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Power Efficiency of Next-Generation Optical Access Architectures

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Abstract: A theoretical model for the power consumption of access networks is presented. The analysis based on this model provides insights into optimal number of lines per equipment and the use of active vs. passive equipment.

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1. Introduction

Environmental sustainability has become an important social and business movement in the past years. Customer demand for environmentally sustainable solutions has increased and tougher regulations are being adopted. In March 2007, the European Council endorsed objectives of reducing Europe's greenhouse gas emissions by 20% from the 1990 levels by the year 2020 [1]. For some operators energy related costs, contribute to 50% of the network operating expenses, indicating great potential for energy efficiency [2]. The information and communication technologies (ICT) sector today accounts for 2-2.25% of the global CO2e emissions and this is expected to double by 2020 [2]. However, the ICT (Information and Communication Technologies) sector is also regarded as a potential solution to global climate change and a key for shifting to a carbon lean lifestyle. With the plentitude of architectural solutions for broadband access networks it is important to understand the relationship between access network architecture and power consumption. Existing architectures have been considered in [3]. In this work we identify some general relations between network architecture and network power consumption. In particular we consider location of active equipment in the access network and extrapolate to future architecture solutions.

2. Model for access network power consumption

A simplified access network model is considered in order to gain insights on architectural aspects of power consumption. A hierarchical model consisting of three levels is considered where Node 1 is the first aggregation point closest to the subscriber. In this work we focus on network power consumption excluding customer premises equipment (CPE) which is assumed to be similar for different architectures. Furthermore, we only consider raw power equipment consumption at the DC input (e.g. -48 V). Total site power consumption including rectifier losses and climate system consumption is obtained by multiplication by a site factor (~1.7). For the future discussion, we assume for simplicity that the split is equal to M at all nodes ($M_1 = M_2 = M_3 = M$).

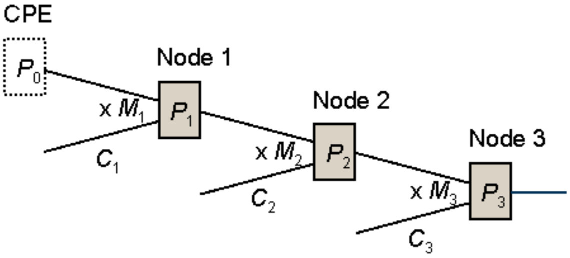

Figure 1: Schematic access network model where C_n is capacity and M_n is split.

For access systems, power consumption per subscriber reflects network power consumption. In our model, power consumption per subscriber is given by

$$P(M) = \frac{P_1(M)}{M} + \frac{P_2(M)}{M^2} + \frac{P_3(M)}{M^3},$$

where power consumption of each node can be modeled as $P_n(M) = k_n M + m_n$. Note that power consumption per node in our model increases linearly with number of connected ports. The coefficients k_n (increase per line) and m_n (baseline) are technology dependent. This simple model displays two important facts. For active equipment further from the subscriber and higher in the network hierarchy, power consumption is shared among more users, leading to a reduced contribution to the network power consumption. At the same time, for equipment higher in the network hierarchy, increased capacity is required, leading to increased per node power consumption. Hence, which part of the access network that dominates power consumption depends on the detailed balance between the split ratio at each network level and the increased node power consumption due to increased capacity requirements.

As a reference system we consider a point-to-point (P2P) access network with Fast Ethernet (FE) access (C_1=100 Mbps) to subscribers. Aggregation from Node 1 to Node 2 is through giga-bit Ethernet (GbE) with C_2=1 Gbps. Aggregation from Node 2 to Node 3 is 10GbE (C_3=10 Gbps). For the considered P2P system we note that for each step higher in the network hierarchy, the number of users sharing a node increases by a factor M while the capacity increases by a factor N=10. The increased capacity leads to an increased node power consumption as illustrated in Table 1. Table 1 shows how the power consumption parameters, k_n and m_n, depend on technology. The parameters for Node 1 and 2 were extracted from the EC code of conduct for 2010 [4]. Using the extracted power consumption coefficients we calculate the network power consumption per subscriber and per level (Figure 2a). Figure 2b shows the relative power consumption of the different levels. Note that for any reasonable split ratio, the network level closest to the subscriber represents the largest contribution to the power consumption. In conclusion, for the considered P2P system, when comparing power consumption of different network levels, we note that reduction of power consumption due to increased split is more significant than the increase in power consumption due to higher capacity. Efforts to reduce power consumption should therefore target level 1 in the access architecture.

Table 1. Parameters for P2P node power consumption based on [4].

	k_n	m_n
Node 1	~0.5 W	~30 W
Node 2	2.9 W	111 W
Node 3	14 W	168 W

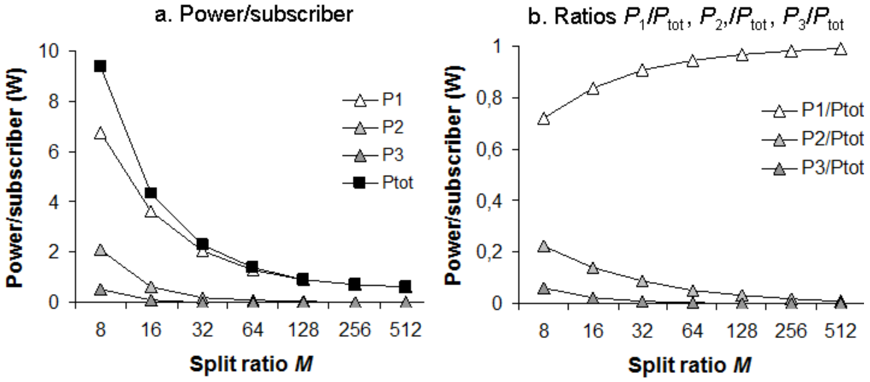

Figure 2. Graphs show for P2P access, (a) network level and total power consumption per subscriber depending on split M, and (b) relative size of power consumption for different network levels depending on M.

4. Passive optical networks

Ideally the active equipment at level 1 is removed. This scenario is enabled by passive optical networks (PON) which provide a powerful point-to-multipoint solution to the increasing capacity demand in the access part of the communication infrastructure. A PON consists of an optical line terminal (OLT) located at the provider central office and a number of optical network terminals (ONTs) at the customer premises. The ONTs are connected to the OLT via a single fiber which is fanned out by a passive optical splitter to each connected ONT. In a fiber-to-the-home (FTTH) arrangement the passive splitter replaces the active equipment at level 1. As a penalty, Node 2 requires increased functionality leading to increased power consumption. Again we are presented with a trade off related to the placement of active equipment (or power consumption) in the access architecture. And again we note that by moving power consuming functionality higher up in the network, total power consumption is decreased as seen by comparing Figure 2b and Figure 3. PON introduces a number of important changes to the network. The PON provides giga-bit links to the subscriber. Hence, even though the P2P and PON networks may be dimensioned for the same average traffic load, PON provides support for increased peak rates. In addition, a large amount of broadcast traffic can be put in the system as each subscriber has giga-bit capable connections.

5. Next-generation networks

Considering the fact that over-all power consumption is decreased by moving active functionality higher up in the access network architecture, how should future generations of access networks be constructed? Two potential solutions will here be discussed. The natural continuation of PON, is to increase the line rate and replace Node 2 by another passive splitter with a penalty of increased power consumption at Node 3 (Table 2). This solution further increases the peak rate service to 10 Gbps. Due to limits in the optical budget, the solution is however not feasible without use of reach extenders (RE). Several solutions for reach extension exist such as semiconductor optical amplifiers (SOA), optical electrical optical conversion (OEO), and remote protocol termination (RPT). Hence, some active equipment must remain at Node 2. Reach extenders are here used both for increasing the reach and the split. Depending on RE solution the architecture allows for different degrees of power consuming functionality to be moved from Node 2 to 3. Figure 3 presents results using estimates for OEO as RE and power consumption values from [4] for current generation multiplied by a factor ($\alpha_{10G\text{-}PON}$) representing the increased power consumption of the OLT due to the increased line rate. This factor was extracted from [4] for the P2P OLT. We have assumed a maximum TDM split of 128, corresponding to $M=\sqrt{128}=11.3$. The second solution is a hybrid wave-length division multiplexing (WDM) / time-division multiplexing (TDM) PON, with the conventional PON line rate, but where the OLTs are moved to Node 3, and Node 2 is replaced by a passive AWG (Table 2). This solution requires less degree of power amplification. However, it does not increase the TDM split and peak rate in the system as the previous scenario and service for a given M is comparable to service within the original PON architecture considered in section 4 for the same M. Figure 3 presents results using values for TDM-PON from [4] where the maximum WDM split is assumed to be 32. Note that this solution potentially would benefit more than other solutions from future photonic and electronic integration with reduced PON port power consumption ($\alpha_{WDM/TDM\text{-}PON}$) not included in Figure 3. Hence, results presented in Figure 3 show a comparison of the worst-case scenarios for PON OEO and hybrid WDM/TDM PON. The future power consumption of these architectures will depend on the evolution of power consumption for a 10G-PON port ($\alpha_{10G\text{-}PON}$) and a WDM/TDM PON port ($\alpha_{WDM/TDM\text{-}PON}$) in terms of current generation PON [4] with future electronic and photonic integration.

Table 2. Specification of configurations

	Node 1	Node 2	Node 3
P2P	FE switch	GbE switch	10GbE switch
PON	Passive splitter	OLT	10GbE switch
LR-PON	Passive splitter	RE + passive splitter	OLT
WDM/ TDM-PON	Passive splitter	RE+AWG	OLT

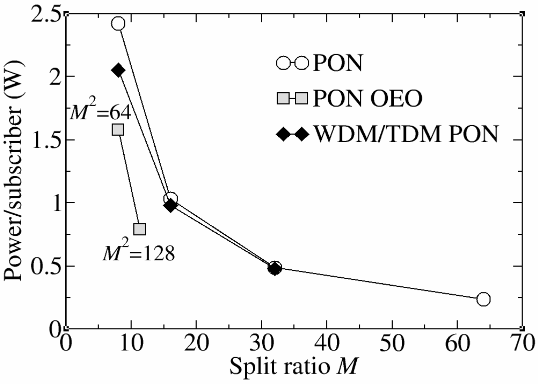

Figure 3. Comparison of configurations

5. Conclusions

PON is a favorable access technology in terms of power efficiency. This can be understood in terms of location of active equipment in the access network where PON leads to benefits in terms of power savings of electronic integration. We extract some basic principles for power efficiency in access networks and extrapolate to future network scenarios including long-reach TDM PON with increased split and hybrid WDM/TDM PON. Both long-reach TDM PON with increased split and hybrid WDM/TDM PON show potential for improved power efficiency through electronic and photonic integration.

6. References

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