# TD 3.2: Energy-efficient design of core networks

On the Energy Consumption of IP-over-WDM Architectures

TREND Plenary Meeting
Ghent, 14-15/02/2012

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# Previous results…

- Power consumption comparison of three different transport network architectures
  - Basic IP-over-WDM (B-IPoWDM)
  - Opaque IP-over-WDM (O-IPoWDM)
  - Transparent IP-over-WDM (Tp-IPoWDM)
- Tp-IPoWDM exploits optical switching and performs grooming only when necessary
  - Reduces OEO conversions and electronic processing
  - T.IP-BG power saving up to 50% than the other architectures
- … more in-depth search looking at:
  - physical impairments: Translucent IPoWDM (Tl-IPoWDM)
  - impact of topological parameters (framework)

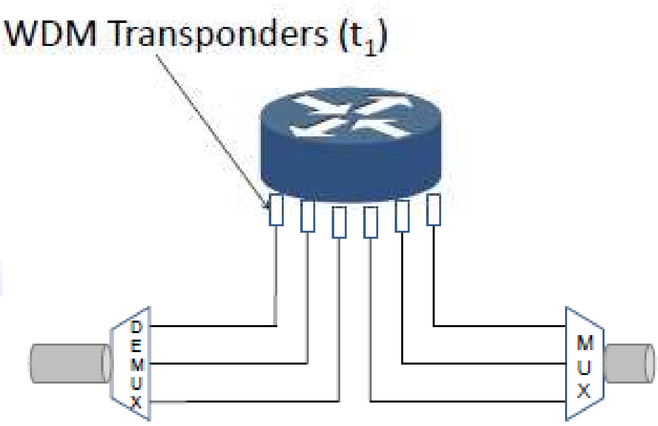
# Outline

- Architectures description (recall)
  - Basic IP-over-WDM (B-IPoWDM)
  - Opaque IP-over-WDM (O-IPoWDM)
  - Transparent IP-over-WDM (Tp-IPoWDM)
  - Translucent IP-over-WDM (Tl-IPoWDM)
- Power contributions
- Consumption model
- Case-studies
- Results
- Conclusion



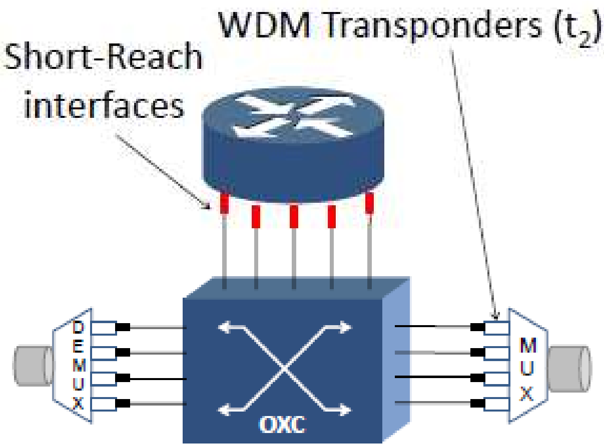
# Architectures description

- Basic IPoWDM (*i =1*)
  - OE + EO signal conversion and electronic traffic processing at *each hop* through WDM transponders ($t_1$)
  - Switching is *always* performed in the electronic domain
  - Signal regeneration at *each hop*



# Architectures description

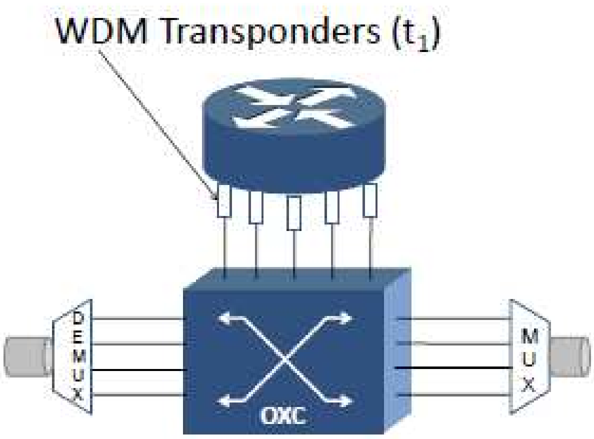
- Opaque IPoWDM *(i = 2)*
  - OEO signal conversion at *<u>each hop</u>* through WDM transponders ($t_2$)
  - *Electronic* processing & switching (in interm. nodes)
    - performed *<u>only when necessary</u>* (grooming)
    - → use SR-interfaces
    - otherwise, *optical* switching (OXC)
  - Signal regeneration at *<u>each hop</u>* ($t_2$ transponders)





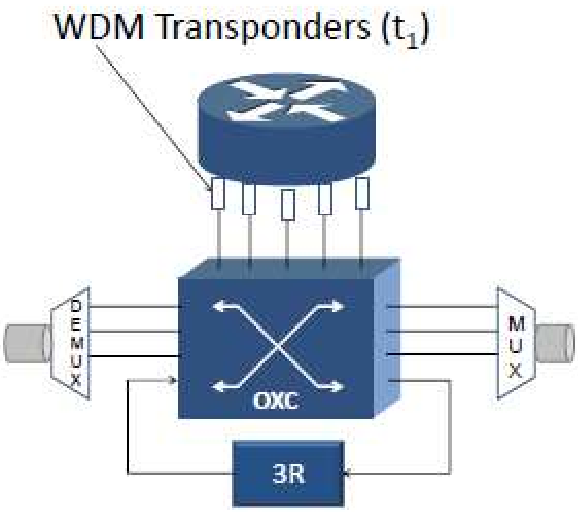

# Architectures description

- Transparent IPoWDM *(i = 3)*
  - *Electronic* processing & switching (in interm. nodes)
    - performed *<u>only when necessary</u>* (grooming and/or signal regeneration)
    - → use $t_1$ transponders
    - otherwise, *optical* switching (OXC)
  - <u>Remind</u>: max reach in the optical domain ~ 2000 km



# Architectures description

- Translucent IPoWDM ((*i = 4*)
  - *Electronic* processing & switching (in interm. nodes)
    - performed *only when necessary* (grooming)
    - → use $t_1$ transponders
    - otherwise, *optical* switching (OXC)
  - Signal regeneration performed in the WDM layer (3R-regenerators)
  - Remind: max reach in the optical domain ~ 2000 km






# Power contributions

- WDM transponders
  - $t_1$ : 34.5 W @10 Gbit/s ($P_{t_1}$)
  - $t_2$ : 18.3 W @10 Gbit/s ($P_{t_2}$)
- SR interfaces
  - 16.3 W @ 10 Gbit/s ($P_{SR}$)
- IP routers
  - 9280 W for a 640 Gbit/s rack ($P_r$)
- Optical Amplifiers (EDFAs)
  - 200 W for 40 wavelengths @ 10 Gbit/s ($P_A$)
- 3R-regenerators
  - 50 W for 1 wavelength @ 10 Gbit/s ($P_{reg}$)
- Optical switching (neglected)
  - 0.5 W for 1 wavelength @ 10 Gbit/s

# Consumption model

- Tuned parameters:
  - nr of nodes: $N$
  - average link length (km): $L$
  - average nr of hops: $H$
  - total aggregate traffic: $T$

NOTE: we consider regular networks identified by their topological parameters

- Constant inputs:
  - transparent reach: $\rho$ = 2000 km
  - amplification span length: $L_s$ = 80 km
  - link capacity: $C_{link}$ = 400 Gbit/s (40 λs @10 Gbit/s)
  - routers capacity: $C_r$ = 640 Gbit/s (1 rack)
  - WDM transponders, SR interfaces, 3R-reg: $C_{t_1} = C_{t_2} = C_{SR} = C_{reg}$ = 10 Gbit/s
  - average nodal degree: $n$=3
  - nr of links: $l=N*n/2$
  - devices consumption: $P_{t_1}$ , $P_{t_2}$ , $P_{SR}$ , $P_r$ , $P_A$ , $P_{reg}$



# Other inputs for all arch. ($i$ = 1,2,3,4)

- Fraction of intermediate nodes where electronic processing is performed: $h_i$
  - $h_i$ : computed with the results of previous ILP (TREND Paris meeting), i.e., electronic processing of O- Tp- and Tl-IPoWDM with respect to $P_e$ of B-IPoWDM:

$$\frac{P_e\{i\}}{P_e\{B-IPoWDM\}}$$

- Maximum load per source-destination pair in dynamic scenario that allows for P{blk}=$10^{-4}$: $\alpha_i$ (Erl)
  - $\alpha_i$ : computed by simulation in a network with # λ/link sufficient to accommodate a shortest-path connection per S-D pair

| | B-IPoWDM | O-IPoWDM | Tp-IPoWDM | Tl-IPoWDM |
|---|---|---|---|---|
| $h_i$ | 1 | 0.38 | 0.32 | 0.2 |
| $\alpha_i$ | 0.8 | 0.64 | 0.55 | 0.6 |

# Consumption model

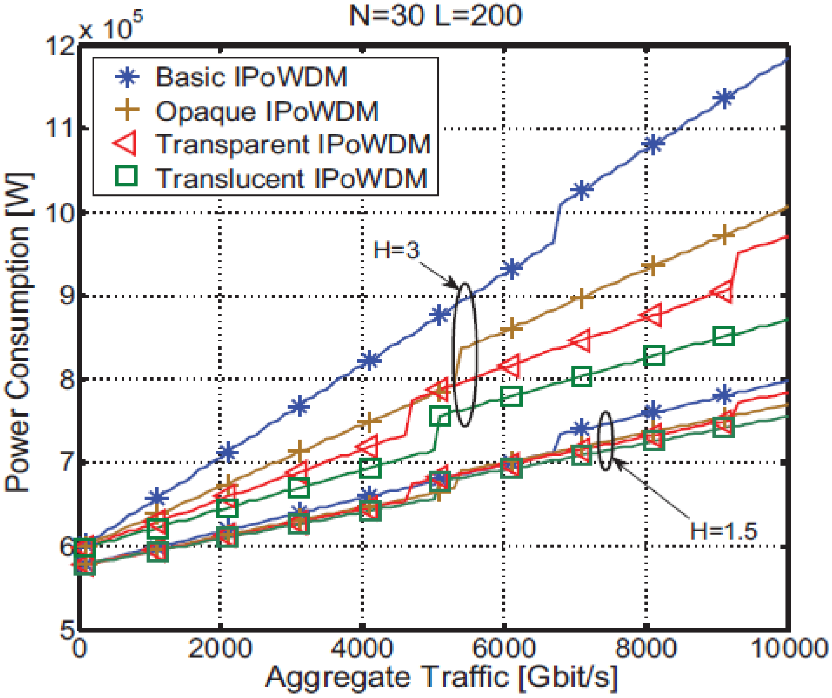
- Routers:
  - Source/destination + intermediate nodes
- Amplifiers (link)
  - 1 EDFA every 80 km + 2 at the edges (booster + pre-amplifier)
- Transponders
  - $t_1$ for B- Tp- and Tl-IPoWDM
  - $t_2$ for O-IPoWDM
- SR interfaces
  - computed like $t_1$ transponders
- 3R-regenerators
  - only for Tl-IPoWDM (<u>note</u>: it can also be accomplished in IP routers when grooming/degrooming is performed)



# Case-studies

- Regular networks identified by their topological parameters
  - Nr of <u>nodes</u> (*N*) & links (*l*), average nr of <u>hops</u> (*H*), average link <u>length</u> (*L*) …
- Tuned parameters (low vs high values)
  - *H*=1.5; *H*=3;
  - *N*=10; *N*=30;
  - *L*=200 km; *L*=2000 km;
- Get total power consumption for increasing aggregated traffic (*T*)
  - *T* is assumed as uniformly distributed among each nodes couple

# Results




Increasing *H* and *T*:

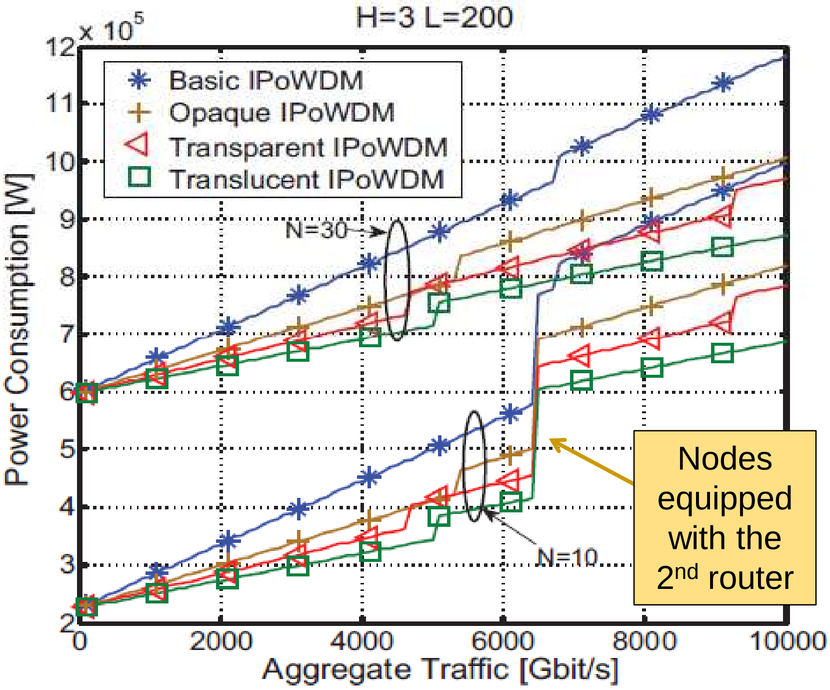
- consumption gap increases due to higher electronic proc.
- Tl-IPoWDM becomes more energy-efficient

Low *H* and *T*:

- Several 'windows' where the most energy-efficient architecture is not obvious



# Results

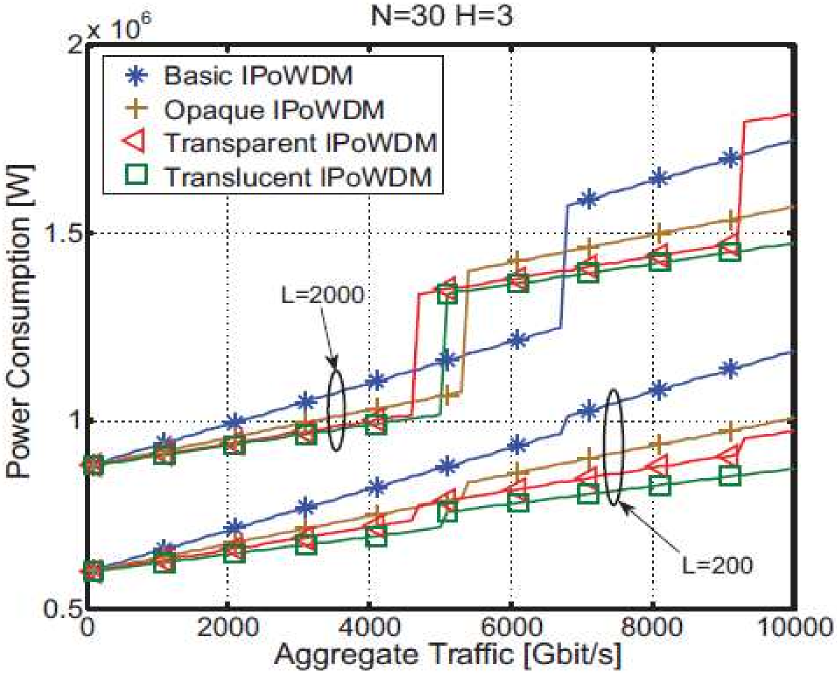



Increasing *N*:

- More routers (low-loaded) to be equipped in the nodes
- This difference vanishes for higher *T*

Varying *N* does not affect the choice of the most en-eff architecture (translucent)

# Results




Increasing *L* (km):

- More difficult to find the most en-eff architecture
- Trade-off regenerate vs capacity utilize ($P_{amp}$ dominates)

TI-IPoWDM is in general the most en-eff (always for low *L*)



# Conclusion

- Translucent is more energy-efficient than Transparent
  - in Tp-IPoWDM, signal regeneration accomplished at the IP layer even at high traffic loads when traffic grooming is unlikely to be performed due to high wavelength filling
- Transparent and Opaque often intersect (especially for high *L*)
  - Tp-IPoWDM is less energy-efficient as routers are used to regenerate signals (the difference between the Tp- and O-IPoWDM vanishes)
- Power consumption strongly depends on network parameters
  - *H*: affects electronic processing
  - *L*: affects EDFAs consumption
  - *N* (crucial only for low traffic): more routers lightly-loaded