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Dynamic Bandwidth Allocation in Fiber-Wireless (FiWi) Networks

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***Abstract*—**Fiber-Wireless (FiWi) networks are a promising candidate for future broadband access networks. These networks combine the optical network as the back end where different passive optical network (PON) technologies are realized and the wireless network as the front end where different wireless technologies are adopted, e.g. LTE, WiMAX, Wi-Fi, and Wireless Mesh Networks (WMNs). The convergence of both optical and wireless technologies requires designing architectures with robust efficient and effective bandwidth allocation schemes. Different bandwidth allocation algorithms have been proposed in FiWi networks aiming to enhance the different segments of FiWi networks including wireless and optical subnetworks. In this survey, we focus on the differentiating between the different bandwidth allocation algorithms according to their enhancement segment of FiWi networks. We classify these techniques into wireless, optical and Hybrid bandwidth allocation techniques.

***Keywords*—**Fiber-Wireless (FiWi), dynamic bandwidth allocation (DBA), passive optical networks (PON), media access control (MAC).

I. Introduction

FIBER wireless networks are the integration of both optical and wireless networks over the same infrastructure. These networks may be denoted as wireless optical broadband access networks (WOBAN) [1]-[3], Hybrid optical wireless access networks (HOWAN) [4] or Fiber-Wireless (FiWi) networks which will be used during this survey.

Optical access networks like passive optical network PON are supporting end users with high bandwidth and high speed. However, they could not support the ubiquitous service and the fiber deployment to end users requires enormous cost. On the other side, wireless access networks support the mobility and low cost deployment but it is limited in capacity due to the interference and the limited spectrum. Thus, FiWi networks have been emerged as promising solution to provide convenient harmony between substantial access bandwidth and cost effectiveness in the infrastructure deployment by integrating the complementary features characterizing both optical and wireless networks. FiWi networks will be able to tackle the shortcomings of both optical and wireless networks that manifest when they operate individually. The commercial deployment of FiWi access networks still face number of challenges. One of these challenges is to solve the bandwidth-limited constraint in the wireless networks using the enormous amount of available bandwidth of optical network. Several bandwidth allocation algorithms have been investigated to enhance bandwidth allocation mechanisms separately used in the wireless and optical networks so that both networks could be converged properly. These algorithms will be the focus of this survey.

The remainder of this paper is organized as follows. Section II presents the bandwidth allocation in FiWi. Section III discusses the wireless bandwidth allocation techniques. Section IV explains the optical bandwidth allocation techniques. Section V discusses the hybrid bandwidth allocation techniques. Section VI concludes the paper.

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II. Bandwidth Allocation in FiWi

The main goal of bandwidth allocation procedure is to share network resources between the users on the same network. This process manages the distribution of available bandwidth in terms of Bytes, timeslots, channels, sub channels, and subcarriers to the users. Bandwidth allocation algorithms could be static/fixed or dynamic bandwidth allocation algorithms (DBA). The static algorithms distribute bandwidth equally between users in the same network. These algorithms suffer from inefficient utilization of bandwidth thus degrading the network performance. Therefore, researches on DBA algorithms have gained many researchers attention in FiWi networks.

The bandwidth algorithms in PON and FiWi networks could be classified into Centralized, Decentralized, and Hierarchical based on where at the network the bandwidth allocation decisions are performed. In the centralized bandwidth allocation algorithms, the OLT takes on the whole responsibility of performing bandwidth allocation decisions. Conversely, in the decentralized bandwidth allocation algorithms, the bandwidth allocation decisions are applied at ONUs. These techniques require supporting the peer-to-peer communication between ONUs accordingly the ONU bandwidth requests could be received by the neighboring ONUs. Finally, in the Hierarchical bandwidth allocation algorithms the OLT allocates the bandwidth to ONUs then the ONUs reallocate the granted bandwidth for its interior queue of different traffic types. Another classification of the bandwidth allocation algorithms is prediction based and non-prediction based on the traffic prediction [5], [6].

The design of a robust, effective, and efficient bandwidth algorithm is one of the most challenging objectives of deploying FiWi networks. Several dynamic bandwidth allocation techniques have been proposed in the research community aiming to smoothly converge both optical and wireless networks. We classify these techniques according the segment of enhancement in the network into three categories wireless, optical and hybrid techniques as shown in Fig. 1. In Wireless techniques, the main objective is to boost wireless front end of FiWi networks without performing any optimization in the optical back end. Conversely, the main goal of optical techniques is to enhance optical scheduling techniques considering that front end of network is wireless. Eventually, the Hybrid techniques comprise the enhancement of both optical and wireless subnetworks. Then we compare between different optical and hybrid bandwidth allocation techniques according to different characteristics as shown in Table II.

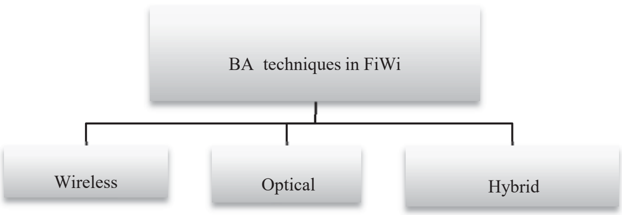

Fig. 1 Classification of BA techniques in FiWi

III. Wireless Bandwidth Allocation Techniques

These techniques do not involve any adaptation in the optical subnetwork of FiWi networks. The main goal of these techniques is to mitigate the capacity limitation in the wireless subnetwork considering that the backhauling of the wireless network is optical. The optical part of FiWi networks has higher capacity than wireless part thus the capacity of wireless access should be improved using low cost solution network. Several researches [1]-[3], [7], [8] have been proposed to address this issue. In these papers, the possibility of equipping wireless nodes with additional radio interfaces has been discussed to increase the capacity of wireless access networks.

Authors in [1]-[3], [7] demonstrated that the FiWi networks are combination of WMN as wireless frontend and PON as optical backend. In [8], the FiWi networks are a combination Ethernet Passive Optical Network (EPON) and Worldwide Interoperability for Microwave Access (WiMAX) networks.

Due to the high cost of equipping all wireless nodes with multi radio, authors in [1] suggested deploying multi radio at bottleneck wireless nodes (e.g. gateways). An Integer Liner Program (ILP) scheme has been proposed aiming to study that placement of additional radio interfaces at bottleneck wireless nodes achieving the same performance as a FiWi networks with multi-radios at all nodes with the minimum possible deployment cost.

Authors in [2] suggested equipping the highly loaded wireless nodes with multi radios. In this paper, a channel assignment mechanism has been proposed considering many factors including flow and capacity, and radio assignment of wireless optical broadband access networks. The suggested channel assignment scheme conserved similar level of contention by executing load balancing of traffic across different channels. In the proposed scheme, assigning the channels among N nodes in the topology depends on existing traffic between each two nodes. If two nodes u and v have traffic between them, then at least one of the radios of each node require working on the same channel. Otherwise, nodes u, v can work on orthogonal channels avoiding interference between them. Each node will be assigned to number of channels equally to its radios.

In [3] the channel assignment problem in multi radio wireless optical broadband access networks has been explored. This paper showed that using mesh routers equipped with multiple radios adjusted to non-overlapping channels could effectively relieve the capacity problem in wireless optical broadband access networks. In this paper, it is proved that using 12 orthogonal channels is much more effective than using 3 orthogonal channels avoiding the rapidly exhaustion of the spectrum.

Authors in [7] have studied a frequency assignment approach in multi-radio multi-channel FiWi networks. The aim of this study is to carefully planning frequency assignment to increase network parallel transmissions and reducing time division thus throughput could be increased.

In [8], a utility-based bandwidth allocation method has been proposed to be applied at each base station considering the periodic changes in the number of users, channel quality of each user, users' requested bandwidth, application, and so on. The main objective of the proposed bandwidth allocation method is to improve the QoS satisfaction (fairness) of all users while conserving the system throughput. In Table I, we summarized the discussed wireless bandwidth allocation (BA) algorithms in terms of various characteristics such as, the implemented optical technology, the implemented wireless technology and the implementation method used to study the technique.

TABLE I
Summarized Comparison of Wireless BA Algorithm

	Optical Technology	Wireless Technology	Performance Evaluation
[1]-[3]	PON	WMN	CPLEX ILP solver
[7]	PON	WMN	OMNET++ simulator
[8]	EPON	WiMAX	Ruby

IV. Optical Bandwidth Allocation Techniques

In these techniques, the bandwidth allocation process involves enhancement of optical backend of FiWi networks neglecting the optimization of wireless networks. Several optical based DBA algorithms have been suggested in the literature adopted on different FiWi networks' architectures, which combine different technologies of optical and wireless networks.

The integration of both EPON and WiMAX technologies has been emerged a possible architecture to properly deploy FiWi networks. Several DBA algorithms have been examined considering the MAC integration of both EPON and WiMAX [9]-[12].

In [9], a QoS-based DBA algorithm combined with the prediction-based fair excessive bandwidth allocation PFEBA [13] mechanism in EPON has been suggested in which the system performance will be increased. By integrating the medium access control (MAC) of both EPON and WiMAX, the suggested QoS based Dynamic Bandwidth Allocation (QDBA) can decrease the packet delay. In addition, a queue-based scheduling mechanism has been proposed in which the delay will be reduced by assigning high priority traffic to a fixed a location in the frame.

The authors in [10] have proposed QoS aware DBA scheme at the medium access control that is specially designed to the unique features of WEN (WiMAX EPON Networks). In the proposed DBA, the bandwidth is allocated to the upstream traffic from IEEE 802.16 SS subscriber station to the OLT. This scheme is consisted of a set of DBA algorithms operating on various WEN devices in a cascading and cooperative method confirming that contracted QoS parameters of each service type have been regularly complied. The proposed scheme considers bandwidth fairness from both station and class of service (CoS) points of view.

In [11], a novel prediction based scheduling technique has been proposed aiming to improve delay without decreasing the throughput. The proposed algorithm consists of two phases performed at OLT and ONU separately. At the OLT, an inter-ONU scheduling has been performed to allocate the bandwidth to ONUs based on the available bandwidth requests and traffic prediction without considering different traffic classes. Then an intra-ONU scheduling is implemented at each ONU to allocate the granted bandwidth to each traffic class of ONU queue.

In [12], a prediction-aware DBA scheme for FiWi networks has been proposed considering the high propagation delay of exchanging control messages between the optical and wireless domains. In this paper, the optical domain of FiWi networks is implemented by a 10Gbps Ethernet PON (10G-EPON) and the wireless domain is supported by WiMAX access stations. In the proposed DBA scheme, FiWi Surplus Traffic Prediction (FiWi-STP) algorithm is implemented at ONU-BS using a hidden Markov chain to estimate the traffic that might be received during the propagation delay of coordination message exchange between the optical and the wireless units. The ONU-BS updates the bandwidth request message to include the actual ONU-BS queue length and the results of prediction model before sending it to OLT. The OLT applies the limited service scheme to grant the requested bytes for each ONU-BS. Other DBA algorithms have been proposed on FiWi networks architectures integrating TDM/WDM PON as optical backend and WMN as wireless front end as in [14]. Authors in [14] have proposed a new arrayed waveguide grating (AWG) WDM/ TDM PON architecture to provide direct inter ONU-communication without visiting the OLT. An efficient load balancing wavelength assignment (WA) scheme has been suggested in which each wavelength is shared between subset of ONU depending on the estimated traffic load expected to arrive from wireless subnetwork at ONUs. The wavelength can be shared between multiple ONUs using TDMA as the capacity provided by each wavelength is much greater than traffic carried by ONU to/from the wireless subnetwork. This difference in capacity is happened due to interference and shortage in bandwidth in the wireless subnetwork. In addition, a novel decentralized DBA protocol has been investigated to provide bandwidth allocation for inter-ONU communication. In this protocol, the ONU (of a given group) has been defined to send or receive data on the bandwidth shared by other ONUs. This decentralized DBA protocol provides fairness among ONUs and increases maximum throughput.

OFDMA PON LTE is also one of the possible integration methods to deploy FiWi networks that has been discussed in literature and its DBA algorithms has been investigated as in [15], [16].

Authors in [15] have proposed an innovative group mapping and scheduling scheme taking into consideration the efficient assurance of the different quality of service (QoS) characteristics of LTE users when the backend of LTE networks is OFDMA PON. In the proposed group mapping method, the LTE QoS class identifiers (QCIs) are grouped and mapped to the OFDMA-PON priorities according to class-of-service (CoS) differentiation. The main aim of this proposed weighted dynamic subcarrier allocation (WDSA) algorithm is to allocate subcarriers to enhanced node B/optical network units (eNB/ONUS). In this algorithm, different weights are assigned to differentiate between different priorities of different traffic types thus, fairness could be guaranteed. In [16] the authors have extended their work in [15] so that the WDSA could be applied to both wired and wireless traffic.

Integrating GPON and WiFi is also another integration method to converge both optical and wireless domains over the same network as discussed in [17]. In this paper, a dynamic bandwidth allocation algorithm has been proposed considering that the optical backend implements Time division multiple access (TDMA) and the wireless front end applies Carrier Sense Multiple Access with Collision Avoidance. Two different methods have been implemented in the DBA algorithm, which are called Status Reporting Excessive bandwidth (SREB) and non-status Reporting Excessive Bandwidth (NSREB). In the SREB method, the OLT waits receiving all ONUs' bandwidth request messages (REPORT) to perform the DBA process. However, in the NSREB method, the OLT performs an estimation of ONUs' bandwidth requirement as no report messages are sent from ONUs to OLT.

V. Hybrid Bandwidth Allocation Techniques

In these techniques, implementing DBA algorithm requires the improvement of optical and wireless segments of FiWi networks [18], [19].

The authors in [18] have examined hybrid TDM/WDM fiber-wireless networks targeting to increase the maximum throughput as well as discovering a proper wavelength assignment scheme of ONUs to realize the approximate maximal throughput when using the minimum number of wavelengths. In wireless subnetworks, an LP-based multi-path routing has been suggested such that the maximal network throughput can be estimated and the minimum number of wavelength needed can be achieved. Also, an Approximate Wavelength Assignment (AWA) Algorithm has been proposed in the optical part of FiWi networks using the number of the wavelengths and expected traffic load range of each ONU to assign the wavelengths to ONUs so that the bandwidth utilization of wavelengths will be increased.

TABLE II
SUMMARIZED COMPARISON OF OPTICAL AND HYBRID BA TECHNIQUES

	Optical Technology	Wireless Technology	Supported communications	Bandwidth Allocation Role	Traffic Prediction	Performance evaluation
[9] QDBA	EPON	WiMAX	Upstream	Hierarchical	Prediction based	OPNET Simulator
[10]	EPON	WiMAX	Upstream	Hierarchical	Non Prediction based	OPNET Simulator
[11]	EPON	WiMAX	Upstream	Hierarchical	Prediction based	Not determined
[12]	10GEPON	WiMAX	Upstream	Hierarchical	Prediction based	Not determined
[14] WA	TDM/WDM PON	WMN	Upstream	Centralized	Prediction based	NS-2 Simulator
[14] DBA	TDM/WDM PON	WMN	Peer to Peer	Decentralized	Non Prediction based	NS-2 Simulator
[15],[16]	OFDMA PON	LTE in [15] LTE-A in [16]	Upstream	Hierarchical	Non Prediction based	OPNET
[17] DBA using SREB	GPON	WiFi	Upstream	Hierarchical	Non Prediction based	Matlab
[17] DBA using NSREB	GPON	WiFi	Upstream	Hierarchical	Prediction based	Matlab
[18] AWA	TDM/WDM PON	WMN	Upstream	Centralized	Prediction based	Not Determined
[19]	EPON	WiMAX	Downstream	Hierarchical	Non Prediction based	NS-2 Simulator

The authors in [19] proposed a two-stage downlink packet scheduling and resource allocation technique implemented on the EPON-WiMAX integrated networks aiming to improve the throughput and ensure the QoS characteristics. In the first stage, a load-balancing packet scheduling technique has been implemented at OLT to control sending packets over the optical network (EPON). In the second stage, a WF^2Q [20] scheduling mechanism is implemented to accomplish sending of the packets through the wireless network (WiMAX). In addition, an MFCS algorithm has been proposed to optimally choose the best combination of the application layer forward error correction (AL-FEC) [21] and modeling coding scheme (MCS). This algorithm is used for receiving packets at the WiMAX Subscriber Stations (SS) of different SINR values to improve the time consumption of resources (time slots).

In Table II, a summarized comparison of both optical and hybrid bandwidth allocation (BA) algorithms is shown.

VI. CONCLUSION

The integration of both optical and wireless domains has been emerged as viable solution to accommodate the bandwidth-intensive applications of future broadband access networks. This integration is a complex task requires the cooperative optimization of performance improving the MAC mechanisms, which are separately implemented in both wireless and optical networks (e.g., hybrid access control protocols, wireless frame aggregation and optical burst assembly, integrated routing algorithms, integrated scheduling and bandwidth allocation, and integrated admission control). In this survey, we discuss the different bandwidth allocation algorithms that have been proposed in the FiWi research area. We classified these techniques into wireless, optical and hybrid techniques according the segment of the improvement in the FiWi networks.

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