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INTEGRATED OPTICAL AND WIRELESS ACCESS NETWORKS: FROM THE ENERGY CONSUMPTION PERSPECTIVE

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ABSTRACT

Integrated optical and wireless technologies is one of the emerging access network solution that offers to combine the robustness and high capacity of optical networks with the mobility and ubiquity of wireless networks. This article reviews the potential of integrating the wireless and optical access networks for future broadband access networks taking into account the energy consumption and energy modeling for evaluating the energy efficiency of such networks.

Keywords: broadband access networks, energy consumption, energy efficiency.

INTRODUCTION

Over the last three decades, research and technology on Passive Optical Network (PON) have been explored, resulting in the wide deployment of this technology to implement various Fiber-to-the-x (FTTx) solutions which deliver high bandwidth to the users at reduce cost and low energy per bit. However, since 2007 International Telecommunication Union-Telecommunication Sector (ITU-T) and Institute of Electrical and Electronics Engineers (IEEE) are discussing the future solution for PON with extended data rates in order to meet broadband consumer demand (Effenberger *et al.* 2007), (Zuoqian, 2008). They proposed next generation PON (NG-PON) where the planning was divided into two phases; NG-PON1 and NG-PON2. NG-PON1 is expected to deliver data rates up to 10 Gbps based on the existing Gigabit-capable PON (GPON) legacy whereas NG-PON2 include research area of time and wavelength division multiplexed PON (TWDM-PON) which capable to provide data rates no less than 40 Gbps. The next generation optical access networks showing trends of deploying optical fiber all the way to the customer premises. However, challenges exist where cost of deployment and maintenance is very significant. On the other hand, wireless access technologies support mobility and untethered access and provide ease of deployment and cost effectiveness. Unfortunately, wireless access is constrained due to strict bandwidth limitation. Combining the complementary feature of these two technologies (optical and wireless) can potentially provide ubiquitous broadband access to satisfy future user demand.

The works and research on the integration of optical and wireless access networks have begun around the year of 2009. Alcatel-Lucent have considered to leverage GPON for mobile backhaul network (Alcatel-Lucent 2009) due to the growing demand for bandwidth hungry applications and services which resulting in significant increase in the cost of deployment. This is because current mobile backhaul network is not cost effective since the cost scale linearly with bandwidth. Therefore, future broadband access network not only have to provide access to information anytime anywhere, but also help to meet the cost challenges of supporting 3G services while effectively preparing for future Long Term Evolution (LTE) networks (Alcatel-Lucent 2009). These solutions leverage the integration of GPON triple play network and wireless technologies to provide effective tetherless connectivity and cost effective at high bandwidth transmission. Such integration will also provide the advantages of optical fiber capacity and wireless communication mobility (Chowdhury *et al.* 2014), (Maier, 2014), (Luo *et al.* 2006).

Despite its ever increasing capacity and ability to support new bandwidth intensive applications, high energy consumption of the access network infrastructure demands particular attention. It is well known that access networks has significant contribution in the network related energy consumption and hence responsible for substantial percentage of CO2 emissions. With the continuous growth of wireless users and traffic volumes, its energy consumption is estimated to grow of about 12% per year (Ricciardi *et al.* 2013). Consequently, energy efficiency has become one of the important aspects worth to be considered by the service and network providers due to the both the increasing operational costs related to energy consumption and increasing awareness of global warming and climate change.

Most of the research in the integrated optical and wireless access networks focuses on the physical (PHY), medium access control (MAC) and network layers with the goal to develop and investigate low cost enabling technologies as well as Layer 2 and 3 protocols and algorithms. However, as access networks have been reported to dominate the energy consumption of the Internet thus gives significant contribution in greenhouse footprint, the design of energy efficient "green" optical wireless access networks has gained scholarly attention. Unfortunately, the potential of the integration wireless with the existing fiber based PON in terms of power consumption in the physical layer remains significantly unexplored. Most published works consider the optical and wireless access networks in terms of energy

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consumption separately where some compare the energy performances between those access networks. The network energy modeling can provide information on energy consumption of the considered access technologies. Accordingly, energy performance optimization, network architecture improvement and other network parameters enhancement can be applied to those particular access technologies. To the best of our knowledge, only few publications (Aleksic *et al.* 2013), (Gowda *et al.* 2014), (Ricciardi *et al.* 2013) have addressed the task at modeling the energy consumption of integrated optical wireless networks, in which (Gowda *et al.* 2014) provide energy model for in-building network instead of access networks.

WIRELESS INTEGRATION TO OPTICAL ACCESS NETWORKS

Residential users are increasingly accessing bandwidth hungry services such as Internet access, video streaming and other online applications (Alcatel-Lucent 2009). With advanced technology provided by the mobile operators such as tablet pc and smartphones, demand from broadband users to access Internet services changing and they start asking for access to their services anywhere. Forecast for consumption volumes of Internet traffic in the period until 2018 as depicted in Figure-1 shows that in 2013, approximately one third of the total web traffic was generated by mobile and portable devices (or non PC devices). In 2018 this figure will rise to 57%. Furthermore, trends have shown that traffic from wireless and mobile devices will surpass traffic from wired devices by year 2018. Wireless networks such as Wireless Fidelity (Wi-Fi) and cellular networks will have 61% share of all IP-traffic in 2018 while the remaining 39% will be fixed transmission line (Cisco VNI : Forecast and Methodology , 2013 – 2018, 2014). This shows that traffic from wireless devices will exceed traffic in wired devices in the near future. Therefore, leveraging both high capacity optical access networks and mobility of wireless access network by converging them is expected to support emerging broadband applications and services.

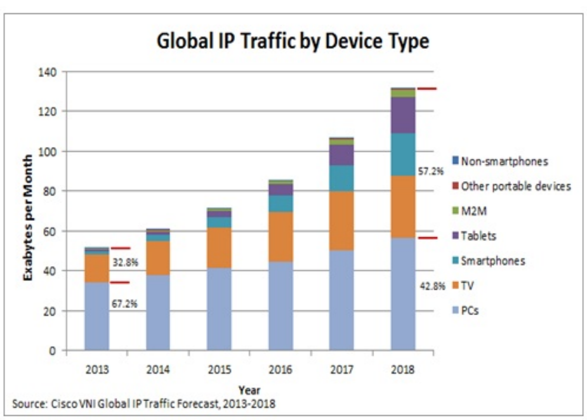

Figure-1. Global IP traffic forecast by device type from 2013 to 2018.

The integration of optical backhaul and wireless front-end in the literature is known through several names, hybrid optical wireless access network (HOWAN) (Chowdhury *et al.* 2014), fiber-wireless (FiWi) (Maier 2014) and wireless optical broadband access network (WOBAN) (Shaddad *et al.* 2014). In this paper, similar terminology as the source will be used to maintain consistency between this survey and the references. The hybrid optical and wireless access networks are realized by integrating wireless access technologies, for example, cellular, WiFi, WiMAX and LTE with the installed optical fiber infrastructure. While WiFi is based on IEEE 802.11 standard, WiMAX is an access technologies based on IEEE 802.16 standard. WiFi provides several bit rates according to its standardization in which the minimum bit rate is 54 Mbps for IEEE 802.11a and maximum bit rate is 600Mbps for IEEE 802.11n with limited range of 100-200m. On the other hand, a WiMAX base station (BS) can support a total data rate up to 75Mbps to residential and business users within 5km range (Shaddad *et al.* 2014). LTE is one of the emerging radio technologies where it provides theoretical uplink peak data rates of 75Mbps and the downlink data rate of 300Mbps using advanced antenna techniques such as multiple input multiple output (MIMO).

METRICS TO EVALUATE ENERGY PERFORMANCE

In the process of studying, investigating and evaluating energy in optical communication network particularly at access network, various metrics have been introduced in order to describe the energy performance of such networks. Some of the metrics to describe energy performance of access networks are energy/power consumption, energy estimation, energy saving and energy efficiency. Energy/power consumption is used to describe the amount of energy consumed in which it is typically measured within a specified period of time (i.e. Watt-hour). Energy consumption in the access network is usually defined as power per user. On the other hand, energy estimation is used to estimate energy consumption and compare the energy performance in different type of access networks. In order to reduce the energy consumption of access network, several power saving methods have been introduced. Therefore, energy saving metric is used and represented in percentage to show how much power saving is achieved when power saving method is applied. Finally, energy efficiency is “using less energy to provide the same service”. This shows that in order to reduce energy consumption of access networks, quality of services should not be compromised.

There are several methods to evaluate energy efficiency in the access networks. The energy efficiency of the access networks can be defined as the energy consumed per bit of data transferred (Baliga *et al.* 2008). Therefore the metrics to measure energy efficiency is the bit/energy (b/J). This parameter allows the energy efficiency quantification as well as the identification of the improvement when applying a novel proposal. There are

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several reported works (Aleksic *et al.* 2013), (Lambert *et al.* 2014), (Newaz *et al.* 2013) on evaluating energy efficiency of access networks where the detailed energy modeling will be discussed in the next section. The authors in (Aleksic *et al.* 2013), (Newaz *et al.* 2013) used bit/energy as the metric to evaluate energy efficiency. However, (Lambert *et al.* 2014) has evaluated the energy efficiency by using network dimensioning approach where they proposed three stage power consumption analysis. The three stages are PON dimensioning based on technology reach and capacity, user demands and QoS requirements, city deployment algorithm and power consumption calculation.

POWER CONSUMPTION MODEL FOR ACCESS NETWORKS

Power consumption measurement of optical and wireless networking devices have rarely been performed in the past. This, in turn, led to unrealistic and/or oversimplified models being used in simulations. Typically, power consumption for optical and wireless access networks have been assessed separately. Although integrated optical and wireless access networks have received considerable attention for future broadband access networks, energy/power consumption for this network remains unexplored. To the best of our knowledge, only (Aleksic *et al.* 2013) have reported work on evaluating energy consumption of this integrated network and their model will be discussed further in this section.

Basically, the energy models reported in the literature can be classified into three different types; theoretical model, analytic models and empirical models. In theoretical models, the energy consumption is expressed as a function of the load that tries to follow the trend of real devices power consumption. Thus, this model simply describe the energy consumption at an higher abstraction level without providing detailed energy consumption for each subsystem or component. On the other hand, analytic models used mathematical description of the operating environment of the network elements to defined the energy consumption. Meanwhile, empirical models rely on known energy consumption values of real world devices whether based on values extracted from manufacturer's datasheets or on some experimentally measured values.

Generic power consumption model

A theoretical energy consumption model was presented in (Baliga *et al.* 2008) which is one of the earliest work found in analyzing energy consumption in access network. Their power consumption model as expressed in equation.1 is generic and can be applied in wired and wireless access network. The model then has been extensively used in several reported works for evaluating the energy consumption performance in different access networks.

$$P_{user} = 2\frac{P_{TU}}{M_{TU}} + 2\frac{P_{RN}}{M_{RN}} + P_{CPE} \quad (1)$$

P_{user} = power consumption per user,
P_{TU} = power consumed by terminal unit (TU),
P_{RN} = power consumed by remote node (RN),
P_{CPE} = power consumed by the customer premises equipment (CPE),
M_{TU} = number of users that share TU
M_{RN} = number of users that share RN

Therefore, for example if the model wants to be applied for PON, TU will be the OLT, RN is the splitter and CPE is the ONU whereas for wireless, TU will represents the Ethernet switch, RN is the base station and CPE is the modem.

Power consumption model for PON

In PON, most of the reported works found in the literature used analytical approach in the modeling of the energy consumption. Authors in (Lambert *et al.* 2013), (Skubic *et al.* 2012) have proposed power consumption model for NG-PONs. (Skubic *et al.* 2012) have model power consumption by dividing ONU and OLT into two categories; common baseline and system specific. The model for energy consumption is illustrated in Figure-2. The total energy consumption is calculated from the contribution of baseline, system specific and DC-DC loss for ONU and reach extenders (REs) and additional site factor for OLT and RN.

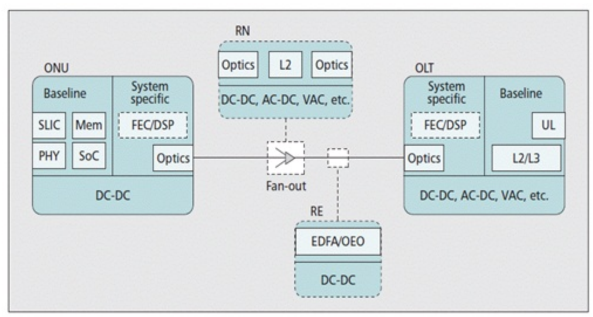

Figure-2. Model for energy consumption comparison by (Skubic *et al.* 2012).

Meanwhile (Lambert *et al.* 2013) have specified that the power consumption of access networks consists of:

- Power consumption of the ONU
- OLT PON ports: #OLT PON ports x power consumption per port
- General OLT function: #OLT chassis x PON/chassis x bandwidth (US+DS) x 1W/Gb/s
- Uplink ports: #OLT chassis x uplink energy consumption.

The schematic overview of their model is presented in Figure-3. They estimated the total power consumption based on their proposed model by using network.

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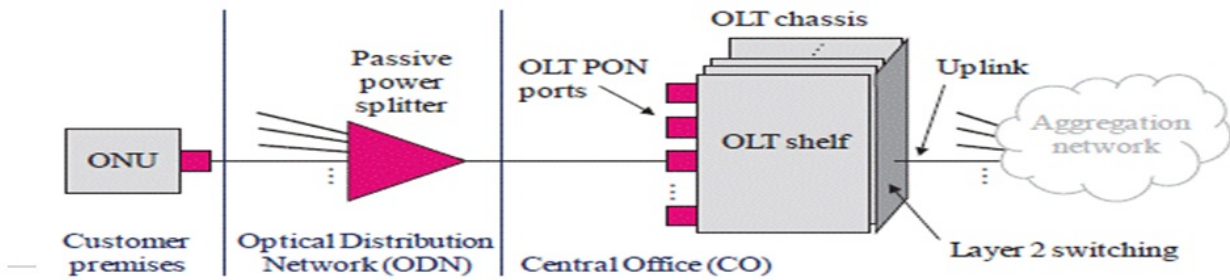

Figure-3. Schematic overview of the access networks and its power consumption components by (Lambert *et al.*2013).

Dimensioning approach which consists of PON dimensioning based on user demand and quality of service (QoS) parameters and city deployment algorithm.

Power consumption model for wireless access

In wireless access, analytical and empirical approach have been used to define energy consumption of such networks. For example, (Deruyck *et al.* 2011), (Yang, *et al.* 2011) have reported the analytical power consumption model for wireless access networks. They consider power consumption of base stations (BSs) only since they are responsible for roughly two-thirds of the total CO2 emissions of these radio access networks. The model provided by (Deruyck *et al.* 2011) is based on the power consumption by each component within the BS as follows:

$$P_{el} = \eta_{sector} \cdot \left(\eta_{TX} \cdot \left(P_{el/amp} + P_{el/trans}\right) + P_{el/proc} + P_{el/rect}\right) + P_{el/micro} + P_{el/airco} \quad (2)$$

P_{el} = power consumption of the BS,
η_{sector} = number of sectors in the cell,
η_{TX} = number of transmitting antennas per sector,
$P_{el/amp}$ = power consumption of the power amplifier,
$P_{el/trans}$ = power consumption of the transceiver,
$P_{el/proc}$ = power consumption of the DSP,
$P_{el/rect}$ = power consumption of the rectifier,
$P_{el/micro}$ = power consumption of the microwave link,
$P_{el/airco}$ = power consumption of the air conditioning

In the meantime, (Yang *et al.* 2011) has provided model for power consumption of RoF BS for different wireless signal transport scheme, namely baseband-over-fiber, analog RF-over-fiber, analog IF-over-fiber, digitized IF-over-fiber, and digitized RF-over-fiber. The power consumption model for baseband-over-fiber is expressed as:

$$P_{BBOF} = \eta_{sector} \times \left(P_{TX}/\mu_{PA}/L_{feeder} + P_{BBU} + P_{DDC/DUC} + P_{ADC/DAC} + P_{DPD} + P_{RFU} + P_c\right) \times (1 + L_{PS}) \times (1/\mu_c) \quad (3)$$

P_{BBOF} = power consumption of baseband-over-fiber,
P_{TX} = transmitting power,
μ_{PA} = power amplifier efficiency,
L_{feeder} = feeder loss,
L_{PS} = power supply loss,
μ_c = cooling efficiency,
P_{BBU} = power consumption of the baseband unit,
$P_{DDC/DUC}$ = power consumption of the digital up/down converter,
$P_{ADC/DAC}$ = power consumption of the analog-to-digital and digital-to-analog converter,
P_{DPD} = power consumption of the digital pre-distorter,
P_{RFU} = power consumption of the RF unit
P_c = power consumption of the clock management

Other BS architectures used similar model but not all components in the model are involved.

Empirical power consumption model have been presented in (Halperin *et al.* 2010; Tauber *et al.* 2011; Gomez *et al.* 2012). In (Halperin *et al.* 2010), the experiment is aimed at assessing the impact of a certain features (e.g. channel width, transmission power, modulation and coding schemes, etc.) has on the global energy consumption figures. In (Tauber *et al.* 2011), the authors present a joint experimental evaluation of energy consumption and performance in IEEE 802.11 based WLAN. The authors have exploited an application level approach, varying the packet size and transmission rate and evaluating energy consumption across a wide transmission rate. Other works have been reported by (Gomez *et al.* 2012) presented measurement-based methodology for characterizing the energy consumption behavior of networked wireless devices. They derived their energy consumption figures as a function of (i) the traffic load, (ii) the modulation and coding schemes and (iii) the size of the datagrams used.

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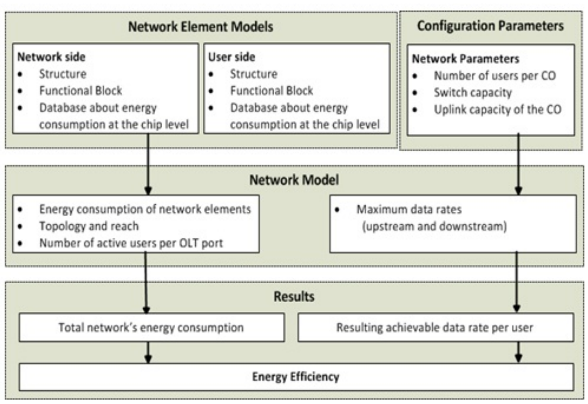
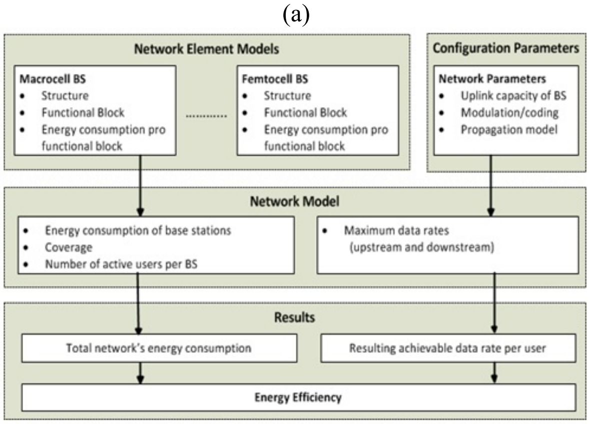
Energy efficiency for quantifying energy performance

Apart from energy consumption, another metric involves in energy issue is energy efficiency (EE). Common metric applied for evaluating EE is bit/energy (bit/J). The model reported in (Aleksic *et al.* 2013), (Aleksić & Lovrić, 2010), (Newaz *et al.* 2013) have evaluated EE of access networks. (Newaz *et al.* 2013) have focused on evaluating EE at ONU. They provides analytical model to obtain EE where energy consumption is obtained by multiplying the power consumed in downlink and uplink transmissions for different period of time known as observation period. Then, they calculated the total transmit and receive bits and finally obtained the energy efficiency by dividing it with the energy consumption value.

Contrary, (Aleksić & Lovrić 2010) presented model for energy efficiency of wired access network as a whole. Their model is depicted in Figure-4 (a) where EE is obtained by dividing the achievable data rate per user by the total energy consumed by a single user. They extend their work in (Aleksic *et al.* 2013) by assessing EE for combined wireless/optical access networks. They use similar model as previous work for optical access network whereas the model for wireless access is depicted in Figure-4 (b).



(a)



(b)

Figure-4. Model for evaluation of energy efficiency by (Aleksic *et al.* 2013; Aleksić & Lovrić 2010) for (a) Optical access networks and (b) Wireless access network.

CONCLUSIONS

This paper overviews the access networks that leverage both optical and wireless technologies in order to support bandwidth demand fueled by the tremendous growth of the Internet in terms of number of users and the amount of data transferred. Apart of meeting the requirement for high capacity, high speed and long reach access networks, research efforts have considerably been focused on designing and developing energy efficient next generation access network based on PON. Furthermore, current research direction have developed significant interest towards integrating optical and wireless access networks so that the advantages of high capacity optical network and high mobility wireless networks can be fully exploited. However, the potential of this integrated access technologies in energy point of view is not fully explored. Future direction may consider the evaluation of energy consumption for this integrated access network to allow the optimization of energy performance as well as providing valuable information so that in the network design process, focus can be done to the most energy saving strategies. In addition, energy modeling could assist to optimize network-wide routing and management decisions for minimizing energy consumption.

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