Improving energy efficiency in passive optical networks with service guarantees

L. Valcarenghi[1], M. Chincoli[2], P. Monti[2], L. Wosinska[2], Neelakandan Manihatty Bojan[1], D. Pham Van[1], P. Castoldi[1]
1: Scuola Superiore Sant'Anna, Pisa, Italy - 2: ONLab, KTH, Kista, Sweden

Problem Description

Energy Efficient Light bulb (Compact fluorescent bulbs)

~20 W
(~100 W traditional light bulb tungsten filament lamps)
6 hours/day → 120 Wh/day

Gigabit Ethernet Optical Network Unit (ONU)

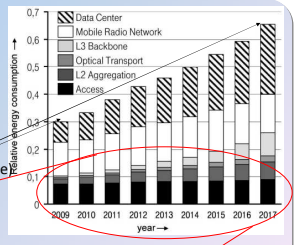
~10 W

24 hours/day → 240 Wh/day

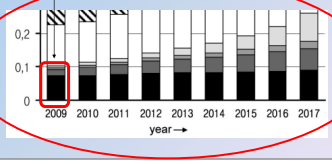
- Except home networks, access networks, together with mobile radio networks, are the major contributors to energy consumption in communications networks
  - Because of the high number of Customer Premises Equipments (CPE)
  - Because of the bandwidth underutilization

Access=Fixed Access Network= Fiber to the Exchange (FTTE) and Fiber to the Cabinet (FTTC): fiber + xDSL; FTTH (PON)

Home Networks (remaining percentage)



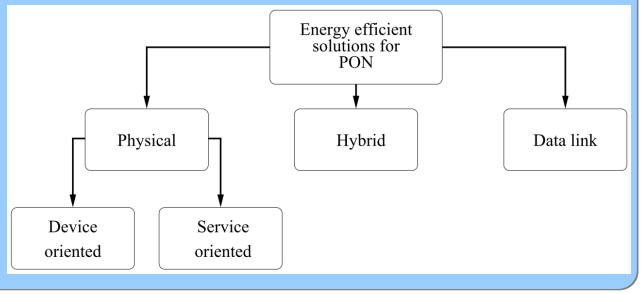
Wired Networks Access 80%



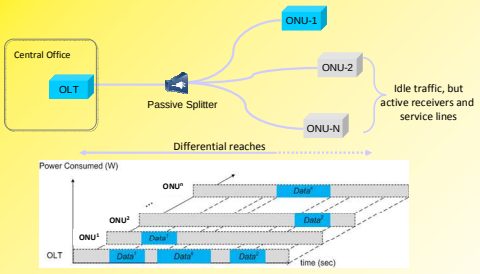
Source: C. Lange, D. Kosiankowski, R. Weidmann, and A. Gladisch, "Energy Consumption of telecommunication networks and related improvement options", IEEE JSTQE, March/April, 2011

Proposed Approaches

- *Physical layer* solutions target physical layer of PON architectures without modifying the upper layer protocols
  - *Device-oriented* solutions reduce energy consumption of physical devices
  - *Service-oriented* solutions improve the performance of the services provided by the physical layer to enable upper layer solutions
- *Data Link* solutions target the data link layer of the IEEE 802.3 architecture (i.e., the MAC layer) or the Transmission Convergence (TC) layer in GPON
  - Based on the possibility of switching network elements to a low power mode (e.g., sleep mode)
- *Hybrid* solutions are the ones that combine physical and data link layer solutions to reduce energy consumption (e.g., sleep mode and adaptive link rate).



Main Parameters



When to sleep

For how long

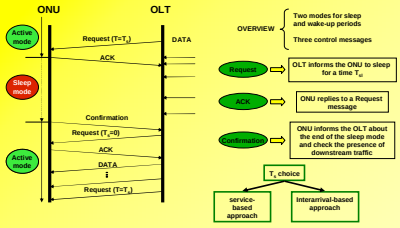
Maximize energy efficiency

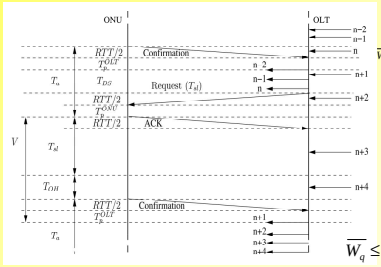
Gurantee QoS constraints (e.g.,delay)

Proposed Solution

Service based variable sleep period

- Service-based variable sleep period (initially proposed by R. Kubo, *et al.*, "Adaptive Power Saving Mechanism for 10 Gigabit Class PON Systems," IEICE Transactions on Communications, vol. 2, no. E93.B, pp. 280–288, 2010)
- Guarantee delay constraints to applications subscribed by ONU end-users
  - By computing the maximum allowed sleep time based on subscribed services and queueing theory system model





Modified SPW with service-based variable sleep period

POLLING SYSTEM WITH GATED SERVICE POLICY WITH IDENTICAL STATIONS

$$\overline{W_q} = \frac{\overline{V^2} - \overline{V}^2}{2\cdot\overline{V}} + \frac{\overline{V}\cdot(1+\lambda\cdot\overline{S})}{2\cdot(1-\lambda\cdot\overline{S})} + \frac{\lambda\cdot\overline{S^2}}{2\cdot(1-\lambda\cdot\overline{S})}$$

$$\overline{W_q} \approx \frac{\overline{V}}{2}$$

$$V = T_{sl} + T_{OH} + RTT$$

$$\overline{W_q} \approx \frac{V}{2} = \frac{T_{sl} + T_{OH} + RTT}{2}$$

$$\overline{W_q} \le IPTD$$

$\overline{W_q}$	Queuing delay
V	Vacation time=Idle time
S	Service time
N	Number of stations

Service Subscription → **Update IPTD (min IPTD)** → $T_s = 2*IPTD - T_{OH} - RTT$ → **Inform ONU T_{sl}**

Simulation Results

T_{sl}=197.2 ms

Input parameters			Simulation Results		
Service	$IPTD$ [ms]	IPDV [ms]	D [ms]	IPDV [ms]	η [%]
1	1000	1000	99.8(± 0.2)	277.9(± 0.3)	88.9 (±5.3X10^{-6})
2	400	1000	100.8(± 2)	277.1(± 2.5)	
3	1000	1000	99.7(± 0.05)	277.6(± 0.1)	
4	100	50	99.7(± 0.2)	277.7(± 0.3)	

T_{sl}=797.2 ms

Input parameters			Simulation Results		
Service	$IPTD$ [ms]	IPDV [ms]	D [ms]	IPDV [ms]	η [%]
1	1000	1000	400(± 0.1)	1112.4(± 0.4)	89.7 (±1.6X10^{-6})
2	400	1000	401.1(± 0.7)	1112.2(± 3.7)	

T_{sl}=797.2 ms

Input parameters			Simulation Results		
Service	$IPTD$ [ms]	IPDV [ms]	D [ms]	IPDV [ms]	η [%]
2	400	1000	399.9(± 1.4)	1111.7(± 2.7)	89.7 (±1.4X10^{-6})
3	1000	1000	399.7(± 0.1)	1112.8(± 0.1)	

IPTD = IP packet Transfer Delay
IPDV = IP packet Delay Variation

Parameters

One ONU
One OLT
Different QoS mix

Service Type	QoS Class	IPTD Delay [ms]	IPDV [ms]	Data Rate B_i [b/s]
Web Browsing	5	U	U	30.4k
Internet Relay Chat	3	400	U	1k
Multimedia on Web	4	1000	U	28.8k-500k
Voice over IP	0	100	50	5.3k-64k

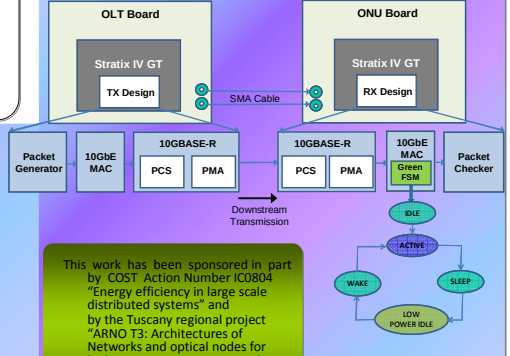
•"End-user multimedia QoS categories," ITU-T Recommendation G.1010, nov. 2001.
•"Network performance objectives for IP-based services," ITU-T Recommendation Y.1541, Dec. 2011.
• "Ethernet frame transfer and availability performance," ITU-T Recommendation Y.1563, Jan. 2009.

Parameter	Variable	Value
Overhead time	T_{OH}	2ms
Round-trip time	RTT	0.4ms
Power consumption in sleep mode	P_{sl}	1 W
Power consumption in active mode	P_a	10 W
Frame size	f_s	1250 B
Transmission rate		10 Gb/s

Summary

- Different service mix IPTD guaranteed
- Energy Efficiency maximized

Ongoing Work



This work has been sponsored in part by COST Action Number IC0804 "Energy efficiency in large scale distributed systems" and by the Tuscany regional project "ARNO T3: Architectures of Networks and optical nodes for high-capapcity transmission, the access-metro-core transport based integrated photonic technologies".

Testbed Implementation for Green Labeling

- Aims
  - Characterize the energy efficiency of proposed solutions
  - Develop new solutions for NG-PON2