



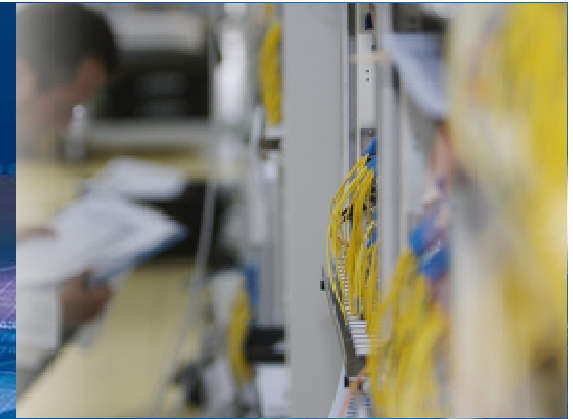
Performance, Cost, and Energy Consumption in Next-Generation WDM-based Access

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Agenda



- ▶ NGA Requirements and Solutions
- ▶ WDM-based NGA

NGA Requirements and Solutions



NGA Requirements

▶ **Things that are less clear**

- ▶ The requirements themselves
 - ▶ Maximum reach? Range is between 50 km and 100+ km
 - ▶ Per-PON client count? Range is between 1:64 and 1:1000+
 - ▶ Per-client bit rate? 1+ Gb/s, but what level of oversubscription?
- ▶ Active sites allowed? (they *can* make things simpler and cheaper...)
- ▶ Lowest TCO vs. lowest initial invest?

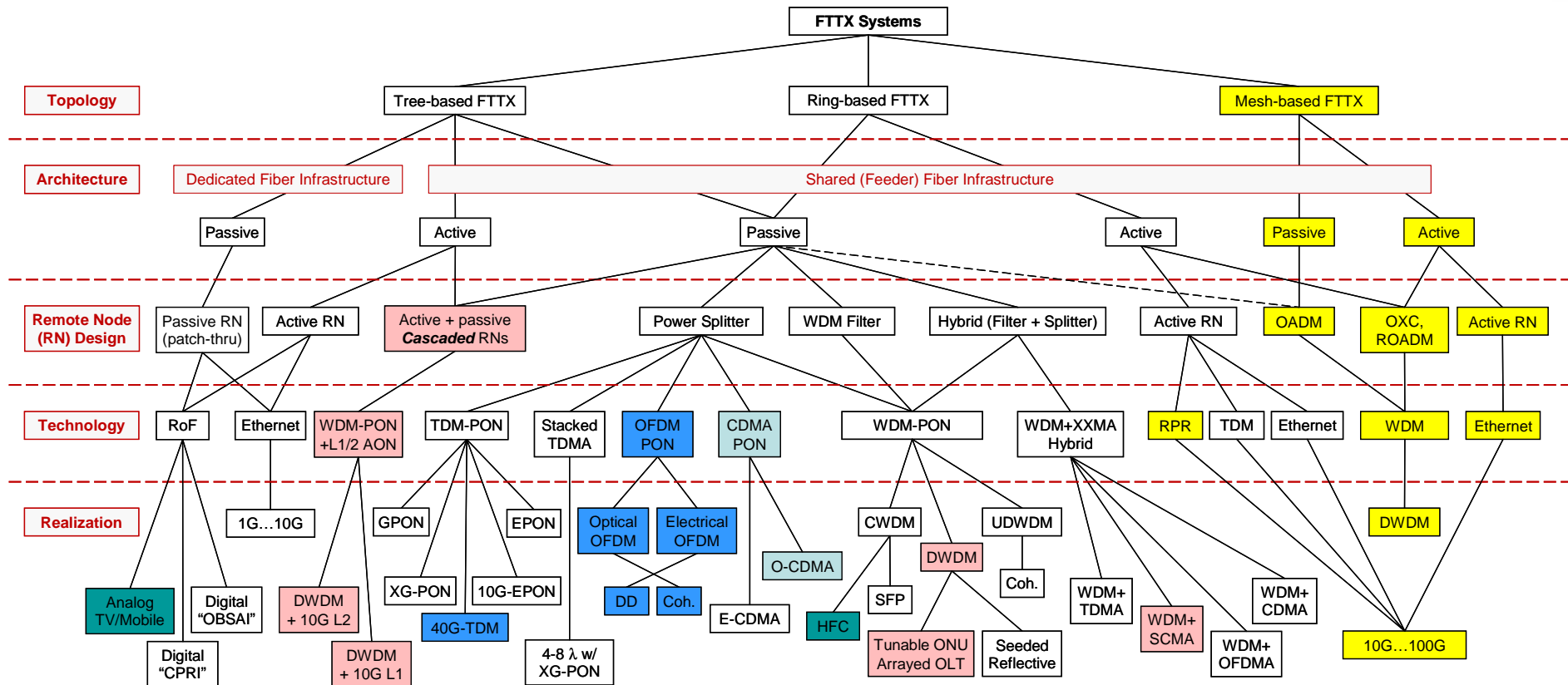
▶ **Things that are clear**

▶ **Since NGA must be cheap**

- ▶ **Restrict transceivers to 27 dB power-budget class**
- ▶ **Restrict transceivers to 1 Gb/s class**

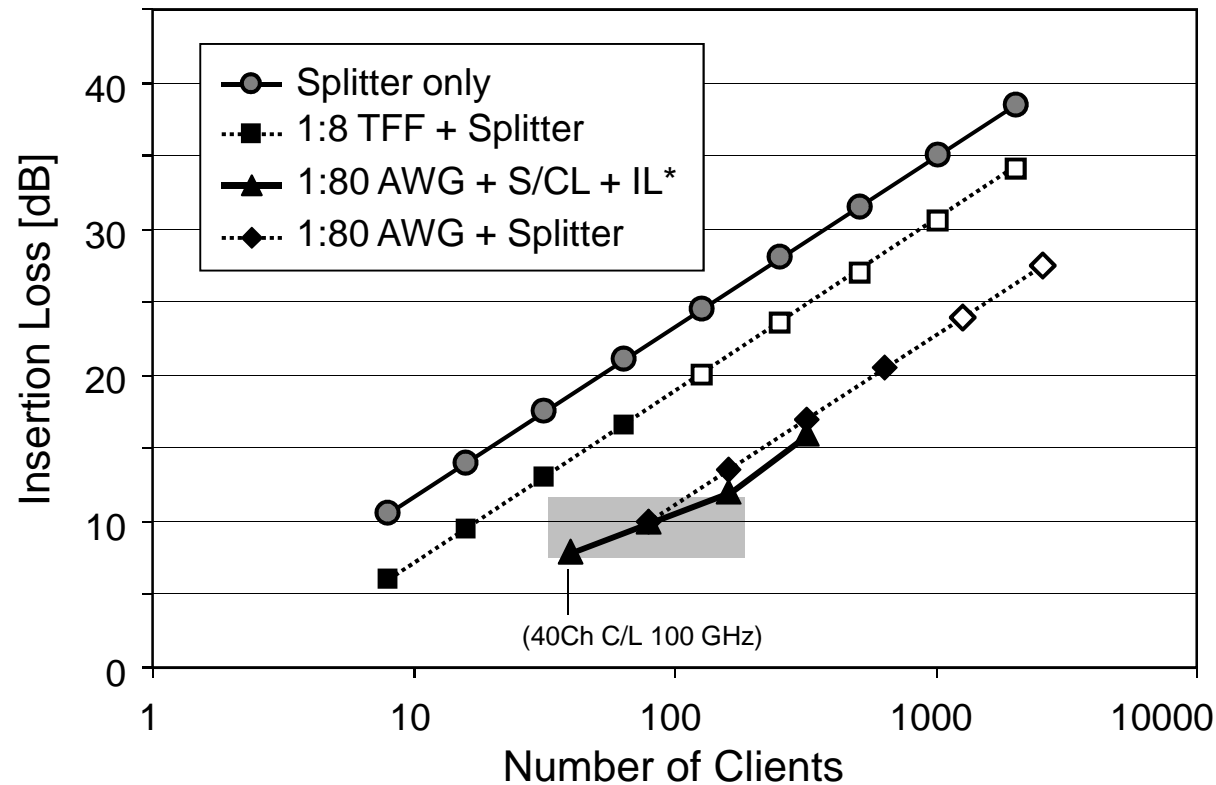
which leads to a simple WDM-PON

Possible Solutions



- ▶ There are many possible, potential solutions for NGA
- ▶ Not all of them fit the requirements (perfectly)

Insertion Loss vs. Fan-out



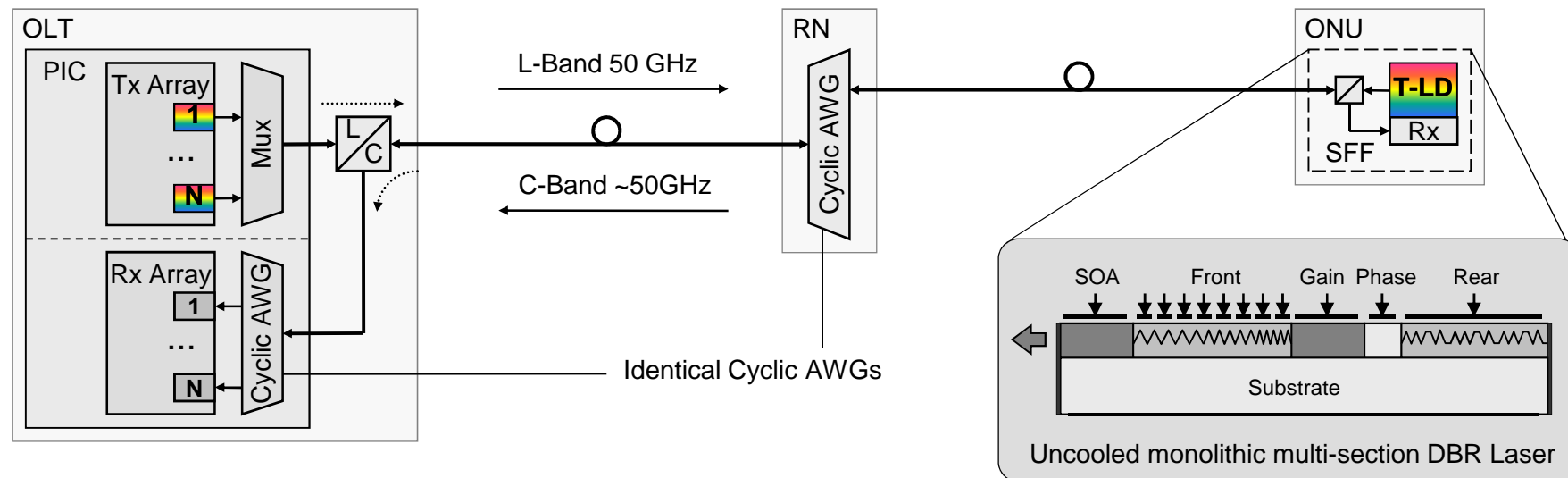
*) Interleaver

1:8 TFF / 1:40 AWG / 1:80 AWG	3 / 4 / 5 dB
1:8 / 1:16 / 1:1024 Power Splitter/Combiner	12 / 14 / 35 dB
Band Splitter / Interleaver (IL)	1 / 2 dB
50 km Fiber EOL incl. Patches etc.	16 dB

WDM-based NGA



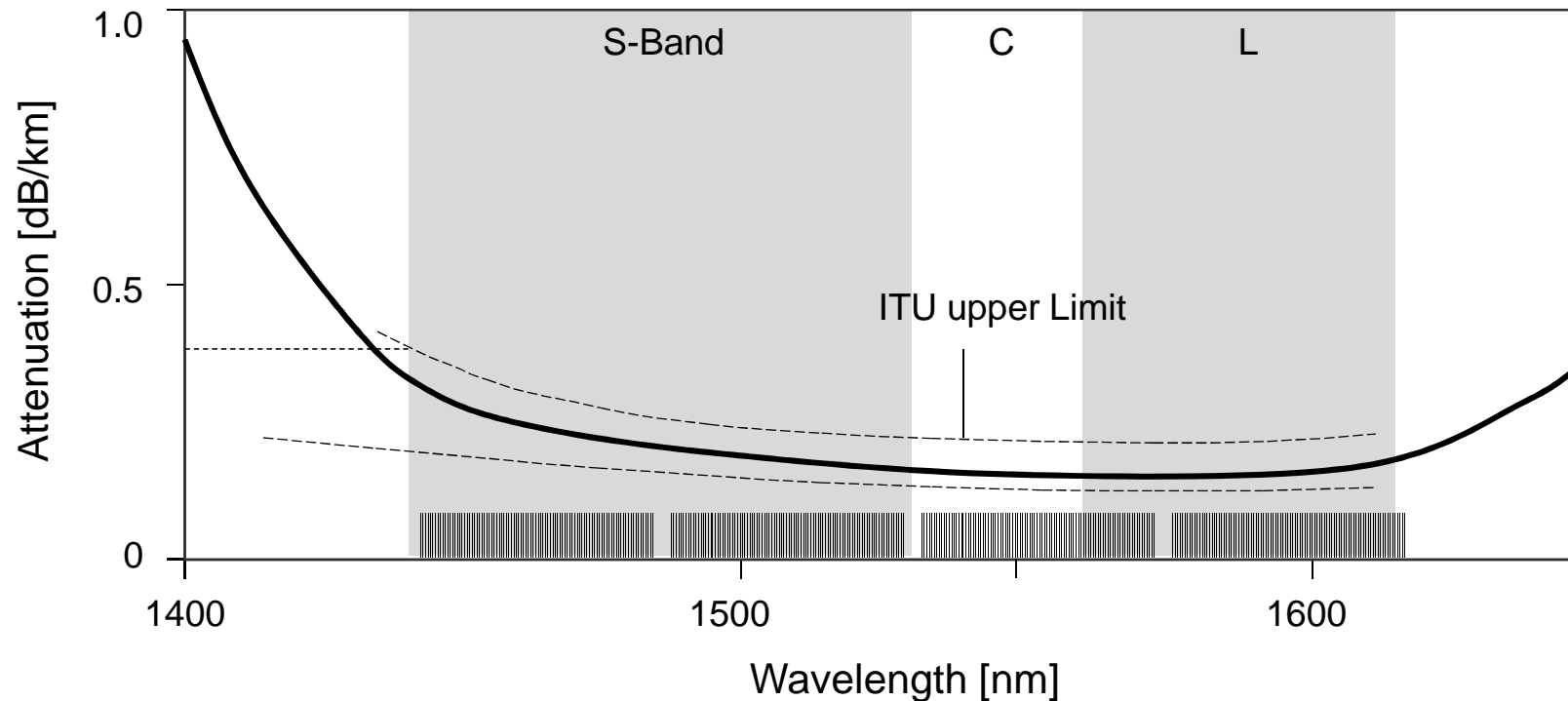
Simple WDM-PON (64...96 Ch)



- ▶ Lowest cost for **dedicated 1G** per client
- ▶ Tunable uncooled 1Gb/s / 27dB lasers – sufficient for 50 km with low-loss AWGs
- ▶ Also enables lowest energy consumption

Cost (per client)	150\$ total	Energy (per client)	2.5 W
AWG ports	20\$	OLT array port	0.5 W
OLT array port	50\$	OLT switching	1.0 W
ONU TRX	75\$	ONU	1.0 W
OLT switching	5\$		

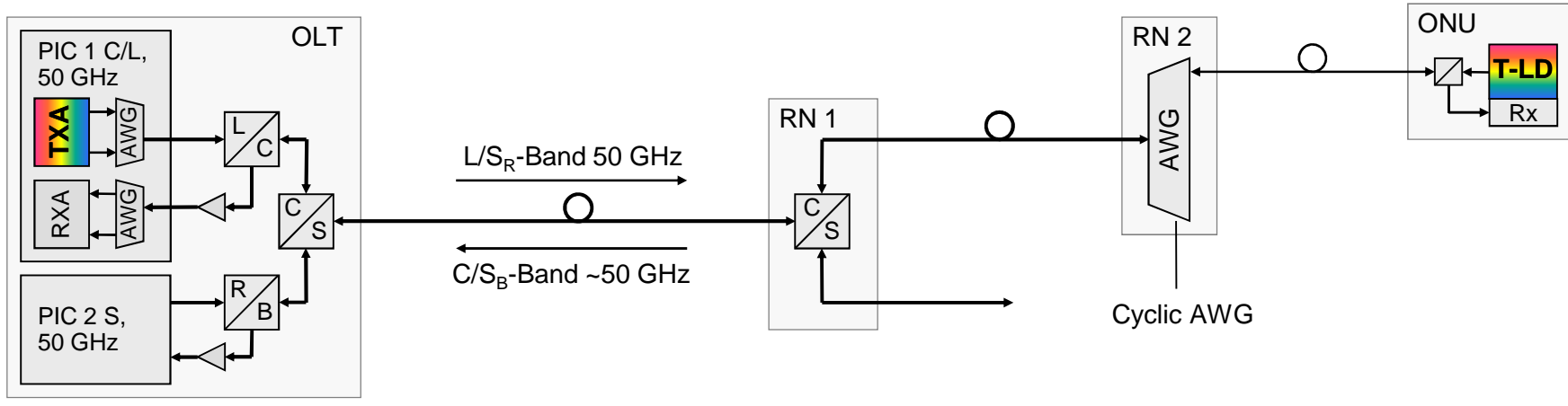
Fiber Attenuation



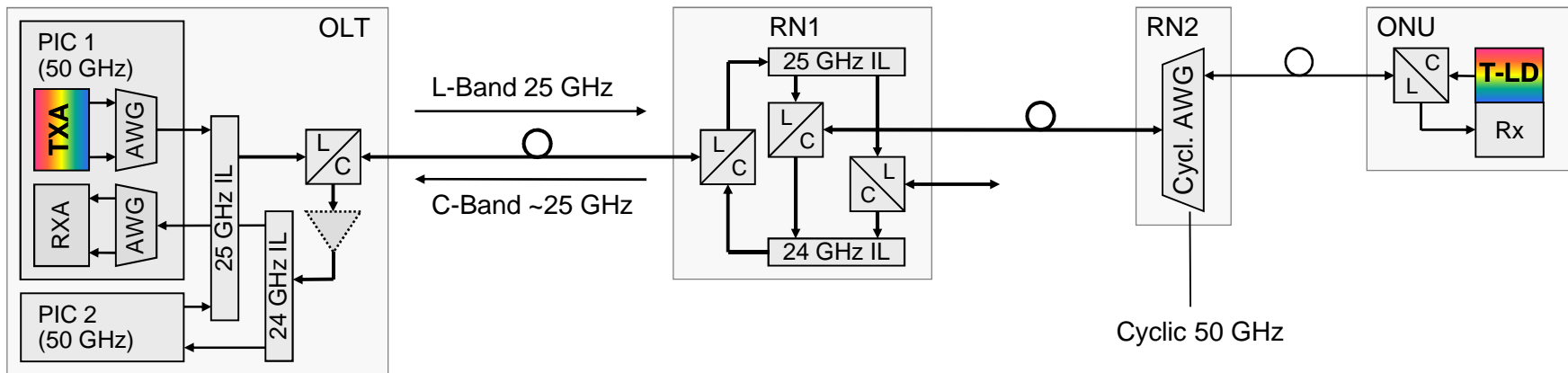
- ▶ Cyclic, athermal AWGs provide low loss in (at least) 4 bands à 96 channels
- ▶ Extension into S-band for higher capacity, broadcast, or monitoring

Extended WDM-PON (128...384 Ch)

Doubling channel count through S-band addition



Doubling channel count through interleaving down to 25GHz grid



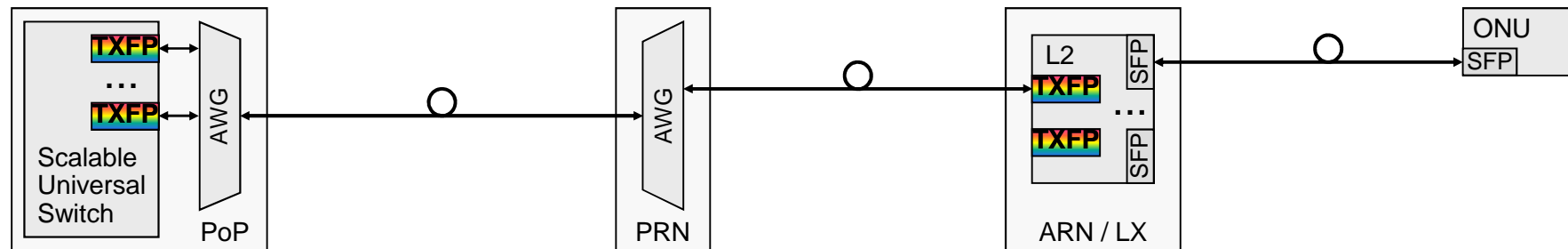
Combining C+L+S-band and 25GHz leads to up to 384 channels

Fiber Power Budget Classes

	80Ch, C/L, 50 GHz	160Ch, S/C/L, 50 GHz	320Ch, S/C/L, 25 GHz
	Fiber Power Budget		
$P_{TX, MIN} = +4 \text{ dBm}$, $P_{RX, MIN} = -23 \text{ dBm}$	~15 dB	~12 dB	~7 dB
Additional APD or OLT Pre-amplifier	~23 dB	~20 dB	~15 dB
APD plus OLT Booster/Pre-amplifier	~30 dB	~27 dB	~22 dB

- ▶ Different power-budget – and cost – classes
- ▶ High power budget at high channel count for fully passive ODN possible

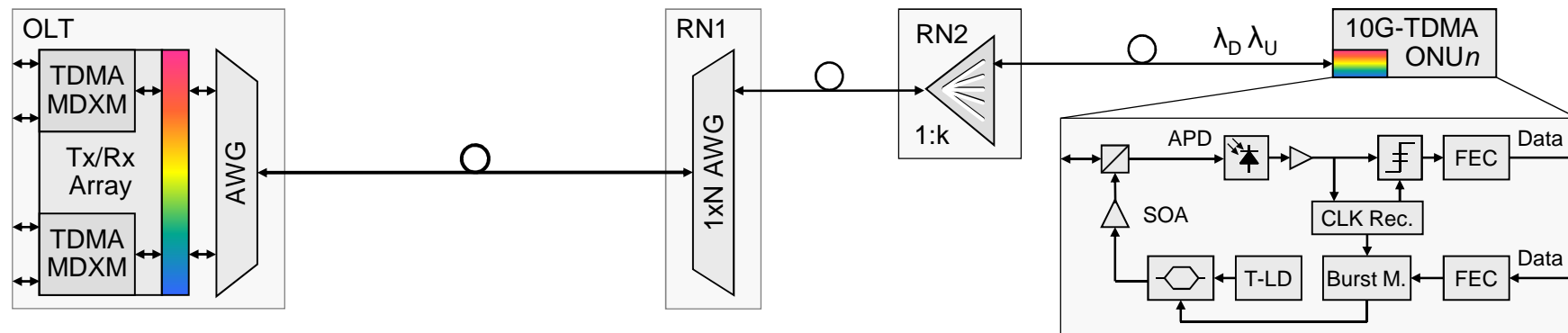
Hybrid WDM-PON/AON



- ▶ Lowest cost for high fan-out, but requires active access sites
- ▶ Also very low energy consumption for high fan-out
- ▶ Easily achieves 50 + 10 km
- ▶ Example: 40 x 10G, each carrying 24 clients (960 clients, ~400Mb/s guaranteed)

Cost (per client)	147\$ total	Energy (per client)	3.3 W
AWG ports	2\$	PoP switching	1.0 W
10G TRX	100\$ (!)	LX switching	1.0 W
Switch (PoP)	5\$	LX TRX (2 x TXFP)	0.3 W
Switch (LX)	10\$	CPE TRX (2 x grey SFP)	1.0 W
CPE TRX (2 x grey SFP)	30\$		

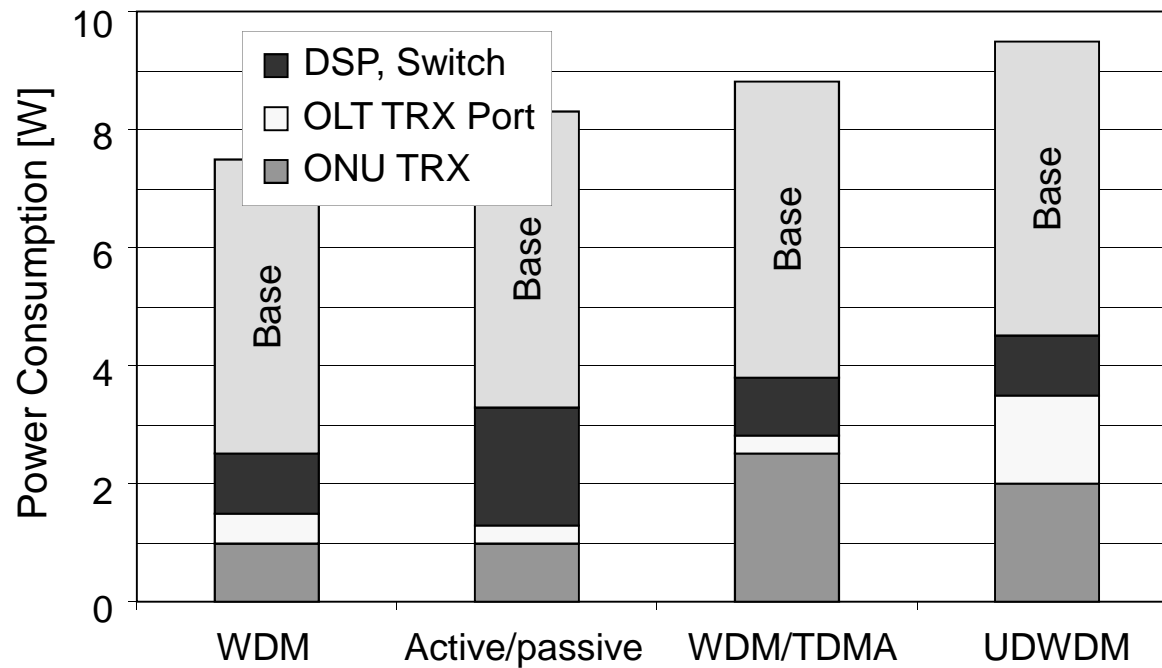
Hybrid WDM/TDMA-PON



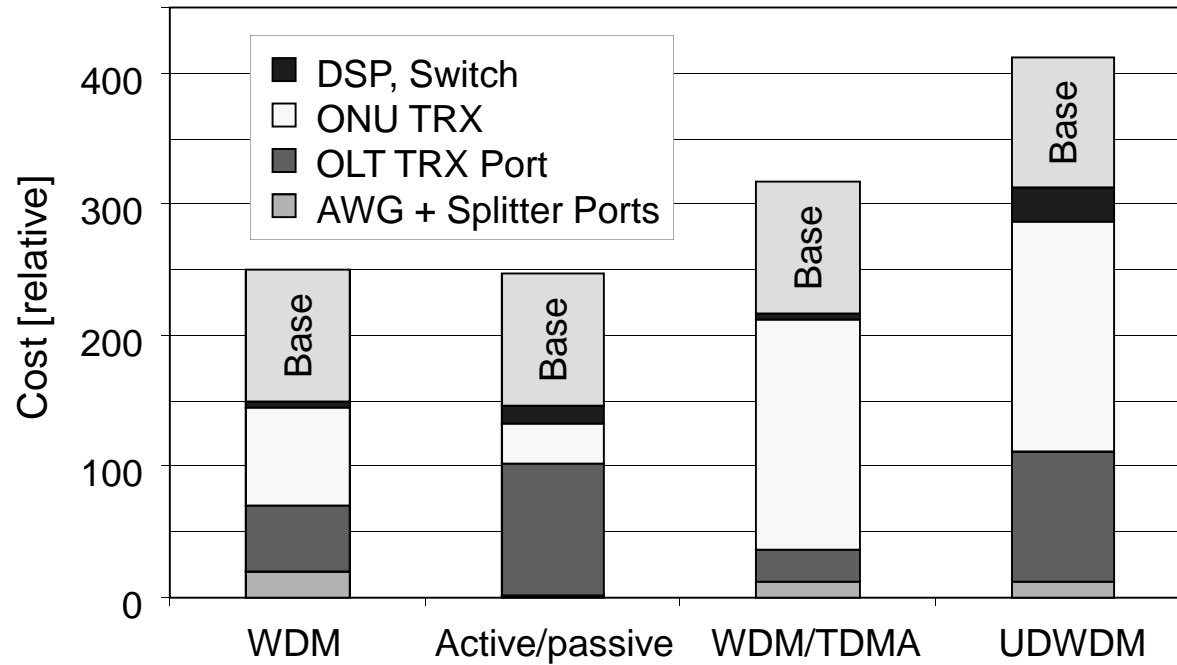
- ▶ Cheapest passive hybrid PON for high client count
- ▶ Requires 10G 35dB burst-mode transceivers for 50 km
- ▶ Still comparatively low energy consumption
- ▶ Example: 40 wavelengths à 10 Gb/s, passively split 1:16 (640 clients, ~600 Mb/s)

Cost	217\$ total	Energy	3.8 W
AWG/splitter ports	12\$	OLT port	0.25 W
OLT port	22\$	OLT switching	1.0 W
OLT amplifiers	3\$	OLT amplifiers	0.05 W
ONU TRX	175\$	ONU	2.5 W
OLT switching	5\$		

Power Consumption Comparison



Cost Comparison



Conclusions

- ▶ Only WDM provides the scalability for high client count *and* high sustained bit rates
- ▶ WDM-PON client count can be extended (S-band, 25 GHz, PON+AON, hybrid PON, UDWDM)
- ▶ Pure WDM-PON leads to lowest cost and power consumption (but does not scale to beyond 400 clients)



Thank you

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IMPORTANT NOTICE

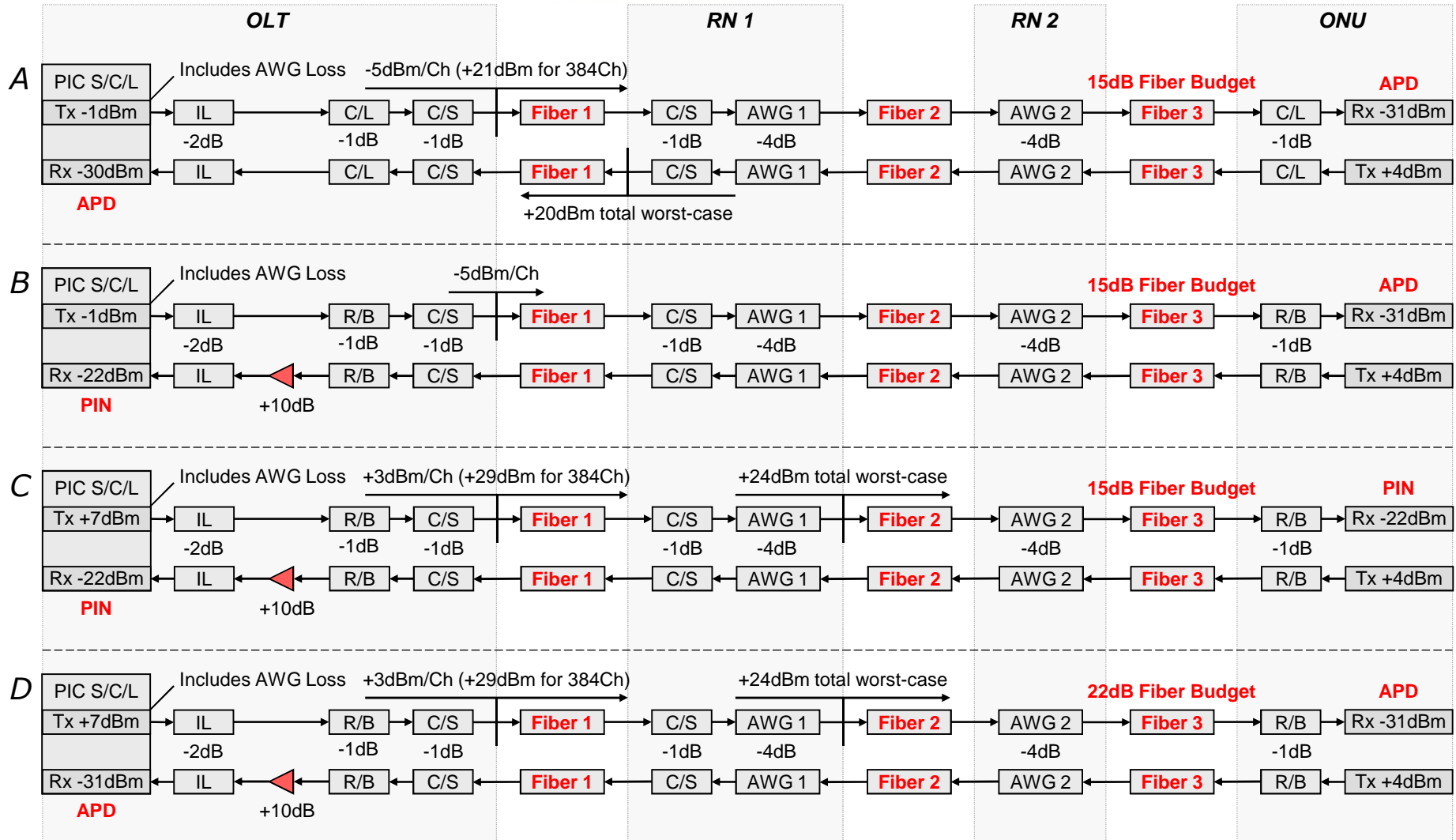
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Power Budget for 25 GHz, S/C/L



PON Analysis - Parameters

ONU housing, OLT shelves, PSUs, controllers etc. are not considered here (cost, power con.) because they are common to all approaches

Component	Energy Con.	Cost
10G base TRX (SFF, coolerless, w/o Locker, 22 dB, not used hereinafter)	1.25 W	100
10G TXFP (TEC, Locker, 25 dB)	3.5 W	1200
10G Burst-mode TRX, 35 dB (SFF, APD, SOA, FEC, coolerless, w/o Locker)	2.5 W	175
30GHz TRX (coherent, TEC, Locker, 16 Channels à 1G / 3 GHz)	8 W	1600
30GHz TRX (32 dB, coolerless, w/o Locker, single channel)	2.5 W	175
10G REAM-SOA, incl. Fraction of MFL, 1G 26 dB Rx (!)	1 W	85
10G REAM-SOA, incl. Fraction of MFL, 10G 35 dB Rx (!)	2 W	175
1G coherent ONU TRX, pol.-diverse or w/ Pol. Scrambler	2 W	175
1G tunable ONU TRX	1 W	75
40x1G Laser/Rx Array	20 W	2000
40x1G REAM/Rx Array plus MFL and Circulators	20 W	2400
1G grey SFP, 10 dB	0.5 W	15
ASIC 1G SCMA ONU	1 W	10
ASIC 10G OFDM ONU	4 W	40
ASIC 10G OFDM / SCMA OLT 16Ch	8 W	160
ASIC 50G UDWDMA OLT 16Ch	16 W	320
ASIC CDMA OLT 8Ch	4 W	120
OLT EDFA Booster/Preamp Combo	25 W	2000
Circulator	--	100
AWG Port / Power Splitter/Combiner Port	--	20 / 10
OLT / PoP Switch per 1G	1 W	5
Baseline cost per client (CPE, OLT shelf, motherboards)	5 W	100