 1550- nm, Two Wavelength Windows

- Downstream and Upstream
- 1550 nm DFB
  - Losses from model (calculated)
    - 6.1 dB
  - Additional Losses (estimated)
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 7.6 dB

Single Fiber, Point to Point, 1550+ nm, 1550- nm, Two Wavelength Windows

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1550+ nm
Downstream Laser Type	DFB
Upstream Wavelength	1550- nm
Upstream Laser Type	DFB
Downstream Power Budget	7.6 dB
Upstream Power Budget	7.6 dB
Head End Tx	-12.4 dBm to –7.4 dBm
Head End Rx	-20 dBm
Tail End Tx	-12.4 dBm to –7.4 dBm
Tail End Rx	-20 dBm

Single Fiber, Point to Multipoint (EPON)

Point to Multipoint (EPON)

- 10 km
- 1:16 split
- Star topology
- Extended temperature at subscriber
- Wavelength Configurations
  - 1550 nm (1490 nm) DFB downstream / 1310 nm FP upstream
  - 1550 nm (1490 nm) DFB downstream / 1310 nm DFB upstream
  - 1550+ nm DFB downstream / 1550- nm DFB upstream
  - 1310+ nm DFB downstream / 1310- nm DFB upstream
- Output power and receiver sensitivities set to minimize tail end optics costs

Assumptions

- 1310 nm
  - Center Wavelength - 1280 nm to 1350 nm
  - Spectral Width, k
    - FP - 2.8 nm, k = 0.5
    - DFB - 0.2 nm, k = 0
  - Attenuation - 0.5 dB/km
- 1550 nm
  - Center Wavelength 1550 nm (1490 nm results in similar loss budgets)
  - Spectral Width - DFB - 0.2 nm
  - Attenuation - 0.3 dB/km
- Splitter 1:16 - 14.3 dB

Determining the Power Budget

- Existing Gigabit Ethernet Optical Budget
  - ISI (Intersymbol Interference)
  - Attenuation
  - MPN (Mode Partition Noise)
  - RIN
  - Extinction Ratio
  - Connectors - 2 dB
- Budget Model Enhancements for Single Fiber
  - Interferometric Noise and Crosstalk Penalty (not included, needs to be investigated)
  - Splitter
  - Passive Optical Mux/Demux

Single Fiber, Point to Multipoint, 1550 nm, 1310 nm FP

- Downstream
- 1550 nm DFB*
  - Losses from model (calculated)
    - 6.1 dB
  - Additional Losses (estimated)
    - 14.3 Splitter
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 21.9 dB

*Analysis applicable for 1490 nm

- Upstream
- 1310 nm FP
  - Losses from model (calculated)
    - 9.6 dB
  - Additional Losses (estimated)
    - 14.3 Splitter
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 25.4 dB

Single Fiber, Point to Multipoint, 1550 nm, 1310 nm FP

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1550 nm
Downstream Laser Type	DFB
Upstream Wavelength	1310 nm
Upstream Laser Type	FP
Downstream Power Budget	21.9 dB
Upstream Power Budget	25.4 dB
Head End Tx	-0.1 to +4.9 dBm
Head End Rx	-30 dBm
Tail End Tx	-4.6 to +0.4dBm
Tail End Rx	-22 dBm

Single Fiber, Point to Multipoint, 1550 nm, 1310 nm DFB

- Downstream
- 1550 nm DFB
  - Losses from model (calculated)
    - 6.1 dB
  - Additional Losses (estimated)
    - 14.3 Splitter
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 21.9 dB Downstream

- Upstream
- 1310 nm DFB
  - Losses from model (calculated)
    - 8.1 dB
  - Additional Losses (estimated)
    - 14.3 Splitter
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 23.9 dB

*Analysis applicable for 1490 nm

Single Fiber, Point to Multipoint , 1550 nm, 1310 nm DFB

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1550 nm
Downstream Laser Type	DFB
Upstream Wavelength	1310 nm
Upstream Laser Type	DFB
Downstream Power Budget	21.9 dB
Upstream Power Budget	23.9 dB
Head End Tx	-0.1 to +4.9 dBm
Head End Rx	-30 dBm
Tail End Tx	-6.1 to –1.1 dBm
Tail End Rx	-22 dBm

Single Fiber, Point to Multipoint , 1550+ nm, 1550- nm

- Downstream and Upstream
- 1550 nm DFB
  - Losses from model (calculated)
    - 6.1 dB
  - Additional Losses (estimated)
    - 14.3 Splitter
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 21.9 dB Downstream

Single Fiber, Point to Multipoint , 1550+ nm, 1550- nm

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1550+ nm
Downstream Laser Type	DFB
Upstream Wavelength	1550- nm
Upstream Laser Type	DFB
Downstream Power Budget	21.9 dB
Upstream Power Budget	21.9 dB
Head End Tx	-0.1 to +4.9 dBm
Head End Rx	-30 dBm
Tail End Tx	-8.1 to –3.1 dBm
Tail End Rx	-22 dBm

Single Fiber, Point to Multipoint , 1310+ nm, 1310- nm DFB

- Downstream and Upstream
- 1310 nm DFB
  - Losses from model (calculated)
    - 8.1 dB
  - Additional Losses (estimated)
    - 14.3 Splitter
    - 1.5 dB Optical Mux/Demux
  - Power Budget - 23.9 dB

Single Fiber, Point to Multipoint , 1310+ nm, 1310- nm DFB

Type of link	Point to Point
# of Fibers	1
Downstream Wavelength	1310+ nm
Downstream Laser Type	DFB
Upstream Wavelength	1310- nm
Upstream Laser Type	DFB
Downstream Power Budget	23.9 dB
Upstream Power Budget	23.9 dB
Head End Tx	+1.9 to +6.9 dBm
Head End Rx	-30 dBm
Tail End Tx	-6.1 to –1.1 dBm
Tail End Rx	-22 dBm

Summary Table

Type of Link	Dual Fiber, P2P	Single Fiber, P2P, 1310 nm	Single Fiber, P2P, 1310+nm, 1310-nm	Single Fiber, P2P, 1550 nm, 1310 nm	Single Fiber, P2P, 1550 nm, 1550 nm	Single Fiber, P2P, 1550+nm, 1550-nm	Single Fiber, P2MP, 1550 nm, 1310 nm FP	Single Fiber, P2MP, 1550 nm, 1310 nm DFB	Single Fiber, P2MP, 1550+nm, 1550-nm	Single Fiber, P2MP, 1310+nm, 1310-nm
# of Fibers	2	1	1	1	1	1	1	1	1	1
Downstream Wavelength	1310	1310	1310+	1550	1550	1550+	1550	1550	1550+	1310+
Downstream Laser Type	FP	FP	DFB	DFB	DFB	DFB	DFB	DFB	DFB	DFB
Upstream Wavelength	1310	1310	1310-	1310	1550	1550-	1310	1310	1550-	1310-
Upstream Laser Type	FP	FP	DFB	FP	DFB	DFB	FP	DFB	DFB	DFB
Downstream Power Budget (dB)	9.6	19.7	9.6	7.6	16.2	7.6	21.9	21.9	21.9	23.9
Upstream Power Budget (dB)	9.6	19.7	9.6	11.1	16.2	7.6	25.4	23.9	21.9	23.9
Head End Min Tx (dBm)	-10.4	-1.3	-10.4	-12.4	-5	-12.4	-0.1	-0.1	-0.1	1.9
Head End Rx (dBm)	-20	-21	-20	-21	-21.2	-20	-30	-30	-30	-30
Tail End Min Tx (dBm)	-10.4	-1.3	-10.4	-9.9	-5	-12.4	-4.6	-6.1	-8.1	-6.1
Tail End Rx (dBm)	-20	-21	-20	-20	-21.2	-20	-22	-22	-22	-22

Conclusions

- All calculations based on reference case of extended 1000Base-LX
- Single Fiber Point to Point and Point to Multipoint (EPON) Technically Feasible
- Optical Components
  - Extended temperature at subscriber
  - For EPON - lower cost optics at tail end
  - No technology breakthroughs required
    - 1310 nm FP and DFB lasers
    - 1550 nm DFB lasers
    - 1310 nm or 1550 nm VCSELs
    - Standard and high quality PINs
    - Avalanche Photodiodes
    - Passive components