Alleviating the High Propagation Delays in FiWi Networks: A Prediction-based DBA Scheme for 10G-EPON-WiMAX Systems

Panagiotis Sarigiannidis
and Malamati Louta
Dept. of Informatics
and Telecommunications Engineering
University of Western Macedonia
Kozani, Greece
Email: {psarigiannidis,louta}@uowm.gr

Georgios Papadimitriou
Dept. of Informatics
Aristotle University of Thessaloniki
Thessaloniki, Greece
Email: gp@csd.auth.gr

Ioannis Moscholios
and Anthony Boucouvalas
Dept. of Informatics
and Telecommunications
University of Peloponnese
Tripoli, Greece
Email: {idm,acb}@uop.gr

Dimitrios Kleftouris
Dept. of Information Technology
Alexander Technological Institute of Thessaloniki
Thessaloniki, Greece
Email: klefturi@it.teithe.gr

***Abstract*—Fiber Wireless (FiWi) networks constitute a very promising, cost-effective solution to cope with modern demanding services and applications in access networks. One of the most challenging objective lies in the design of a robust, efficient and effective bandwidth allocation. The design of such a Dynamic Bandwidth Allocation (DBA) scheme should take into account the large propagation delays between mobile users and the Central Office (CO). In this work, we endeavor to address this challenge by proposing a prediction-aware DBA scheme for FiWi networks, where the optical domain is implemented by a 10Gbps Ethernet PON (10G-EPON) and the wireless domain is supported by WiMAX access stations. In order to ensure an effective DBA scheme a hidden Markov chain model is devised for estimating the surplus traffic requests of each mobile user during the coordination message exchange between the optical and the wireless domains. In addition, a fair bandwidth distribution is applied based on the results of the prediction module. Based on the obtained simulation results the proposed scheme presents a good network performance in terms of prediction accuracy and packet delay.**

***Index Terms*—bandwidth allocation; FiWi; hidden Markov chains; prediction.**

I. INTRODUCTION

The aim of modern communication systems is to provide users, in larger regions, with ubiquitous access to information services at a high Quality of Service (QoS) level and in a cost-efficient manner. To achieve this aim, access networks connecting users to core networks should scale up in bandwidth capacity while at the same time network connectivity has to be independent of the users location. A viable access solution to this challenging problem is a hybrid wireless-optical network, known as Fiber Wireless (FiWi) networks. FiWi networks form a powerful optical backhaul with huge capacity while they incorporate a large-coverage wireless front-end architecture. The optical infrastructure, based on a Passive Optical Network (PON), while the wireless access points, implemented by a 4G technology (e.g., Worldwide Interoperability for Microwave Access (WiMAX) or Long Term Evolution (LTE)) could expand the broadband access connectivity to the end users.

The bridging of the two different technologies is a complicated task that requires the design of modern architectures which should incorporate robust, efficient and effective bandwidth allocation schemes. The design of such a Dynamic Bandwidth Allocation (DBA) scheme should take into account the large propagation delays between the final mobile users and the Central Office (CO), where the main optical terminal equipment is located.

Several DBA schemes for FiWi networks can be found in the literature. The work in [1] is considered as a DBA benchmark scheme introducing a QoS-aware bandwidth distribution framework for EPON-WiMAX hybrid networks. In addition, in [2] presented a hierarchical QoS-aware DBA (HQA-DBA) algorithm applied in both OLT and ONU-BS. This scheme seems to reduce the average network delay and the packet drop probability. In [3], a DBA framework was proposed that intends to increase the channel utilization by limiting the signaling overhead. Authors in [4], tried to converge a multi-channel PON with a multi-channel wireless access front-end. The work in [5] proposed a game theory approach giving emphasis to the fairness provisioning. The reader is encouraged to study the survey in [6] for more DBA schemes and algorithms. A common drawback of the most DBA schemes found in the literature is that they neglect the time of the coordination process as a critical impact on the polling performance. Having in mind that a FiWi network incorporates high propagation delays, as the coordination messages are carried between the

978-1-4673-7626-6/15/$31.00 ©2015 IEEE

two domains, an intelligent bandwidth allocation scheme is required to alleviate this shortcoming.

In this paper, we propose a prediction-aware DBA scheme for FiWi networks by assuming that a FiWi network consists of an asymmetric 10 Gbps Ethernet PON (10G-EPON) and WiMAX Base Stations (BSs) in the front-end. In order to ensure an effective integrated DBA scheme, a hidden Markov chain model is devised, so as to estimate the traffic requests of each user during the propagation of the control messages between the various network units withing the FiWi network. The proposed model is able to predict the surplus bandwidth a user might need, as the user waits for the delivery of the coordination messages. In addition, a fair bandwidth distribution is applied based on the results of the prediction component. The proposed FiWi Surplus Traffic Prediction (FiWi-STP) presents a good performance based on the obtained simulation results, where the prediction error rate is quite low and the network performance is considerably improved in terms of average packet delay compared to a DBA benchmark scheme.

The remainder of this paper is organized as follows. Section II briefly presents the background of FiWi networks. In Section III, the proposed FiWi DBA scheme is presented, while Section IV presents the performance evaluation environment as well as obtained simulation results. Finally, Section V concludes this paper.

II. BACKGROUND

One of the most promising FiWi integration is when an Ethernet PON is combined with WiMAX BSs. This combination offers a straightforward integration since 10G-EPON (or EPON) and WiMAX architectures share much similarity in protocol framing [7].

Within the 10G-EPON, an Optical Line Terminal (OLT) is located in the CO. A set of Optical Networks Units (ONUs) are connected to the OLT using optical fibers. Each ONU is enhanced with a WiMAX BS in a single device having two interfaces; an optical one which is connected with the OLT using optical fibers and a wireless one which provides an access channel to the Mobile Stations (MSs). A passive splitter/combiner combines multiple optical signals from the ONUs towards the OLT. On the opposite way, the optical signal originated by the OLT is split between a number of optical fibers, one for each ONU-BS.

The integration of the ONU and the BS may be implemented in a various ways. The direct and independent architecture of the ONU-BS seems to be quite functional since it offers simplicity and low cost [8]. For instance, a simple Ethernet cable could directly interconnect the ONU with the BS.

The bandwidth distribution within the 10G-EPON domain is governed by the The Multi-Point Control Protocol (MPCP). Two coordination messages are utilized in order to carry transmission opportunities messages between the OLT and the ONU-BSs. First, the GATE message is used by the OLT for allocating transmission opportunities to ONU-BSs. The GATE message includes the advertised transmission time and transmission duration for a specific ONU-BS. An in-band control channel is employed to bear the GATE messages in the downlink direction. Second, the REPORT message is used by the ONU-BS for informing the OLT about the queue occupancy. Each REPORT message is piggybacked into the Ethernet frame and it is carried using the upstream data channel.

Considering the QoS provisioning, the triple priority policy is adopted in this work, where the three priority classes, originated by the 10G-EPON, define the main QoS differentiation service classes of the whole FiWi network and the priorities of the enabled wireless technology are accordingly adapted to the three priorities of the 10G-EPON [6]. Hence, the three service classes of 10G-EPON with the three service classes of WiMAX are merged into three unified priorities services, namely Unsolicited Grant Service/Expedited Forwarding (UGS/EF), real-time Polling Service/Assured Forwarding (rtPS/AF) Best Effort/Best Effort (BE/BE) traffic classes.

III. PROPOSED FIWI DBA SCHEME

A. Network Modeling

A FiWi access network is considered where the optical domain consists of a 10G-EPON in a tree topology. Each ONU is bridged with a WiMAX BS forming an ONU-BS. A number of N ONU-BSs are considered in the FiWi network. Each ONU-BS is connected with optical means to the OLT, while mobile users are connected to the wireless interface of the ONU-BS. A total number of W MSs are considered in the FiWi network. Each MS is connected to a single (one of the N available) ONU-BS.

Within the 10G-EPON, the uplink transmission is supported by a 1310 nm wavelength. According to the standard, the uplink transmission rate is 1.25 Gbps. The downlink transmission rate, carried by a 1550 nm wavelength, supports a transmission rate of 10 Gbps. An in-band control channel is used to coordinate the transmission opportunities between the OLT and the ONU-BSs. The in-band control channel supports the same transmission rates in both directions. The 10G-EPON systems incorporates the MPCP scheme to handle the coordination. The most common schedule policy used in FiWi networks is the interleaved polling with stop, which is adopted in this work too. This policy implies that the OLT waits to receive the REPORT message from the last ONU-BS in a cycle before polling the first ONU-BS in the next cycle. Hence, a cycle is defined as the time for polling all ONU-BSs. This work focuses on the design of an uplink DBA scheme for 10G-EPON-WiMAX systems since the data delivery in the downlink direction implies a broadcast transmission without switching requirements.

Let $M = \{m_1, m_2, ..., m_W\}$ denote the set of W MSs and $O = \{o_1, o_2, ..., o_N\}$ denote the set of N ONU-BSs. Also, assume that $R_t^{i,j,r}$ symbolize the REPORT bandwidth request of i MS that is connected to j ONU-BS regarding r traffic class for the t cycle. Three traffic classes are defined; hence $r = \{1, 2, 3\}$. In accordance, $G_t^{i,j,r}$ stands for the granted bandwidth to the i MS that belongs to the j ONU-BS regarding r traffic class for the t cycle.

The limited service scheme is adopted where the OLT grants the requested number of bytes, but no more than an upper threshold for each ONU-BS. The limited service scheme is adopted in this paper, where the upper threshold is defined by the wireless capacity. For instance, it is impractical to grant to a ONU-BS more bandwidth than the WiMAX BS can utilize since the additional bandwidth is wasted. Let C_{WiMAX} denote the uplink capacity of the front-end wireless domain. Thus, the OLT grants to each ONU-BS the requested number of bytes, but no more than C_{WiMAX}.

B. Prediction Module

The proposed prediction module aims at empowering the schedule decisions of each ONU-BS. Each ONU-BS receives the granted bandwidth from the OLT and it distributes it to the connected MSs. In essence, the designed module intends to estimate the surplus (additional) bandwidth request of each MS during the time needed for the polling scheme between the OLT and the MSs. To this end, we devise a rigorous prediction module, as a stochastic process, to enhance the effectiveness of the bandwidth allocation process. The prediction module tries to estimate the surplus bandwidth of the delay sensitive traffic classes (first and second traffic class) for each MS for the next cycle. Definition 1 defines a discrete state, discrete time stochastic system:

Definition 1: The surplus uplink bandwidth request that is formed during the polling process in each MS is considered as a stochastic process. It is defined as a family of random variables $U_t^{i,j,\grave{r}} : t, i \in M, j \in O, \grave{r} = \{1, 2\}$. Each random variable $U_t^{i,j,\grave{r}}$ is indexed by the discrete time parameter $t \in T$ and the indexes i, j and $\grave{r}$ which denote the MS, the ONU-BS this MS belongs and the traffic class respectively. The set of all possible values of $U_t^{i,j,\grave{r}}$ is denoted as the state space of the stochastic process.

In order to bound and better specify the surplus uplink bandwidth it should be stressed that the OLT grants to each ONU-BS no more bandwidth than the wireless capacity, i.e., C_{WiMAX}. As a result, the $U_t^{i,j,\grave{r}}$ random value is expressed as a fraction of the wireless capacity C_{WiMAX}. In particular, to keep the stochastic process discrete the random value is realized as a percent of the C_{WiMAX}, between 0% and 100%. The following Definition 2 describes the state space of the $U_t^{i,j,\grave{r}}$ random value in a formal way:

Definition 2: The set of state space of the stochastic process $U_t^{i,j,\grave{r}} : t, i \in M, j \in O, \grave{r} = \{1, 2\}$ is defined as $S = 0, 1, ..., 100$.

According to Definition 2, the surplus uplink bandwidth of each MS for the first and the second traffic classes in each cycle t is described by a single normalized value in terms of C_{WiMAX} percent. For example, if $C_{WiMAX} = 7560 Bytes$ and $U_4^{2,1,1} = 10$ implies that the second MS that belongs to the first ONU-BS has surplus uplink bandwidth request (for the first priority) equal to 10% of the C_{WiMAX}, that is 756 Bytes, during the fourth cycle. The current stochastic process can be further described by a Markov process, since each new random variable $U_t^{i,j,\grave{r}}$ is formed based on the time-previous value $U_{t-1}^{i,j,\grave{r}}$, given that the system does not preserve older values, except of the immediate previous one. In this way, this stochastic process is transformed into a Markov process in Definition 3:

Definition 3: The stochastic process $U_t^{i,j,\grave{r}} : t, i \in M, j \in O, \grave{r} = \{1, 2\}$ constitutes a Markov process, since for each time instance $t_0 < t_1 < ... < t_n < t_{n+1}$ the value of the random variable $U_t^{i,j,\grave{r}}$ depends only on the previous value $U_{t-1}^{i,j,\grave{r}}$ given the state space S. Hence, it holds:

$$P(U_{t_{n+1}}^{i,j,\grave{r}} = s_{n+1} | U_{t_n}^{i,j,\grave{r}} = s_n, U_{t_{n-1}}^{i,j,\grave{r}} = s_{n-1}, ..., U_{t_0}^{i,j,\grave{r}} = s_0) = P(U_{t_{n+1}}^{i,j,\grave{r}} = s_{n+1} | U_{t_n^{i,j,\grave{r}}}) \tag{1}$$

It is clear that the state s_{n+1} stands for the state at time t_{n+1}, as a result of the random variable $U_{t_{n+1}}^{i,j,\grave{r}}$ considering the surplus bandwidth of i MS. Next, the (one-step) transition probability distribution of the Markov process is defined:

Definition 4: The probability of transiting (in one step) from state k to state l, where $k, l \in S$, at time e is defined as $p_{k,l}^{i,j,\grave{r}}(e)$:

$$p_{k,l}^{i,j,\grave{r}}(e) = P(U_{t_{e+1}}^{i,j,\grave{r}} = l = s_{e+1} | U_{t_e}^{i,j,\grave{r}} = k = s_e) \tag{2}$$

In essence, the proposed prediction module intends to estimate the arrival rate of all MSs during each cycle. To this end, it maintains a history record of the most recent actual surplus bandwidth requests of all MSs for the first and the second traffic classes. This history record is realized by a history vector $H_k^{i,j,\grave{r}}$ as follows:

$$H_k^{i,j,\grave{r}} = \{h_k^{i,j,\grave{r}}(1), h_k^{i,j,\grave{r}}(2), ..., h_k^{i,j,\grave{r}}(V)\} \tag{3}$$

In the above equation, i refers to the MS, j refers to the ONU-BS that this MS is connected and $\grave{r}$ refers to the traffic class. The parameter V expresses the length of the history vector. Each vector position stores the V most recent actual samples of the surplus bandwidth recorded according to the reported request of all MSs. In particular, $H_k^{i,j,\grave{r}}$ stores the surplus bandwidth of i MS that belongs to the j ONU-BS regarding $\grave{r}$ when the current state is k, where $k \in S$. Each history vector maintains the V most recent transitions, given the current state k. For example, the value $h_{10}^{2,1,1}(3) = 15$ implies that the actual surplus bandwidth request of the second MS that belongs to the first ONU-BS regarding the first traffic class becomes 15% from 10% three transitions back.

The history vector is updated in each cycle. Upon receiving the REPORT message of each MS, the ONU-BS compares it with the difference between the granted bandwidth and the previous REPORT message. Then, the (actual) surplus bandwidth request is calculated. For example, suppose that a MS requests 50 Bytes during the $e-th$ cycle. The ONU-BS grants 50 Bytes to this MS in the $(e+1)-th$ cycle. Concurrently, the ONU-BS receives the new REPORT message of this MS; assume that the MS requests now 70 Bytes. Thus, the surplus bandwidth appears to be $50+70-50=70$ Bytes. The surplus bandwidth is defined as follows:

$$U_t^{i,j,\hat{r}} = \frac{G_t^{i,j,\hat{r}} + R_t^{i,j,\hat{r}} - R_{t-1}^{i,j,\hat{r}}}{C_{WiMAX}} \tag{4}$$

Therefore, in each cycle the history vector is updated by taking into account the current surplus bandwidth as previously defined. Given that at time t the state of i MS that belongs to j ONU-BS regarding traffic class $\hat{r}$ is s_t and at time t', where $t' > t$, the state of the same MS is $s_{t'}$, the history vector is updated as follows:

$$H_{s_t}^{i,j,\hat{r}}(h) = H_{s_t}^{i,j,\hat{r}}(h-1), 1 < h \leq V \tag{5}$$

$$H_{s_t}^{i,j,\hat{r}}(1) = s_{t'} \tag{6}$$

Obviously, the state $s_{t'}$ corresponds to the surplus bandwidth $U_t^{i,j,\hat{r}}$.

The transition probabilities are also updated following the history vector update:

$$p_{s_t,z}^{i,j,\hat{r}}(t) = \frac{\sum_{k=1,h_{s_t}^{i,j,\hat{r}}(k)=z}^{V} 1}{V}, \forall z \in S \tag{7}$$

In the final stage, the prediction module proceeds to surplus bandwidth estimations. Given the the current state is s_t, the module predicts the state that is most likely to happen, or in other words the most frequent state:

$$F_{s_t}^{i,j,\hat{r}}(t+1) = argmax_z[p_{s_t,z}^{i,j,\hat{r}}(t)] \tag{8}$$

Vector $F_{s_t}^{i,j,\hat{r}}(t+1)$ implies the predicted state for the i MS that belongs to j ONU-BS regarding traffic class $\hat{r}$ for cycle $t+1$ given that the prior state (at time t) is s_t. For instance, the prediction $F_{60}^{2,1,1}(5) = 50$ means that the surplus bandwidth for the second MS that belongs to the first ONU-BS regarding the first traffic class is predicted equal to 50% of the C_{WiMAX}, given that the current state is 60 (meaning a 60% of the C_{WiMAX}) at the fifth cycle.

C. Prediction-aware Bandwidth Distribution

The way of bandwidth distribution in ONU-BSs follows the well known max-min fairness algorithm. Each ONU-BS receives the reported bandwidth from each MS regarding the three traffic classes, it calculate the predicted surplus bandwidth and then it applies the max-min fairness algorithm, keeping a minimum threshold for the second and the third priorities. Assume that T_2 and T_3 stand for the minimum threshold of the rtPS/AF and BE/BE traffic classes respectively, expressed as a portion of the granted bandwidth (by the OLT) to this ONU-BS. Initially, it allocates bandwidth to the UGS/EF of each MS. It calculates the excess bandwidth, if any, and then it allocates bandwidth to the rtPS/AF traffic class of each MS. Lastly, it calculates the excess bandwidth of rtPS/AF distribution and it allocates bandwidth to BE/BE traffic class. Note that in any traffic class it take into account the summation of the (actual) reported bandwidth of each MS plus the predicted one.

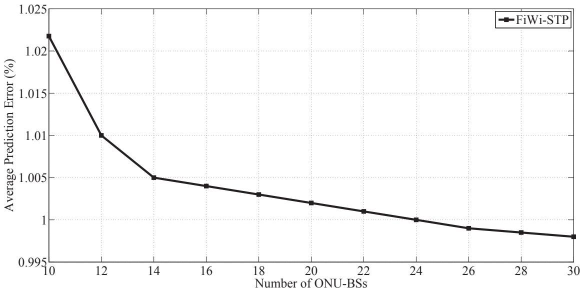

Fig. 1. Scenario1: Prediction error rate.

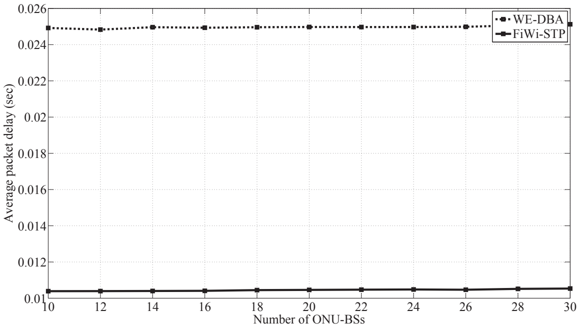

Fig. 2. Scenario1: Average packet delay.

IV. PERFORMANCE EVALUATION

A. Evaluation Enviroment

A standard-compliant FiWi network has been carried out using the Matlab simulation tool. The FiWi network consists of an asymmetric 10G-EPON in the optical domain and multiple WiMAX BSs, embedded in the ONU-BS device. The 10G-EPON supports an upstream rate of 1.25 Gbps while the downstream rate was set to 10.3125 Gbps. A guard time equal to 1 μsec was interleaved between upstream allocations for protection reasons. The MPCP scheme was utilized as the main coordination polling process within the 10G-EPON. The distance between the ONU-BSs and the OLT was uniformly distributed between $[20, 30]$ Km. All MSs were equipped with 10 MBytes buffer size. The limited service scheme was adopted for the MPCP operation, where each ONU-BS was permitted to REPORT up to C_{WiMAX} Bytes. The C_{WiMAX} parameter depends on the wireless channel configuration and it was determined as follows. The Partial Usage of the SubChannels (PUSC) mode was embraced where the WiMAX frame was configured in Time Division Duplex (TDD) mode with 10 msec length. The frame was divided into two sub-frames, the downlink and the uplink sub-frame. The downlink-to-uplink ratio was set $1:1$, providing 630 slots for the uplink sub-frame. The modulation coding schemes were the 16QAM-1/2 offering 96 bits per slot in the uplink transmission rate. As a result, the total offered bandwidth of the WiMAX domain becomes 7560 Bytes per frame in the uplink direction. Hence, $C_{WiMAX} = 7560$.

For comparison reasons, the MSs traffic profile was adopted

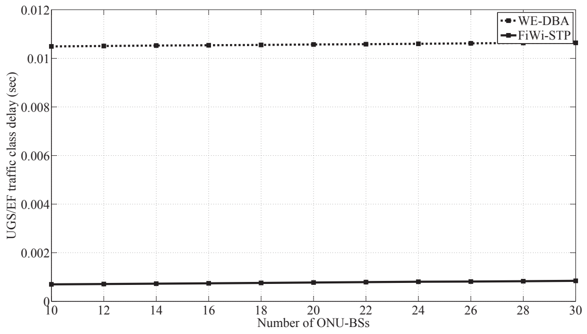

Fig. 3. Scenario1: UGS/EF traffic class delay.

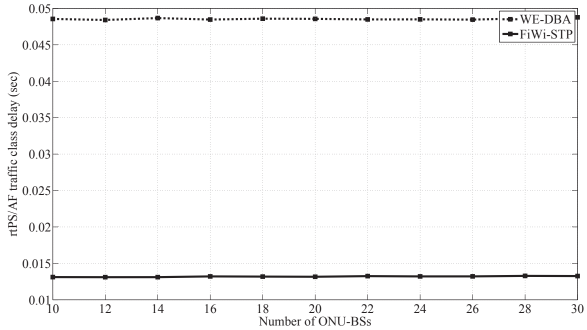

Fig. 4. Scenario1: rtPS/AF traffic class delay.

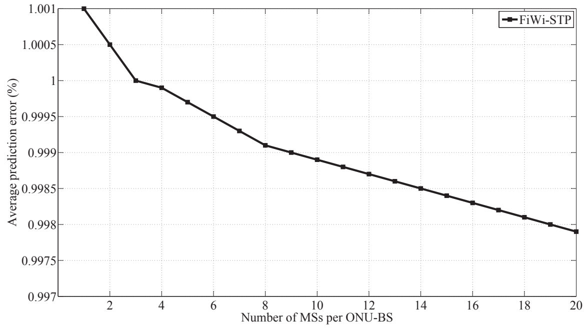

Fig. 5. Scenario2: Prediction error rate.

from [1]. According to this profile, each MS supports three traffic classes, including a Constant Bit Rate (CBR) flow of UGS/EF with average rate of 512 kbps, a Variable Bit Rate (VBR) flow of rtPS/AF with average rate of 1 Mbps and a VBR traffic flow of BE/BE with average rate of 512 kbps. VBR traffic was generated using multiple self-similar sources, where the burst size (i.e., number of packets in a burst) is modeled by Pareto distribution. The shape parameter was 2.2 while the inter-burst gaps were Pareto distributed with 1.5.

First, the prediction accuracy is measured in terms of average error rate. The error rate is defined as $ER = \frac{|PredictedValue-ActualValue|}{TotalStates}$. For example, if the prediction module computes state 20 and the actual value is 30, considering 101 states, then $ER = 9.9\%$.

Second, the proposed DBA scheme is compared with the WE-DBA [1]. WE-DBA assumes a pre-allocated BE/BE bandwidth when the ONU-BSs distributes uplink transmission opportunities to the connected MSs. This rate was set 300 kbps for the simulation experiments conducted. In our scheme, the parameters A_2^{min} and A_3^{min} were set 30% and 10% of the total granted bandwidth respectively. The assessment scenarios include WE-DBA and FiWi-STP performance comparison in terms of average packet delay, UGS/EF traffic class delay, rtPS/AF packet delay.

B. Simulation Results

The presentation of the obtained simulation results is divided into two scenarios. The first scenario encloses the performance evaluation as the number of ONU-BSs increased while the number of connected MSs in the FiWi network remained stable. The MS population impact is investigated in the second scenario, where the number of ONU-BSs remained unchanged and the number of MSs was increased.

Figure 1 presents the prediction error in the first scenario. The number of ONU-BSs changed from 10 to 30 while the number of MSs per ONU-BS was 10. Each ONU-BS supported identical number of MSs. Thus, the FiWi network consisted from 100 to 300 MSs totally. According to the obtained prediction error, it is easy to infer that it is observed low and below 2%. Moreover, the error rate is in decline as the number of ONU-BSs, and therefore the number of MSs, were increased. This is attached to the fact that as the number of MSs is getting larger the number of samples increases, hence the prediction becomes more accurate. In any case, the observed error rate is quite safe, fact that indicates the usage of the proposed stochastic system in real environments. Figure 2 depicts the average packet delay considering the uplink communication between the MSs and the OLT. It is measured in terms of seconds. It is clear that the proposed FiWi-STP scheme outperforms the benchmark scheme since it succeeds a considerable delay reduce. This improvement is due to the beneficial effect of the prediction module, while allows the ONU-BS to make more effective bandwidth requests for the connected MSs taking into account the surplus uplink bandwidth. Thus, the extended wait of the arrived data packets due to the high propagation delays of the coordination messages is avoided. The next two figures shed more light into the examination of the average packet delay. Figure 3 and Figure 4 illustrate the UGS/EF and the rtPS/AF traffic class packet delay. The observed results from both figures validate the superiority of FiWi-STP. It manages to reducing the average packet delay of the sensitive services such as the voice and the live video. In other words, this improvement allows the accommodation of more users in the FiWi network, resulting in higher revenues for the telecom operator.

The prediction accuracy for the second scenario is depicted in Figure 5. The number of ONU-BSs remained stable and equal to 15. The population of MSs was changed from 10 to 20 per ONU-BS. The level of prediction error observed is at the same level as in Figure 1. Once more, it is evident that the prediction module is quite accurate to cope with

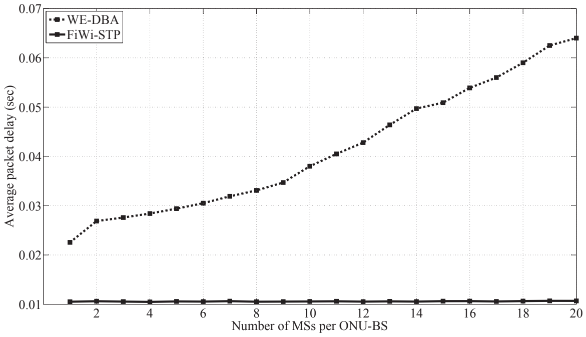

Fig. 6. Scenario2: Average packet delay.

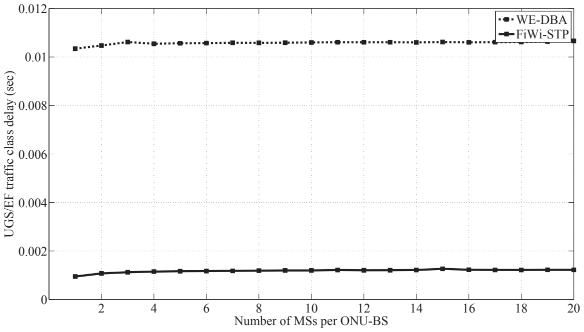

Fig. 7. Scenario2: UGS/EF traffic class delay.

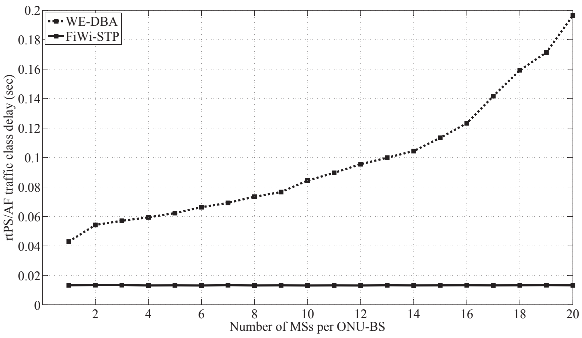

Fig. 8. Scenario2: rtPS/AF traffic class delay.

FiWi access traffic requirements. Figure 6 shows the average packet delay when the number of MSs was increased. As the traffic requesting is getting more pressing the packet delay observed by WE-DBA follows grow reaching almost 0.065 secs. On the other hand, FiWi-STP presents stable delay. It is able to efficiently manage the pressing need for bandwidth by estimating the additional levels of bandwidth through the prediction module. Due to accurate predictions, the applied DBA framework significantly reduces the average packet delay, even when the traffic pressure is really intensive. The same indications are obtained by observing the sensitive application packet delay in Figure 7 (UGS/EF) and in Figure 8 (rtPS/AF). The difference between FiWi-STP and WE-DBA seems to be notable; WE-DBA presents 0.036 and 0.17 more latency than FiWi-STP, in terms of secs, in delivering UGS/EF and rtPS/AF traffic flow respectively.

Summing up, the prediction module enhancement is proven beneficial to the FiWi network since it supports quite accurate predictions as well as efficient bandwidth distribution amongst MSs.

V. CONCLUSIONS

A rigorous prediction-aware DBA scheme was presented in this study for efficiently delivering data packets in FiWi access networks. The rationale behind the prediction module lies in the MS's surplus bandwidth request accurate estimations. The underlying model is based on hidden markov chains, where the level of requested bandwidth is predicted for the next cycle regarding the sensitive traffic classes, i.e., the UGS/EF and the rtPS/AF traffic flows. Extensive simulation results indicated that the impact of the proposed scheme is beneficial to the network performance providing effective efficient bandwidth distribution.

ACKNOWLEDGEMENT

This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: ARCHIMEDES III. Investing in knowledge society through the ESF.

REFERENCES

[1] K. Yang, S. Ou, K. Guild, and H.-H. Chen, "Convergence of ethernet pon and ieee 802.16 broadband access networks and its qos-aware dynamic bandwidth allocation scheme," *Selected Areas in Communications, IEEE Journal on*, vol. 27, no. 2, pp. 101–116, February 2009.

[2] L. Jiang, M. lei Fu, and Z. chun Le, "Hierarchical qos-aware dynamic bandwidth allocation algorithm for wireless optical broadband access network," in *Electronics, Communications and Control (ICECC), 2011 International Conference on*, Sept 2011, pp. 4329–4332.

[3] S. Ou, K. Yang, and H.-H. Chen, "Integrated dynamic bandwidth allocation in converged passive optical networks and ieee 802.16 networks," *Systems Journal, IEEE*, vol. 4, no. 4, pp. 467–476, Dec 2010.

[4] N. Moradpoor, G. Parr, S. McClean, and B. Scotney, "{IIDWBA} algorithm for integrated hybrid {PON} with wireless technologies for next generation broadband access networks," *Optical Switching and Networking*, vol. 10, no. 4, pp. 439 – 457, 2013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1573427713000544

[5] J. Coimbra, G. Schtz, and N. Correia, "A game-based algorithm for fair bandwidth allocation in fibre-wireless access networks," *Optical Switching and Networking*, vol. 10, no. 2, pp. 149 – 162, 2013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1573427712000756

[6] A. Sarigiannidis, M. Iloridou, P. Nicopolitidis, G. Papadimitriou, F. Pavlidou, P. Sarigiannidis, M. Louta, and V. Vitsas, "Architectures and bandwidth allocation schemes for hybrid wireless-optical networks," *Communications Surveys Tutorials, IEEE*, vol. 17, no. 1, pp. 427–468, Firstquarter 2015.

[7] R. Shaddad, A. Mohammad, S. Al-Gailani, A. Al-hetar, and M. Elmagzoub, "A survey on access technologies for broadband optical and wireless networks," *Journal of Network and Computer Applications*, vol. 41, no. 0, pp. 459 – 472, 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1084804514000058

[8] N. Ghazisaidi and M. Maier, "Fiber-wireless (fiwi) access networks: Challenges and opportunities," *Network, IEEE*, vol. 25, no. 1, pp. 36–42, January 2011.