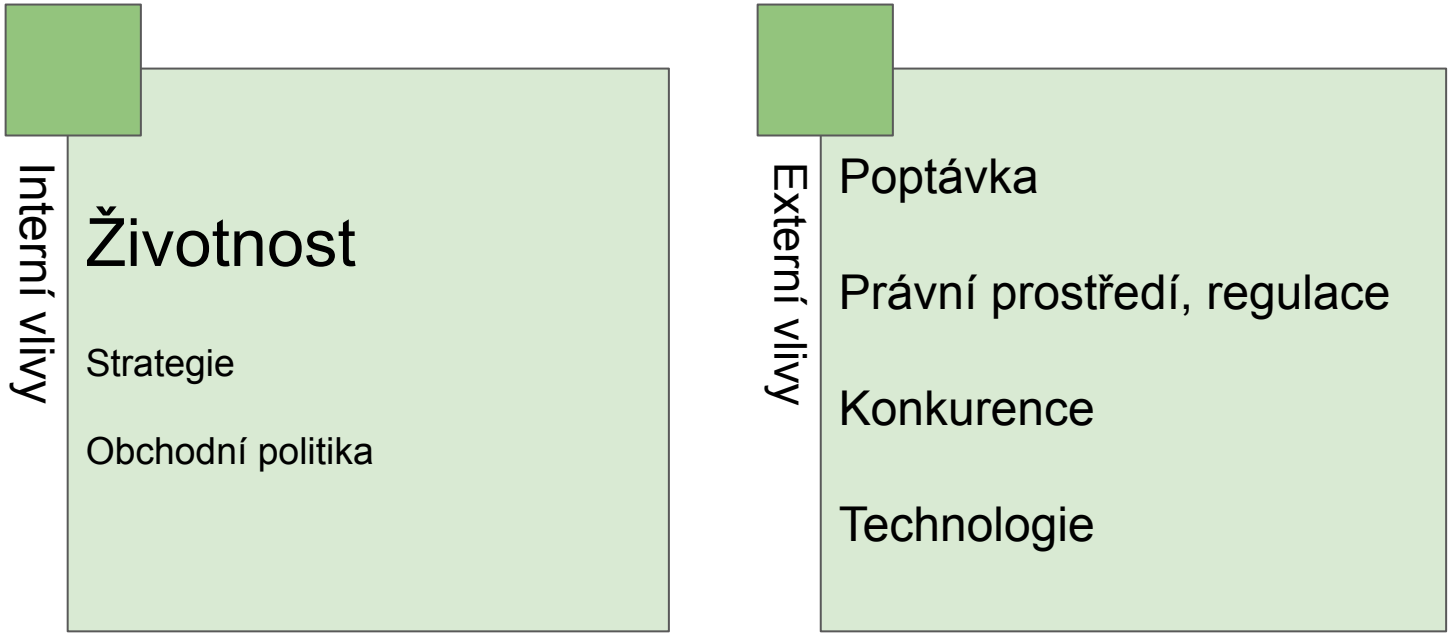
Úskalí migrace na vysokorychlostní optické standardy

Štěpán Beneš

TL;DR

Proč danou tématiku řešit ?



Jakou rychlost budu potřebovat ?

- Globální IP traffic vzrostl od roku 2016 (93 ExaB/měs) do roku 2021 3x (271 ExaB/měs)
- ve špičkách narostl dokonce 5x

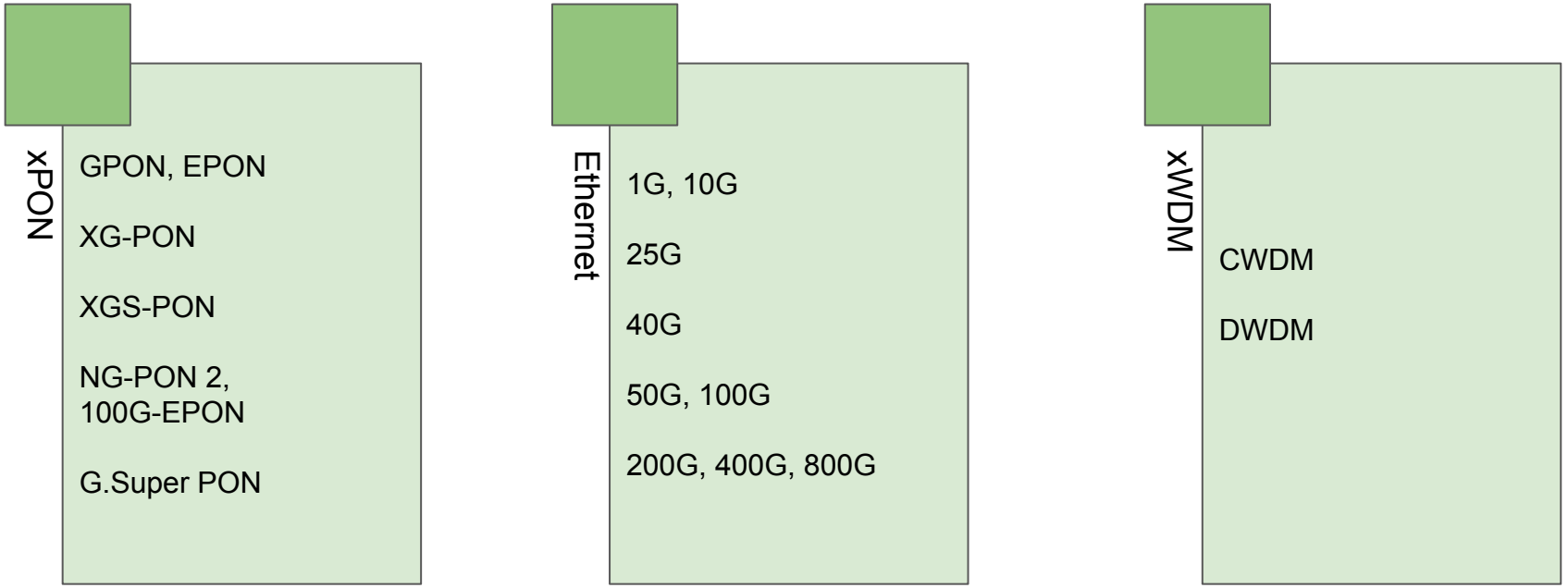
- roste náročnost jednotlivých aplikací
  - (u)HD streaming
  - (u)HD VoD (10+ Mbps)
- objevují se nové
  - cloud gaming (30+ Mbps)
  - Immersive VR (350 Mbps)

- CoVID
  - změna chování
  - virtuální office

Figure 13. Significant demand for bandwidth and video in the connected home of the future

Source: Cisco Annual Internet Report, 2018–2023

Technologický vývoj

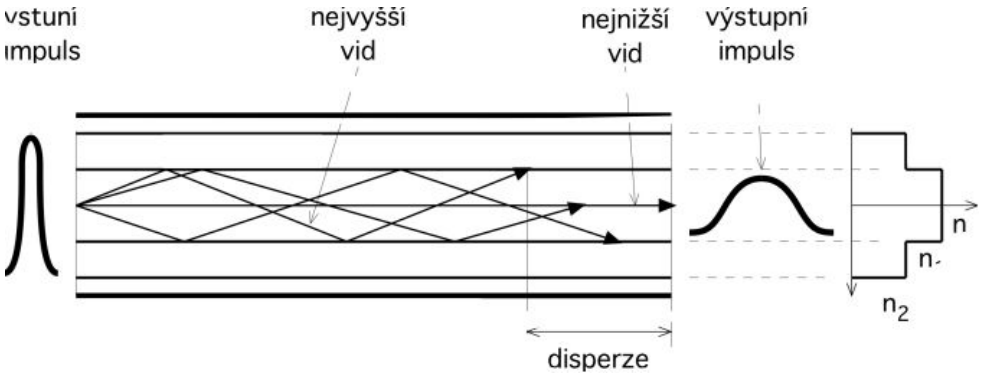


Klíčové parametry optických vláken

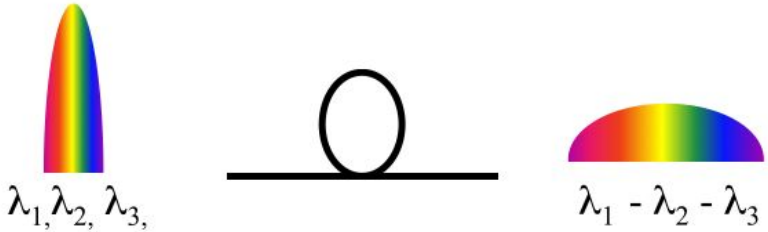
- šířka pásma [MHz . km];
- numerická apertura;
- disperze;
- útlum [dB];
- ztráty na makroskopických neregularitách;
- minimální poloměr ohybu;
- obsah OH;
- MDF

Klíčové parametry optických vláken - disperze

- vidová disperze

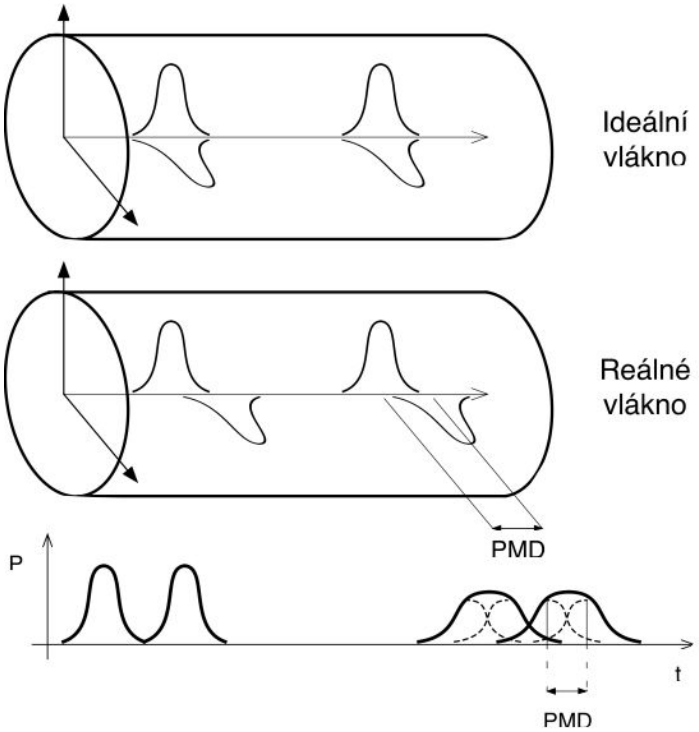


- chromatická disperze
  v,n = f(λ)



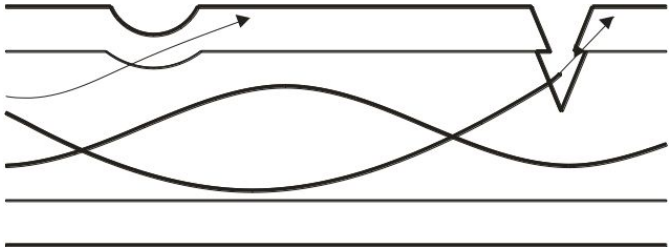
Klíčové parametry optických vláken - disperze

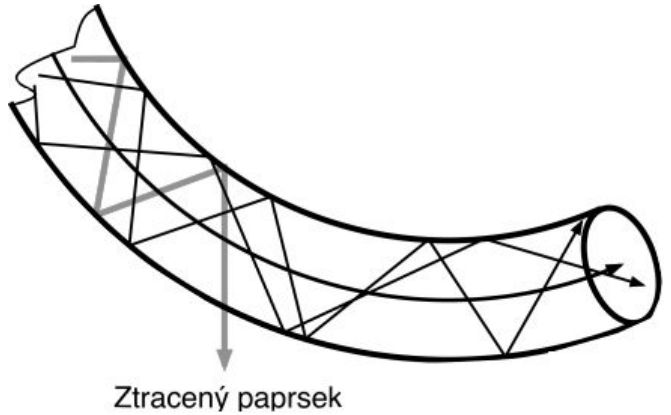
- polarizační vidová disperze PMD



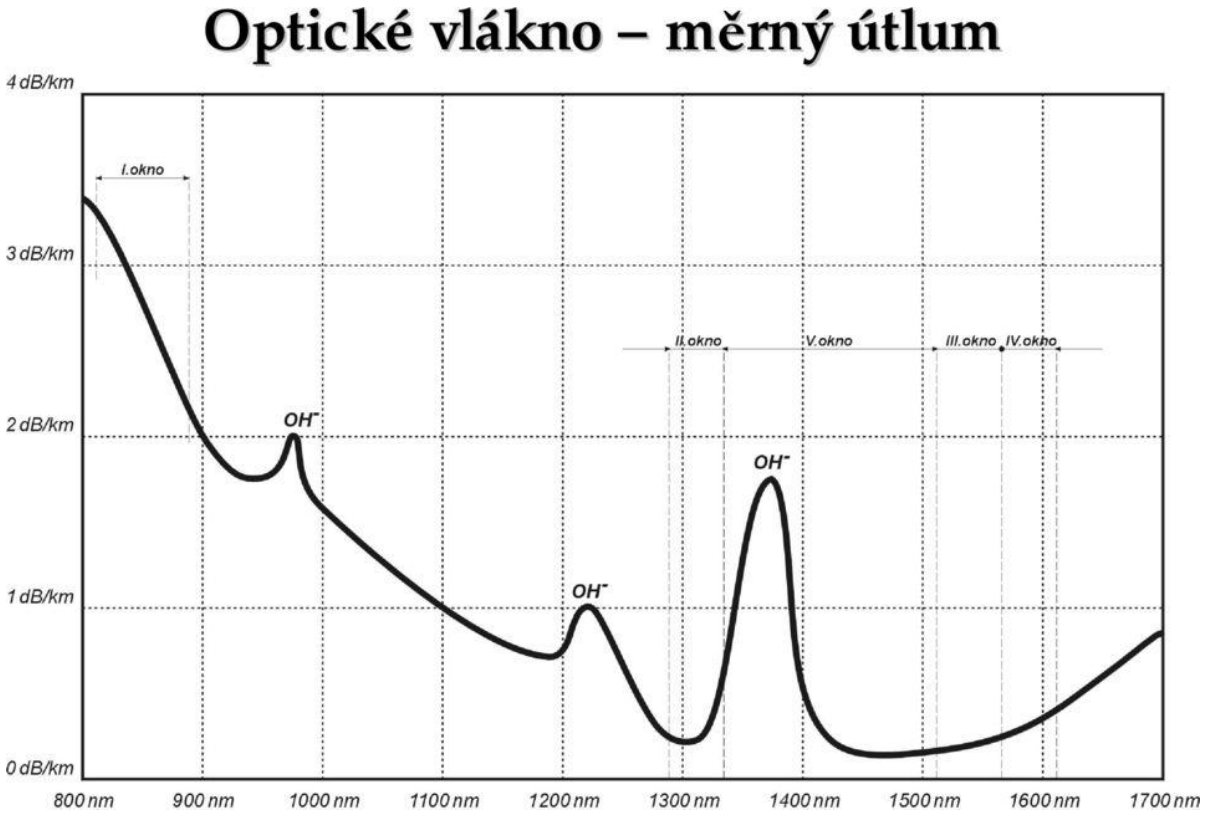
Klíčové parametry optických vláken - útlum

- u(λ)=10*log(P1/P2)[dB]
- příčiny
  - útlum absorpcí
    - vlastní
    - nevlastní - ionty kovů, OH-
  - Rayleighův rozptyl
  - rozptyl na makroskopických neregularitách
  - rozptyl na mikroohybech
  - rozptyl na makroohybech a jiných deformací



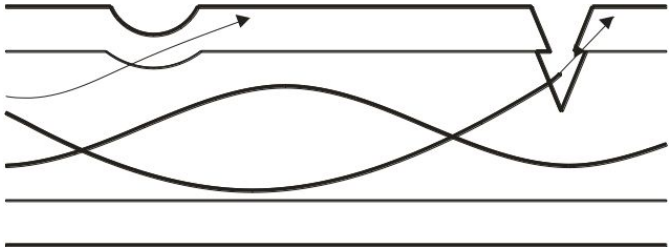


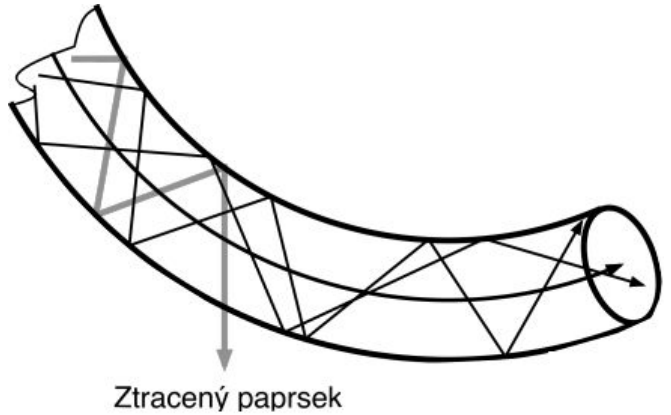
Klíčové parametry optických vláken - útlum



Klíčové parametry optických vláken - útlum

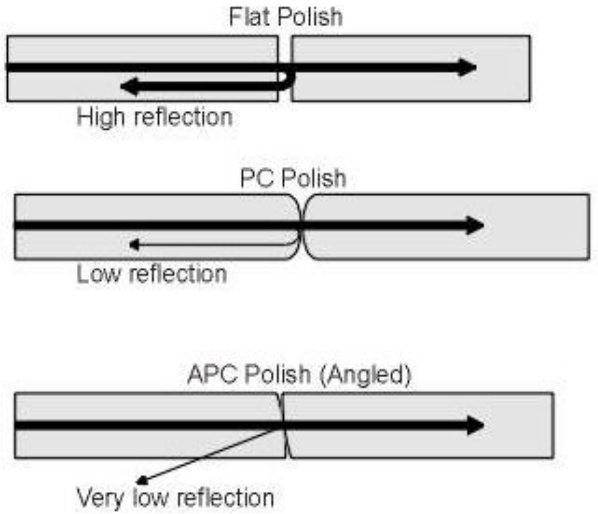
- u(λ)=10*log(P1/P2)[dB]
- příčiny
  - útlum absorpcí
    - vlastní
    - nevlastní - ion kovů, OH-
  - Rayleighův rozptyl
  - rozptyl na makroskopických neregularitách
  - rozptyl na mikroohybech
  - rozptyl na makroohybech a jiných deformací





Další parametry ODN

- reflektance, odrazivost
- ORL - útlum odraz



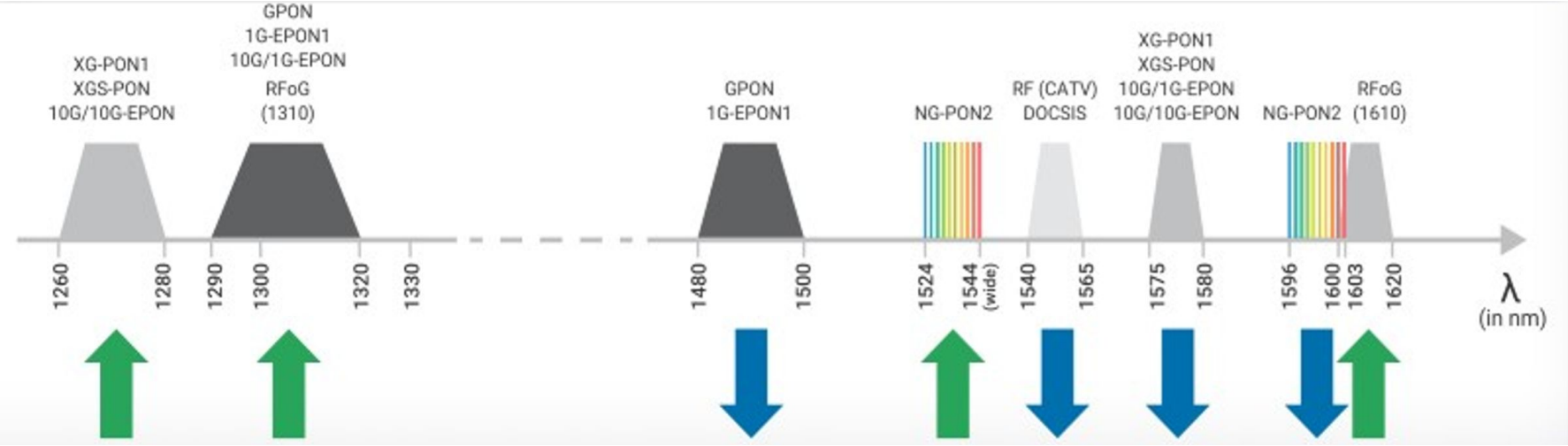
Koexistence xPON

TYP	**GPON** ITU G.984	**XGPON** ITU G.987	**XGSPON** ITU G.9807
Freq	Downstream: 1480 ~ 1500 nm Upstream: 1290 ~ 1330 nm	Downstream: 1575 ~ 1580 nm Upstream: 1260 ~ 1280 nm	Downstream: 1575 ~ 1580 nm Upstream: 1260 ~ 1280 nm
Split ratio	1:64 (1:128)	1:256	1:256
Classes	A : 5-20 dB B : 10-25 dB C : 15-30 dB B+: 13-28 dB C+: 17-32 dB	14 – 29 dB 16 – 31 dB 18 – 33 dB 20 – 35 dB	14 – 29 dB 16 – 31 dB 18 – 33 dB 20 – 35 dB
Max. distance	60km	100km	100km
Mod. speed	Downstream: 2.488 Gbit/s Upstream: 1.244 Gbit/s	Downstream: 9.953 Gbit/s Upstream: 2.488 Gbit/s	Downstream: 9.953 Gbit/s Upstream: 9.953 Gbit/s

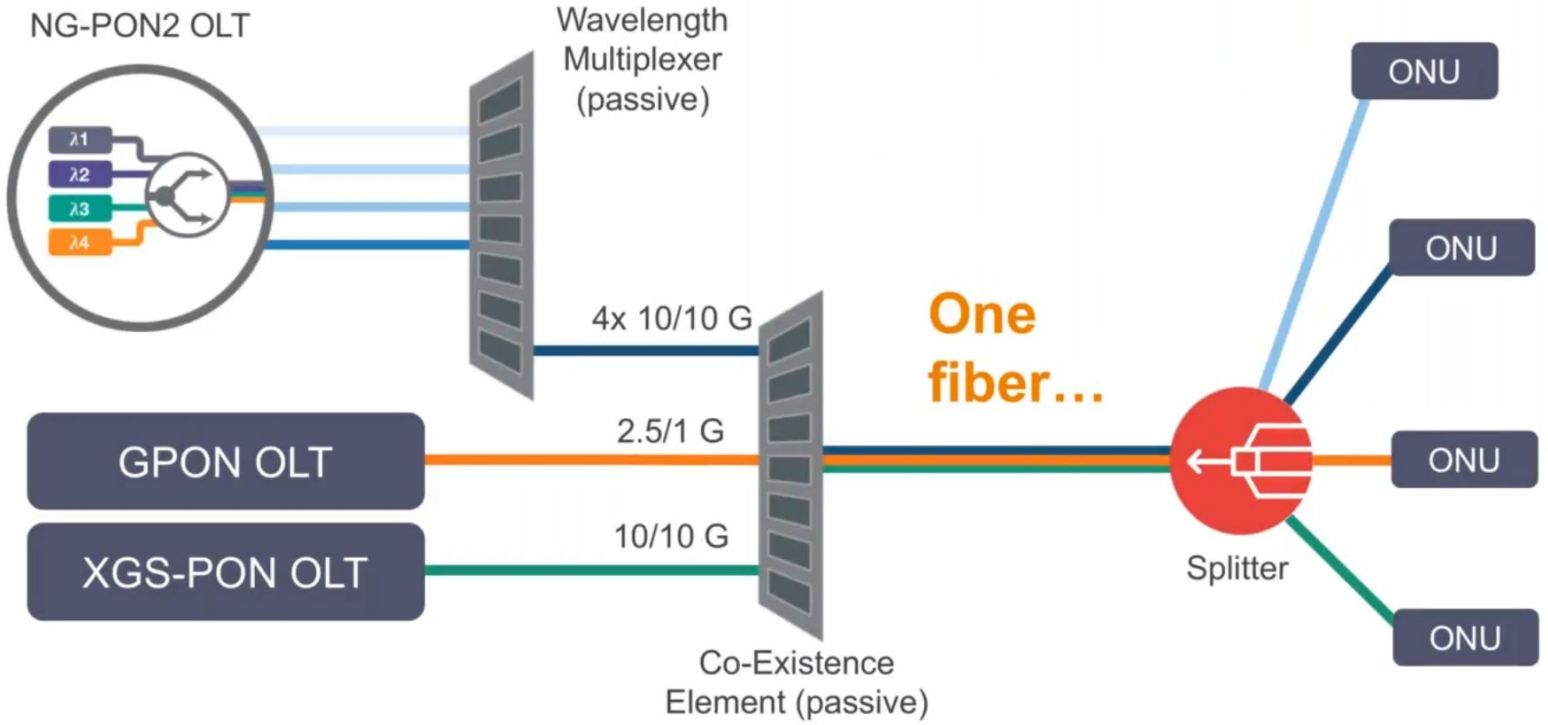
Koexistence xPON

XGS-PON & GPON Transceiver Information	
Type	Class C+
Operating Wavelength	GPON Channel: Tx:1490nm Rx:1310nm XGS-PON Channel: Tx: 1577nm Rx:1270nm
Encapsulation Type	SFP+
Port Rate	GPON Channel: Tx: 2.488Gbit/s Rx: 1.244Gbit/s XGS-PON Channel: Tx: 9.953Gbit/s Rx: 9.953/2.488Gbit/s
Minimum Output Optical Power	GPON Channel: 3dBm XGS-PON Channel: 5dBm
Maximum Output Optical Power	GPON Channel: 7dBm XGS-PON Channel: 8dBm
Maximum Receiver Sensitivity	GPON Channel:-32dBm XG-PON Channel: -30.5dBm XGS-PON Channel:-29dBm
Optical Connector Type	SC
Optical Fiber Type	Single-mode
Overload Optical Power	GPON Channel:-12dBm XG-PON Channel: -10dBm XGS-PON Channel: -8dBm
Extinction Ratio	8.2dB

Koexistence xPON



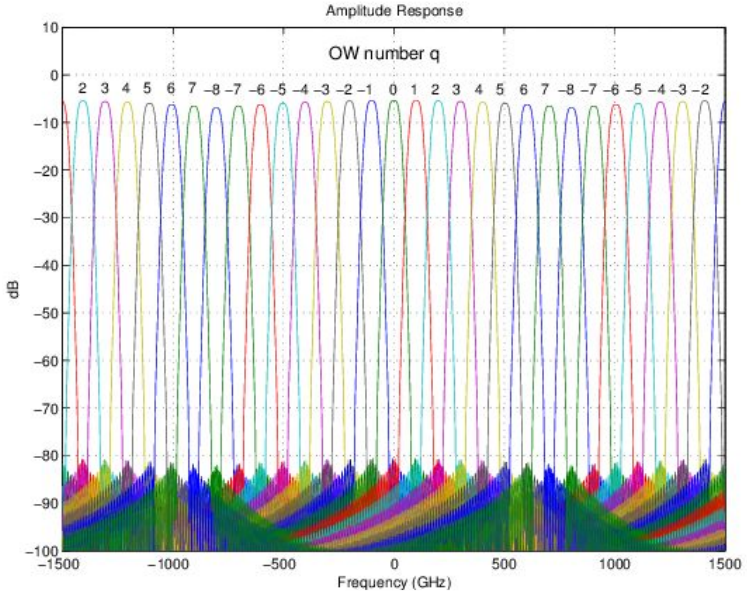
Koexistence xPON



Koexistence xPON

Super PON

AWG Splitter - λ router



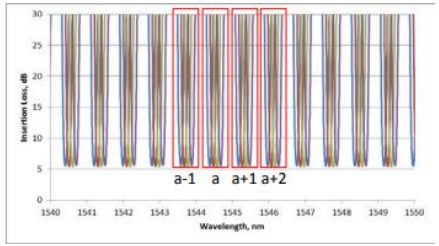
$$\lambda_c = \frac{n_c \times \Delta L}{m}$$

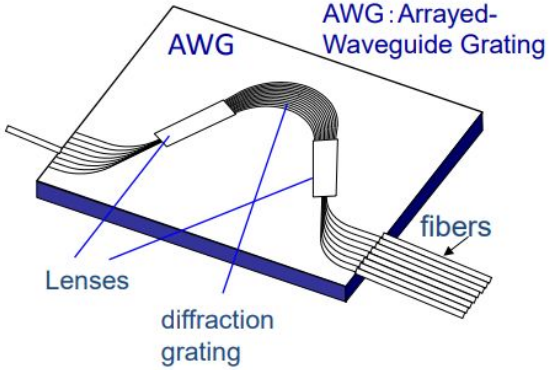
$m = a-1, \quad a, \quad a+1, \quad a+2 \cdots$

ΔL: Waveguide path length difference
m: Diffraction order
FSR: Free Spectral Range

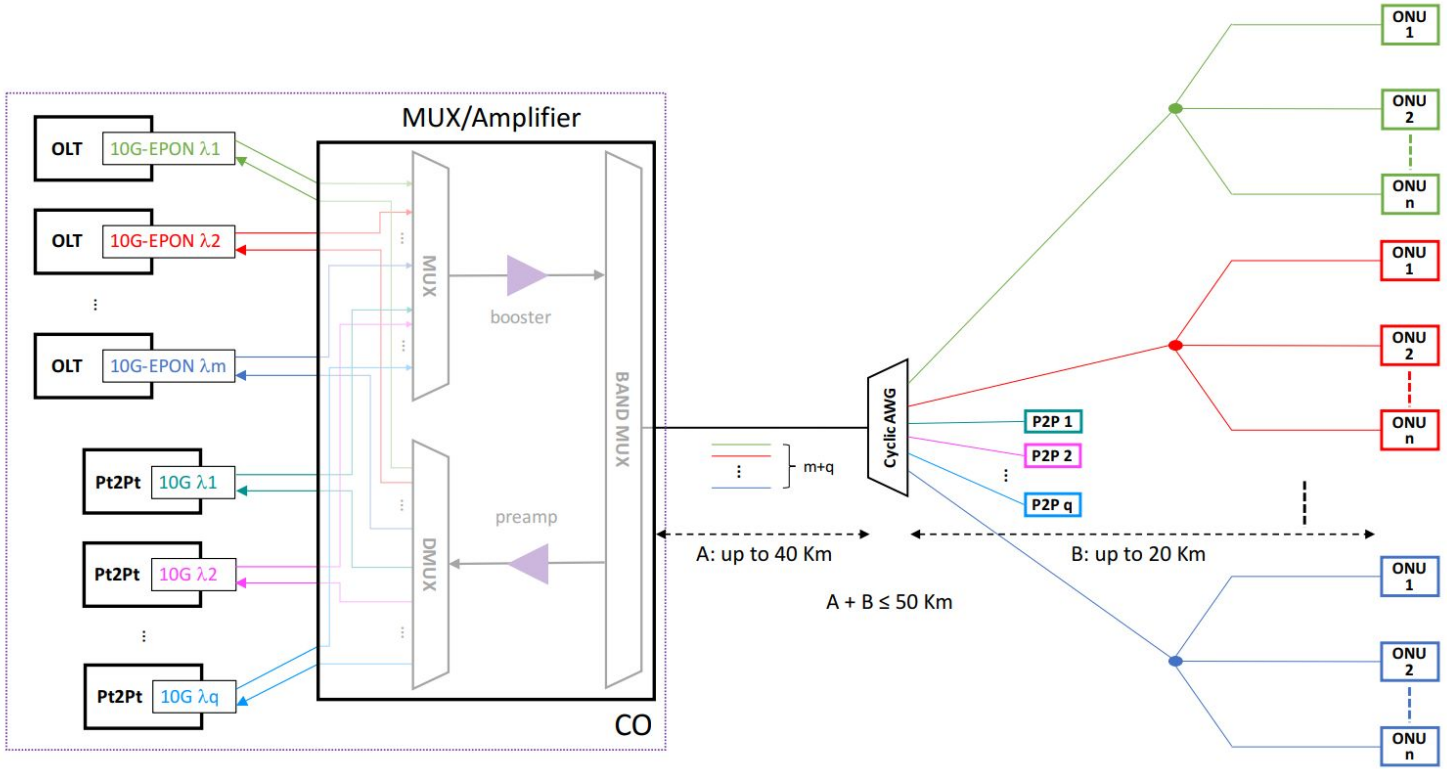
$$FSR = N\frac{\lambda_c}{m}$$

Example Cyclic AWG Spectrum

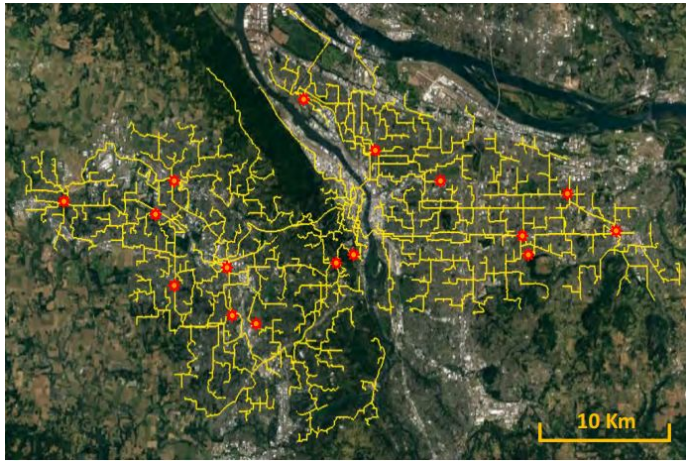


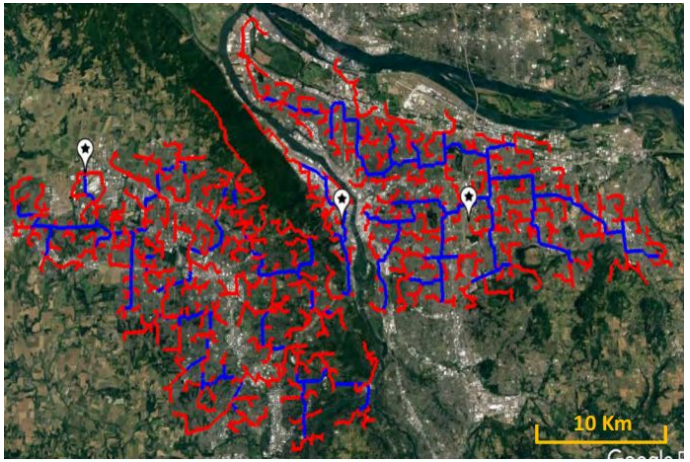


Super PON


MUX/Amplifier
OLT
10G-EPON λ1
OLT
10G-EPON λ2
OLT
10G-EPON λm
Pt2Pt
10G λ1
Pt2Pt
10G λ2
Pt2Pt
10G λq
MUX
DMUX
booster
preamp
BAND MUX
CO
m+q
Cyclic AWG
P2P 1
P2P 2
P2P q
A: up to 40 Km
B: up to 20 Km
A + B ≤ 50 Km
ONU 1
ONU 2
ONU n
ONU 1
ONU 2
ONU n
ONU 1
ONU 2
ONU n

Super PON



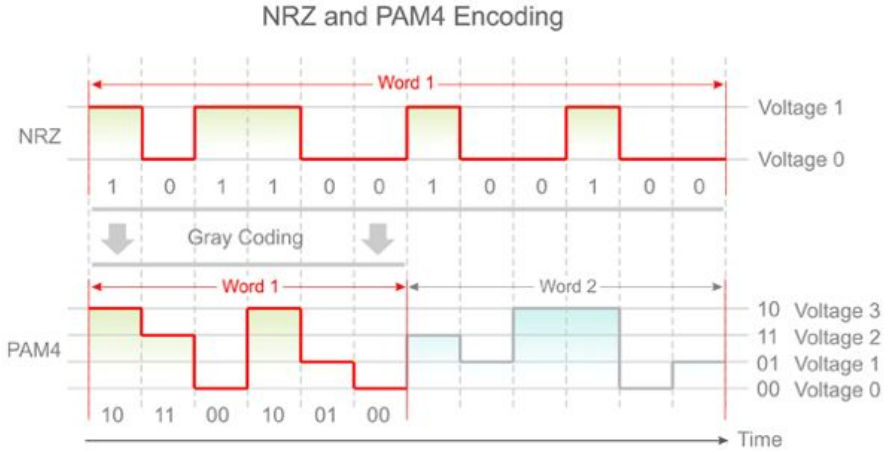


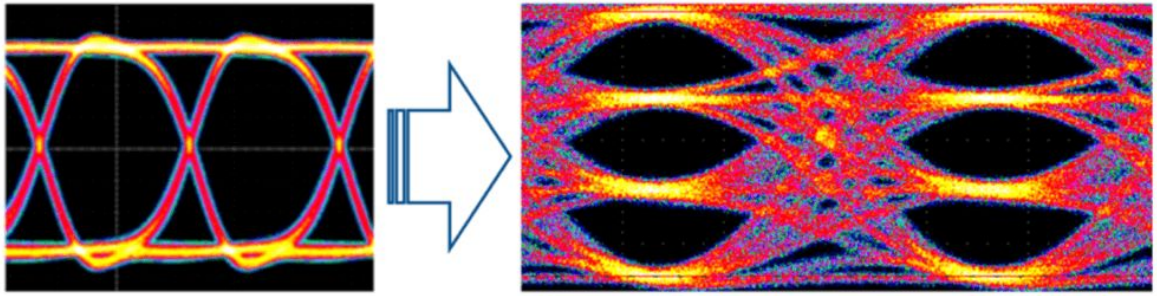
- Významně méně CO
- lepší utilizace backbone vláken

Ethernet - svět chaosu

- Normy - IEEE, proprietal
- Rychlost
  - 1G, 10G, 25G
  - 40G, 50G
  - 100G
  - 200G, 400G, 800G
- Tranciever:
  - GbIC, mGbIC, SFP, SFP+
  - CXP, CFP2, CFP4
  - QSFP+, QSFP28
  - CFP8, QSFP56, QSFP-DD
- Médium
- Vzdálenosti - KR, SR, LR, ER, FR, …
- další parametry - BiDi, WDM, …
- kompaktibilita HW, interoperabilita

Ethernet - svět chaosu





NRZ

PAM4

Ethernet - svět chaosu

Name	Standard	Status	Media	Connector	Transceiver Module	Reach in m	# Media (⇆)	# Lambdas (→)	# Lanes (→)	Notes
100 Gigabit Ethernet (100 GbE) (1st Generation: 10GbE-based) - (Data rate: 100 Gbit/s - Line code: 64b/66b × NRZ - Line rate: 10x 10.3125 GBd = 103.125 GBd - Full-Duplex) [101][102][103]										
100GBASE-CR10 *Direct Attach*	802.3ba-2010 (CL85)	phase-out	twinaxial balanced	CXP (SFF-8642) CFP2 CFP4 QSFP+	CXP CFP2 CFP4 QSFP+	7	20	N/A	10	Data centres (inter-rack); CXP connector uses center 10 out of 12 channels.
100GBASE-SR10	802.3ba-2010 (CL82/86)	phase-out	Fibre **850 nm**	MPO/MTP (MPO-24)	CXP CFP CFP2 CFP4 CPAK	OM3: 100 OM4: 150	20	1	10	
10×10G	*proprietary* *(MSA, Jan 2010)*	phase-out	Fibre 1523 nm , 1531 nm 1539 nm , 1547 nm 1555 nm , 1563 nm 1571 nm , 1579 nm 1587 nm , 1595 nm	LC	CFP	OSx: 2k / 10k / 40k	2	10	10	**WDM** Multi-vendor standard[104]

Ethernet - svět chaosu

100 Gigabit Ethernet (100 GbE) (2nd Generation: 25GbE-based) - (Data rate: 100 Gbit/s - Line code: 256b/257b × RS-FEC(528,514) × NRZ - Line rate: 4x 25.78125 GBd = 103.125 GBd - Full-Duplex) [101][102][103][105]										
100GBASE-KR4	802.3bj-2014 (CL93)	current	Cu-Backplane	N/A	N/A	1	8	N/A	4	PCBs; total insertion loss of up to 35 dB at 12.9 GHz
100GBASE-KP4	802.3bj-2014 (CL94)	current	Cu-Backplane	N/A	N/A	1	8	N/A	4	PCBs; **Line code: RS-FEC(544,514) × PAM4** **× 92/90 framing and 31320/31280 lane identification** **Line rate: 4x 13.59375 GBd = 54.375 GBd** total insertion loss of up to 33 dB at 7 GHz
100GBASE-CR4 *Direct Attach*	802.3bj-2010 (CL92)	current	twinaxial balanced	**QSFP28** (SFF-8665) CFP2 CFP4	N/A	5	8	N/A	4	Data centres (inter-rack)
100GBASE-SR4	802.3bm-2015 (CL95)	current	Fibre **850 nm**	MPO/MTP (MPO-12)	**QSFP28** CFP2 CFP4 CPAK	OM3: 70 OM4: 100	8	1	4	
100GBASE-SR2-BiDi (***BiD**irectional*)	*proprietary* *(non IEEE)*	current	Fibre **850 nm** **900 nm**	LC	**QSFP28**	OM3: 70 OM4: 100	2	2	2	**WDM** **Line rate: 2x (2x 26.5625 GBd with PAM4)** duplex fiber with both being used to transmit and receive; The major selling point of this variant is its ability to run over existing 25G multi-mode fiber (i.e. allowing easy migration from 25G to 100G).
100GBASE-SWDM4	*proprietary* *(MSA, Nov 2017)*	current	Fibre **844 – 858 nm** **874 – 888 nm** **904 – 918 nm** **934 – 948 nm**	LC	**QSFP28**	OM3: 75 OM4: 100 OM5: 150	2	4	4	**SWDM**[106]
100GBASE-LR4	802.3ba-2010 (CL88)	current	Fibre 1295.56 nm 1300.05 nm 1304.59 nm 1309.14 nm	LC	**QSFP28** CFP CFP2 CFP4 CPAK	OSx: 10k	2	4	4	**WDM** **Line code: 64b/66b × NRZ**
100GBASE-ER4	802.3ba-2010 (CL88)	current			**QSFP28** CFP CFP2	OSx: 40k	2	4	4	**WDM** **Line code: 64b/66b × NRZ**
100GBASE-PSM4	*proprietary* *(MSA, Jan 2014)*	current	Fibre 1310 nm	MPO/MTP (MPO-12)	**QSFP28** CFP4	OSx: 500	8	1	4	Data centres; **Line code: 64b/66b × NRZ or 256b/257b × RS-FEC(528,514) × NRZ** Multi-vendor standard [107]
100GBASE-CWDM4	*proprietary* *(MSA, Mar 2014)*	current	Fibre 1264.5 – 1277.5 nm 1284.5 – 1297.5 nm 1304.5 – 1317.5 nm 1324.5 – 1337.5 nm	LC	**QSFP28** CFP2 CFP4	OSx: 2k	2	4	4	Data centres; **WDM** Multi-vendor standard[108][109]
100GBASE-4WDM-10	*proprietary* *(MSA, Oct 2018)*	current			**QSFP28** CFP4	OSx: 10k	2	4	4	**WDM** Multi-vendor standard[110]
100GBASE-4WDM-20	*proprietary* *(MSA, Jul 2017)*	current	Fibre 1294.53 – 1296.59 nm 1299.02 – 1301.09 nm 1303.54 – 1305.63 nm 1308.09 – 1310.19 nm			OSx: 20k				**WDM** Multi-vendor standard[111]
100GBASE-4WDM-40	*proprietary* *(non IEEE)* *(MSA, Jul 2017)*	current				OSx: 40k				**WDM** Multi-vendor standard[111]
100GBASE-CLR4	*proprietary* *(MSA, Apr 2014)*	current	Fibre 1264.5 – 1277.5 nm 1284.5 – 1297.5 nm 1304.5 – 1317.5 nm 1324.5 – 1337.5 nm		**QSFP28**	OSx: 2k	2	4	4	Data centres; **WDM** **Line code: 64b/66b × NRZ or 256b/257b × RS-FEC(528,514) × NRZ** Interoperable with 100GBASE-CWDM4 when using RS-FEC; Multi-vendor standard[108][112]
100GBASE-CWDM4	*proprietary* *(OCP MSA, Mar 2014)*	current	Fibre 1504 – 1566 nm	LC	**QSFP28**	OSx: 2k	2	4	4	Data centres; **WDM** **Line code: 64b/66b × NRZ or 256b/257b × RS-FEC(528,514) × NRZ** Derived from 100GBASE-CWDM4 to allow cheaper transceivers; Multi-vendor standard[113]

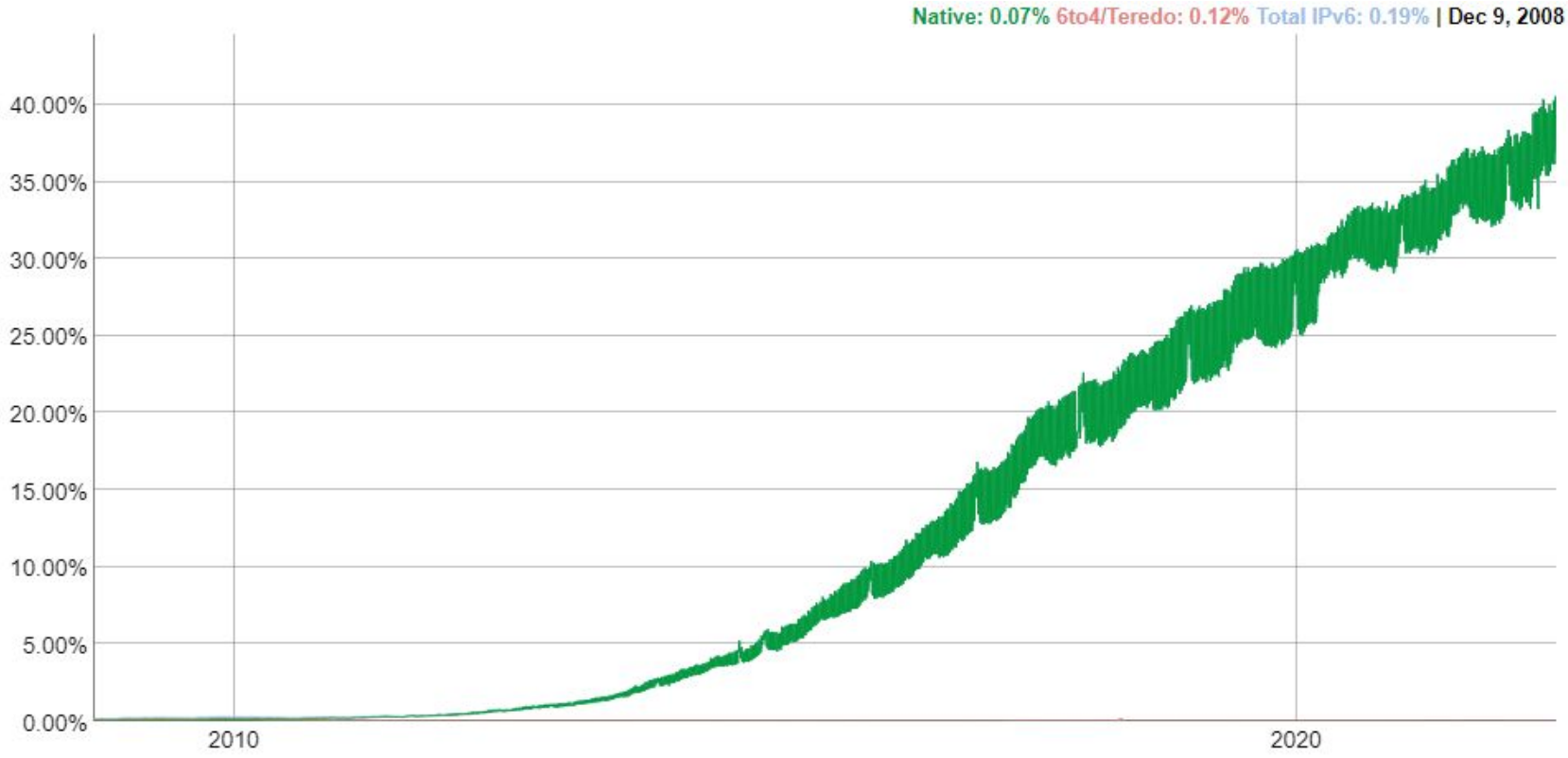
Ethernet - svět chaosu

100 Gigabit Ethernet (100 GbE) (3rd Generation: 50GbE-based) - (Data rate: 100 Gbit/s - Line code: 256b/257b × RS-FEC(544,514) × PAM4 - Line rate: 2x 26.5625 GBd x2 = 106.25 GBd - Full-Duplex) [102][103]										
100GBASE-KR2	802.3cd-2018 (CL137)	current	Cu-Backplane	N/A	N/A	1	4	N/A	2	PCBs
100GBASE-CR2	802.3cd-2018 (CL136)	current	twinaxial balanced	**QSFP28, microQSFP, QSFP-DD, OSFP** (SFF-8665)	N/A	3	4	N/A	2	Data centres (in-rack)
100GBASE-SR2	802.3cd-2018 (CL138)	current	Fibre **850 nm**	MPO 4 fibres	**QSFP28**	OM3: 70 OM4: 100	4	1	2	

Ethernet - svět chaosu

100 Gigabit Ethernet (100 GbE) (4th Generation: 100GbE-based) - (Data rate: 100 Gbit/s - Line code: 256b/257b × RS-FEC(544,514) × PAM4 - Line rate: 1x 53.1250 GBd x2 = 106.25 GBd - Full-Duplex)										
100GBASE-KR1	802.3ck (CL163)	development	Cu-Backplane	N/A	N/A		2	N/A	1	total insertion loss ≤ 28 dB at 26.56 GHz.
100GBASE-CR1	802.3ck (CL162)	development	twinaxial balanced	**SFP112, SFP-DD112, DSFP, QSFP112, QSFP-DD800, OSFP**	N/A	2	2	N/A	1	
100GBASE-VR1	802.3db (CL167)	development	Fibre **842 – 948 nm**	LC	**QSFP28**	OM3: 30 OM4: 50	2	1	1	
100GBASE-SR1	802.3db (CL167)	development	Fibre **844 – 863 nm**	LC	**QSFP28**	OM3: 60 OM4: 100	2	1	1	
100GBASE-DR	802.3cd-2018 (CL140)	current	Fibre 1311 nm	LC	**QSFP28**	OSx: 500	2	1	1	
100GBASE-FR1	802.3cu-2021 (CL140)	current	Fibre 1311 nm	LC	**QSFP28**	OSx: 2k	2	1	1	Multi-vendor standard[114]
100GBASE-LR1	802.3cu-2021 (CL140)	current	Fibre 1311 nm	LC	**QSFP28**	OSx: 10k	2	1	1	Multi-vendor standard[114]
100GBASE-LR1-20	*proprietary (MSA, Nov 2020)*	current	Fibre 1311 nm	LC	**QSFP28**	OSx: 20k	2	1	1	Multi-vendor standard[115]
100GBASE-ER1-30	*proprietary (MSA, Nov 2020)*	current	Fibre 1311 nm	LC	**QSFP28**	OSx: 30k	2	1	1	Multi-vendor standard[115]
100GBASE-ER1-40	*proprietary (MSA, Nov 2020)*	current	Fibre 1311 nm	LC	**QSFP28**	OSx: 40k	2	1	1	Multi-vendor standard[115]
100GBASE-ZR	802.3ct-2021 (CL153/154)	current	Fibre 1546.119 nm	LC	CFP	OS2: 80k+	2	1	1	**Line code: DP-DQPSK × SC-FEC** **Line rate: 27.9525 GBd** Reduced bandwidth and line rate for ultra long distances.[116]

IPv6


Native: 0.07% 6to4/Teredo: 0.12% Total IPv6: 0.19% | Dec 9, 2008
40.00%
35.00%
30.00%
25.00%
20.00%
15.00%
10.00%
5.00%
0.00%
2010
2020

IPv6