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Cooperative QoS Control Scheme Based on Scheduling Information in FiWi Access Network

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ABSTRACT Fiber-wireless (FiWi) access networks comprising wireless local area networks (WLANs) and passive optical networks (PONs) have attracted much attention recently for future cyber-physical systems (CPSs). Because of the explosive growth of smart devices such as smart phones and sensors, the number of such devices has also grown phenomenally that require real time communication demanding quality of service (QoS)-centric applications for CPSs, such as smart grid, medical, and traffic control systems, which construct smart society. To deal with such situations, the FiWi access networks may be a suitable choice since they are capable of providing both wide bandwidth and flexibility. However, combining the WLAN and PON in FiWi that are inherently different networking technologies leads to inefficient data transmission in the point of junction of the WLAN and PON. Therefore, the QoS of real time communication degrades significantly. In this paper, we address this problem involving QoS degradation in the FiWi networks, and propose a QoS control scheme, which is based on cooperation between the WLAN and PON. Through computer-based simulations, we demonstrate that our proposed scheme can significantly improve the QoS performance of the FiWi access networks for CPSs.

INDEX TERMS Fiber-wireless (FiWi), passive optical network (PON), quality of service (QoS).

I. INTRODUCTION

Recently, due to the wide development of wireless access networks, we can use high speed wireless communication by utilizing next generation wireless access networks, such as Worldwide Interoperability for Microwave Access (WiMAX) [1] and Long Term Evolution (LTE) in cellular network, or even by using IEEE 802.11n and 802.11ac based Wireless Local Area Networks (WLANs).

In addition, due to the development of smart and portable devices (e.g., smart phones, smart sensors, and so forth), Cyber-Physical Systems (CPSs) have attracted much attention [2], [3]. By utilizing the wireless networks to interact among cyber and physical components, CPSs can improve many smart systems such as smart grid, medical, and traffic control systems which construct smart society. Although the development of wireless techniques gives us fascinatingly convenient communication facilities, the network capacity of the backhaul network will gradually, if not drastically, diminish as it is not enough to meet the demands of the mobile users, number of whom has been increasing by leaps and bounds. In order to deal with such a mass users demands, the optical network is considered by many researchers to be suitable for the backhaul network because it is capable of providing stable communication and huge bandwidth. Therefore, the Fiber-Wireless (FiWi) network [4], [5], which integrates optical networks and wireless access networks attract more attention for supporting next generation CPSs in a future ubiquitous network.

In this paper, we focus on a FiWi access network comprising WLAN and Passive Optical Network (PON) [6] technologies for CPSs as shown in Fig. 1. The WLAN consists of fixed Access Points (APs) and mobile users, sensors, or ‘‘movable stations’’ (STAs). An AP manages the communications of a number of STAs, which are in the AP’s coverage area. On the

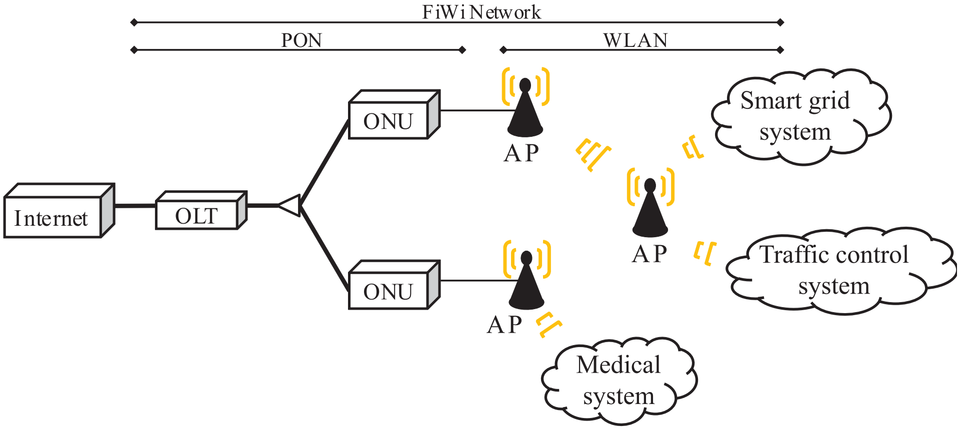

FIGURE 1. Concept of FiWi access networks for CPSs.

other hand, the PON consists of an Optical Line Terminal (OLT), Optical Network Units (ONUs), and a passive splitter (note that all of these devices are fixed). The OLT controls both uplink and downlink transmission of all the ONUs, which are connected to the OLT through the passive splitter. In this network, we can construct a WLAN flexibly because the AP can be conveniently set without any complex design such as deployment of base stations in cellular networks. Also, the PON provides a wide bandwidth and stable communication with low power consumption since it uses passive devices equipped with power saving schemes. In addition, the cost of constructing each WLAN and PON is reasonably low. Due to these features, the FiWi may be considered to be an attractive technology to meet the high bandwidth requirement of the ever increasing number of mobile users and sensors for CPSs.

A FiWi access network based on WLAN and PON technologies is, however, not without its shortcomings. A critical shortcoming of such a FiWi network is its transmission latency, which can seriously affect the QoS of real time communications. When a STA starts real time communication, the communication between the AP and STA is controlled by IEEE 802.11e [7] in order to guarantee the QoS of this communication. After that, the communication packets are transmitted to the OLT through the ONU. For this, the packets remain buffered in the ONU until the OLT allows the ONU to transmit by means of Dynamic Bandwidth Allocation (DBA) [8], [9]. As a consequence, a transmission latency occurs in the ONU. This transmission latency causes degradation of QoS for real time communications, e.g., transmission delay, jitter, and packets drop. This problem mainly arises due to the fact that the corresponding QoS control schemes of the WLAN and PON technologies (i.e., the IEEE 802.11e and the DBA, respectively) operate independently. In other words, they do not operate in a synchronized fashion, and contributes to the transmission latency, which severely degrades the QoS. In order to solve this problem, in our paper, we propose a cooperative QoS control scheme between the WLAN and PON.

The remainder of this paper is organized as follows. A summary of recent relevant works is presented in Section II. Section III introduces QoS control techniques of both WLAN and PON. Section IV presents our proposed QoS control scheme. Section V evaluates the proposed method through computer-based simulations, and presents an analysis of the simulation results. Finally, Section VI concludes this paper.

II. RELATED WORK

A number of QoS provisioning techniques have been developed recently for “Radio and Fiber” (R&F) networks. In the work in [10], both centralized and distributed scheduling techniques were investigated for effectively combining Ethernet PON (EPON) and WiMAX technologies aiming at enhancing QoS requirements such as network throughput and end-to-end latency. Also, in the work conducted by Suzuki *et al.* [11], a bandwidth allocation method to improve user QoS satisfaction without decreasing system throughput in FiWi access networks (which combine EPON with WiMax networks) was proposed. Their proposal was based upon a utility-based resource allocation scheme comprising two stages. In the first stage, the user assignment among the base stations is determined which is followed by an estimation of tentative slot allocations such that the entire system throughput over all the APs is increased. The second stage is independently conducted in each of the APs to increase the system utility by exchanging slots among the users within the same AP. By this way, Suzuki *et al.* showed that the increase of the system throughput and the improvement of the system utility in their considered FiWi access network have a trade-off relationship.

Bandwidth allocation related research work have been carried out by other prominent researchers also. For instance, in the work in [12], a QoS-aware DBA scheme was envisioned to allow bandwidth fairness at the ONU-AP junction. In that work, the ONU-AP interface, based on the status of its queue, sends optical bandwidth requests to the OLT. By this way, it improves a number of QoS parameters, such as the network throughput, latency, and bandwidth utilization. Shaw *et al.* [13] reported that designing suitable routing algorithms may be exploited for enhancing QoS support in R&F networks as the routing algorithms are critical for load balancing and congestion control purposes in PONs. Shaw *et al.* used this hypothesis to propose a new routing technique for PON to improve the network throughput and delay performance. On the other hand, routing algorithms for the wireless side were investigated in the work conducted by Sarkar *et al.* [14]. The investigation from that work reported that the Risk-And-Delay-Aware Routing algorithm (RADAR), in contrast with other routing protocols in the wireless side, exhibits the best QoS performance in terms of throughput, latency, and load balancing.

An interesting work conducted in [15] highlights the fact that FiWi networking research on "layer 2" has started, however, not yet gained much maturity. The work enumerates a number of important research challenges in FiWi environments, namely integrated channel assignment and bandwidth allocation, combined path selection, end-to-end QoS support, and so on. By arguing that a more intensive study of advanced QoS provisioning schemes is required to support multimedia applications and services in R&F networks such as FiWi, it then proposed an Ethernet-based "SuperMAN" access-metro network with optical-wireless interfaces involving EPON and WLAN-based mesh networks. It was also shown in that work that deploying hierarchical frame aggregation across EPON and WLAN-based mesh networks substantially enhances the throughput-delay performance.

A new framework was presented to meet strict and diverse QoS requirements over FiWi networks in [16]. The framework exploits the available resources in the considered FiWi networks. Under the framework, the performance of EPON and WiMAX was studied. Future directions on designing an advanced DBA were also given in [16] for enabling a proactive admission policy for FiWi networks while meeting the QoS requirements of the users.

The trade-off between energy saving and QoS support for multi-media content delivery in FiWi broadband access networks was investigated in [17]. Also, a green QoS differentiated routing scheme was proposed in [17] showing that there are different ways of meeting QoS demands in FiWi networks. Furthermore, the research conducted in [18] also attests to the benefit of adopting FiWi access networks as they bring great prospects for energy savings in addition to cost-effective solutions. It is worth mentioning that the research in [18] highlights the following important point. The flexibility of FiWi networks in terms of energy saving becomes useful only if the QoS experienced by the users can be kept at acceptable levels. For instance, more communication hops can lead to increase in delay and decrease in throughput, and this QoS degradation may be noticed particularly in the wireless segment of a FiWi network.

A broader trend in the need to satisfy the QoS requirements of FiWi network users is delineated in the work in [19]. The work demonstrates how low cost EPONs and wireless mesh networks can be combined to facilitate the communication of smart power grid systems. The work further shows that as the load of the FiWi network increases, the performance degradation in terms of packets drop and the delay increases because of lack of "QoS protection". As a solution, an adaptive admission control technique to provide QoS support for FiWi smart grid communication networks was proposed in [19].

III. FIWI ACCESS NETWORK

In this section, we introduce the basic QoS provisioning methods adopted by the wireless (based on IEEE 802.11e WLAN) segment and the fiber part (PON) of a FiWi access network. First, the QoS control technique of the 802.11e is described briefly. Second, the DBA employed by the PON technology is delineated. Finally, the problem of transmission latency in the combined WLAN-PON is explained.

A. QoS CONTROL TECHNIQUE OF IEEE 802.11e BASED WLAN

IEEE 802.11e offers a MAC layer protocol, which may perform QoS control in the WLAN. As a standard of the original 802.11 for MAC layer, Point Coordination Function (PCF) and Distributed Coordination Function (DCF), and Hybrid Coordination Function (HCF) which unified both DCF and PCF are specified. In 802.11e, QoS control is realized by extending HCF, and two types of QoS control techniques, namely Enhanced Distributed Channel Access (EDCA) and HCF Controlled Channel Access (HCCA) are specified [20]. Depending on the need of the WLAN users (i.e., STAs), either of these QoS control techniques may be utilized.

When the STAs demand priority of data, EDCA can be employed. An advantage of EDCA is that it can be implemented in devices at a reasonably low cost because of its simple control. However, QoS parameters such as bandwidth, delay and jitter cannot be guaranteed accurately in EDCA since it is just a priority based control. Also, when the high priority data occupy the whole network transmission, the priority control offered by EDCA may not function adequately.

On the other hand, HCCA is based on QoS parameters, which STAs often require. Therefore, the QoS parameters specified by a STA can be guaranteed strictly by using HCCA. However, in order to offer a strict QoS guarantee, the number of STAs which an AP may support is restricted. In other words, in HCCA, the number of STAs, QoS demands of which may be satisfied, is limited.

The fundamental communication procedure of the HCCA QoS control technique of 802.11e is shown in Fig. 2, and briefly described below.

i) A STA negotiates QoS requirements to AP by sending QoS parameters.

ii) The AP calculates transmission opportunity (TXOP) which is the period that the STA can transmit the data based on the QoS requirements.
iii) The STA starts to transmit the data when it receives the QoS-Poll frame (i.e., permission from the AP to start transmission) which the AP sends if no other STA is currently using the channel.
iv) The STA transmits its own data exclusively during its TXOP.

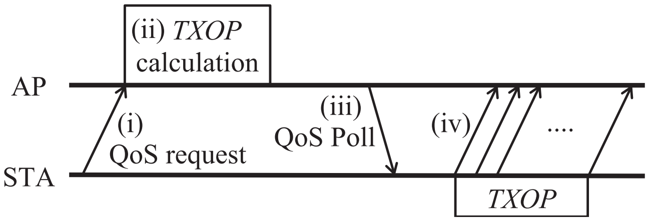

FIGURE 2. **HCCA - the QoS control policy in the IEEE 802.11e based WLAN.**

To calculate the TXOP, first we need to compute the number of frames, N, which the STA needs to transmit as follows.

$$N = \left\lceil \frac{SI \times \rho}{L} \right\rceil. \quad (1)$$

As shown in Eq. 1, N can be calculated by dividing the product of the data rate in STA (denoted by ρ) and the length of the service interval SI by the frame length L. Ceiling function is applied to the division result in order to ensure the maximum number of frames, which the STA can transmit. Now, the TXOP of the STA can be calculated as follows.

$$TXOP = \frac{N \times L}{R}. \quad (2)$$

In Eq. 2, the $TXOP$ is calculated by dividing the transmission data, $(N \times L)$, by the transmission rate between the STA and AP, denoted by R.

B. QoS CONTROL TECHNIQUE OF PON

In the fiber side of our considered FiWi network, namely PON, the upstream traffic is controlled by Dynamic Bandwidth Allocation (DBA). DBA is executed by the OLT, and the allocated bandwidth of each ONU connected to the OLT can be changed along with its allocated buffer. There are two well known DBA methods, namely Status Reporting DBA (SR-DBA) and Traffic Monitoring DBA (TM-DBA) [21]. In SR-DBA, the following process is adopted by the OLT and each of the ONUs.

i) An ONU buffers the upstream traffic.
ii) The ONU records the amount of traffic to a “REPORT” frame, and sends to the OLT.
iii) The OLT collects all the REPORT frames from the ONUs, and calculates the bandwidth to be allocated to each ONU.
iv) The OLT records the allocated bandwidth to the “GATE” frame, and sends to each ONU.
v) Each ONU sends upstream traffic according to the received “GATE” frame with the next REPORT frame.

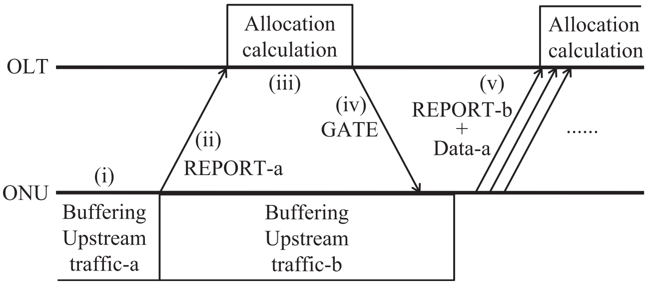

FIGURE 3. **Concept of SR-DBA.**

The entire process is shown in Fig. 3. Here, the GATE and REPORT frames are the control frames of Multi Point Control Protocol (MPCP), which controls the upstream transmission. The REPORT frame reports the amount of upstream traffic, which each ONU has buffered, to the OLT. On the other hand, the GATE frame directs the amount of traffic the OLT has allowed to transmit, along with the beginning time to transmit, to every ONU in order to avoid collision in the upstream traffic.

Thus, the SR-DBA scheme aims at allocating the bandwidth adequately based on every ONU’s REPORT frame. However, transmission latency always happens as the SR-DBA scheme needs to wait for receiving the REPORT frame from each ONU. As a consequence, the responsiveness toward the arrival traffic is low in this scheme.

On the other hand, TM-DBA allocates bandwidth based on the amount of traffic the OLT has received. In TM-DBA, the OLT assigns a small amount of additional bandwidth to each ONU on a continuous manner. In case the ONU has no traffic to transmit, it sends idle frames during the excess allocation it receives (as shown in Fig. 4(a)). When the OLT notices that an ONU is not transmitting any more idle frame (as shown in Fig. 4(b)), it realizes that the ONU is currently in need of bandwidth. Therefore, the OLT increases the bandwidth allocation to that particular ONU. Once the ONU has finished transferring its data, the OLT notices a significantly large number of idle frames from that ONU. Accordingly, the OLT reduces its bandwidth allocation to the ONU as shown in Fig. 4(a). While it does not impose any requirement upon the ONU, the TM-DBA method does not have any provision for the OLT to know how to allocate bandwidth across several ONUs that need more bandwidth. Thus, it causes transmission latency to a part of the data which is not transmitted during the allocation. Moreover, also the excess bandwidth allocation increase the transmission latency of the data from other ONUs.

In summary, while the utilization efficiency of bandwidth and responsiveness of these two schemes (i.e., SR-DBA and

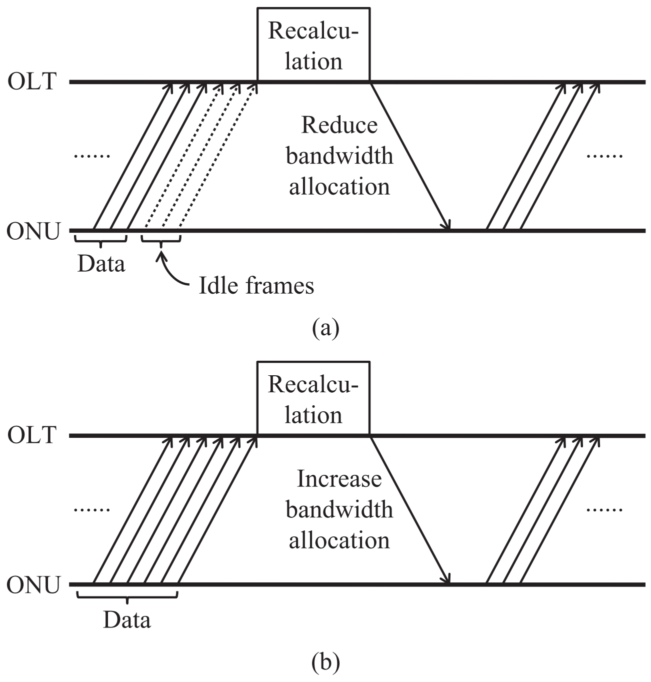

FIGURE 4. TM-DBA concept. (a) In case the ONU is allocated excess bandwidth. (b) In case the ONU needs more bandwidth.

TM-DBA) are different, they both suffer from the communication latency problem.

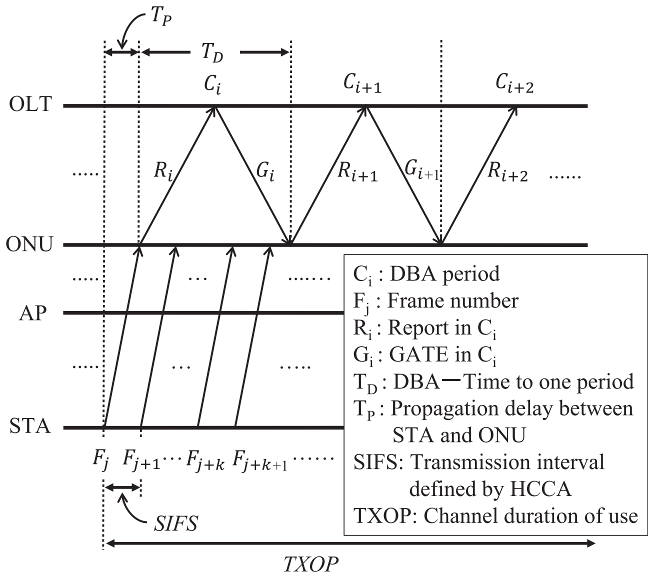

FIGURE 5. Network model of the considered FiWi network model.

C. ANALYSIS OF TRANSMISSION LATENCY IN FiWi

According to the behavior of the IEEE 802.11e HCCA and PON's DBA, we consider the network model as depicted in Fig. 5, and formulate the resultant transmission latency of the $(j+k)^{th}$ transmitted frame D_{j+k}. D_{j+k} denotes the time gap after the STA sends the $(j+k)^{th}$ frame until the ONU starts to transmit the frame to the OLT. In Fig. 5, C_i, R_i, and G_i present the i^{th} DBA period, Report frame, and GATE frame, respectively. Additionally, F_j shows the j^{th} frame. D_{j+k} can be expressed as a summation of the fixed latency and variable latency. The fixed latency refers to the duration between a reported frame and the transmitted frame. On the other hand, the variable latency indicates the duration between the arrived traffic and the reported traffic. Then, D_{j+k} may be expressed as follows.

$$D_{j+k} = \left\lceil \frac{k \times SIFS}{T_D} \right\rceil \cdot T_D - k \times SIFS + T_D + T_P. \tag{3}$$

Here, *SIFS* represents the fixed time defined by the IEEE 802.11e standard for transmitting a frame. T_D refers to a DBA period/cycle. Also, T_P denotes the propagation delay between the STA and the ONU, and may be expressed as follows.

$$T_P = \frac{d_{STA-ONU}}{c}, \tag{4}$$

where $d_{STA-ONU}$ and c denote the propagation distance between the STA and the ONU, and light speed, respectively.

The average transmission latency of all frames transmitted from the STA, namely $D_{average}$, is expressed as follows.

$$D_{average} = \frac{\sum_{k=1}^{N} D_{j+k}}{N}. \tag{5}$$

Eq. 5 shows that the factor of increasing the transmission latency is the length of DBA period (also known as the DBA cycle).

IV. PROPOSED SCHEME

As explained in the earlier section, the existing DBA methods are not efficient because these methods cannot be used together with the utilization efficiency of the bandwidth and responsiveness for decreasing the transmission latency in the ONU. The main reason why the existing DBA methods are inefficient is that the arrival traffic toward the ONU cannot be accurately predicted. So, we propose an efficient DBA scheme for decreasing the transmission latency in the ONU with high utilization efficiency of bandwidth. In order to achieve an efficient DBA scheme, we consider cooperation between the WLAN and PON in the considered FiWi network. In our proposed scheme, there are two parts to realize the cooperation between the WLAN and PON.

A. HCCA INFORMATION OF WLAN

The behavior of HCCA is divided into two parts, namely QoS negotiation and scheduling. QoS negotiation means that the STA attempts to make a logical connection to the AP with several QoS requirements, i.e., the maximum delay, data rate, frame length, and so on. Then, the AP calculates TXOP, which is the length of transmission time to meet the STA's QoS requirements. On the other hand, scheduling means that the AP allows the STA, which has completed QoS negotiation, to transmit a data during TXOP. QoS negotiation and scheduling are conducted in the Contention Period (CP) and Contention Free Period (CFP), and these two periods are conducted in a cycle of Service Interval (SI) periodically.

When the STA tries to start its network service, it transmits information about QoS requirements of its network service to the AP in the QoS negotiation part. Then, the AP calculates TXOP by using Eq. 2.

After finishing the QoS negotiation, the AP begins the scheduling part. In this part, the AP confirms whether the TXOP can be scheduled in the CFP or not. Here, we refer to the TXOP which will be scheduled as the "new TXOP", and refer to a duration time of the scheduled TXOPs as the "total TXOP". If the sum of the new TXOP and the total TXOP is less than the length of CFP, the new TXOP can be scheduled in the CFP, and the STA can transmit its data during TXOP in every SI.

Through the whole process of HCCA, the AP can know the exact information about the transmission schedule of all the STAs connected to the AP. Here, we define the information as "HCCA information", and assume that every AP in the FiWi access network uses HCCA. Therefore, every AP in the FiWi access network is supposed to possess the HCCA information.

B. COOPERATIVE DBA WITH HCCA INFORMATION

The ONU collects the HCCA information from the APs connected to the ONU. The collection of HCCA scheduling information is performed for every SI of each AP because the transmission situation can be changed for every SI of each AP. After this collection, the ONU can know the arrival traffic from all the APs connected to the ONU. Here, we discuss the availability of this process from the point of view of overhead during the process. In general, the duration time of SI is significantly longer than that of the DBA period, which means that the process is not executed so frequently. Therefore, the HCCA collection is available because the effect of the overhead is quite small.

After collecting the HCCA information, the ONU calculates the amount of the traffic arrived in the DBA period, denoted by C_i. In the FiWi access network, every ONU has APs (AP_p) connecting STAs ($STA_{p,q}$), which have already completed the HCCA scheduling. Here, we define the p and q as the identification number of the ONU and that of the STA connecting to the ONU, respectively. Additionally, the maximum number of p and that of q, which show the total number of ONUs and STAs connecting with an ONU, is expressed as P and Q, respectively. Moreover, we define the $STA_{p,q}$'s transmission time in C_i as T_{REPORT}. During T_{REPORT}, the number of arrival frames, denoted by $N_{p,q}(T_{\mathrm{REPORT}})$, is calculated as follows.

$$N_{p,q}(T_{\mathrm{REPORT}}) = \mathrm{ceil}\left(\frac{T_{\mathrm{REPORT}} \times \rho_{p,q}}{L}\right), \tag{6}$$

where $\rho_{p,q}$ and L denote the data rate of the $STA_{p,q}$ and frame length.

The amount of traffic $S_{p,q}$ is calculated as follows.

$$S_{p,q}(T_{\mathrm{REPORT}}) = N_{p,q}(T_{\mathrm{REPORT}}) \cdot L. \tag{7}$$

Therefore, the arrival traffic during C_i is calculated by the above mentioned equations, and the amount of the traffic is buffered in R_i. The ONU can use R_i for the REPORT of ith DBA cycle, which means that the transmission latency of the arrival traffic becomes shorter than that in the existing methods, because the OLT can allocate bandwidth to the ONU accurately enough to transmit all the arrival traffic.

TABLE 1. Simulation parameters.

Number of OLTs	1
Number of ONUs	1–32
Number of APs per ONU	15
Number of STAs	Random
Bandwidth of PONs [Gbps]	10
Bandwidth of WLANs [Mbps]	200
Allocation factor of TM-DBA	1, 2, 3
Simulation time	1000 DBA cycles

V. PERFORMANCE EVALUATION

A. SIMULATION ENVIRONMENT

In this section, we evaluate the performance of our proposal through extensive computer simulation programed in Ruby. The simulation parameters are summarized in Table 1. In this simulation, the supposed FiWi access network is constructed by an OLT and some ONUs on the PON side, and some APs having some STAs on the WLAN side. The number of ONUs is varied from 1 to 32 and each ONU has 15 APs. The number of STAs is randomly changed and each STA generates traffic to the APs. The bandwidth of the PON side and that of the WLSN side are set to 10 Gbps and 200 Mbps, respectively, by reference to 10G-PON and 802.11n. We suppose that the FiWi access network has enough bandwidth for providing the requested bandwidth from the ONU because sufficient bandwidth is needed to meet the QoS demands of the real time QoS.

In our conducted simulations, we compare our proposed cooperative DBA method with the afore-mentioned two existing methods, SR-DBA and TM-DBA. TM-DBA has a factor for allocating bandwidth ranging from 1 to 3. In TM-DBA, the allocated bandwidth to the ONU is obtained for the product of the amount of traffic OLT received from the ONU during a DBA period and this factor. The performance comparison is conducted in terms of the efficiency of bandwidth utilization, transmission delay, and usage of buffer in the ONU. These parameters are defined as the summation of each values over all the ONUs divided by the total number of ONUs.

B. SIMULATION RESULTS

We set the length of DBA cycle to 0.5 msec, and plotted the performances of each simulation parameter as demonstrated in Fig. 6 for different numbers of ONUs. Fig. 6(a) shows that our proposal maintains its efficiency of bandwidth utilization as much as SR-DBA's for the various numbers of ONUs. On the other hand, according to the size of the allocation factor, the efficiency of band-

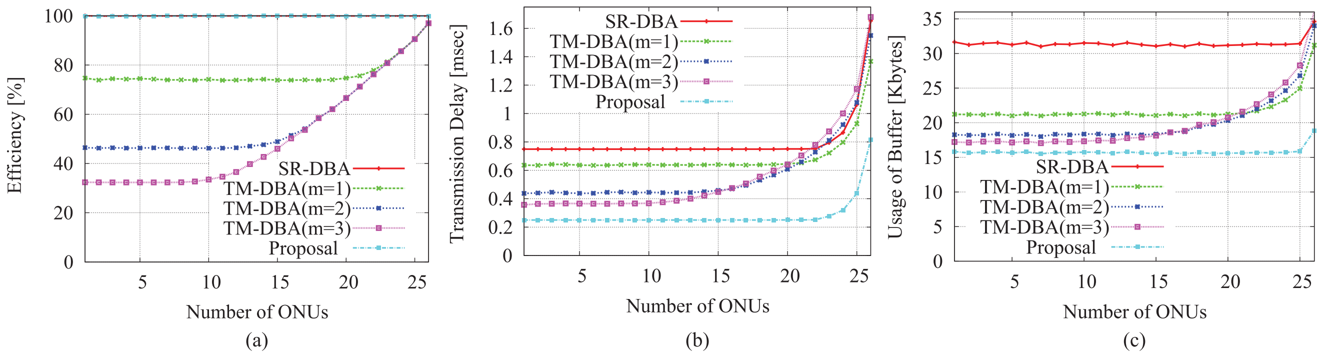

FIGURE 6. Comparison of performance of the various methods with varying numbers of users (i.e., ONUs). (a) Efficiency of bandwidth utilization. (b) Transmission delay. (c) Usage of buffer.

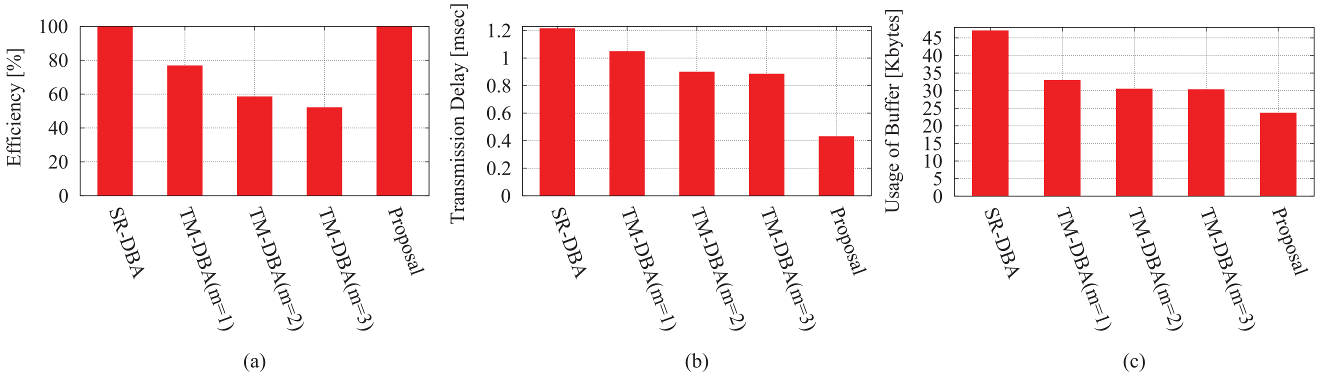

FIGURE 7. Comparison of performance improvement among different methods including our proposal. (a) Efficiency of bandwidth utilization. (b) Transmission delay. (c) Usage of buffer.

width utilization in TM-DBA tends to worsen. In other words, TM-DBA cannot achieve accurate bandwidth allocation because it is just a linear prediction made by the OLT. Fig. 6(b) demonstrates that our proposal constantly achieves low transmission delay in contrast with other existing methods. In smaller number of ONUs scenarios, TM-DBA performs low transmission delay proportional with the size of the allocation factor. Moreover, in Fig. 6(c), the usage of received buffer is also improved, which shows that our proposal scheme can transmit traffic in the ONU immediately. Fig. 7(a)– 7(c) show the average values ranging the length of DBA cycle from 0.5 to 1.0 msec. In Fig. 7(a), our proposal maintains the same efficiency as that of SR-DBA. In Fig. 7(b) and 7(c), the buffering delay and buffer occupancy of our proposal are improved up to 65% and 50%, respectively, compared with those in SR-DBA. These results show that our proposal achieves superior performance regardless of the length of the DBA cycle. Therefore, QoS for real time communications for CPS is improved by our proposed method.

VI. CONCLUSION

FiWi networks, which are made up of WLAN and PON have a potential for providing real time QoS to facilitate future CPSs. However, the transmission latency is caused by non-matching QoS control schemes used in the WLAN and PON segments of FiWi networks, and it affects the real time QoS, such as transmission delay, jitter, and packets drop. In existing methods, especially DBA used by the PON, it is not possible to provide bandwidth efficiency and responsiveness at the same time when WLAN is combined with the PON technology. To solve this problem, in this paper, we proposed a QoS control scheme, which allows cooperation between the WLAN and PON in order to achieve both bandwidth efficiency and responsiveness. The results of our conducted simulations demonstrate that our proposal can significantly improve various QoS parameters for real time communications for CPSs in contrast with existing methods. Thus, our proposal can be considered to be an effective QoS control method in QoS adaptive networks for CPSs such as FiWi access networks comprising heterogeneous network technologies.

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