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Techno-economic analysis of EPON and WiMAX for future Fiber-Wireless (FiWi) networks

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ABSTRACT

Hybrid Fiber-Wireless (FiWi) networks become rapidly mature and represent a promising candidate for reducing power consumption, costs, and bandwidth bottlenecks of next-generation broadband access networks. Two key FiWi technologies with similar design goals are Ethernet Passive Optical Network (EPON) and WiMAX. In this paper, we develop a powerful and flexible techno-economic analysis to compare the two technologies, taking into account not only equipment and installation costs but also OAM related costs such as power consumption and repairing costs for a wide range of different network failure scenarios, terrain types, and wireless channel conditions. The presented results give insight into the cost-performance trade-offs of current and next-generation EPON and WiMAX networks.

1. Introduction

Fiber-to-the-x (FTTx) networks bring fiber close or all the way to the end user, whereby *x* denotes the discontinuity between optical fiber and some other, either wired or wireless, transmission medium. For instance, hybrid optical fiber-twisted copper pair architectures are widely deployed by telephone companies in today's Digital Subscriber Line (DSL) based broadband access networks. However, recent studies indicate that in terms of power consumption and economic sustainability there is a clear advantage of replacing legacy copper infrastructure with optical fiber, giving rise to "green" all-optical access networks [1]. The emergence of quad-play services (voice, video, data, and mobility) leads to a stronger integration of optical and wireless access networks. The resultant bimodal Fiber-Wireless (FiWi) access networks aim at providing wired and wireless services over the same infrastructure simultaneously, thus potentially leading to major cost savings. FiWi networks hold great promise to mitigate the digital divide and change the way we live and work by replacing commuting with teleworking [2].

Recently, various FiWi network architectures have been investigated by integrating different optical and wireless technologies [3]. Stanford University's multi-tier optical-wireless network architecture proposed in [4] might be viewed as a state-of-the-art FiWi network which allows for the gradual capacity upgrade of the wireless backhaul with optical point-to-point and/or Point-to-MultiPoint (PMP) Wavelength Division Multiplexing (WDM) fiber links. While introducing optical fiber at higher network layers, e.g., aggregation layer, helps alleviate emerging bandwidth bottlenecks, the last hop is expected to be wireless for ubiquity and convenience, e.g., low-cost WLAN and home mesh networks [5]. Between these two FiWi network hierarchy levels lies the "sweet-spot" where optical technologies interface with their wireless counterparts. Two important sweet-spot technologies that play a key role in emerging FiWi networks are IEEE 802.3ah Ethernet Passive Optical Network (EPON) and IEEE 802.16 WiMAX.

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Clearly, EPON and WiMAX networks may be cascaded, as proposed in [6]. However, given the similarities of EPON and WiMAX (e.g., PMP topology with a central control station performing dynamic bandwidth allocation by means of centralized polling and scheduling) we argue that the two technologies are more likely to target the same network segment rather than being cascaded to cover different network segments. In other words, we expect that network operators will make a choice between EPON and WiMAX depending on a number of factors, e.g., right-of-way, and elaborate on the techno-economic comparison of the two technologies.

For the comparison of wired and wireless network technologies various techno-economic evaluation techniques have been proposed, as we will see shortly in Section 4. During the last decade, the techno-economic evaluation of various network technologies has been an active research area. To meet the different requirements of emerging network services, a service migration cost analysis was presented in [7]. The cost modeling of the migration from best-effort access networks to multi-service Quality-of-Service (QoS) enabled access networks based on Ethernet and ATM was proposed in [8]. The obtained results show that deployment cost savings can be achieved by using Ethernet-based access network architectures. It is important to note that most of the previous techno-economic evaluations focused either on optical fiber only (e.g., [9,10]) or wireless only network architectures (e.g., [11]). Up to date, only a few preliminary techno-economic evaluations of FiWi networks have been reported. A cost comparison of VDSL and a FiWi architecture consisting of cascaded EPON and WiMAX networks was carried out in [12]. The obtained results indicate the superior cost-efficiency of FiWi networks over conventional VDSL solutions. In [13], a deployment cost comparison of wired (i.e., xDSL and cable modem), optical fiber, WiFi, and integrated EPON and WiMAX/WiFi network architectures was done. The reported results show that a hybrid FiWi network architecture (consisting of EPON and WiMAX) represents a cost-effective solution for future broadband urban area networks. It is important to note that next-generation EPON and WiMAX network technologies were not considered in [13]. Different FiWi network design heuristics were investigated in terms of processing time, complexity, and installation cost in [14]. The optimum real-estate cost deployment of Optical Network Units (ONUs) in integrated FiWi networks was studied in [15,16]. Despite these preliminary studies, a more thorough techno-economic evaluation of FiWi networks is necessary in order to gain deeper insights into the design, configuration, and performance optimization of emerging FiWi networks that are based on EPON and/or WiMAX technologies.

Moreover, recently, the IEEE standard 802.3av for 10 Gbit/s EPON was approved in September 2009 which supports both symmetric 10 Gbit/s downstream and upstream, and asymmetric 10 Gbit/s downstream and 1 Gbit/s upstream data rates to provide backward compatibility with the current 1 Gbit/s EPON. While the line coding for the current EPON is 8B/10B, the next-generation optical access network (i.e., IEEE 802.3av 10 Gbit/s EPON) uses the 64B/66B line coding which reduces the bit-to-baud overhead significantly [17]. The techno-economic analysis of emerging IEEE standards 802.3av 10 Gbit/s EPON and 802.16m 1 Gbit/s WiMAX networks is another attractive research study.

The remainder of this paper is structured as follows. Section 2 introduces the various components of total cost of network ownership. In Section 3, we briefly overview the technical features of EPON and WiMAX. Section 4 contains our comparative techno-economic analysis of EPON and WiMAX. Results of this comparison are presented in Section 5, including the emerging IEEE standards 802.3av 10 Gbit/s EPON and 802.16m 1 Gbit/s WiMAX networks. Section 6 concludes the paper.

2. Total cost of ownership (TCO)

The total network deploying expenditures for network operators are called Total Cost of Ownership (TCO). Typically, TCO is categorized into: (i) CAPital EXpenditures (CAPEX) and (ii) OPerational EXpenditures (OPEX). In this section, we provide a general overview of the most important TCO components widely considered in previous techno-economic network studies.

2.1. CAPEX

CAPEX consist of initial network equipment and network installation costs, network infrastructure costs (e.g., cabling and right-of-way), and network management system. Additionally, CAPEX cover the upgrading and protection spare network equipment and installation costs. The first-time installation cost is covered by CAPEX, in case it should be done by network operators. We note that the first-time installation is usually done by the equipment vendors. Non-telecom costs such as building and furniture costs are usually considered part of network CAPEX [18].

2.2. OPEX

OPEX comprise network Operation, Administration, and Maintenance (OAM) costs. More specifically, OPEX cover the network power consumption and equipment cooling, troubleshooting, repairing, service (i.e., bandwidth, service provisioning, and management), and human resource costs, e.g., wages and salaries. The non-telecom costs, e.g., room air-conditioning and heating, are defined as network OPEX [18]. According to [19], the network OPEX may be classified as follows:

1. *OPEX for setting up a network:* which include in-advance planning cost, e.g., initial network planning cost and travel cost for contacting and negotiating with different equipment vendors.
2. *OPEX to operate an existing network:* which comprise continuous cost of infrastructure (e.g., power consumption and cooling costs), maintenance cost, failure reparation cost, provisioning and service management cost, pricing and billing cost, operational network planning cost (e.g., day-to-day planning, re-optimization, and upgrade planning), and marketing cost.