Research Article

A novel QoE based cross-layer scheduling scheme for video applications in 802.11 wireless LANs

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Abstract

In the past two decades, 802.11 based Wireless Local Area Networks (WLANs) have gained popularity in offering Internet services and increasingly supporting data driven video streaming applications. Such services demand enhanced view quality to all the end-users in the network. However, due to the sharing of limited resources and lack of proper scheduling mechanisms, WLANs are unable to meet the requirements of numerous video users and provide them better quality. Therefore, an effective resource scheduling approach is needed that can achieve high user satisfaction for the ever changing user needs for quality video viewing. In this paper, a Quality of Experience based Cross-Layer Scheduling (QoECLS) scheme to enhance the user experience for video applications in WLANs is proposed. Here, the Mean Opinion Score has been used as a measure to evaluate the user experience. In order to provide the average user throughput with guarantee of fairness among users, the QoECLS scheme uses cross-layer information from the application and physical layer, respectively. The QoECLS algorithm allocates transmission resources by considering application feedback along with channel state information and buffer status. The performance of the QoECLS approach was extensively studied through simulations and the results showed an improvement in user experience and throughput, while maintaining fairness among the users. In terms of throughput, the proposed scheme achieves 25%, 45 %, and 50% improvement compared to QoE Aware Scheduling scheme, Modified-Largest Weighted Delay First scheduler and Exponential-Proportional Fair scheduler, respectively.

Keywords Quality of experience · Mean opinion score · Resource allocation · Scheduling · Throughput · Fairness

1 Introduction

The rapidly evolving technologies like Cellular mobile networks and Wireless Local Area Networks (WLANs) are becoming highly popular and widely used to cater to the ever changing demands of users. It is expected that 59% of the data traffic will be diverted to Wi-Fi from mobile links and 79% of this traffic will be of video content by 2022 [1]. WLAN based on IEEE 802.11 has emerged as a popular wireless access system due to its low price, easy deployment, and high data speeds [2]. Nowadays, Wi-Fi hotspot services are widely used in public and crowded places like airports, shopping malls, stadiums, office zones, etc. The usage of this Wi-Fi hotspot services is becoming highly video content-oriented and it has become a herculean task for the service providers to provide the required service quality to all the users [3]. In order to achieve the required performance by the network, resource schedulers have been incorporated previously to offer Quality of Service (QoS). QoS is the ability of the network to deliver satisfactory service to users. It is typically led by some factors like throughput, delay, packet loss, and jitter. However, with the changing demands and requirements of the users, QoS management is lagging in achieving

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high end-user satisfaction or Quality of Experience (QoE). Hence, a change in criterion from QoS to QoE based radio resource management has taken place in the current Wireless LANs [4].

QoE is a user-centric method, which generally assesses the user experience during the usage of Internet. It measures the users opinion and acceptability of the service quality [5]. Currently, the concept of QoE is gaining popularity and became a significant research topic among Cellular systems and WLANs designers and researchers [6]. In addition, providing support to numerous users is one of the key requirements of WLANs and this requires further investigation on QoE-oriented schedulers for these networks [7]. However, most of the research has focused on the improvement of QoE in Long Term Evolution (LTE) networks.

Conventionally, a wireless resource scheduler is meant for allocating resources and transmitting the packets in the queues based on their priorities and requirements. To provide the necessary QoE to the user stations (STAs), schedulers should take into account certain parameters from other layers of the protocol structure [8]. Schedulers can be divided into QoE unaware schedulers and QoE aware schedulers. QoE unware schedulers do not consider the application inputs from the users and they usually take advantage of channel variations to prioritize the users. Schedulers that take into account channel conditions, application feedback, and user requirements are known as QoE aware schedulers.

1.1 Related work

A few research studies regarding WLANs have focused on scheduling mechanisms to improve the QoE of video applications in multiuser scenarios. In [9], the QoE aware multicast mechanism was proposed which defines a multicast service that will meet the QoE requirements of the end-user for scalable video communications. This method guarantees QoS along with QoE requirements of the end-user for 802.11b. Extensive simulations were carried out to assess some key QoS performance specifiers and QoE of the video application. However, the assessment was done in traditional 802.11b WLAN with limited number of user stations.

In [10], the author proposed a Bi-level resource allocation algorithm for the users viewing video content in a WLAN. At the first level, the resource allocation algorithm aims to allocate enough wireless resources to Access Point (AP) by adjusting the minimum contention windows of both access point and background traffic users. At the second level, the resource allocation algorithm schedules the video queues in AP properly to guarantee the fairness among the video users. The author has shown that this Bi-level resource allocation algorithm yields improved performance concerning QoE and fairness over IEEE 802.11e and IEEE 802.11 Distributed Coordination Function (DCF) with round-robin. However, this mechanism is only suitable for legacy WLANs like 802.11b and 802.11e. The author in [11] has proposed an admission control and Medium Access Control (MAC) layer framework criteria that collectively maximizes the QoE of HyperText Transfer Protocol (HTTP) video streaming and ensures the requested throughput. The assessment of this algorithm was done with an expanding number of background stations and it was verified that the proposed algorithm surpasses the legacy 802.11 DCF in QoE enhancement by a factor of Six. However, this approach did not consider the real-time video requirements of user stations, and the throughput evaluation was done only with background stations.

In [12], the author considered a scenario of video streaming by high-density users and focused on enhancing the video quality in such scenarios. A viable QoE-aware scheduling strategy for video bitstream in IEEE 802.11n/ac networks was considered by utilizing quality parameters like packet importance information, packet delay, and channel quality. Further, the author proved that the proposed scheme considerably improves the video quality and fairness among the users. However, the assessment of QoE was done based on the transmission reliability of video sequences to the user stations. That is, it focused on reducing distortion in video sequences by measuring the importance of packets in the transmission. Task level scheduling was introduced in [13] to ensure a maximum amount of packets are transferred in each time slot and provide better user experience by satisfying the ratio requirements of each task. Further in this paper, the author proposed a novel scheduling approach termed Remaining Time Based Maximal (RTBM) scheduling scheme that moves the link level QoS issue to QoE based application aware problem. The author showed that RTBM scheme significantly enhances the QoE of every single application. However, the drawback of this work is that the overall QoE performance was not achieved. In [14], the author proposed a selective queuing mechanism to preserve the video quality during transmission in 802.11e WLANs. This approach improves the QoE of end-users by avoiding the transmission of I-frames instead of dropping them during queue congestion. However, the assessment was done in wireless network with limited number of users and for specific video content.

Though most of the previous studies adapted cross-layer framework to improve the QoE of video users, they are only suitable for legacy 802.11b and 802.11e WLANs, which are not in wide use now. Another weakness of these studies is that they are much concerned about the transmission aspects like video distortion among the user stations. Moreover, some studies have focused on enhancing the QoE by considering the user application with different link qualities. This technique is only suitable for providing user satisfaction for a specific application and it will not consider the overall network performance. Therefore, instead of focusing more on video transmission and reliability aspects, it is necessary to investigate the scheduling mechanisms that enhance the video quality by adapting to the user requirements.

Hence, a novel QoE based Cross-Layer Scheduling (QoECLS) scheme has been proposed in this paper to guarantee QoE and fairness among various users. The proposed cross-layer scheduler allocates the resources according to view rates and channel qualities. Further, it is responsible to prepare the transmission plan and prioritize the users based on their requirements. The perception of video quality from users can be obtained either subjectively or objectively [15]. Subjective assessment is a direct process that involves the collection of opinions from users about the quality of multimedia content, which is under test. Mean Opinion Score (MOS) is considered as commonly employed subjective method for QoE evaluation. MOS defined in ITU-T Recommendation P.800.1 [16] is a numerical value extending from 1 to 5, and it indicates the quality of multimedia application perceived by the end-user. However, this process has a few shortcomings, specifically, it is expensive, time-consuming, and not used frequently. Objective quality techniques were proposed to overcome the drawbacks of the above subjective method and to attain a proper QoE prediction.

The objective technique is based on mathematical procedures that establish a quantitative measure for the multimedia content. Therefore, in this paper, an objective video quality measurement technique is formulated to accomplish a good approximation of MOS. The opinion model given in ITU-T Recommendation G.1071 [17] for network planning of video and audio streaming applications has been used to measure the MOS values.

This QoECLS approach considers the application view rates in addition to channel quality to decide the transmission schedule. The main highlights of this approach are outlined as given below.

1. A novel QoE based cross-layer scheduling scheme is proposed that guarantees throughput and fairness even when there is an increase in number of users of video content.
2. QoE assessment is done by considering the application feedback and user stations channel conditions.
3. For comparison, state-of-the-art algorithms are considered such as the recent QoE Aware Scheduling Scheme (QoEAS) [12], Modified-Largest Weighted Delay First (M-LWDF) [18], and Exponential Proportional Fairness (EXP-PF) [19].
4. From the (network simulation) ns3 simulation, it has been shown that the proposed QoECLS algorithm achieves better QoE efficiency with respect to throughput and fairness specifically when the number of video users is large.

The rest of the paper is structured as follows. In Sect. 2, the motivation behind the chosen problem is clearly explained using a practical scenario. In Sect. 3, the proposed QoE based cross-layer scheduling scheme is discussed, along with the cross-layer proposal and design of the QoECLS algorithm. In Sect. 4, the description of simulation parameters and performance evaluation metrics is presented, followed by a discussion of results. Finally, Sect. 5 presents the conclusion of the paper.

2 Motivation for the study

In this section, first the scheduling problem in Wireless LANs is described. Then, the motivation behind the proposed scheme is explained with a suitable example.

Due to the advancements in Physical (PHY) layer technologies, concurrent data transmission to many users was made possible in the current WLANs, which enables an increase in wireless connectivity and data requests from the user stations. User selection is the first step in the process of scheduling. This is primarily done by using the Channel State Information (CSI) from the client stations. Based on the channel state, requested data, and offered transmission rates the AP schedules the users randomly. However, this process does not guarantee QoE satisfaction to the end-users. Therefore, a cross-layer scheduling approach is proposed to improve the throughput and provide the satisfying quality to all the users. Let us consider the motivation scenario depicted in Fig. 1 that contains an AP and six user stations connected with wireless links. Let us assume that the AP operates in contention free mode and the wireless links carry video traffic to the users.

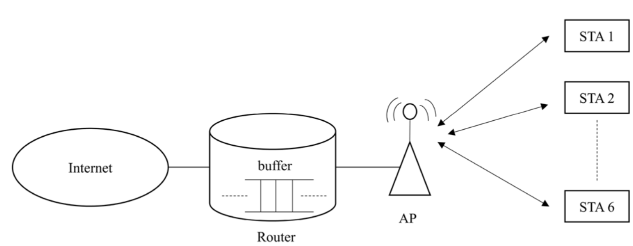

Fig. 1 Typical WLAN scenario

The main objective of the proposed approach is to provide better throughput performance to all the user stations by adapting the transmission time according to average view quality. Let us consider the problem of scheduling six user stations and the maximum duration for the transmission process be 16s. Streaming applications like video must operate over a timescale of (10-100ms) since they require several frame transmissions to complete the downlink transmission. In order to avoid video freezes, each user group is scheduled dynamically (e.g., every 10ms) to accommodate the actual data sizes. In fact the allocation is done over short timescale to respond to dynamic behaviour of the channel and long timescale for static conditions. The default allocation of scheduling time and corresponding view rates is shown in Table 1. Initially, STA 1 and STA 2 require 4s each to complete the transmission with a PHY rate of 1 Mbps. While STA 3, STA 4, STA 5, and STA 6 are experiencing low rates due to their channel conditions. Here, the intention is to enhance the video quality to low rate users. Since STA1 and STA 2 are viewing the video with high quality, it will not be annoying if he/she is switched to medium quality. This is achieved by taking the average view quality among all the users and adapting the transmission times accordingly. The video view rates at each user station will vary depending on the channel conditions. For each scheduling interval, the change in the view rates is captured and average view rate among the user group is obtained. Using the average view rate and corresponding PHY rate, the transmission time for each user station is obtained. Then, each user station is scheduled for the corresponding transmission time. One such instance of time allocation using the proposed approach is shown in Table 2. In this case, the video quality of STA1 and STA 2 is compromised to improve the quality of the remaining users. To achieve the average view quality the view rates of STA 1 and STA 2 is adjusted to 2000 Kbps with 2s per each transmission. So, the video view rates of the remaining user stations are improved due to the availability of excess time. Video view rate adaptation allows the transmission to be done at average view rate with specific transmission time, depending on the channel conditions. As shown in Tables 1 and 2 below, it can be observed that nearly 50% increase in the video view rate is achieved among STA 3, STA 4, STA 5, and STA 6 with the proposed allocation scheme. Though the transmission time required for STA 1 and STA 2 is adjusted to 2s, they can still achieve the satisfied quality due to capability of receiving data at higher rates.

Table 1 Default allocation of scheduling time and corresponding view rates

User station	View rate (Kbps)	PHY rate (Mbps)	Time (s)
STA 1	4000	1	4
STA 2	4000	1	4
STA 3	1024	512	2
STA 4	1024	512	2
STA 5	512	256	2
STA 6	512	256	2

Table 2 Distribution of scheduling time using proposed approach

User station	View rate (Kbps)	PHY rate (Mbps)	Time (s)
STA 1	2000	1	2
STA 2	2000	1	2
STA 3	1500	512	3
STA 4	1500	512	3
STA 5	768	256	3
STA 6	768	256	3

3 The QoECLS scheme

3.1 QoE based cross-layer scheduling

This section describes the QoE based cross-layer scheduling scheme that considers application view rates, channel feedbacks, and QoS demands jointly for decision-making. The proposed cross-layer architecture is shown in Fig. 2. It consists of different modules, namely, video application, Joint Assessment and Allocation (JAA), QoE cross-layer scheduler and transmitter. In the video application module, the video packets will be forwarded and placed in user's buffer in the AP before obtaining scheduling opportunities. In this approach, a module known as joint assessment and allocation was introduced, which is responsible for measuring quality assessment and allocating resources based on the user video requirements. For the purpose of allocating transmission time and scheduling the users,

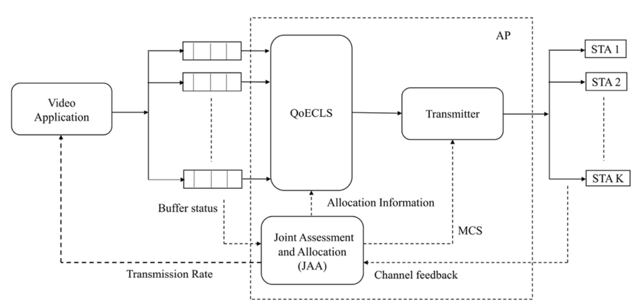

Fig. 2 Cross-layer proposal

two kinds of information is considered in the approach. The view rate feedback will be obtained through the video server at the application layer of WLAN protocol stack. Then, this information will be forwarded to QoECLS to perform the scheduling of user stations. During the acquisition of view rates, the user station is not explicitly sending any feedback to the AP. The channel quality feedback from the user stations will be collected at the PHY layer of the communication stack. Based on the perceived view rates and PHY rates, the required transmission time to each user station is calculated. The scheduling algorithm will run at the MAC level of the AP. Once the scheduling opportunities were obtained, the user stations will be scheduled according to their transmission times.

The simulation framework for the proposed scheduler is portrayed in Fig. 3. It consists of various modules namely application inputs, MOS output, and quality assessment. Here, infrastructure based WLAN with randomly placed user stations is considered for evaluation. The application view rates and channel feedbacks are considered at the scheduler to determine the required transmission time for each user station. The MOS value obtained quantifies QoE and represents the sensed video quality. The mapping between video quality, MOS, and user experience is derived at the output module. Quality assessment is performed using various metrics like throughput, fairness, delay, packet loss rate, and jitter. The evaluation of performance is made in terms of loss and delay sensitive video traffic and its effect on QoE is assessed with the aid of ns3 simulator. The performance of the proposed QoE scheme is evaluated with the recent QoEAS [12] scheme, and well-known M-LWDF [18], EXP-PF [19] schedulers, respectively. Though M-LWDF and EXP-PF are delay and channel-aware strategies that do not take the QoE into account, these schemes were selected because they are widely used as benchmarks in the literature. In addition, these two schemes behave well in certain QoS measurements for real-time video applications. A brief discussion

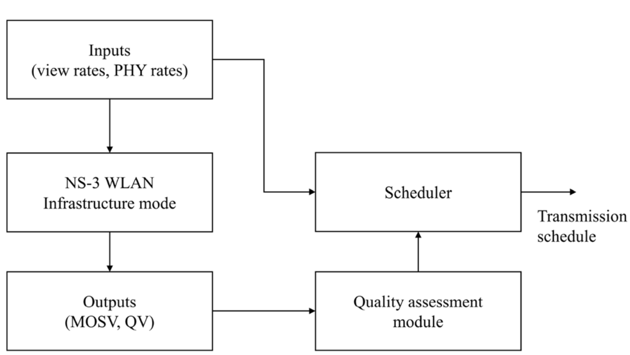

Fig. 3 QoE based simulation framework

of these algorithms and the proposed scheme is given below.

M-LWDF is an algorithm that specifically takes both the current channel variations and the status of queue size into consideration. It can provide QoS guarantee by ascertaining a low packet loss ratio and minimum throughput. At each time instant t, the user with the highest score is chosen according to the following criteria. Equation 1 indicates the metric employed to represent the M-LWDF Scheduler.

$$m_i = \arg\max_i \alpha_i \left[\frac{r_i(t)}{\bar{R}_i(t)}\right] w_i \tag{1}$$

and,

$$\alpha_i = \frac{-\log \delta_i}{\tau_i} \tag{2}$$

Where, α_i is an arbitrary constant, w_i is the Head-of-Line (HoL) delay, $\frac{r_i(t)}{\bar{R}_i(t)}$ is the ratio of instantaneous to average data rate, and $i \in K$ be the number of users. For an efficient bandwidth utilization, M-LWDF discards the packets that were not delivered until the end of the delay deadline. Hence, it tries to attain a low packet loss ratio with good throughput and fairness. Another promising technique that prioritizes real-time flows is EXP-PF scheme. It considers the properties of the both exponential and proportional fair function. The former ensures the delay constraints of real-time services, while the latter maximizes the system throughput. EXP-PF schedules multiple users at each scheduling time and the priority metric adapted for each user is obtained from Eq. 3,

$$m_i = \arg\max_i \exp\left[\frac{\alpha_i w_i(t) - \overline{w(t)}}{1 + \sqrt{\overline{w(t)}}}\right]\left[\frac{r_i(t)}{\bar{R}_i(t)}\right] \tag{3}$$

and,

$$\overline{w(t)} = \frac{1}{K}\sum_{i=1}^{K} \alpha_i w_i(t) \tag{4}$$

The above M-LWDF and EXP-PF algorithms can provide QoS to the users based on channel conditions and queuing information. The primary reason for considering these algorithms for comparison is their ability to provide service to delay-sensitive video applications [20]. In addition to the above techniques, another recent technique, termed QoEAS, which enhances the video quality in 802.11ac networks is studied in this paper. It utilizes packet importance information, packet delay, and the channel qualities to select packets for the scheduling process. The packet information is obtained from the gradient of its QoE function in order to achieve quality realization. The packet scheduling is performed according to a maximal weighted utility gradient as illustrated in Eq. 5,

$$m_i = \arg\max_i N_i(t)\left|U_i(w_i(t))\right|c_i(t) \tag{5}$$

Where, $N_i(t)$ is the packet importance index of HoL packet for the user i and time slot t,$U_i(w_i(t))$ is the delay utility function and $c_i(t)$ is the maximum achievable transmission rate. Video quality can be improved and user fairness is maintained with the help of delay, and channel aware QoEAS scheme. However, in reality, users may not get the required quality due to an insufficient amount of resources or time. Thus, to provide an enhanced experience to the users, it is required that resources be delivered according to QoE. In the next section, the design of the proposed scheduling scheme is discussed, followed by its assessment.

3.2 Design of the QoECLS

Considering an infrastructure based WLAN, where the AP serves K video users with different downlink data requests. The proposed scheduler is situated at the AP and is responsible for allocating the transmission resources among the users. The JAA module at the AP determines the transmission rates, based on channel conditions and the amount of data to be sent. Note that the transmission time of each user can be short for small queue sizes and/or good channel conditions. It may be longer for large queue sizes and/or bad channel conditions. The intention here is to control the distribution of transmission times based on application bitrate feedback at the user stations. That is, the requested download rate may be high, but due to bad channel conditions, the user may not be served properly due to an unfair allocation of resources. To solve the problem, a cross-layer scheduling scheme QoECLS for WLANs is proposed, that works as follows: Assume that the AP runs in Point Coordination Function (PCF) mode to enable contention-free access for real-time traffic. At the start of every Contention-Free Period (CFP), AP transmits a beacon frame to all the stations in the basic service set after it finds that the medium is idle for the duration of PCF Inter Frame Space (PIFS). AP polls each user station in the polling list to know whether they are willing to receive the data. The AP continues to poll at each station until the maximum duration of the contention-free period is reached. During this phase, it collects information like application view rates and PHY rates from the polled stations. Based on the channel qualities, the best possible transmission mode is selected by the transmitter. However, in practice, the view rates experienced by the user stations depend on time-varying channel conditions. These parameters are considered as major design inputs of the scheduler. The procedure for QoECLS scheduling is described in the form of steps presented in Algorithm 1.

Algorithm 1 QoE cross-layer scheduler

The Scheduling algorithm runs at the AP.
Assumption: AP runs in PCF mode
Input: Polling list, PHY rates, view rates
Output: Decides which clients to be scheduled in a given interval

```
1: AP obtains the opportunity to access the medium
2: for every T seconds do
3: list the view rates of client stations
4: obtain the average view quality Q_avg using Eq. 6
5: end for
6: for each client station i ∈ [1, K] do
7: calculate T_i using Eq. 7
8: schedule the i for T_i
9: end for
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In the first step, the AP polls the user stations. The scheduling operation starts by listing the view rates and PHY rates of user stations. Then, the average view quality of the users associated with AP can be obtained using Eq. 6 as follows,

$$Q_{\text{avg}} = \frac{1}{K}\sum_{i=1}^{K} Q_i \tag{6}$$

In order to improve the user perceived quality with fairness guarantee, the time required is defined as the ratio of average view quality (Q_{avg}) to physical transmission rate R_i indicated in Eq. 7,

$$T_i = \frac{Q_{\text{avg}}}{R_i} \tag{7}$$

After computing all the scheduling metrics, the last step is to schedule the client stations.

4 Results and discussion

In this section, a brief introduction to the simulation parameters is presented. This is followed by a description of the performance evaluation metrics and the discussion of the results. To study the performance of the proposed scheme, extensive simulations using ns3 simulation tool are conducted. The recent QoEAS [12] and two well-known scheduling algorithms M-LWDF [18], EXP-PF [19] are chosen to study the effectiveness of the QoECLS scheme. Each simulation result presented below is the mean value of 10 simulation runs and the bars in the graphs represent the deviation from the mean values. The deviation levels in the graphs represent the 95% confidence interval values for the chosen metrics. Table 3 shows various parameters used in the simulation for evaluation.

The essential performance evaluation metrics are MOS, throughput, packet loss rate, packet delay, fairness, and jitter. The video traces used in the simulation are generated using evalvid tool [21], which is encoded with H.264 standard. The WLAN scenario of each client station receiving video flows has been considered. User stations report the channel feedback to the access point. In each scheduling interval, the AP assigns time slots to the requested users according to the algorithm. M-LWDF and EXP-PF handle the delay by putting the HoL threshold to 0.1s. The delay threshold in QoEAS scheme is set to 100ms.

4.1 Performance evaluation metrics

The QoECLS performance is evaluated on the basis of certain network-level metrics and objective QoE assessment. The network performance metrics can be defined as throughput, fairness, delay, packet loss rate, and jitter. MOS is used as a standardized QoE metric indicating the user-perceived quality for multimedia services especially video applications. The overall estimated video quality MOSV, expressed on the MOS scale is given by,

$$\mathrm{MOSV} = MOSfromR(QV) \tag{8}$$

Where, QV represents the overall estimated video quality and is obtained by using,

$$\mathrm{QV} = 100 - \mathrm{QcodV} - \mathrm{QtraV} \tag{9}$$

Where, QcodV is the estimated video quality for video compression and QtraV is the estimated video quality for video transmission errors. MOS from R(QV) transforms the estimated QV values on 100-point scale to MOS levels [1, 5] scale. It is a function defined in ITU-T Recommendation G.1071 [17] that converts QV to the MOS evaluation range. Accordingly, the objective quality evaluation MOS is obtained. The typical correlation between QV, MOS scores, and the user experience with video applications are shown in Table 4.

Assessed video quality relies upon the real bitrate seen by the users. The proposed QoE scheme is devised in conjunction with the MOS score to wholly exploit the user experience in WLANs.

Table 3 Simulation parameters

Parameters	Values
Number of user STAs	10–80
STA placement	Random
Carrier frequency	5 GHz
Channel bandwidth	80 MHz
Traffic model	Video:H.264
Video bitrate	400–4000 Kbps
Video frame rate	30 fps
WLAN	802.11ac
PHY data rates	300 Mbps
Slot time	9 µs
PIFS	25 µs
MAC packet size	2000B

4.2 Results and discussion

The variation of the MOS values as a function of expanding users is illustrated in Fig. 4. The results indicate that the QoE scheme performs well compared to other scheduling techniques, and this improvement is obtained by considering bitrate feedback in the allocation of resources. QoECLS maintains a MOS value above 4.8 for up to 40 client stations. Thereafter, a slight reduction in MOS can be observed. QoEAS uses packet important index, HoL packet information to prioritize the packets and enhance the video quality. The packet importance index is derived based on the QoE gradient. Hence, it performs well compared to other delay and channel aware schemes. The M-LWDF algorithm results in the lowest MOS value of

Table 4 Relation among QV, MOS and user experience

QV	MOS	User experience
> 90	5	Excellent
80–90	4	Good
70–80	3	Fair
50–70	2	Poor
< 50	1	Bad

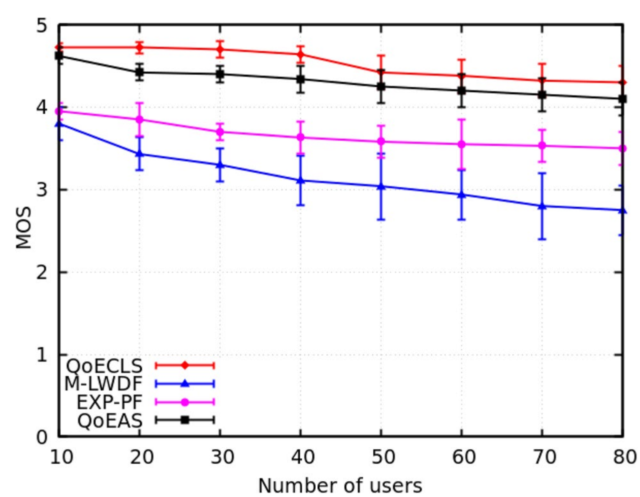

Fig. 4 MOS variation in terms of users

3. It maintains throughput with adequate allocation of resources but its performance decreases due to packet loss. Since M-LWDF is a QoS and channel aware scheduling policy it might guarantee delay requirements and provides a balance between fairness and QoS requirements. The users with EXP-PF experience consistent video quality when the number of users increases above 30.

Figure 5 depicts the average throughput and the result demonstrates that the throughput of proposed QoECLS is relatively better to other schedulers. It achieves a maximum throughput gain of 25%, 45%, and 50% over QoEAS, EXP-PF, and M-LWDF, respectively. Although, throughput does not directly reflect the video quality, it is considered as a key performance indicator for multimedia applications like videos. Hence, with an aim to provide minimum quality to video users, QoECLS acts fairly among client stations. Compared to other two schemes, QoEAS performs well in terms of providing average throughput to the users. The M-LWDF and EXP-PF schedulers are almost showing similar performance despite the number of users, channel conditions and perceived quality. EXP-PF has relatively high throughput compared to M-LWDF, as it tries to balance the throughput along with fairness. However, as the number of user stations increases, the throughput of these schedulers degrades.

Figure 6 represents the results of packet loss rate. The result indicates that QoECLS and QoEAS exhibit similar performance. For instance, the maximum packet drop is 0.1 for both the schemes. M-LWDF shows a stable performance for the user traffic less than 30. EXP-PF exhibits its optimal behaviour over M-LWDF, when the user traffic crosses a strength of 40. Hence the QoECLS scheme and QoEAS maintain low PLR with rising number of users.

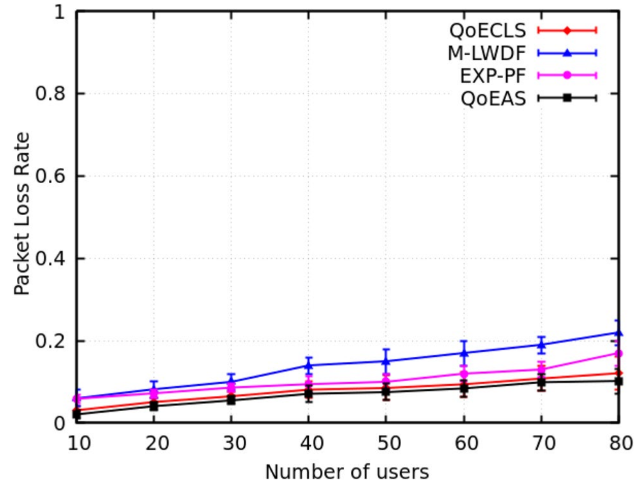

Fig. 6 Packet loss rate comparison of various algorithms in terms of users

The variation of delay concerning users is shown in Fig. 7. The QoEAS algorithm has lowest delay among all the schemes, because of the use of delay utility function and packet importance index in scheduling the user stations. The QoECLS scheme and EXP-PF algorithm show similar performance for user traffic up to 40. The QoECLS is in second place, since it aims to enhance the user opinion, while considering the throughput requirements of video application users. The maximum delay bound for QoECLS and EXP-PF schemes is from 5 ms to 15 ms.

To assess the degree of fairness for video applications, the Jains fairness index [22] is used. As shown in Fig. 8, the QoECLS scheme achieves fairness close to 1, even the network size scales up. The reason is that the QoECLS handle video traffic by considering the bitrate requirements of the application. On the other side, M-LWDF and EXP-PF are showing

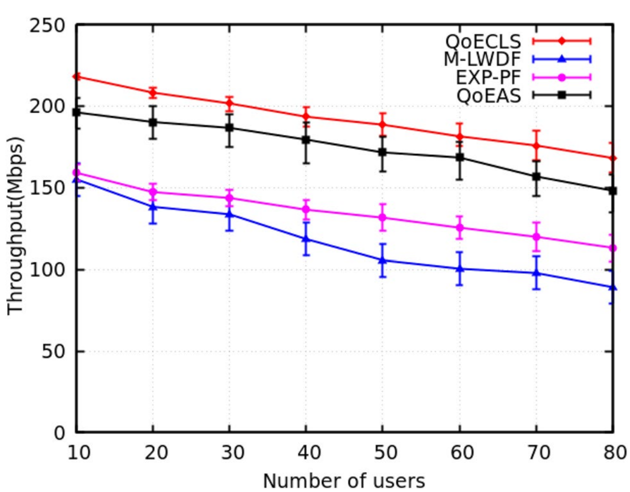

Fig. 5 Throughput comparison of various algorithms in terms of users

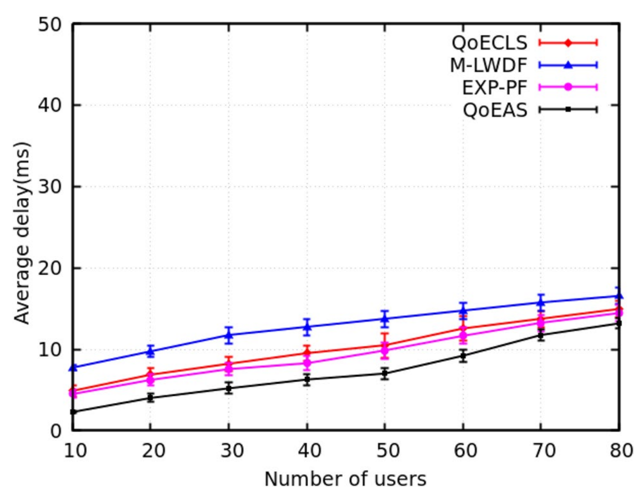

Fig. 7 Delay comparison of various algorithms in terms of users

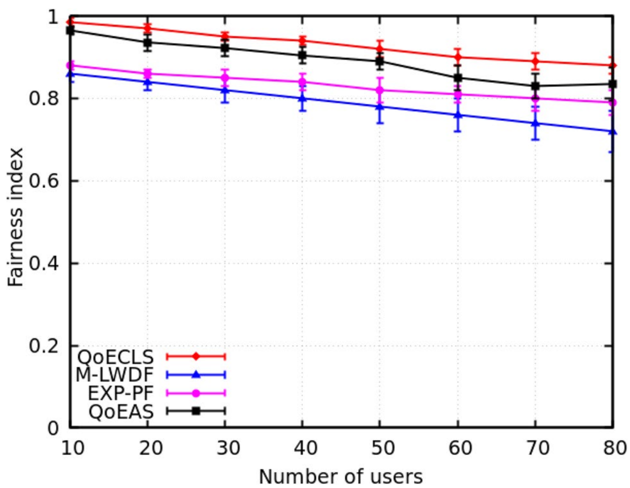

Fig. 8 Fairness index comparison of different schemes

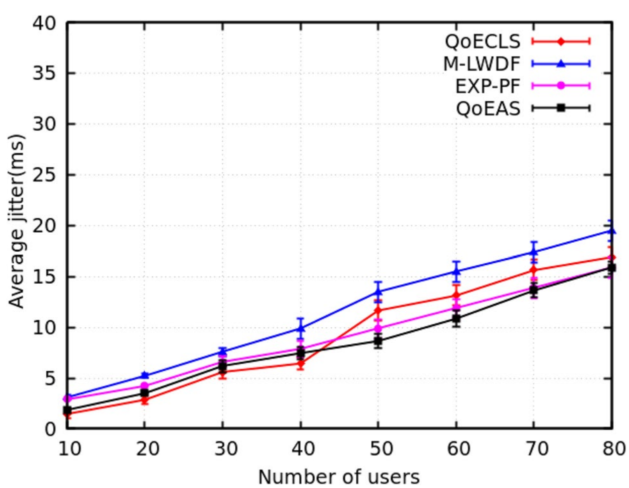

Fig. 9 Jitter variation in terms of users

similar performance in terms of fairness. Hence, M-LWDF results in a low level of fairness and QoECLS performs well compared to all the schemes.

Figure 9 represents the jitter analysis. It is shown that QoEAS and EXP-PF maintain low jitter compared to other schemes because they are very stringent in delay requirements. QoECLS performs well up to 40 users, and then it starts increasing. It is understood that with the rising number of service requests, the users with high video demand requires additional time to complete the entire transmission. Hence, there is an increase in delay variation concerning the number of user stations.

5 Conclusions

In this paper, a QoE based cross-layer scheduling scheme for video applications in WLANs has been introduced. It enhances the user experience and provides fairness among the users by utilizing parameters such as channel quality, buffer status, and view rate feedback respectively. This framework employs different modules, namely, video application, joint assessment and allocation, QoE cross-layer scheduler and transmitter. In the video application module, the video packets will be forwarded and placed in queues based on the required transmission rate. Next, the joint assessment and allocation module performs the QoE assessment and forwards the allocation information to the scheduler. Then, in each scheduling interval, the QoECLS schedules the users according to their transmission times. The results obtained convey that the proposed QoE based cross-layer scheduling scheme achieves substantial improvements over all other approaches in terms of user experience, throughput, fairness, delay, packet loss, and jitter. The overall throughput improvement is 40% compared to the QoEAS, M-LWDF and EXP-PF scheduling schemes. Further, the proposed scheme maintains MOS value above 4.5 and fairness close to 1, even as the network size scales up. Future work may include addressing the complexity issues, overhead analysis, and optimization of the QoECLS scheme.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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