Core Optical Networking & Transmission Working Group Overview

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Co-Chair, CONT WG

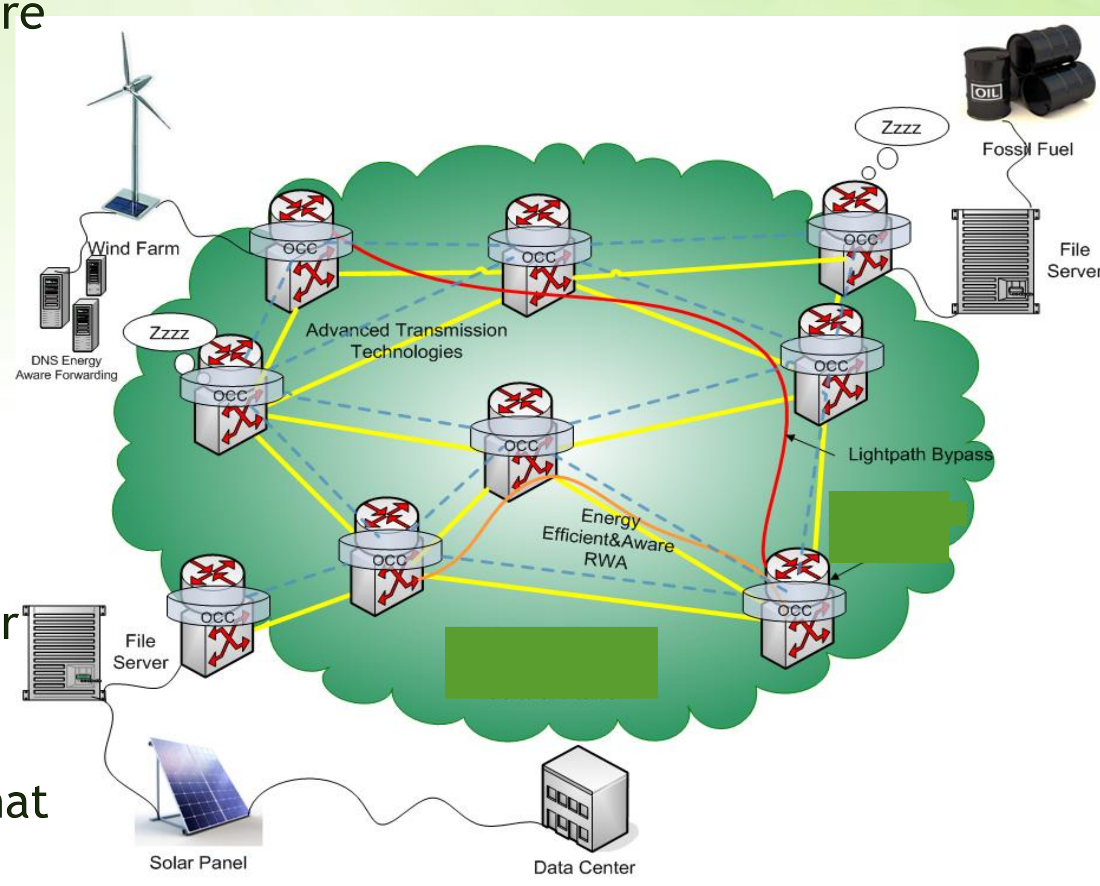
CONT WG Focus

With the term “optical networking” we denote high-capacity telecommunications networks based on optical technologies and components that provide the functionality of routing, grooming and restoration at the wavelength level as well as wavelength-based services provisioning. The Core Optical Networking and Transmission Working Group covers topics related to the Metro and Long Haul segments of a transport network. Focusing on the particular network segments, **all wavelength-related (Layer 1) operations** fall inside the activities of the WG. Such areas may include but are not limited to:

- optical transport/transmission systems,
- optical network elements and sub-systems,
- optical circuit switching and wavelength switching,
- survivability, reliability, and security of optical networks,
- interfacing of the wavelength transport/switching elements to the control plane,
- optical communication components and devices,
- coding and forward error correction in optical systems,
- architecture of fiber, free-space, and hybrid optical networks,
- transparency and all-optical networks,
- signalling and information models for optical network control and management,
- architectures, protocols, and algorithms for dynamic optical networks,
- operations support systems for optical networks,
- modelling and simulation of optical networks,
- advanced optoelectronic circuits and optical signal processing,
- quantum optical communication
- novel core transmission/communication technologies

Our WG vision

- Energy Efficient WDM Architecture
- Advanced transmission technologies
- Minimal opto-electronic conversions
- Energy Constrained RWA
- Energy-enabled Control Plane for energy-aware operation
- Give priority to all equipment that run on clean energy sources



Metropolitan network- energy efficiency study introduction

- First issue: wide variety of metro networks
  - various topologies (ring, mesh, star,…)
  - Size (number of nodes and links, connection lengths,…)
  - Mode of WDM transportation (transparent, opaque)
  - WDM data rates

- Our assumptions:
  - topology and traffic based on an existing regional network (by courtesy of *France Telecom* operator)
  - RWA based on an opaque transmission assumption to favor data merge (layer 2)
  - 10Gbps capacity (and transponder devices) per WDM channel

Involved GT members: BL, IBBT, DCU, FT

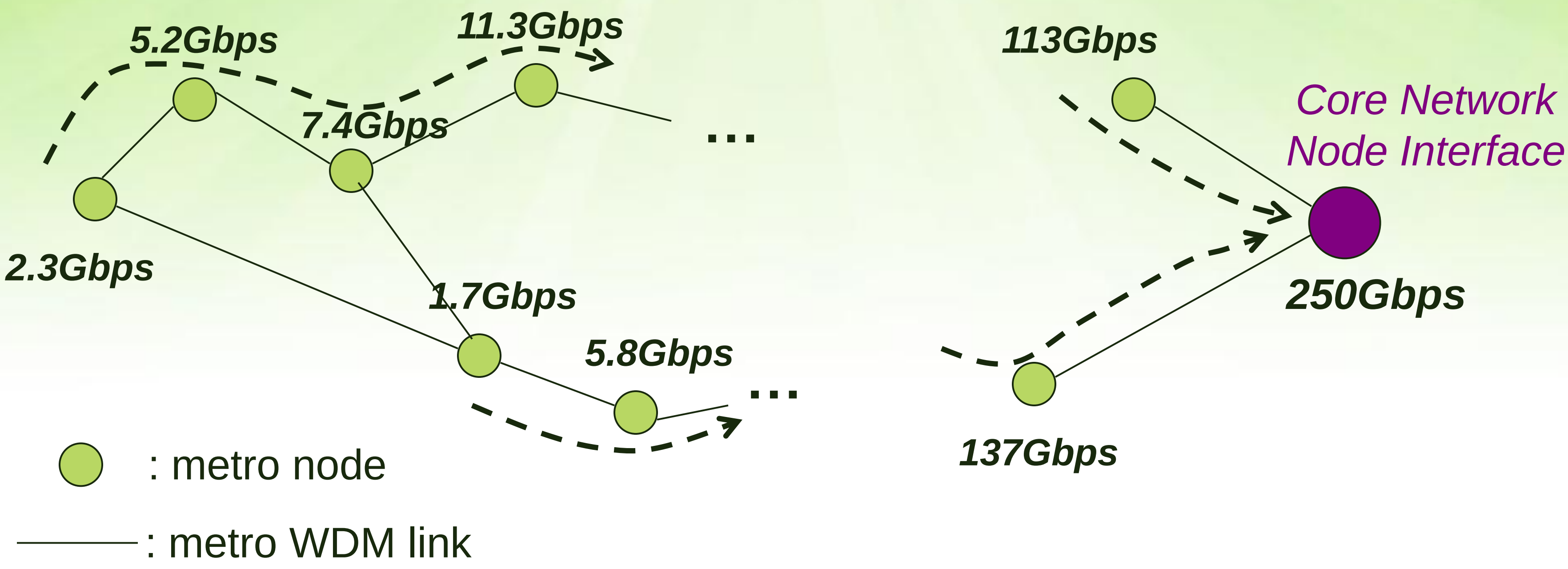
Metropolitan network- topology & traffic assumptions

- Topology:
  - mesh, 44 nodes, 59 links (avg node connectivity degree=2.6)
  - 1 fiber per link & per direction
  - 300km between most distant nodes (avg node distance=39 km)
  - 1 link=1 span=> **No need for intermediate optical amplifier between nodes**
  - 1 interface node for connection to the long haul network

- Traffic matrix (layer 2 data rate here):

  260Gbps overall routed traffic per direction that splits as follows:
  - 250Gbps from/to long haul network
  - 10Gbps local metro traffic

Metropolitan network-
data aggregation => better utilization of WDM channels



XX Gbps : layer 2 accumulated data rate to/from core network

- *Average amount of aggregated traffic per node: 23Gbps*
- *Overall number of 10Gbps transponders to handle the traffic: 124*

WDM Network Energy Efficiency Model Adaptation to the Metro Network Case

No power contribution from links: Links<100km length =>No reamplification

$$Eff^{-1}_{Metro\_Optical} = \eta_{pr}\eta_c\left(\frac{Power_0}{Capa} + \cancel{\frac{Power_1}{Capa}}\right)$$

[Unit: Watts/Gbps]

Network nodes contribution
(cross-connect & transponder systems)

~~Network links contribution~~
(Optical Line Amplifier systems)

- $\boldsymbol{\eta_C}$ factor accounts for the energy consumption of the cooling and power supply at the operator site

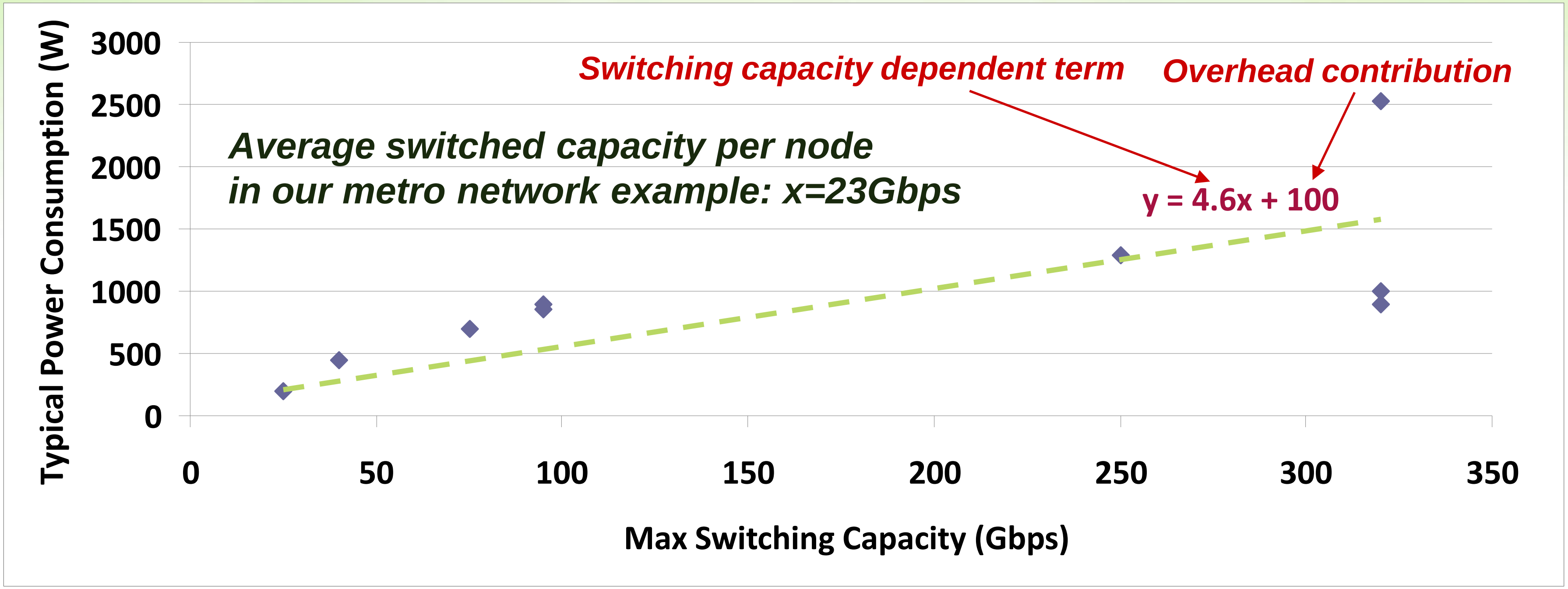
- η_{pr} factor accounts for provisioning and for the protection paths of the connections used in network

=> What is needed? -> calculate Power$_0$ & Capa terms for the metropolitan network case

Metropolitan Network Case
Power at the node stage ($Power_{TR0}$)

1a - Cross-connect systems:

Power consumption of electrical cross-connects for metro network derived from available manufacturer data sheets



see GT CONT data base for product data sheet references & links

Metropolitan Network Case
Power at the node stage ($Power_{TR0}$)

1b - Cross-connect systems:

- *Assumption: opto-electronic conversion at each node to allow for data grooming => electrical cross-connects* (XC)

$$OverallMetroXCPower = N \cdot \widetilde{\mathrm{Capa}}_{\mathrm{n}} \cdot \mathrm{PowerPerSwitchedGb} + N \cdot PowerXCOverhead$$

- ***PowerPerSwitchedGb***: switched capacity dependent power
- ***N:*** the number of nodes in the network
- $\widetilde{\mathrm{Capa}}_{\mathrm{n}}$: average switched capacity per node
- ***PowerWDMCtrlPlane***: power contribution of the XC overhead

$$OverallMetroXCPower = 44 \cdot 23Gbps \cdot (4.6W / Gbps) + 44 \cdot 100W \approx 9.06kW$$

Metropolitan Network Case
Power at the node stage ($Power_{TR0}$) - 2

2 – Transponder systems:

$$OverallTspsPower_r = \sum_{n=1}^{N} \mathrm{TspsPower}_r \approx N \cdot \tilde{T}_n \cdot OverheadFactor_r \cdot PowerPerTransp_r$$

N: Nb of metro network nodes=44
$\tilde{T}_n$: Avg nb of transponder cards per node=124/44=2.82
OverheadFactor: Power contribution factor of the transponder control board=1.4
PowerPerTranspr: Power per transponder card (*r* :10Gbps case)=34W

$$OverallTspsPower = 124 \cdot 1.4 \cdot 34W \approx 6kW$$

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Metro network energy efficiency estimation

$$Eff_{Metro\_Optical}^{-1} = \eta_{pr}\eta_c \left(\frac{Power_{TR0}}{Capa_{TR0}} \right)$$

$$Power_{\mathrm{Metro\_Optical}} = \eta_{pr} \cdot \eta_c \cdot Power_{TR0} = 2 \cdot 2 \cdot (9.06kW + 6kW) \approx 60kW$$

Capacity:
- Overall layer 2 routed traffic: 2x260=520Gbps
- Estimated average filling ratio of 10Gbps WDM channels: 83%*
  => related gross WDM traffic: $Capa_{TR0}$=520/0.83=630Gbps
 (*in practice, network would work under a lower utilisation assumption*)

Final energy efficiency estimate for the metropolitan network physical layer:

$$\boxed{Eff_{Metro\_Optical}^{-1} = 60kW / 630Gbps = 95W / Gbps^{*}}$$

: optimistic assumption

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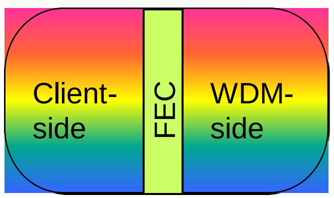
Core optical network energy efficiency update

First publication release exploring the power consumption of 100Gbps coherent transponder:

New estimation: 350W (previous guess,without data sheet inputs: 188W)

Add/Drop transponder



	Component	Unit	TSP	Power dissipation (W)	Ref
Client side	Client-card	10	•	3.5	[7]
Client side	Framer	1	•	25	[8]
FEC	FEC	1	•	7	[9]
E/O modulation	Drivers	4	•	9	[10]
E/O modulation	Laser (on-off)	1	•	6.6	[11]
O/E Receiver	Local oscillator	1	•	6.6	[11]
O/E Receiver	Photodiode + TIA	4	•	0.4	[12]
O/E Receiver	ADC	4	•	2	[13]
O/E Receiver	DSP	1	•	100	[13]
FEC	FEC	1	•	7	[9]
Client side	Deframer	1	•	25	[8]
Client side	Client-card	10	•	3.5	[7]
	Management power		•	+20% total power	[12]
	Total power		**351W**		

From « Power Management of Optoelectronic Interfaces for Dynamic Optical Networks »,A. Morea & al, ECOC 2011

Optical network energy efficiency summary

1) Long haul network case

- New energy efficency estimation figure for 100Gbps WDM data rate based long haul network: **68W/Gbps**

- This is equivalent to the estimation based on a basic 10Gbps WDM data rate based network

- switching from 10Gbps to 100 Gbps brings a factor 10 gain in optical network capacity but **no gain according to current estimate in energy efficiency**.

2) Metropolitan network case

- Energy efficiency estimation figure under above assumptions: **95W/Gbps**

All additional details can be found in the new release of the « Green Touch CONT Report on Baseline Power consumption »

Note: W/Gbps figures here only include optical amplifiers, cross-connects and transponder systems (physical layer energy efficiency)

Equipment Models – Data collection

	A	B	C	D	E	F	G	H	I	J
3	SDH / SONET cross connects									
4	Brand	Model	Year 1st release	Remarks	Max Switching Capacity (Gbps)	Max Power Consumption (W)	Typical Power Consumption (W)	Typ/Max	Inv. Efficiency (W/Gbps)	Link
5	Cisco	15600	2002		320	2800	*2100*		6.6	http://www.cisco.com/en/US/prod/collateral/optical/ps5724/ps4533/prod
6	Ciena	CN3600	2006 ?		95	1200	850	71%	8.9	http://www.ciena.com/products/3600/technical/
7	Sycamore	SN9000	2007		320	1200	1000	83%	3.1	www.sycamorenet.com/corporate/collateral/PB_sn9000_gov.pdf
8	Tejas	TJ1600c		**Ward VH:** Seems more like a core product, see the diagram in the product	320	1200	*900*		2.8	http://www.tejasnetworks.com/products_mspp_TJ1600C.html
9	Tejas	TJ1400		Less important equipment from Tejas	60	250	*187.5*		3.1	http://www.tejasnetworks.com/images/Product%20Brochures/tejas_xtn/tj
10										
11										
12	*Values missing*									
13	Alactel Lucent	1660								
14	Alactel Lucent	1675								
15	Alactel Lucent	1678 MCC		**Ward VH:** Added because seems suitable, although no power values	640					http://www.alcatel-lucent.com/wps/portal/!ut/p/kcxml/04_Sj9SPykssy0xPLI
16										
17	*Not considered (too old, or unclear values)*									
18	Tellabs	5500 ccs	1991	Matrix VC12, very old design	250	1720	*1290*		5.2	http://www.tellabs.com/products/5000/tlab5500_ccs.pdf
19	Force 10	Traverse 2000	2002	Not considered, as old matrix VC12 instead of VC4	95	1600	900	56%	9.5	http://www.force10networks.com/products/pdf/Force10_Traverse_DS.pdf
20	Force 10	Traverse 1600	2002	Not considered, as old matrix VC12 instead of VC4	75	1200	700	58%	9.3	http://www.force10networks.com/products/pdf/Force10_Traverse_DS.pdf
21	Force 10	Traverse 600	2002	Not considered, as old matrix VC12 instead of VC4	25	400	200	50%	8.0	http://www.force10networks.com/products/pdf/Force10_Traverse_DS.pdf
22	Tejas	TJ1610		E1 matrix, over sized : VC4 matrix	40	600	*450*		11.3	http://www.tejasnetworks.com/products_mspp_TJ1610.html
23	Alcatel Lucent	1671-SC		**Frank Smyth:** Not told whether this is max or typ. Also, this includes switch only. Control shelf is further 341W and I/O	240	1246	*934.5*		3.9	http://www.alcatel-lucent.com/wps/DocumentStreamerServlet?LMSG_CAB
24	Fujitsu	Flashwave 9500		**Frank Smyth:** This is a packet optical convergence platform so may not fit in this grouping **Ward VH:** Indeed, doesn't really seem fit for metro. And is listed under the 'core networks' products from Fujitsu. So I've removed it from the chart	480	4200	800	19%	1.7	http://www.fujitsu.com/global/services/telecom/product/flashwave-9500.
25										
26										

Data base has been updated – available to Green Touch members on Kavi

Involved GT members: IBBT, DCU, BL

Targets and Challenges

- (a) Achieve 5x improvement in reach-dependent power consumption, mostly of power amplifiers, including pump lasers, pump drivers, TEC's in amplifiers, better utilization of amplifiers through maximizing fiber capacity
- (b) Achieve 5x improved efficiency at nodes (including subwavelength, wavelength switches, transmitter electronics and control/management electronics)
- (c) Achieve 1.5x (prot.) improved efficiency using optical restoration and physical layer reconfiguration—applies to routers & switches as well
- (d) Achieve 4x network efficiency using dynamic optical networks enabling the reduction of overprovisioning (x2 e) and the adaptive powering of network elements (x2)
- (e) Achieve 1.5x improved efficiency with passively cooled equipment and advanced thermal management techniques
    - Nota: overall efficiency improvement: (a+b)*c*d*e

WG related Projects/demos under discussion

- **Service Energy Aware Sustainable Optical Network project (SEASON)**
  - *Optimize application centers, dynamic optical transport using novel protocols and algorithms for most efficient delivery of high bandwidth services*
    - *Lab demonstration in year 3-4*
- **Half-Moon project**
  - *Optimize energy-efficiency of the optical layer through spectral efficiency adaptation, fast network reconfiguration and on-off capable devices*
    - *Lab demonstration in year 3-4*
- **Technology Demonstration: Energy Efficient Optical OFDM Networking (EFFICOST)**
  - **Lab transmission demonstration**
  - **Network Simulation analysis**
    - *Lab demonstration in 2012*

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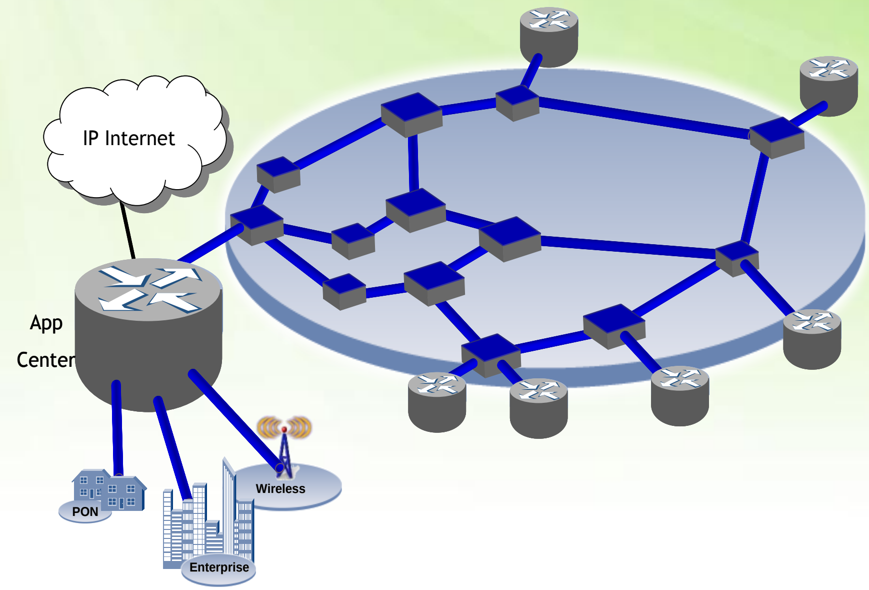
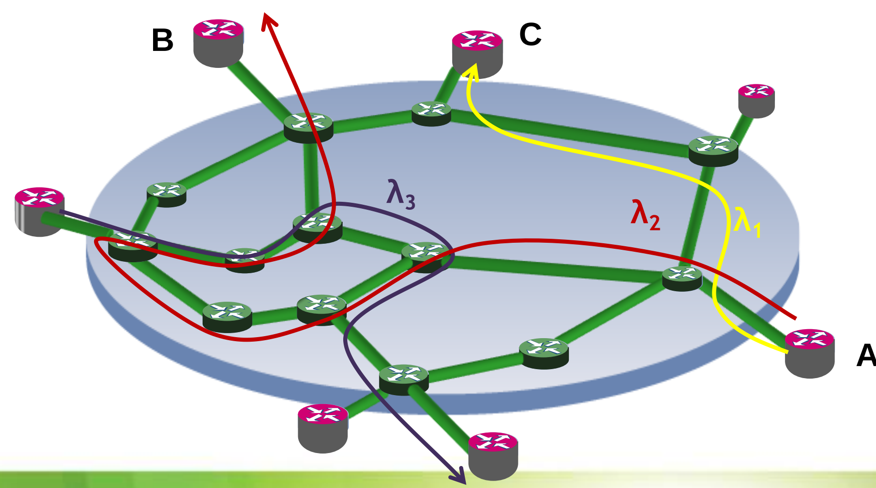
SEASON: Architecting an Energy-Efficient Service-Centric Network

Bell Labs, CEET, Columbia, INRIA, Toronto, UNSW

- SEASON is a clean-slate network design project focusing on opportunities to design networks for maximum energy efficiency through awareness of service requirements
  - Focus on services with high bandwidth
    - Elephant flow picture: 90% of traffic due to 10% of flows
  - Understand from clean-slate perspective how service requirements (bandwidth, duration, latency, multi-cast, security, protection,…) impact energy
  - Focus on core network dynamic functionality and connect with other groups and projects on transmission design, switching hardware





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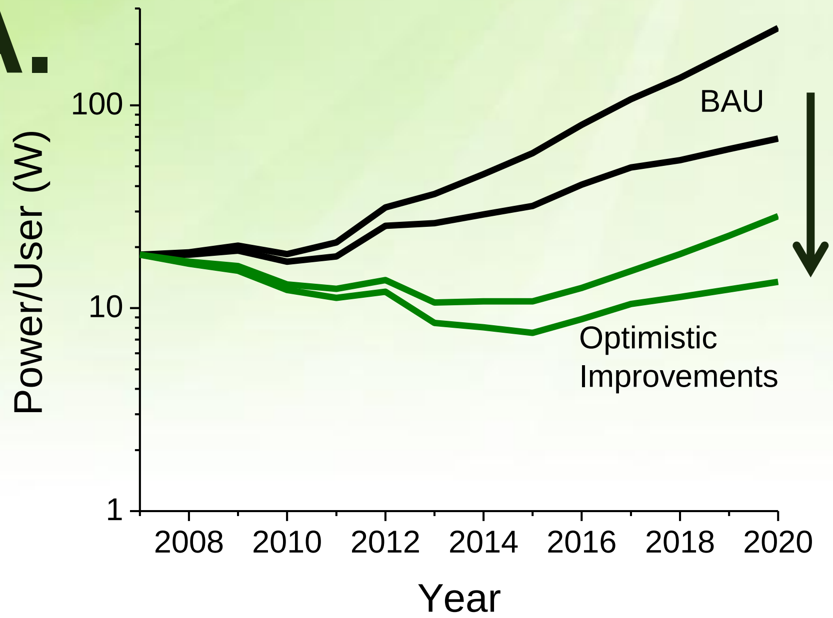
SEASON activities

- Dynamic wavelength switching: performance issues & efficiency benefits (BL, Columbia)
- Physical layer dynamics (BL, U. of Toronto)
- Energy efficient delivery of personalized media services (BL)
- Energy modeling of hybrid dynamic wavelength switched Networks (BL)
- SEASON reference network dimensioning (BL)
- SEASON project extension proposals:
  - Cross-layer scheduling algorithms and simulators (INRIA, BL, UNSW)
  - SEASON physical control dynamics (U. of Toronto, BL)
  - SEASON service protocol (BL, INRIA, UNSW)

Different Directions

A.



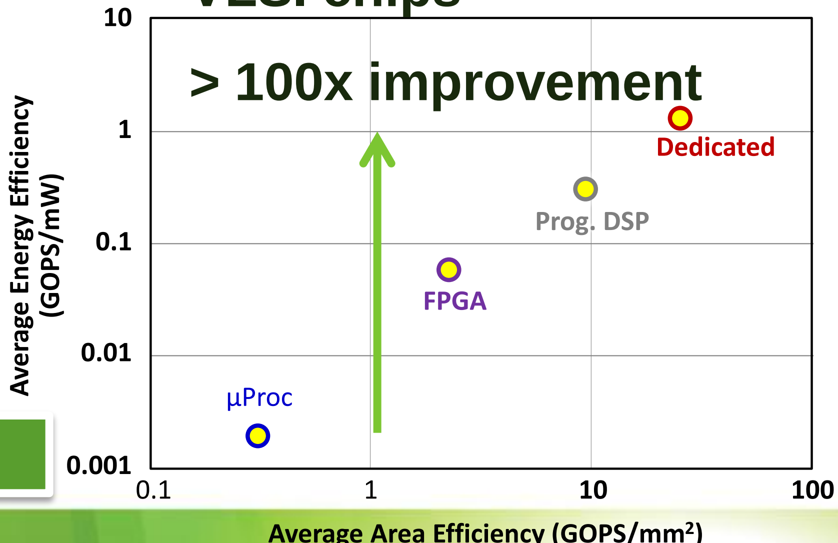
Energy follows load, maximum efficiency in today's network

< 10x improvement

Kilper, et. al., JSTQE 2011

VLSI chips

> 100x improvement



ISSCC & VLSI 1999-2011, averaged

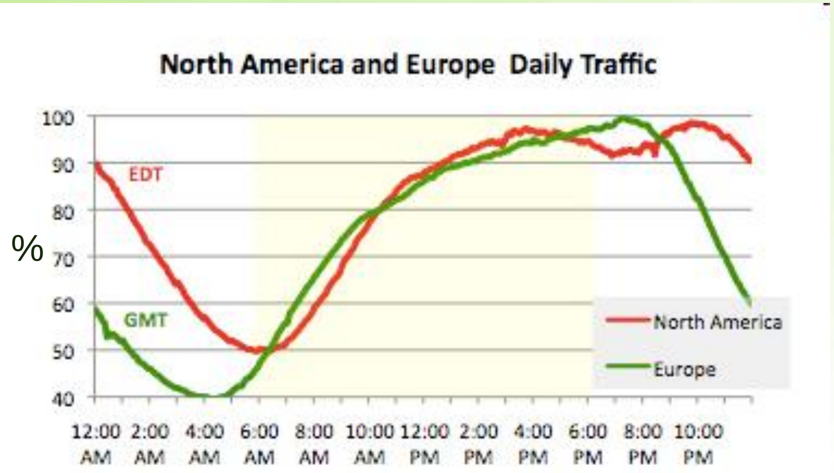
B.

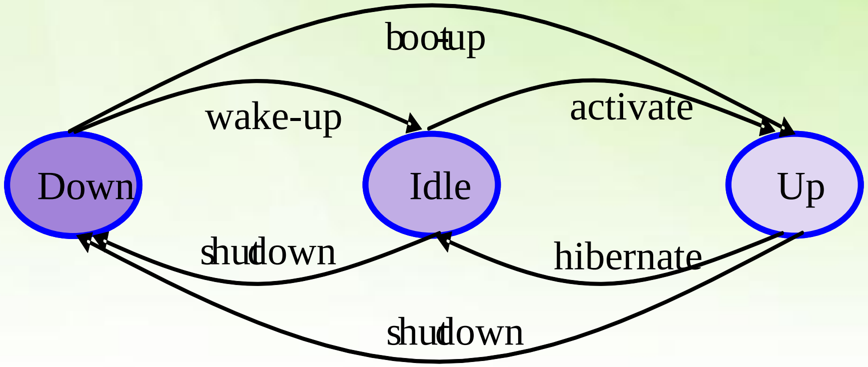
'Service aware', function specific hardware

Apply 'ASIC' concept to networks

HALF-MOON project status

Introduce smart sleep mode functionality inside transponders





C. Labovitz, **What Europeans do at Night**,
http://asert.arbornetworks.com

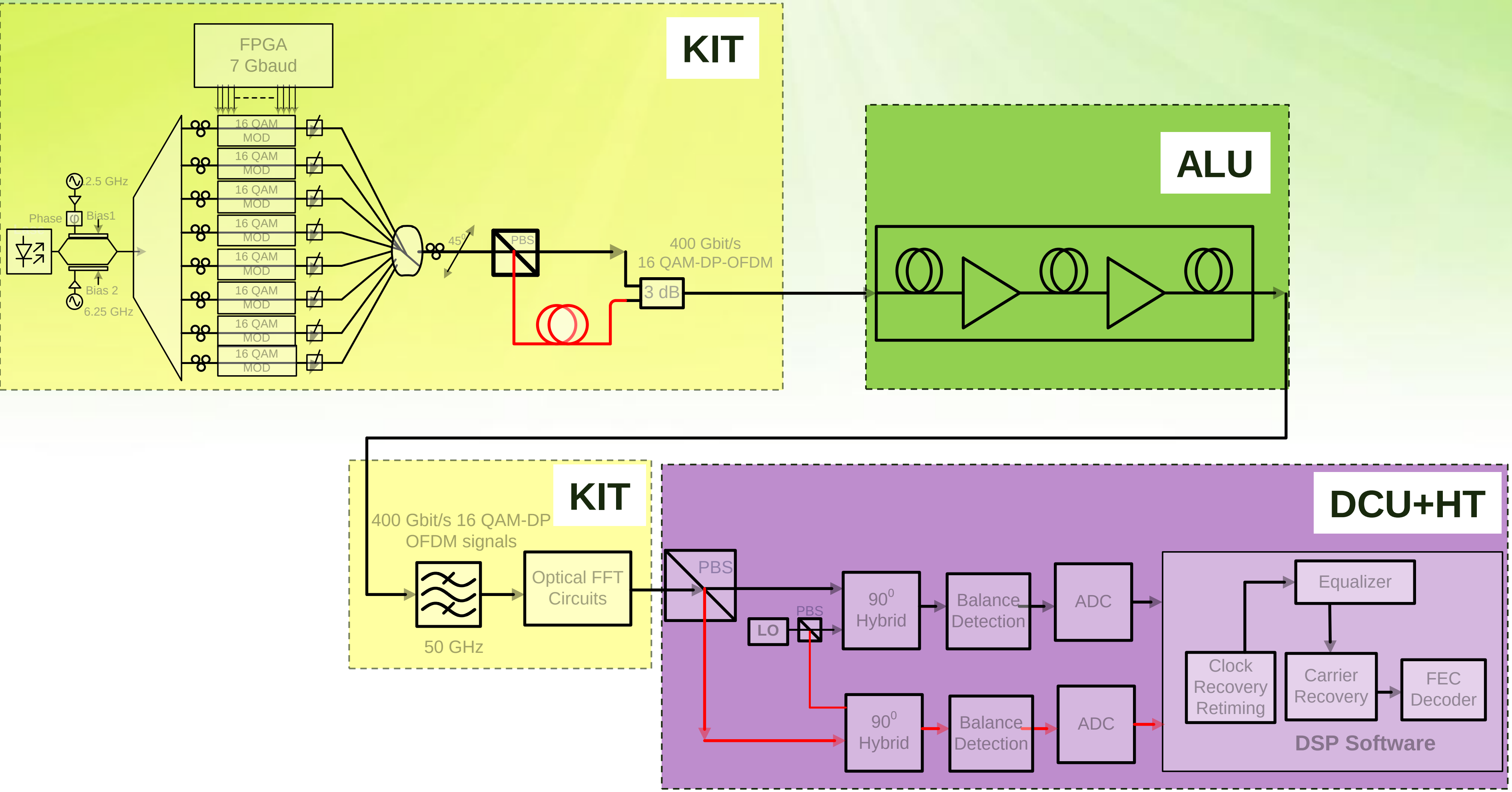
- **Enhancement of GMPLS protocols for enabling the power management of optoelectronic devices in the optical network**
- **Introduction of 3 power states: Up, Down and Idle**
- **Policy for the management of opto-electronic devices at different power states is introduced such as to guarantee a limited blocking ratio for high priority requests (gold class).**

Result: 56% energy savings observed when comparing energy requirements for the network managed with the proposed GMPLS protocol enhancement versus current GMPLS protocol set.

EFICOST: Energy Efficient High Capacity OFDM Signal Transmission

- Participants: Prof. J. Leuthold (KIT), Prof. A. Ellis (DCU), Prof. I. Tomkos (AIT), Dr. D. Kilper (BL), Dr. W. Shieh (UM), Dr. Y. Ye (HT)
- Design and implementation of a energy efficient 400 Gb/s wavelength OFDM transmission system
  - Using power efficient combline generators at the transmitter
  - Using optical FFT circuitry at the receiver to de-multiplex 400 Gbit/s OFDM signals requiring negligible energy
  - Estimating the overall energy efficiency on the system and the network level

400 Gbit/s Optical OFDM Transmission Systems



- ❑ Estimation of the overall network energy consumption
- ❑ Techno-economical study

AIT + UM

CONT WG - Identification of research gaps

- Analog processing vs digital processing
- No activity on cooling / thermal management yet
- Reduction of optical reach versus WDM capacity increase in coherent optical transmission

Thank You

www.greentouch.org