Optical Fiber Technology 18 (2012) 68–80

Contents lists available at SciVerse ScienceDirect

Optical Fiber Technology

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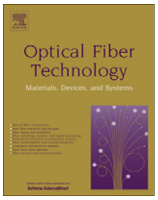

Green survivability in Fiber-Wireless (FiWi) broadband access network

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ARTICLE INFO

Article history:
Received 29 November 2011
Revised 15 December 2011
Available online 10 January 2012

Keywords:
Fiber-Wireless (FiWi) broadband access network
Passive optical network
Wireless access network
Survivability
Energy-saving

ABSTRACT

Fiber-Wireless (FiWi) broadband access network is a promising "last mile" access technology, because it integrates wireless and optical access technologies in terms of their respective merits, such as high capacity and stable transmission from optical access technology, and easy deployment and flexibility from wireless access technology. Since FiWi is expected to carry a large amount of traffic, numerous traffic flows may be interrupted by the failure of network components. Thus, survivability in FiWi is a key issue aiming at reliable and robust service. However, the redundant deployment of backup resource required for survivability usually causes huge energy consumption, which aggravates the global warming and accelerates the incoming of energy crisis. Thus, the energy-saving issue should be considered when it comes to survivability design. In this paper, we focus on the green survivability in FiWi, which is an innovative concept and remains untouched in the previous works to our best knowledge. We first review and discuss some challenging issues about survivability and energy-saving in FiWi, and then we propose some instructive solutions for its green survivability design. Therefore, our work in this paper will provide the technical references and research motivations for the energy-efficient and survivable FiWi development in the future.

1. Introduction

Recently, the explosive growth of bandwidth-intensive applications imposed a challenge on the "last mile" broadband access network, which requires lower cost, higher capacity and better flexibility [1]. As a dominant access technology today, Passive Optical Network (PON) is widely considered as a preferable solution due to its excellence in bandwidth capacity and stability. However, PON fails to enable users to access Internet in an "anywhere–anytime" manner, and it also requires considerable deployment and maintenance costs. As an alternative, wireless access network such as WiFi or WiMax is rapidly gaining popularity due to its flexibility and cost-efficiency. However, the scarce spectrum severely limits its bandwidth capacity. To combine the technical merits of PON and wireless access network, Fiber-Wireless (FiWi) broadband access network was proposed to enable users to access Internet in a flexible and high-capacity way [2–4].

As a broadband network, FiWi is expected to carry a large amount of traffic, thus numerous traffic flows may be interrupted upon network component failure. Therefore, it is necessary to enhance the survivability of FiWi. A general method for network survivability is to reserve the backup resource for the working resource. Normally, traffic flows are carried by the working resource. Once the working resource fails, the traffic interrupted by this failure will be switched from the working resource to the backup resource [5,6]. It is widely recognized by many research organizations that future broadband access network should provide reliable and robust service even in the presence of failure [7,8]. Therefore, how to enhance the survivability of FiWi is a key issue and it should be considered in the future development of FiWi. With the ever-increasing concern over the global warming and energy crisis, energy saving and emission reduction require more research attention. Particularly, the extensive statistics indicate that both energy consumption and carbon emission induced by Internet applications experienced considerable growth during recent years due to the significant amount of traffic. Thus, the development of FiWi also needs to take into account the energy-saving issue.

However, both issues, i.e., survivability and energy-saving, are not independent of each other. It should be noted that the redundant resource required to enhance network survivability will consume more energy. Thus, reducing the energy consumption induced by survivability enhancement, which we refer to as the *Green Survivability* issue, should be considered as a new challenge in the FiWi development. Some works investigate the survivability in optical access network [7–10] and the energy-saving in wireless access network [11–14]. However, we cannot directly apply these schemes and approaches to FiWi because they do not consider the architectural features of FiWi. Thus, there is an urgent need to investigate the schemes and approaches dedicated to the

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doi:10.1016/j.yofte.2011.12.002

survivability and energy-saving in FiWi. Although a few works on FiWi begin to consider the survivability issue [15–22] as well as the energy-saving issue [23–26], they remain untouched the green survivability and thus fail to guarantee survivability with minimum energy consumption. Therefore, the green survivability is a key technology for developing an energy-efficient and survivable FiWi. Also, it is an open issue which deals with a lot of unsolved problems and research gaps.

In this paper, we focus on the green survivability in FiWi, which is an innovative concept and never touched in the previous works to our best knowledge. The rest of this paper is organized as follows. In Section 2, we present the state-of-art of the access technologies including optical access network and wireless access network. Then, we describe the architectural features of FiWi and evaluate its advantage over other existing access technologies. In Section 3, we review the related works on FiWi and put more importance on the statement of our own works. In Section 4, we discuss some challenging issues in terms of energy-saving and survivability in FiWi. In Section 5, we propose some instructive solutions for green survivability in FiWi, so as to provide some technical references and research motivations for the FiWi development in the future. Finally, we conclude this paper and discuss the prospect of our future work in Section 6.

2. Background

2.1. Optical access network

PON is well known as a dominant broadband access technology, because it provides larger bandwidth capacity, lower transmission loss and better tolerance to interference than other wired access technologies such as Digital Subscriber Line (DSL) and Cable Modem (CM) [27–30]. Usually, PON has a tree topology, where an Optical Line Terminal (OLT) in Central Office (CO) is connected with multiple Optical Network Units (ONUs) via feeder fiber, Remote Node (RN) and distribution fibers. The signal transmitted through PON never meets any active element, thus PON can provide more stable transmission without any electromagnetic interference.

Currently, PON can be categorized into Time-Division-Multiplexing PON (TDM-PON), Wavelength-Division-Multiplexing PON (WDM-PON) and hybrid TDM/WDM-PON. TDM-PON is a traditional PON with the upstream service (from ONUs to OLT) and downstream service (from OLT to ONUs) operated on two separate wavelength channels. By using a splitter in RN, the optical signal from OLT is split into multiple paths, and each path is destined to an ONU. Thus, TDM-PON is a Point-to-MultiPoint (P2MP) optical network, and its bandwidth capacity is shared among all ONUs by means of TDM technology. Unlike TDM-PON, WDM-PON is widely acknowledged as a promising candidate for Next-Generation PON (NG-PON), because it can support multiple wavelength channels over the same fiber infrastructure. By using the Arrayed Waveguide Grating (AWG), WDM-PON assign each ONU a separate wavelength channel for upstream service and another separate wavelength channel for downstream service. Thus, WDM-PON is a Point-to-Point (P2P) optical network, and it can provide much larger bandwidth capacity and better scalability than TDM-PON. As a promising solution for the migration from TDM-PON to WDM-PON, the hybrid TDM/WDM-PON has an integrated architecture of TDM-PON and WDM-PON. Generally, there are four approaches to achieve the hybrid TDM/WDM-PON: (1) the hybrid TDM/WDM-PON based on TDM technology, which employs TDM technology to support upstream service and WDM technology to support downstream service; (2) the hybrid TDM/WDM-PON based on WDM technology, which employs the WDM technology to support upstream service and TDM technology to support downstream service; (3) the hybrid TDM/WDM-PON with TDM over WDM, which makes multiple TDM-PONs share the same feeder fiber by means of WDM technology; and (4) the hybrid TDM/WDM-PON with WDM over TDM, which makes multiple WDM-PONs share the same feeder fiber by means of TDM technology.

It is well known that PON can provide larger bandwidth capacity and better stability, but it fails to support the mobile service due to its fixed access. Furthermore, in order to better satisfy the users' bandwidth demands, PON usually needs a longer fiber reach, thus it requires more cost for the network deployment and maintenance [31–35].

2.2. Wireless access network

As another promising access technology, wireless access network is gaining the notable popularity due to its flexibility and easy deployment [36–40]. There are three major technologies for wireless access network, including WiFi, WiMax and cellular technology. WiFi is mainly used in the local area network for the interconnection of User Ends (UEs). Generally, WiFi can be operated in both infrastructure and ad hoc modes. In the infrastructure mode, WiFi needs to employ an Access Point (AP) as a central infrastructure to manage the UEs within a limited coverage which is dependent on the transmission power level of AP. In the ad hoc mode, all the WiFi UEs have the ability of self-management, and they can communicate with each other directly in a multi-hop way. The existing WiFi standard such as IEEE 802.11 a/b/g/n can support the data rate of 54/11/54/300 Mb/s respectively in a range of 100 m. Compared to WiFi, WiMax (IEEE 802.16) employs Base Station (BS) as the central infrastructure, and it supports only the single-hop communication. However, due to the less-crowded spectrum, WiMax can provide larger bandwidth and longer transmission range. Typically, WiMax can support the data rate of up to 75 Mb/s in a range of 3–5 km. Thus, WiMax is mainly used for metropolitan-area network. Some research organizations have proposed that WiMax will be a promising alternative for the wired access technology such as DSL and CM to provide the "last mile" broadband access service for UEs. Cellular technology is widely used in the mobile communication systems, which deploy a BS in each cell to mainly support the voice and low-rate data applications. According to the 3rd Generation Partnership Project (3GPP) R5 and R6 specification, the High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA) technologies (jointly known as High-Speed Packet Access, HSPA) can provide the data rate of up to 5 Mb/s in upstream and up to 14 Mb/s in downstream, respectively. As the evolutionary solution of HSPA, the enhanced HSPA (i.e., HSPA+) technology are expected to support the data rate of up to 10 Mb/s in upstream and up to 40 Mb/s in downstream, respectively. Furthermore, the 4th Generation (4G) mobile communication system, which has gained extensive attention, is estimated to provide the data rate of up to 20 Mb/s in upstream and up to 100 Mb/s in downstream, respectively. Compared to optical access technology, wireless access technology enables users to access Internet in a more flexible way and requires a lower deployment cost. However, the scarce spectrum severely limits its bandwidth capacity [41–43].

2.3. Fiber-Wireless broadband access network

As an integration of optical and wireless access technologies, FiWi makes an excellent compromise between both access technologies by combining the large bandwidth capacity and high stability in optical world with the flexibility and low deployment cost in wireless world. Thus, FiWi enables users to enjoy the satisfactory broadband access service in an "anywhere–anytime" way [44,45].