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A QoS provisioning architecture of fiber wireless network based on XGPON and IEEE 802.11ac

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Abstract: The integration of the XGPON network with the 5G WLAN network is a suitable solution for next-generation high-speed access Internet service. We demonstrated the integration of two different standards via the QoS concept. Further, this work also presents a proper mapping scheme of QoS traffic between XG-PON and fifth-generation Wi-Fi standards known as IEEE 802.11ac. The analysis assessment compares the behavior of different IEEE 802.11ac standards with XGPON with-respect-to multimedia traffic in the FiWi network. To assess the performance of the FiWi network, the OMNET++ and INET framework are used to carrying out a comparative analysis in terms of upstream (US) delay and fairness index. The study concludes that the EDCA Wi-Fi module has better performance than the DCF Wi-Fi module with the integrated XGPON system for the FiWi access network.

Keywords: fiber and wireless; QoS; XGPON with 802.11ac.

1 Introduction

The continuous growth in the demand of bandwidth for high-speed Internet with mobility has drawn the attention of the researchers for investigating the fiber-wireless integration techniques [1]. Since Passive Optical Network (PON) offers very high bandwidth, thus, many studies have considered wireless technology with PON to offer a high-bandwidth solution with limited mobility in the access part. A wireless network can be used as a front haul network in the FiWi network. Due to the unlicensed frequency band, the IEEE 802.11-based wireless access network is preferred therefore wireless local area network (WLAN) is its common example. It requires low cost and, low maintenance charges than a typical wireless cellular network [2]. The latest version of the IEEE family (802.11ac) known as “5G Wi-Fi—the 5th generation of Wi-Fi” supports QoS and non-QoS applications. IEEE 802.11ac operates at 5 GHz frequency band with multi-input multi-output (MIMO) technology to provide high-speed Internet for multimedia services. The Medium Access Control (MAC) layer of IEEE 802.11ac provides two main access methods including Distributed Coordination Function (DCF) and enhanced distributed channel access (EDCA). When the high-priority category occupies the wireless channel, the low-priority category might suffer from bandwidth starvation due to low channel access probability in IEEE 802.11ac [3]. On the other hand, the PON is a point to multipoint (P2M) optical access network, it consists of OLT, passive Splitter, and ONU. PON offers huge bandwidth while being a low-cost solution for the distribution of triple-play services to the end-users with high quality of service (QoS). Each receiver sends signals to a central distribution point so that users share the full system transmission capacity [4]. PON can be used as a backhaul network in the fiber wireless (FiWi) network. Typically, FiWi architecture may be divided into two categories, as shown in Figure 1, one is radio over fiber and the second is radio and fiber. Radio over fiber is the integrated network that is working on the physical layer of wireless and fiber optic where wireless signals are traveled over fiber optic link [5]. But radio and fiber is an integrated-network where both technologies are working in their domain and combined through an Ethernet interface. Radio and fiber as also known as fiber and wireless. The fiber and wireless technology integration may be branched into distinct categories namely; wireless-optical mesh networking and wireless-optical access networking [6], both having different applications.

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The focus of this study is on the second category of fiber and wireless networking. Section 2 explains the background of the MAC layer of 802.11ac and 10G passive optical network (XGPON). Section 3 presents the proposed work for FiWi access networking. In Section 4, simulation parameters and results are described for fairness and end to end delay and Section 4 reports the conclusion of the paper.

2 Background

2.1 Distributed coordination function (DCF)

The WLAN is a common type of wireless fidelity (WiFi) network. Typical IEEE802.11x is used for the Wi-Fi network. It is famous due to the unlicensed band, flexibility, mobility support, and low cast features. In general, WLAN covers physical (PHY) and MAC of open system interconnection OSI model. At the MAC layer, the advanced versions of 802.11 like 802.11n and 802.11ac have a chance to support QoS. This paper investigates two modes of MAC layer for WLAN namely; DCF and EDCA in 802.11ac. DCF is a basic mode of 802.11ac and good for best efforts (BEs) or nonreal time (non-RT) traffic because DCF does not support any packet classification mechanism or service differentiation. It uses Carrier Sense Multiple Access mechanisms with Collision Avoidance (CSMA/CA). CSMA/CA applies sense to initialize (listen to talk) transmission method. Collision may occur if multiple nodes send data therefore to reduce the collision among the transmission DCF utilizes the CA mechanism. DCF Inter-Frame Spacing (DIFS) time is used to wait before accessing the medium or before backoff time (T_{BO}) activation by a station [7]. During this time, if the medium is the idle station (ST) may send frames directly to the medium without delay. Otherwise, the transmission is delayed and the random back-off (*BO*) process is started. A value of the back-off timer is uniformly obtained so that (*BO*) (0, *CW* – 1), where *CW* is the size of the backoff (*BO*) contention window. Back-off-time (T_{BO}) determined by Equation (1), where the R_{counter} is known as back-off (*BO*) random counter that is used to maintain the current value of the back-off-time (T_{BO}) and the Slot-Time (T_{slot}) parameter depends on the underlying PHY, and then enters the back-off (*BO*) process [8].

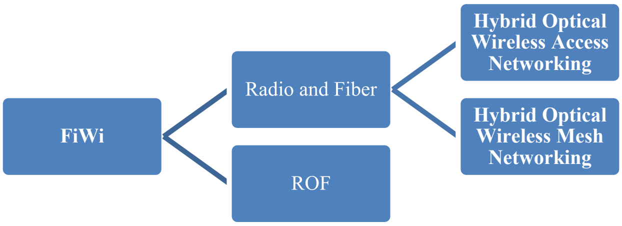

Figure 1: Classification of fiber wireless FiWi network.

$$T_{BO} = R_{\text{counter}} \times T_{\text{slot}} \tag{1}$$

After each retransmission due to a collision or corruption, the *CW* will be doubled until the number of retries (*n*) comes to a certain limit, L_n. Let minimum contention window size (CW_{Min}) denotes the initial back-off (*BO*) window size, and CW_k denotes the *CW* in the k^{th} backoff (*BO*) stages (or backoff (*BO*) counter stages). Once the *CW* reaches a maximum value CW_{Max}, it will remain at the value until it is reset. Therefore, the relationships among CW_k, CW_{Min}, CW_{Max} and L_n are shown in Equation (2).

$$CW_k = \begin{cases} 2^k CW_{\text{Min}} & \text{for } k=0,1,\cdots,j-1, \text{ if } L_n > m \\ 2^j CW_{\text{Min}} = CW_{\text{Max}} & \text{for } k=j,\cdots L_n, \text{ if } L_n > m \\ 2^k CW_{\text{Min}} & \text{for } k=0,1,\cdots,L_n, \text{ if } L_n \leq m \\ & \therefore j=\log_2\left(\dfrac{CW_{\text{Max}}}{CW_{\text{Min}}}\right) \end{cases} \tag{2}$$

2.2 Enhanced distributed channel access (EDCA)

The EDCA method is the variant of DCF. At the MAC layer, EDCA offers differentiated transmission services under four different access categories (ACS) (*i.e.* background traffic [BK] at user priorities (UP) 1 and 2, best-effort traffic (BE) at UP-0&3, video traffic (VI) at UP-4&5, and in last, voice traffic (VO) with the highest-priority level at UP-6&7) [9]. In EDCA each access category's message would contend for the medium access after waiting sometime during an Arbitration interframe space (T_{AIFS}) period. Such time period is expressed in Equation (3) [10].

$$T_{\text{TAIFs}} = aT_{\text{slot}} \times \text{AIFSN}_{ac} + \text{SIFS} \tag{3}$$

where SIFS is a short interface frame space-time and aTslot represents a slot duration time. Each transmission is resumed after SIFS time by a wireless station using 802.11ac standard. AIFSN verifies the total length of AIFS for each access category. TAIFS should be a positive integer that is used by all QoS-STA when it is greater than or equal to two. When AIFS time is greater than or equal to one, it is used by QoS-AP. T_{BO} value for access category (*AC*) in case of EDCA is causally chosen from (0, *CW*) and the value is decreased by one slot before the T_{AIFS}expires. Following the priority mechanism in EDCA, frames with the highest priority in a virtual collision are transmitted first and the rest are required to wait and till the completion of the back-off process with higher *CW* value. When the number of activated ACs initiating the back-off process within a node increases, it results in a virtual collision. At this instant, back-offs counters are set to zero and Virtual Collision Management (VCM) handles the onwards collision control. VCM ensures throughput for the higher-priority *AC* but it puts lower-priority*AC* on bandwidth starvation, *i.e.* an unfair allocation of resources.

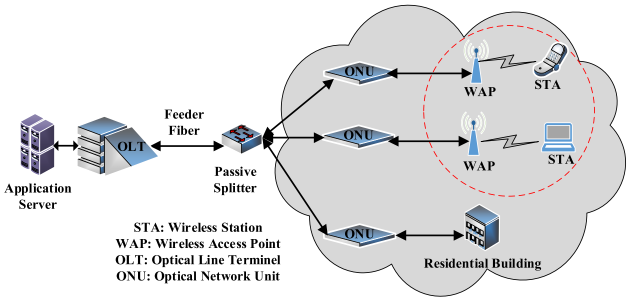

Figure 2: A typical PON network based on tree topology.

2.3 10G-PON XGPON

The Passive optical access (PON) Networks offer unlimited and cost-effective bandwidth under Fiber to The X (FTTx) technologies. This network has a tree topological structure, where there is a central office (CO) at the root, and users are connected to the nodes of the tree, as shown in Figure 2. In the network entities of next-generation PON standard, *i.e.* ten-gigabit-capable PON (XG-PON), optical network units (ONUs) connect the users with the network, and all ONUs are connected with optical line termination (OLT) [11]. In between the ONUs and OLT is the splitter/combiner of the passive nature. It divides the single OLT fiber thread into multiple single optical fibers and vice versa. Transmission from OLT toward ONUS *i.e.* Downstream (DS) and transmissions from ONUs toward single OLT, *i.e.* Upstream (US) require a well-coordinated mechanism such as dynamic bandwidth allocation (DBA). This mechanism governs the US allocation opportunities among all the ONUs on the commonly shared fiber to avoid collisions. OLT in XG-PON categorizes US bandwidth allocation into 05 different transmission containers (T-CONTs) to support QoS provisioning. G987.4 defines each T-CONT class as Class 1 handles constant bit-rate (CBR) applications with strict demands for bandwidth. Class 2 focuses on variable bit-rate (VBR) traffic, suitable for video and voice applications. Class 3 ensures a minimum guaranteed bandwidth (MGB) while class 4 serves the traffic with the best effort (BE) connections. There is also a provision of Class 5 traffic class that may be used to distribute any excess bandwidth to all traffic connections.

3 Proposed QoS Provisioning Mechanism for FiWi Network

Queues and their control mechanisms are supported in both XGPON and WLAN to achieve differentiation of services. Figure 3 presents the proposed FiWi architecture with QoS traffic indications. Its main task is to provide QoS mapping between the XGPON standard and the 5G Wi-Fi standard. Though XGPON and fifth-generation Wi-Fi have different types of services (ToS) with related features. For example, T-CONT 2 is similar to the VO type of WLAN and T-CONT 3 is similar to VI traffic of WLAN. We propose a pre-configured all-in-one Differentiated Services Code Point (DSCP)-to-One FiFo queue mapping for FiWi architecture using DCF mode of WLAN. Table 1 shows the packet classification of DCF where a single FIFO queue (all-in-one mapping) represents all data frames (DFs). This ensures the QoS provisioning in DCF mode where AP and STA are handled in the same way for QoS configuration.

With a single class of service (CoS) mapping for all frames in this scheme, it does not require the packet classification for every packet in the STA module of WLAN and thus avoids the associated overhead of the same in FiWi. In the EDCA module-based Wi-Fi network, UP value is used to identify each packet, shown in Table 1. After marking, the packet is then forwarded to ONU via an Ethernet link through AP. Based on each access category or DSCP value, packets are classified and associated with an appropriate T-CONT type in ONU, as shown in Table 1. Packets are then queued in one of the four FIFO queues leading to DBA-controlled US transmission of the same packet in XG-PON.

The pseudo-code of our proposed work is explained in Table 2. We have simulated the limited functions of XGPON that are needed by our research. We left other functions for future work. OLT assigns four TCONT ids or AllocIds to each ONU during the initialize phase. The main pseudo-code of the proposed work defines the decision for bandwidth grant size for each traffic class (TCONT) in DS traffic, as explained in Table 2. It needs predefined parameters of XGPON and wireless LAN like the number of ONUs (N), maximum and minimum contention window sizes ($CW_{\max}$ and $CW_{\min}$, Short Interframe Space, SifsTime) Time and

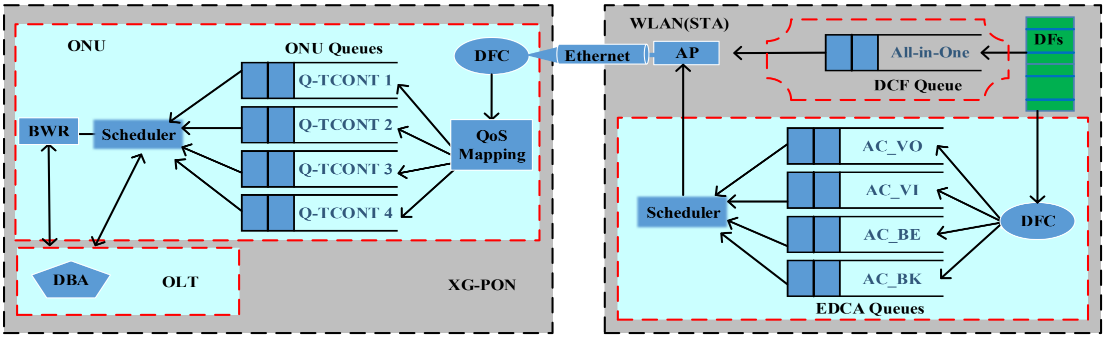

Figure 3: Proposed FiWi architecture with QoS traffic indicators.

Table 1: Mapping policy of the FiWi network.

Application	DSCP	UP	XGPON	EDCA	DCF
FTP	VA & EF	0	Tcont1	AC_BE	All in one
WWW	AF3x & AF4x	1	Tcont4	AC_BK	
Video	DS & AF1x	4	Tcont2	AC_VI	
Voice	CS1	6	Tcont3	AC_VO	

slot time in microseconds and we use 10 Gbps link for US traffic, therefore, we define 155,520 maximum US bytes for one cycle.

4 Simulation Environment and Results

We developed a FiWi testbed with help of XG-PON and pre-existing 5G-Wi-Fi (802.11ac) modules using the INET 4.2 framework [12] and OMNET++5.5 [13] as the literature suggests in the study by Arokkiam et al. [14]. To simulate the proposed architecture under various traffic loads, we created the FiWi access network scenario followed by the XGPON and WLAN standards. We created a tree topology of one OLT with eight ONUs with 10. Gbps US/DS connection at 20 km. Each ONU is further connected with one AP via an Ethernet link. One AP has a dual interface one is wired and the other is wireless. A single hop communication is done from AP to STA and vice versa. There are four different wireless traffic types (*i.e.* video, voice, best effort, and background) that are generated by a traffic generator at each STA. All STAs are randomly deployed within 3000 × 3000 m area. APs and STAs use the 5 Ghz as central frequency and 40 Mhz channel to support the scenario of 5G WLAN using IEEE 802.11ac standard. Table 3 presents the simulation parameters.

Table 2: Proposed work Pseudo-Code.

```
Input: N = ONU, TCONTId or AllocIdN × 4, XGPON parameters and WLAN parameters from Table 3
Output: ONUs receive grant size and DBRu in DS for US traffic
1  // Wireless local area network side
2  Genrated data frames from upper layer
3  Recieved frames at MAC layer of STA
4  If (EDCA = = False){   // deal with DCF mode
5      store all data frames into one queue
6      Run Equations (1) and (2) for frame Tx
7  }Else{   //deal with EDCA mode
8      run DFC and store data frames into seprate queues according to AC
9      Run Equation (3) for frame Tx
10 }
11 Frames arrive at access point (AP)via wirelss channel
12 AP forwards frames to ONU through Ethernet Link
13 // XGPON ONU side
14 Data frames arrival process in ONU
15 run DFC and do QoS mapping based on data frames tags according to Table 1
16 run ONU scheduler
17 If (DBRu = = true AND Grant size > 0 in BWMap) {
18     Fill Buffer Occupancy and Assign the AllocId to TCONT
19 } Else {
20 Buffer Occupancy is empty and Assign the AllocId to TCONT
21 } send US traffic to OLT
22 // XGPON OLT side
23 TCONT arrival proccess in OLT
24 If(Buffer occupancy is empty) {
25     send payload to server
26 } Else {
27 Store each TCONT demand for next cycle and send payload to server
28 } run OLT scheduler
29 Calculate US Grant size for each TCONT
30 USMaxFrameBytes = US Grant size − USMaxFrameBytes
31 if ( US Grant size of any TCONT is less than its Demand
          And USMaxFrameBytes > 0 )
32     Update US Grant size of specific TCONT
33 Braodcast BWMap with DS traffic to ONUs
34 DS arrival process in ONU
35 Repeat from Step 13
```

Only US traffic from WLAN STAs to the server is modeled. According to the designed method, STA generates UDP traffic using independent Poisson distribution. Poisson distribution traffic is generated in STA using an exponential distribution process, at the same mean value of packet generation for all wireless nodes. In the traffic generation, the traffic arrival rate (λ) per application is computed first from Equation (4). For a given TrafficLoad, the traffic arrival rate for the US link is calculated the physical line rate of WLAN (WRate), in bytes, is divided by framerate (σ) to compute the traffic arrival rate, where σ is the average value of packet length in bytes and has a distinct value for each traffic class. is varied from 0.1 to 1.0. The inter-arrival time is sendInterval, computed by Equation (5).

$$\lambda = \frac{\left(\frac{W\text{Rate}}{8\,\text{bits}}\right)}{\sigma} * \text{Traffic Load} \tag{4}$$

$$\text{sendInterval} = \text{Exp}\left(\frac{1}{\lambda}\right) \tag{5}$$

End-to-End Delay (EE_{Delay}) is an average transmission delay of the Nth packet in the network. Equation (6) represents the FiWi end to end delay where AT_N is the arrival time of the Nth packet (all necessary data arrived) at the server node. The generating time of the Nth packet is represented by GTN. The Nth packet's transmitting time is TT_N. After STA, the Nth packet arrives at XGPON and consumes T_{XGPON} as the packet processing time from ONU to OLT. Figure 4 shows the EE_{Delay} analysis of four wireless streams, *i.e.* VO (T2), VI (T3), BK (T4) and BE (T1). EE_{Delay} in DCF increases from lower to higher as load increases, whereas in EDCA mode the EE_{Delay} is lower even when the load is high. Even though the DCF treats all kind of traffic equally but its EE_{Delay} is higher than EDCA mode in FiWi topology.

Table 3: simulation parameters FiWi network.

Simulation parameters	Values
TCONT-1 fixed	100 Mbps (ABmin1 = 3000 B, SIMax = 10)
TCONT-2 Guaranteed	100 Mbps (ABmin2 = 30000 B, SIMax = 10)
TCONT-3 assured	100 Mbps (ABmin3 = 30000 B, SIMax = 10)
TCONT-3 non assured	100 Mbps(ABmin3 = 30,000 B, SIMax = 10)
TCONT-4 BE	100 Mbps (ABmin4 = 30,000 B, SIMax = 10)
US and DS line rate	10 Gbps
US max frame size	155,52 bytes
Number of OLT:ONU:AP	1:8:8
Distance between OLT to ONU	20 km
WLAN standard	IEEE 802.11ac
Max. And min. Of CW	3 and 1023
Slot and sifs time	9us and 16us
WLAN MAC mode	DCF mode and EDCA mode
WLAN channel bandwidth	40 Mhz
Physical WLAN data rate	1.2 Gbps
Traffic model	Poisson distribution model

$$EE_{\text{Delay}} = AT_N - (GT_N + TT_N + T_{\text{XGPON}}) \tag{6}$$

The Jain's fairness index (JFI) ranges between zero and one. JFI value reflects the relationship between overall US bandwidth and allocated US bandwidth in the FiWi access network, thus ensuring a better quality of service. We suppose JFI to calculate how fairly the bandwidth is distributed according to US load, its mathematical relationship is easily verified from Equations (7) and (8).

$$f(y) = \frac{\left[\sum_{i=1}^{s} y_i\right]^{\wedge} 2}{S \times \sum_{i=1}^{s} (y_i)^{\wedge} 2}, \quad \text{if } y_i \geq 0 \tag{7}$$

$$\text{where, } y_i = \begin{cases} \dfrac{AB_i}{TB_i} \text{ if } TB_i > AB_i \\ 1, \text{otherwise} \end{cases} \tag{8}$$

The value y_i is expressed by the ratio of allocated bandwidth (AB_i) and total bandwidth (TB_i) to all ONUs in ith load. The number of contending streams is showed by term s. Figure 5 shows the fairness index vs. offered load of each CoS in FiWi network under DCF and EDCA. $f(y)$ in DCF is almost the same for all kinds of data, whereas EDCA mode shows unfairness for different CoS where higher-priority data can starve lower-priority data. BE(T1) has

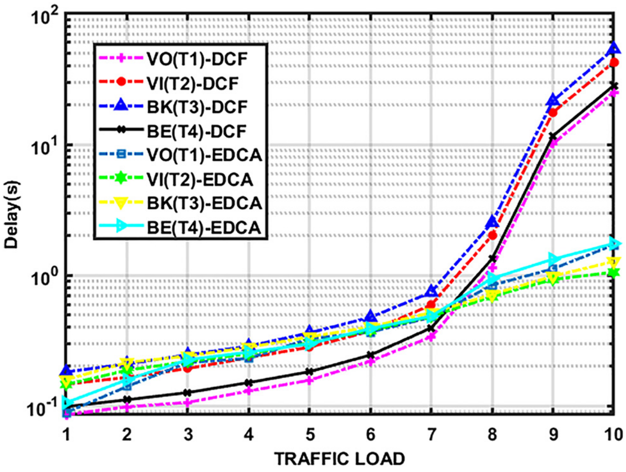

Figure 4: US end-to-end delay versus offered load under DCF and EDCA in FiWi.

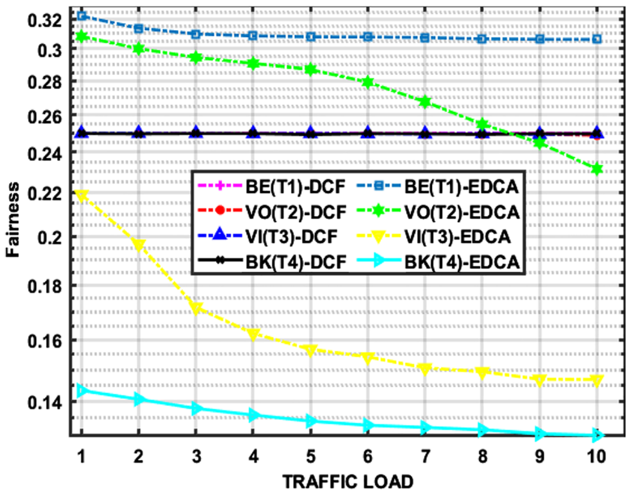

Figure 5: Fairness index vs. offer load using DCF and EDCA in FiWi.

almost constant and the lowest $f(y)$ as CW size of lower-priority data in EDCA belongs to higher value and BK(T4) decreases at higher load. VO(T2) is assured bandwidth traffic for XGPON DBA therefore the CW value is the lowest with the highest priority in the EDCA, its $f(y)$ is higher than other traffics but as traffic load is increased its $f(y)$ value is decreased. VI (T3) is half assured and half nonassured bandwidth class for XGPON DBA. It has second priority in EDCA mode therefore it is $f(y)$ is much better than low-priority traffic but it is also decreased as traffic load is increased.

5 Conclusion

The integration of the XGPON network with the 5G WLAN/WiFi network is a suitable solution for next-generation high-speed access networks. QoS is the main requirement for the FiWi broadband access network. Therefore, we demonstrated the integration of two different standards via the QoS concept. And the proper bandwidth distribution has been implemented. We used recommendations from ITU-T G.987 standard and IEEE Std 802.11ac for designing our FiWi simulation. The analysis assessment compares the behavior of FiWi architecture using WLAN (DCF and EDCA) modes with the XGPON standard. It was observed the variation of US (EE)_Delay and fairness factor with load for various T-CONTs. We demonstrated that lower-priority type of class service suffers from bandwidth starvation as network load increases as observed in standalone EDCA design. But in DCF standard all traffic is equally treated therefore their results are not satisfied with multimedia traffic of FiWi network. In the future, we intend to deal with an improved integrated wireless network design that also offers low-priority EDCA traffic classes as a fair QoS.

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