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# SYMMETRIC UPLINK AND DOWNLINK TRANSMISSIONS FOR NON-SATURATED WLAN IN FIBER-WIRELESS NETWORKS

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## ABSTRACT

The convergence of optical and wireless technologies holds great promise for the development of future broadband access networks. As such, we work on the idea of integrating the gigabits passive optical network (GPON) with infrastructure-based wireless local area network (WLAN) to realize fiber-wireless (Fi-Wi) networks. The study focuses on the enhancement of the wireless side which is seen as the critical bottleneck because the wireless channel is shared by all WLAN access points ('closed system'). The binary exponential backoff (BEB) algorithm in the standard WLAN is the key factor that leads to the throughput degradation and the unfairness between uplink and downlink transmissions. Therefore, two techniques are proposed to overcome the limitations and improve the end user performance in a non-saturated condition. The first technique exploits the accessible content of the GPON control frame and modifies the legacy BEB scheme by introducing optimum constant contention window (CW) sizes. The second technique is a transmission priority scheme that provides symmetric uplink and downlink transmissions for wireless users (WU) and their serving access points (AP).

**Keywords:** Fi-Wi, GPON, WLAN, BEB, CW size, throughput, fairness.

## INTRODUCTION

The ever increasing internet usage has strongly motivated the necessity of upgrading the access network infrastructure. As of now, the network remains a bottleneck in efforts to deliver services to customers due to the limitation of available bandwidth. Fiber optics offer virtually unlimited carrying capacity as the speed can exceed 100 terabits ($10^{15}$ bits) per second over hundreds of kilometres (Hecht, 2011). Gigabit passive optical network (GPON) is preferred for low cost residential users, now has access rates of 2.5 Gbps, and will increase to 10 Gbps (Bindhaiq, Supaat *et al.*, 2014). Even though optical fibers are an ideal media for high-speed broadband networks, the deployment cost was considered prohibitive in the access area, and copper wires still dominate in the current market place. However, due to the fact that the copper wire has reached its maximum speed, fiber will eventually become the dominant access technology in the near future.

On the other hand, wireless is the most convenient for users and gaining more popularity. Statistics in (Cisco, 2014) show that the global mobile data traffic will grow three times faster than fixed IP traffic from 2013 to 2018. This is mainly because the wireless networks offer end users great flexibility and mobility. Wireless local area network (WLAN) is the most favoured wireless network due to its low cost and ease of installation. However, it is limited to a much lower bandwidth than the fixed network and the transmission channel is susceptible to a variety of impairments (Maier, 2014). Wireless usage will saturate unless these issues are addressed.

Interestingly, optical and wireless networks can be viewed as a complementary: fiber has a sufficient bandwidth but does not go everywhere while wireless can go everywhere but has a limited bandwidth. Therefore, fiber-wireless (Fi-Wi) broadband access networks are

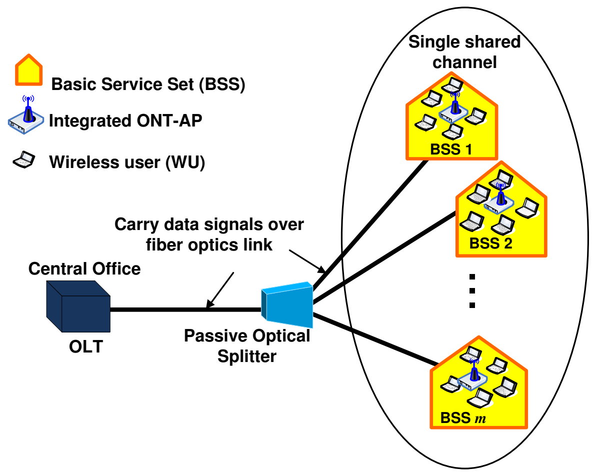


**Figure-1.** Fiber-wireless network scenario.

realized by combining the huge capacity of fiber with the ubiquity and mobility of wireless networks. The development of Fi-Wi networks makes the enhancement of both optical and wireless networks important.

Therefore, this paper studies the Fi-Wi network. The network is realized by integrating a gigabit passive optical network (GPON) of optical media with a 'closed' wireless local area network (WLAN) of wireless media as shown in Figure-1. The integration is employed at the end-user terminal where an optical network terminal (ONT) of GPON and an access point (AP) of WLAN are incorporated into a single device, forming a Fi-Wi hybrid system, also known as radio and fiber (R and F) system (Shen and Tucker, 2007), (Maier, Ghazisaidi *et al.*, 2009). The integrated ONT-AP device acts as a gateway translating media access control (MAC) frames from the optical network to the wireless network and vice versa. Two distinct separate MAC protocols are used to access GPON and WLAN respectively. Thus, the wireless MAC frames only traverse the WLAN and do not have to travel along the optical fibre to be processed at the central office. Consequently, the negative impact of the fiber propagation delay on the network can be avoided. This conclusion is also supported in (Maier, Ghazisaidi *et al.*, 2009).

The study focuses on the enhancement of the wireless side which is seen as the critical bottleneck due to the fact that the wireless channel is shared by all WLAN access points ('closed system'). The binary exponential backoff (BEB) algorithm in the standard WLAN is identified as the key factor that leads to the throughput degradation and the unfairness between uplink and downlink transmissions which have been addressed in our previous works in (Hassan, King *et al.*, 2012) and (Hassan, King *et al.*, 2013) respectively. The paper proposes a technique to maximize throughput while achieving symmetric fairness between uplink and downlink transmissions by exploiting information from the GPON control frame and incorporating a simple analysis into an exhaustive search technique. The rest of the paper is organized as follows. The second section presents the GPON architecture and identifies traffic information that can be used for network enhancement. The third section reviews the techniques to enhance the legacy BEB algorithm in WLAN. The forth section presents the optimized constant contention window scheme. The fifth section proposes and further analyses the AP priority scheme. Finally, the last section concludes the paper.

## GPON ARCHITECTURE AND TRAFFIC INFORMATIONS

Gigabit passive optical network (GPON) becomes a favourite access technology for a fixed local access. This is mainly because the signals in GPON are replicated passively by a splitter without involving any electric component. Hence, the PON deployment incurs less cost since it does not require any electrical power or backup batteries. It also offers higher reliability due to the absence of the electronic components, which are prone to failure (Effenberger, Clearly *et al.*, 2007), (Effenberger, Kani *et al.*, 2010). The optical line terminal (OLT) at the central office is connected to a passive optical power splitter using a single mode optical fiber which divides the optical power into *N* (*N* varies from 16 up to 128) separate paths to the subscribed optical network terminals (ONTs). An individual single-mode fiber strand runs from the optical splitter to each ONT and the physical reach from the OLT to ONTs can go up to 20 km. GPON employs a time division multiplexing (TDM) for downstream (1480-1500 nm) and a time division multiplexing access (TDMA) for upstream (1260-1360 nm) transmissions. Besides, the wavelength 1550-1560 nm is used for downstream video transmission. Several transmission rates for the downstream and the upstream lines are defined in the GPON standard (G.984.1 , 2008). Most often, vendors offer only 2.4 Gbps in downstream and 1.2 Gbps in upstream (Cale, Salihovic *et al.*, 2007). The downstream traffic is broadcast to all ONTs and each frame is labeled with the address of its target ONT. The OLT has full control of upstream transmissions by allocating fixed or variable time slots to each ONT.

Figure-2 illustrates the GPON upstream and downstream frames. The downstream payload comprises a series of GPON encapsulation method (GEM) frames. Each GEM frame consists of a header and an encrypted payload. The header is divided into four subfields including a Port-ID and a payload length indicator (PLI) as shown in Figure. 2. Each Port-ID within the GEM headers is unique to an ONT; it is checked by all to identify their payload. The corresponding PLI field indicates the size of that payload. The upstream bandwidth mapping (US BW Map) subfield within the downstream control block schedules upstream time slots for ONTs' transmissions. The schedule is set in accordance with the traffic information of each ONT's buffer passed over the upstream control block subframe to the OLT.

The broadcast nature of downstream transmissions

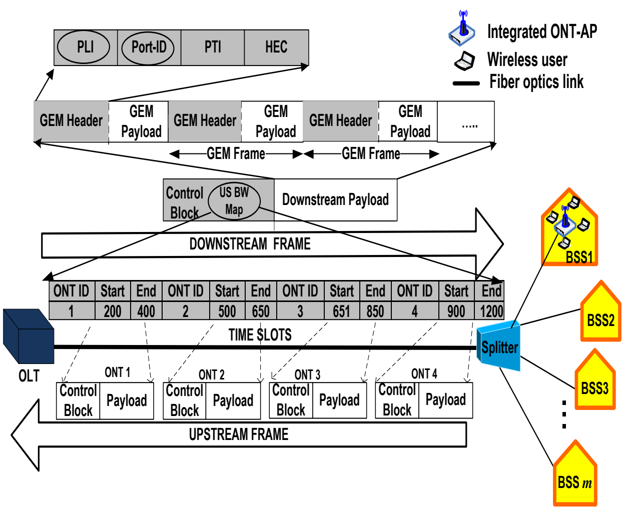


**Figure-2.** GPON frame format (G.984.3, 2008), (Huawei, 2010). The shaded frames are non-encrypted and can be accessed by all ONTs. The circled subfields are used as traffic information.

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allow ONTs to retrieve network traffic information. Three traffic indicators are defined within the integrated ONT-AP. First, the downstream traffic load indicator is obtained by extracting the contents of the PLI subfield in the GEM headers. This provides the size of the downstream traffic going into the ONTs, which in turn is the total traffic transmitted from APs to wireless users (WUs). Second, the traffic load indicator is defined by analyzing the US BW Map subfield; the sum of the lengths of each allocated time slot provides an estimate for the total size of upstream traffic. However, this indicator is lagging because the traffic load has already been transmitted across the WLAN. Assuming the traffic statistics are relatively constant over the measuring period, this indicator corresponds to the total traffic transmitted from WUs to APs. The third indicator gives the total number of active integrated ONT-APs at the air interface by combining the estimate of active ONTs on the upstream and the downstream lines, extracting information from the Port-ID and the US BW Map subfields respectively. At the air interface of the integrated ONT-AP, these three traffic indicators (i.e. upstream traffic size, downstream traffic size and total number of active APs) can be exploited to enhance the performance in the wireless side of Fi-Wi networks.

## RELATED WORKS: ENHANCEMENT IN BEB ALGORITHM

The binary exponential backoff scheme (BEB) in the WLAN standard (IEEE, 1999) has been categorically identified in (Ibrahim and Alouf, 2006) as the key contributor to the performance degradation. This is mainly because the backoff interval set by the contention window (CW) size is always reset to $CW_{min}$ when it initiates a new transmission or after a successful transmission. This resetting CW behavior becomes very unstable when more stations are contending for the same wireless channel because it results in more collisions and deteriorates the whole system performance. Numerous techniques have been proposed in the literature to correctly select the CW size in order to improve the system utilization.

In common, all modifications are made to adjust the contention window size according to the network condition. Variety of approaches has been proposed in the literature to identify the network condition using different types of traffic indicators as classified below.

### A. MAC frames indicator

The proponents of the first category take advantage of the least overhead size information carried by MAC frames including ACK, RTS and CTS frames.

**1) ACK frame:** Stations continuously monitor the traffic on the channel to identify collisions. The presence or absence of an ACK can be used to identify the success or otherwise (collision) of a transmission (Song, Kwak *et al.* ,2003), (Bharghavan, Demers *et al.*, 1994), (Al-Hubaishi, Alahdal *et al.*, 2013), (Chatzimisios, Vitsas *et al.*, 2007).

In (Song, Kwak *et al.*, 2003), the authors propose to exponentially increase the CW size when there is a collision and exponentially decrease the CW size when there is a successful transmission, known as the EIED (exponentially increases exponentially decreases) algorithm. The exponential factors are then optimized to get maximum throughput. The proponents of (Bharghavan, Demers *et al.*, 1994) use a more conservative approach, they linearly decrease the CW size when there is a successful transmission. Similarly, (Chatzimisios, Vitsas *et al.*, 2007) proposes to halve the CW size (unlike BEB where the CW size is reset to minimum) to increase the overall throughput. Further, the work in (Al-Hubaishi, Alahdal *et al.*, 2013) proposes a fairness based algorithm for mobile adhoc networks (MANETs) by adjusting the CW size according to the number of successful transmissions.

In common, all of the above techniques steadily decrease the CW after a successful transmission to retain the overall network state information. Though this approach may have a positive correlation, it usually falls short of predicting the overall network status.

**2) RTS and CTS frames:** The schemes (Wang and Song, 2007), (Li, Tang *et al.*, 2009) proposed in this category use the network allocation vector (NAV) information embedded in RTS and CTS packets as the overall network traffic indicator. The transmitting station explicitly indicates the length of time that it will be using the channel. Consequently, all stations will update their NAV by checking RTS and CTS frames from their transmitting neighbours. Initially, the authors in (Ma, Zhang *et al.*, 2005) utilized NAV information to analytically derive an interference aware metric named network allocation vector count (NAVC). A function is derived to predicate the possible delay and the available bandwidth for a dynamic interference aware routing protocol in a MANET. Later, (Li, Tang *et al.*, 2009) employed NAVC to adjust the contention window size in the routing protocol. Similarly, (Wang and Song, 2007) used NAV information to approximate the intensity of surrounding traffic and the density of stations. Though NAV information can be a good traffic indicator to tune the CW sizes, this approach is only limited to the four handshakes mode (RTS/CTS reservation mechanism) and not available in the basic access mode of IEEE 802.11 DCF access method.

### B. Wireless channel status indicator

All contending stations can listen to each other, allowing them to identify whether the channel is idle or busy. The resultant channel status becomes a traffic indicator of the overall network (Cali, Conti *et al.*, 2000), (Bianchi, Fratta *et al.*, 1996), (Kang, Cha *et al.*, 2010), (Balador, Movaghar *et al.* 2012), (Nasir and Albalt, 2008), and (Deng, Ke *et al.*, 2008). The CW sizes can be manipulated in various ways for throughput enhancement as below.

**1) History based backoff:** Authors in (Balador, Movaghar *et al.*, 2012), (Nasir and Albalt, 2008)use the past channel status to control the current CW size. The work in (Nasir and Albalt, 2008) proposed history based adaptive backoff (HBAB) algorithm that checks the last two states of the channel and decides whether to increase or decrease the CW sizes based on the channel's tendency to being free or busy. Further, a dynamic, deterministic contention window control (DDCWC) scheme (Balador, Movaghar *et al.*, 2012) extended the algorithm to include the last three states in a channel state vector. The backoff range is divided into several small sub-ranges which are selected based on the channel state vector.

**2) Number of backoff pauses:** The pause count backoff (PCB) algorithm proposed in (Liang, Zeadally *et al.*, 2008) observed the number of backoff pauses (due to busy channel) until its backoff counter becomes zero and sets an appropriate CW size that matches the estimated traffic status. However, (Kang, Cha *et al.*, 2010) claimed the PCB algorithm could not adjust to dramatically changing traffic loads because the algorithm could not estimate the number of active stations. Hence, they took one step forward by introducing the estimation-based backoff (EBA) algorithm which estimates the number of active stations by observing the number of idle slots during the backoff period.

### C. Number of idle slots

The works in (Heusse, Rousseau *et al.*, 2005), (Grunenberger, Heusse *et al.*, 2007), (Lopez-Aguilera, Heusse *et al.*, 2008) and (Nassiri, Heusse *et al.*, 2008) dynamically control the CW sizes by monitoring the estimated mean number of idle slots between transmission attempts $I_i$. This method is known as *Idle Sense* (IS), a distributed control method where all contending stations in IS compare their with the target value $I_t$, a common value to all stations, and adapt their CW size using the additive increase multiplicative decrease (AIMD) algorithm. The station gradually increases its CW size when $I_i < I_t$ or multiplicatively decrease the CW if $I_i > I_t$. The CW sizes of all stations will converge to the same value.

### D. Number of contending stations

The techniques in this category use an analytical approach based on Markov models to determine the optimum CW sizes for maximum throughput as a function of the number of *n* contending stations. For example, the adaptive window algorithm (AWA) proposed by (Bianchi, Fratta *et al*., 1996), used the number of active stations in the network to control the CW size; the number of active stations were estimated by observing the activity on the channel. A similar approach is employed in (Cali, Conti *et al.*, 2000) to control a complex *p*-persistent MAC protocol that selects the optimum backoff interval. More recently, (Deng, Ke *et al.*, 2008) identified the relationship between backoff parameters, contention level, and channel bit error rate (BER) in order to propose a distributed algorithm that allows a station to dynamically adjust its contention window size based on turn-around-time measurement of channel status. These analytical approaches may result in better network performance because the algorithms allow each station to independently tune the backoff window size at run time. However, complex computations are required that lead to high power consumption, which is in many cases considered unaffordable in wireless networks context (Nasir and Albalt, 2008) and (Balador, Movaghar *et al,* 2012).

In this paper, information from GPON is used as an alternate traffic indicator in optimizing the contention window sizes as presented in the following section.

## SIMULATION SETUP

A simulation model is designed using OPNET Modeler 15.0 software (Riverbed). IEEE 802.11a protocol of the WLAN standard is modified and applied into a non-saturated network scenario. A network of 32 BSSs is considered. Each integrated ONT-AP serves 5 WUs creating one basic service set (BSS). Every BSS is set to carry an equal amount of traffic. The main OPNET simulation parameters are listed in Table-1. For simplification, two assumptions are made in this work. First, all the GPON's traffic goes directly to the WLAN and the WLAN channel is only dedicated to the GPON traffic. As such, each ONT from the splitter is directly connected to the corresponding AP in the WLAN. Second, a perfect transmission is assumed from the OLT to each ONT with the extracted GPON traffic information made available in the AP of each BSS through the networks integration process (Figure-3).

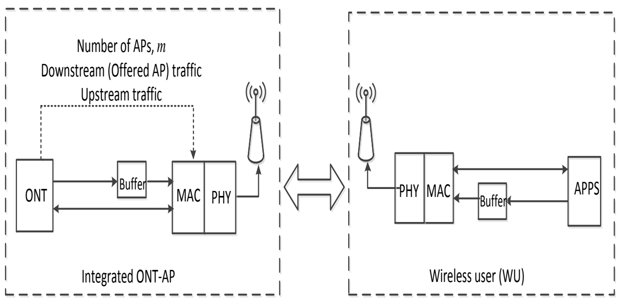


**Figure-3.** Proposed Fi-Wi network with traffic indicators.

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**Table-1.** OPNET simulation parameters.

| Parameter | Value |
|---|---|
| Packet size | 1024 bytes |
| Packet distribution | Exponential |
| Interarrival time | 0.01 sec (AP) and 0.05 sec (WU) |
| Data rate | 54 Mbps |
| Channel bandwidth | 22 Mhz |
| Slot time | 9 μs |
| SIFS | 16 μs |
| DIFS | 34 μs |

## OPTIMIZED CONSTANT CONTENTION WINDOW

This section proposes an optimized constant contention window (OCCW) scheme. An exhaustive search is used to develop a map of optimum CW sizes for different traffic loads in the network. This method takes advantage of GPON's centralized structure to extract traffic information and make it available to all wireless stations. Based on the information, wireless stations select the required optimum CW size from the developed table as shown in Table-2. The optimum constant CW size mapping table is obtained from the extensive simulations carried out in (Hassan, King *et al.* 2012). In this technique, once the CW size is assigned at the beginning of every transmission, it will remain constant throughout the transmission. The normalized throughput is analyzed to evaluate the network performance.

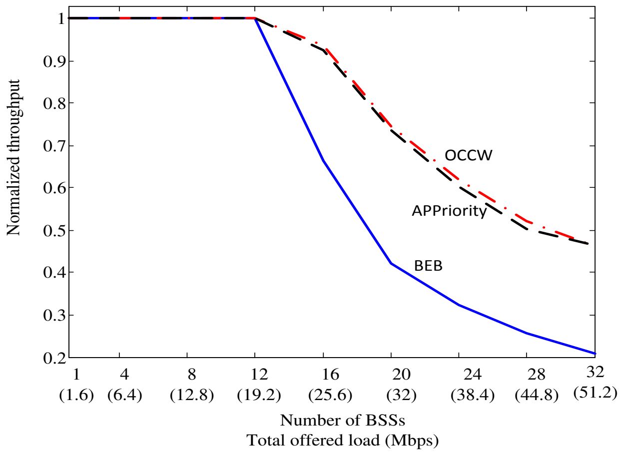


**Figure-4.** The overall normalized throughput.

**Table-2.** Optimum CW sizes map with traffic size.

| Number of BSSs (Offered load, Mbps) | 1 (1.6) | 2 (3.2) | 3 (4.8) | 4 (6.4) | 8 (12.8) | 12 (19.2) | 16 (25.6) | 20 (32) | 24 (38.4) | 28 (44.8) | 32 (51.2) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Optimum CW size (slots) | 16 | 16 | 16 | 16 | 64 | 256 | 1024 | 1024 | 1024 | 2048 | 2048 |

Considering the fact that unsaturated condition in employed in the network scenario of this paper, the normalized throughput is defined as the number of packets successfully received by a station divided by the offered load. Figure-4 compares the overall network throughput between the proposed scheme with the legacy BEB scheme. Both schemes do not experience any throughput degradation under lightly loaded scenario (less than or equal to 12 BSSs (19.2 Mbps)) because the channel is not congested and every station able to successfully transmit the packet. However, the BEB scheme suffers throughput degradation under heavy loaded scenario (more than 12 BSSs (19.2 Mbps)) because the channel starts to reach saturation and the offered traffic is significantly larger than the carried traffic. Thus, the number of packets loss increases because BEB scheme does not consider the traffic size in setting the CW sizes. Conversely, the proposed scheme sets the CW in accordance to the traffic condition. Therefore, it shows a significant 50% throughput improvement relative to BEB at an offered load of 32 Mbps, which is 0.6 of the maximum nominal transmission rate (54 Mbps). The improvement increases to close to 100% at the maximum offered load in the simulation.

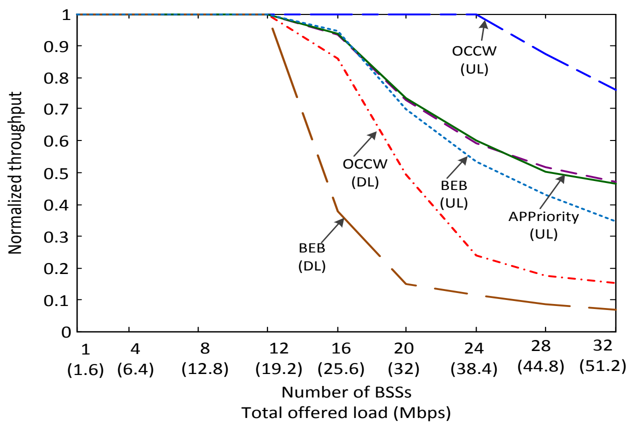


**Figure-5.** The normalized throughput for uplink and downlink transmissions.

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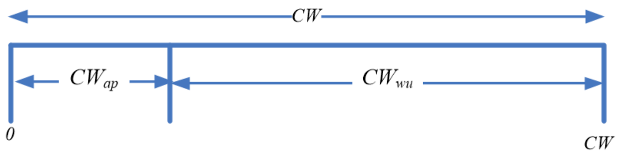


**Figure-6.** Non-overlapped contention window.

## TRANSMISSION PRIORITY SCHEME

In this section, the throughput analyses for the AP and WUs transmissions of the OCCW scheme is observed. From now onwards, the AP and WU transmissions are known as downlink (DL) and uplink (UL) respectively, Figure-5 presents their corresponding normalized throughputs. The figure suggests that there is an extreme unfairness; it is evident that UL transmissions have dominated the channel and caused DL transmissions to suffer from performance degradation particularly when the traffic starts to saturate after 19.2 Mbps. When the number of BSSs increase (more than 16 BSS) and carry more traffic (more than 25.6 Mbps), the DL performance worsens. Even at maximum load (51.2 Mbps) where the UL throughput has deteriorated to 0.75, there exists a performance gap of 0.6 (with the DL throughput at 0.15).

The unfairness in capacity distribution occurs because the proposed OCCW scheme provides all nodes including APs an equal chance of transmission opportunity. This equality is not suitable for the proposed multiple BSSs scenario (resembled the wireless side of the Fi-Wi network) because the AP in each BSS requires more transmission opportunities. The AP interconnects the wired GPON and the wireless side of the Fi-Wi network by forwarding data flows in two directions (upstream and downstream) on behalf of its respective WUs. Each AP in the BSS requires at least equal (symmetry) transmission attempts with its total respective WUs as most of the traffic goes through the

AP (Lopez-Aguilera, Heusse *et al*., 2008). Therefore, APPriority scheme is proposed to reduce the contention window size of an AP. The scheme reduces the CW size for the APs based on $n^j$, the active number of WUs in the $j^{th}$ $BSS^j$. The scheme is arranged in a manner that the CW of the AP ($CW_{ap}$) and the CW of the WU ($CW_{wu}$) do not overlap. In this scheme, as depicted in Figure-6, APs are given the priority to select a backoff slot from 0 to $CW_{ap}$ (exclusive) while the WUs are going to select from $CW_{ap}$ to CW (=$CW_{ap}$ + $CW_{wu}$), thus, using different intervals of the optimized CW. This forces the APs to select a lower number of backoff slots than the WUs. Hence, the APs get earlier transmission chances which results in better throughput and less delay. A symmetry transmission between uplink and downlink requires the probability of AP transmission, $p_{ap}$, to be $n^j$ times greater than the probability of WU transmission: $p_{ap} = n^j p_{wu}$. For CW ≫ 1 and when stations use constant CW sizes for backoff mechanism, the transmission attempt probability is given as follows (Bianchi, 2000),

$$p_{ap} = \frac{1}{CW_{ap}/2} \qquad (1)$$

$$p_{wu} = \frac{1}{CW_{ap} + (CW - CW_{ap})/2} \qquad (2)$$

from which

$$CW_{ap} = \frac{CW}{(n^j - 1)}. \qquad (3)$$

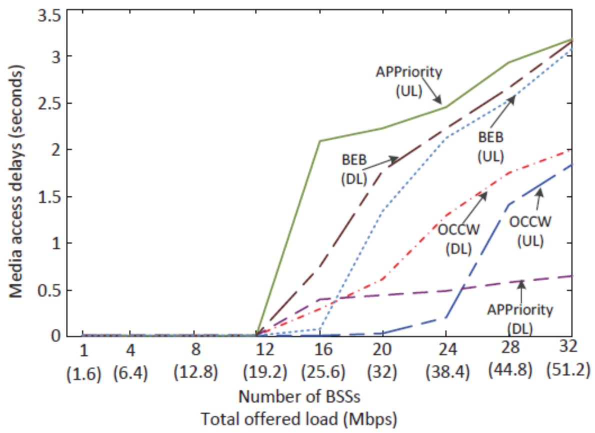


**Figure-7.** Media access delay for DL and UL transmissions.

Thus, for the scenario where each AP serves 5 WUs in every BSS, $n^j$ = 5, then $CW_{ap}$ = CW/4. As such, APs are given the priority to select a backoff slot from 0 to CW/4 (exclusive) while the WUs are going to select from CW/4 to CW where the value of the CW is obtained from Table-2. This forces the APs to select a lower number of backoff slots than the WUs. Hence, the APs get earlier transmission chances which results in better throughput and less delay.

Figure-5 conforms the APPriority scheme brings a balance between uplink and and downlink transmissions irrespective of traffic size. It is achieved without affecting the overall throughput performance as depicted in Figure-4 where the overall normalized throughput of the scheme is at the same level as the OCCW scheme and much better than the legacy BEB scheme. This throughput performance is achieved because in the APPriority scheme, the DL throughput is improved at the price of a loss in UL throughput, keeping the overall throughput similar to that obtained in the OCCW scheme. The DL transmission is improved because of its smaller backoff slots, resulting in higher transmission chances. On the contrary, UL transmission chances are reduced because they have to wait longer due to the higher backoff slots. Therefore, it is observed in Figure-7 that the proposed scheme causes the WUs to attain nearly 5 time longer delays than the APs. In

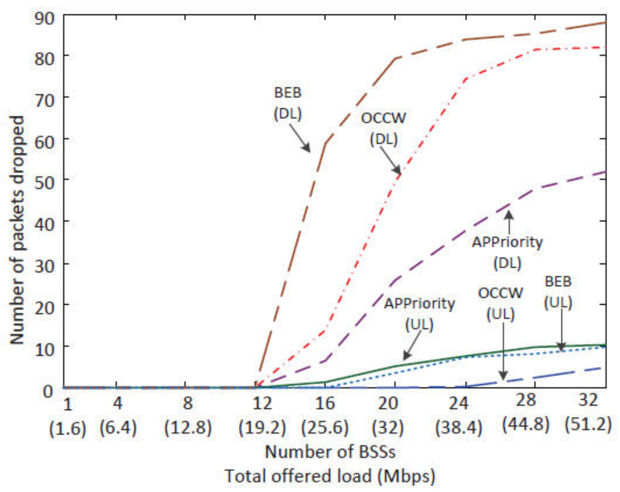


**Figure-8.** Average number packets dropped due to buffer overflow per station.

contrast to OCCW and BEB schemes where their DL delays always higher than the UL but the gap getting closer as the number of APs increases. The APs experience higher delays in the OCCW and BEB schemes because they are not given any priority to transmit and have to compete with the WUs which are 5 time larger in number than the APs.

Figure-8 shows the average number of packets dropped per station due to the buffer overflow for DL and UL transmissions. Buffer overflows occurred because the wireless channel cannot keep up when the heavy offered load (> 12Mbps) saturates the channel. Relative to OCCW and BEB, it is evident that the proposed APPriority scheme reduces the number of packets overflow in the APs (downlink transmissions) because the scheme forced the APs to have more transmission opportunities (reduced $CW_{ap}$ sizes). It is noted that for all the schemes, the number of the DL packets overflowed are always higher than the UL packets as in our simulation set up, the number of DL packets load per AP is made 5 times more than its associate WUs (UL packets) in order to allow a symmetry transmission opportunities between uplink and downlink.

## CONCLUSIONS

The paper studied a Fi-Wi network which integrated GPON with a ‘closed’ infrastructure based WLAN. The term ’closed’ indicated that the network operator has a dedicated spectrum allocation, shared by all WLAN APs in a highly dense populated area.

An optimized constant contention window (OCCW) scheme is proposed for non-saturated multiple BSS WLANs which resemble the wireless side of a Fi-Wi network. OCCW modified the standard BEB algorithm by assigning the constant CW size based on GPON traffic intensity, to achieve the best throughput performance. In comparison to BEB, OCCW improved the throughput by up to 50% and the delay reduced by a factor of 5. However, the OCCW scheme did not do justice to the downlink transmissions in such an infrastructure WLAN. Therefore, the APPriority scheme was proposed to give APs more transmission opportunities. Simulations showed that selecting a smaller CW size for an AP than that of a WU allowed the AP to select smaller backoff slots than the WU. This resulted in an improved downlink throughput and consequently brought fairness between uplink and downlink transmissions. Hence, the huge bandwidth capacity provided by the GPON (backhaul) can be fully utilized in the Fi-Wi network. Interestingly, both schemes showed that problems of throughput and fairness occur under heavily loaded conditions, when the channel reaches saturation. Therefore, our future work will exclusively deal with the saturated condition.

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