QOE-BASED DYNAMIC RESOURCE ALLOCATION FOR MULTIMEDIA TRAFFIC IN IEEE 802.11 WIRELESS NETWORKS

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ABSTRACT

The multimedia streams over the wireless access networks has increased dramatically over the past few years. Since the wireless link is featured with restricted bandwidth and limited resources, increasing demand of real-time applications imposes challenges on wireless networks to provide Quality of Service (QoS). Plenty of schemes were proposed to provide QoS, among which the admission control is a typical method. However, admission control mechanisms only consider the case at the network entering phase. After the admission, another mechanism is needed to continue to monitor the ongoing traffic and to react to fluctuation of resource consumption during the connection. Therefore, other than only using admission control schemes, which try to restrict access to the network, schemes to control on-going best-effort background are proposed in this paper. The proposed dynamical halting and resuming schemes of background traffic provide a finer way to allocate resources for video streams. It is shown via extensive simulations that proposed schemes can provide direct and solid enhancement of Quality-of-Experience (QoE) for video subscribers, and achieve good tradeoff between video quality and bandwidth utilization.

Index Terms**—** Video Streaming, Quality-of-Experience, IEEE 802.11 DCF Networks, Dynamic Control

1. INTRODUCTION

In recent years, rapid deployment of Wi-Fi networks makes it easier for users to connect to the Internet with handy devices, such as netbooks or mobile phones. Correspondingly, multimedia traffic over wireless networks has been increasing dramatically. Unlike the wired network, the wireless network is featured with limited bandwidth and fluctuated link quality. These facts inevitably lead to great difficulty in providing Quality-of-Service (QoS) to various demands of real-time transmission. Therefore, providing QoS support for real-time application poses challenges, and in the meanwhile, attracts intensive attention.

Among all the attempts admission control can stand out as a good approach to satisfy QoS requirement of the multimedia users[1]-[5]. Admission control schemes aim to filter traffic entrance of the network according to the collected status of the network and the QoS requirement of the traffic. Mechanisms proposed in [1] and [2] were to estimate the achievable bandwidth of the network and to prevent the traffic from approaching the bandwidth limit. The channel busy ratio was utilized in [3] as an indicator of the network status and thus a feedback parameter for admission control. The performance of various admission control schemes were summarized in [5]. Although most of proposed schemes claimed to provide a good estimation of the network condition, the resource requirement of admitted traffic may vary over time, which makes the actual QoS unpredictable. For example, the MPEG coding algorithm for video streams alternates between three coding modes (I, P, B), and thus generates packets at varied rate over time [10]. Therefore, the required amount of resources to guarantee QoS for the resulting VBR (Variable Bit Rate) traffic changes over time. All these render dynamic resource allocation on on-going traffic necessary.

Most of proposed control schemes utilized the channel bandwidth and network capacity as an indirect measurement of the service [4][6]; however, they were not aware of the effect of these factors on personal experience of end users. QoE (Quality-of-Experience) was put forward as a direct measurement of overall level of satisfaction on the service as is perceived by end users [7]-[8]. In this paper, QoE is utilized directly by proposed control schemes as a crucial parameter to control the on-going traffic; thus the performance improvement of video streams can reflect enhanced level of satisfaction for end uses. Note that QoE was used for admission control in [9]. In this paper, we further apply the QoE assessment to control on-going best-effort background traffic, and realize a finer way to achieve better QoE.

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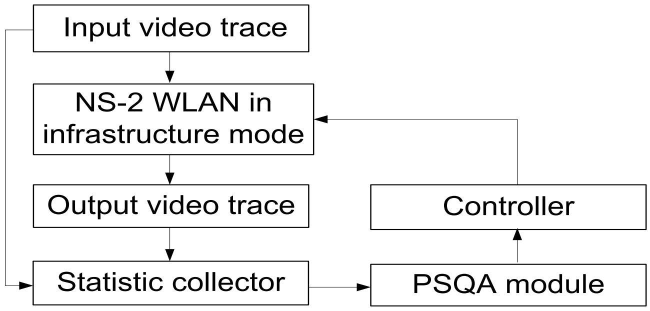

Fig. 1. QoE-based simulation framework.

The remainder of this paper is organized as follows. In Section II the framework of the simulation system is described, and then control schemes on on-going background traffic are proposed. The performance of proposed schemes in simulation scenario are demonstrated in Section III and finally, conclusions are summarized in Section IV.

2. CONTROL SCHEMES ON ON-GOING TRAFFIC

In this section, the QoE-based framework of the network system is firstly established, then the control algorithm on ongoing background traffic will be proposed to improve the quality of video streams.

2.1. Framework of the simulation system

All the modules of the framework are present in Fig. 1. The basic scenario in consideration is that client nodes request video streams from the multimedia server. These wireless nodes operate on widely-adopted IEEE 802.11 DCF (Distributed Coordination Function) basic access mode. The video streams are transmitted by the base station via the wireless channel, together with background traffic. The infrastructure mode ensures that the base station can monitor the status of wireless connections, and thus can apply control to the background traffic in real time.

As shown in Fig. 1, the PSQA (Pseudo-subjective Quality Assessment) module is added to obtain the MOS (Mean Opinion Score) value, which quantifies QoE and reflects the perceived quality of received video. The PSQA module in fact provides a mapping function from packet loss statistics to the MOS value. The statistic collector records the information of packets sent during a sliding window. If the transmitted packet in the window is not received after a specified time interval (usually a few milliseconds), it is marked as lost. Note that the packet is also regarded as lost if its delay is larger than the interval, although it can be actually received. This is because, in the application of video streaming, delayed packets that arrive too late for the play-out can be considered as lost.

The collected statistics collected by the base station include loss rates of frame I, P, B and $MLBS$ (mean loss burst size) of the I frame. The output of the statistic collector is the input of the PSQA module for MOS calculation. In the simulation, the sliding window length for MOS value calculation is set to be 5 seconds, which is a suitable value as suggested in [7]. The sliding window shifts forward every second, and the MOS values are updated accordingly. The MOS value obtained for the ith video connection at time T is referred as *mos(i,T)*. After 5 seconds, the whole window moves out of the initial interval. The detailed calculation of the loss statistics and MOS value can be found in [7] and [9]. Based on the MOS values obtained by the PSQA module, the base station can decide to halt or to resume some background connections.

2.2. Algorithm of control schemes

The target of our proposed scheme is to control best-effort background traffic in order to satisfy the service requirement of real-time video streams. As indicated in [9], the MOS value reflects the level of satisfaction and ranges from 0 to 5. The score 3 indicates a fair quality of the video stream and is the minimum score that the video client can accept. Therefore, we define a threshold $mos_{th} = 3$. If the minimum MOS value among all the video connections at time t, $Min(t) = min_{i=1,..,n}\{mos(i,t)\}$ drops below mos_{th}, the base station will be allowed to halt some background traffic in order to save bandwidth for video streams. The i represents the ith video connection out of total n ones. The time t is a series of discrete values with the window shifted forward every second. The reason that the minimum MOS value is chosen instead of the mean value is that the minimum value can guarantee the required quality for all the video streams. It is clear that this requirement is more stringent than that of the mean value. Therefore, we propose the first condition under which the base station can halt some background traffic: $Min(t) < mos_{th}$. This halting scheme is referred as *"mos_{th}-halt"*.

With this condition each second one background connection will be halted until $Min(t)$ increases above mos_{th}. It should be noted that only with this condition the background connections may be halted more than necessary, since the base station does not wait for the full recovery of the network after halting. Therefore, the base station may cease halting as long as the feedback minimum MOS value increases after halting one background connection. However, the quality of video streams cannot be guaranteed in the circumstance that the minimum MOS value increases rather slowly and does not overshoot mos_{th} for a long time. Hence, we propose Tolerance Interval TI to overcome this issue: if $Min(t)$ increases each second, and yet does not overshoot mos_{th} after TI, the base station will start to halt another background connection. Since the window interval is 5 seconds, the part of the win-

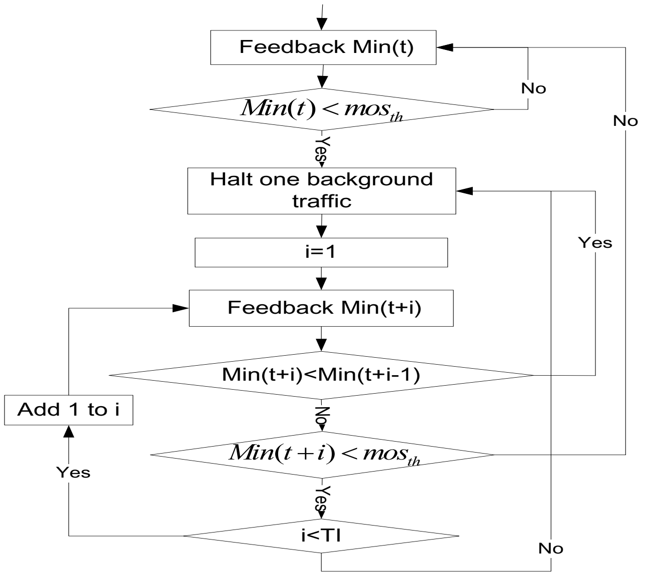

Fig. 2. Operation diagram of halting best-effort background traffic.

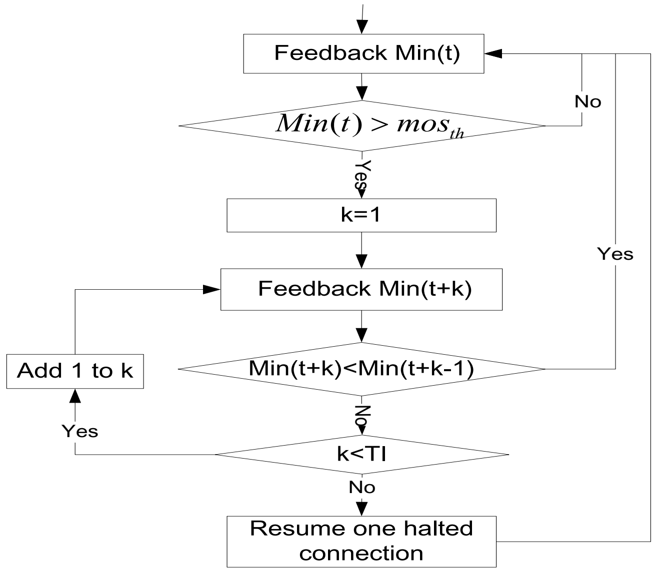

Fig. 3. Operation diagram of resuming best-effort background traffic.

dow that does not overlap with the initial one exceeds half the window for the first time after 3 seconds. Therefore, $TI = 3$ is an acceptable value to infer the trend of the movement of the minimum MOS value.

The whole halting operations are summarized in Fig. 2. The variable i in Fig. 2 actually represents the time interval within which $Min(t)$ is non-decreasing after the previous halting. If i exceeds TI, the base station will halt another background traffic to prevent long-time stay under acceptable level for video clients. To sum up, a second condition $Min(t)$ *is lower than* $Min(t-1)$ *after halting* is added. Only when both conditions are satisfied can the base station halt another background connection. This control is referred to as *"degradation-halt"*.

Moreover, as the rate of video streams varies, the link bandwidth required by video streams changes over time. When the network condition is good, more background traffic can be"squeezed" into the network to make profit of the available bandwidth. As defined before, TI is Tolerance Interval for $Min(t)$ to stay below mos_{th} before another background connection is halted. Similarly, TI can be utilized as an indicator of good condition of the wireless channel: if $Min(t)$ is above mos_{th}, and keeps on increasing over the past interval TI, the base station can resume one background traffic. This resuming operation exploits the available bandwidth and achieves larger throughput of the network. Fig. 3 summarizes the resuming operations. Note that the variable k in Fig. 3 records the number of consecutive increases of $Min(t)$ above mos_{th}.

3. PERFORMANCE EVALUATION

In this section, the proposed halting and resuming schemes are implemented in simulation. We describe the network scenario and system configuration firstly, and then discuss the obtained results.

3.1. Scenario and Configuration

We consider the WLAN access network based on IEEE 802.11b specifications. The proposed control schemes are implemented in NS-2 NIST version [11]. It is assumed that all the nodes are within the coverage of the base station. The base station operates on 802.11 DCF basic access mode and the supporting data rate is 11Mbps. The background traffic is assumed to be CBR (Constant Bit Rate). Although CBR is an simplified type of input traffic, simulations of control on CBR traffic can clearly demonstrate how our proposed scheme works. The halting and resuming control will apply only on the CBR traffic without touching on the video traffic, so that the video connections can have convenient quality improvement without annoying service up and down.

In the simulation, 6 video clients coexist with 12 CBR users. The video clients request for video streams with mean rate $\overline{r}_v$ of 360kbps. The ith request starts from $(2 + 0.03i)$s. The CBR connections start at 2s and the rate $\overline{r}_c$ is 160kbps. All the connections end at 64s. The first two seconds is allocated sufficiently for association operation (Association Request/Reply) between the base station and wireless nodes. Since the traffic rate is identical for all the CBR users, it does not make any difference in choosing which CBR connection to halt; therefore, the CBR connection is randomly chosen by the base station to halt in simulation. However, in consideration of fairness, the base station always gives priority to the connection that is halted firstly in the resuming operation.

In terms of performance, we are interested in quality of video streams and the network throughput. The quality is quantified by the MOS value. The goodput of video streams and the supporting number of CBR connections are used as the reference of network throughput. The goodput is the aggregate received rate of video streams at the application layer of video clients.

3.2. Simulation results

Firstly, let's consider the network performance when no control applies. Fig.4 demonstrates the minimum MOS values, input rate and goodput over time. The input rate is the aggregate rate of video streams fed into the base station. It can be clearly observed from Fig.4 that the input rate varies significantly with time. At around $30s$, the input rate reaches its local peak of $3.2Mbps$, and the network is heavily loaded. The minimum MOS value of video streams drops far below $mos_{th} = 3$. This is validated by a visible gap between the input rate and goodput, which indicates heavy packet loss. At this point the quality of perceived videos is fairly bad. Therefore, it is necessary for the base station to halt some background CBR connections to guarantee service quality for video clients.

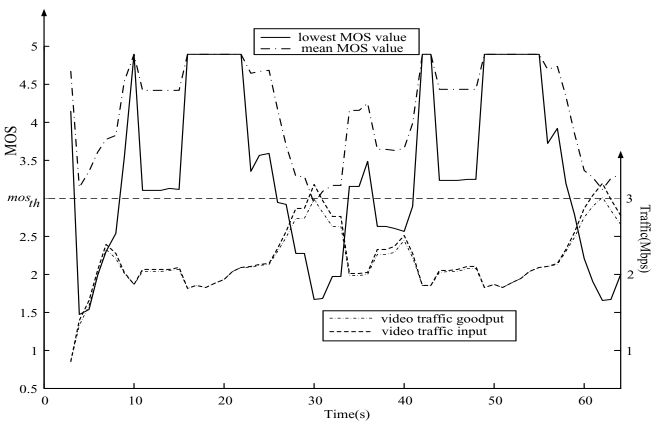

Fig. 4. Network performance without control.

In the following, we apply the mos_{th}-*halt* control, that is, if $Min(t)$ drops below mos_{th}, the base station will halt one CBR connections each second until the quality of video streams achieves the requirement. The network performance is demonstrated in Fig.5. The mean MOS value is averaged over the 6 video clients, and indicates overall quality of video streams over the past window. As can be observed from Fig.5, 5 CBR connections are halted within the first few seconds,

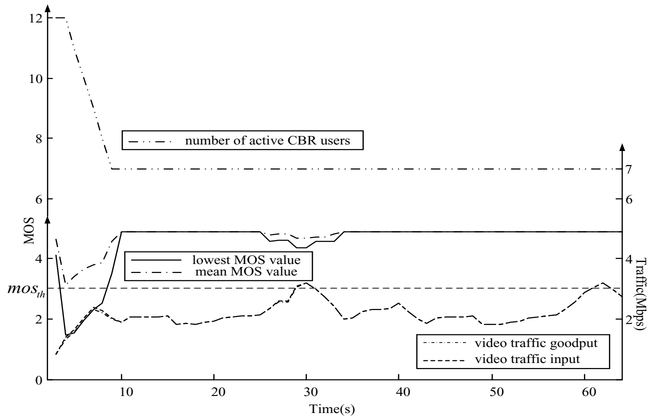

Fig. 5. Network performance with mos_{th}-halt control.

and then both the mean and minimum MOS values increase drastically to almost five, indicating perfect quality of video afterwards.

On the other hand, the perfect quality after halting indicates that some CBR connections are halted more than necessary. Fig.6 demonstrates the network performance under the *degradation-halt* control. It can be clearly observed from Fig.6 that the CBR connections are not halted as frequently as shown in Fig.5. At $9s$, another CBR connection is halted since $Min(t)$ does not overshoot mos_{th}, although it keeps improving in the previous TI seconds. It is clear that only 4 CBR connections are halted, and the overall quality of video streams is improved.

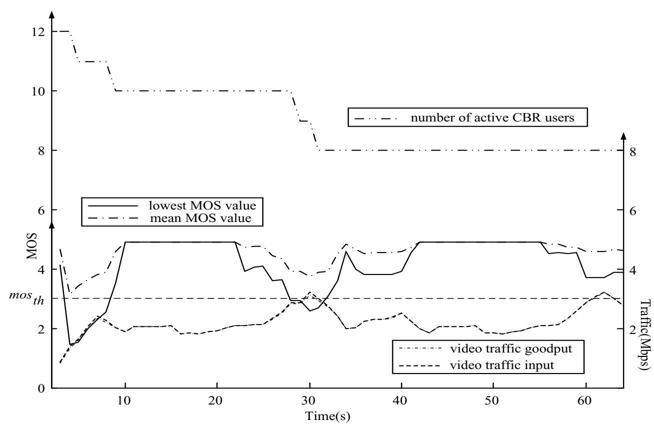

Fig. 6. Network performance with degradation-halt control.

It can be clearly observed from Fig.5 and Fig.6 that when the link condition is not good, the quality of the video streams experiences swift recovery once some background CBR connections are halted. The degradation-halt scheme supports more CBR traffic by making efficient use of the available bandwidth. Although the mean MOS value is not as perfect as the first scheme, the overall performance is acceptable. In other words, this scheme sacrifices video quality slightly to make more profit of the available bandwidth. It can be further observed that $Min(t)$ is much higher than mos_{th} within some time intervals, for example, time intervals $[8, 23]$ and $[42, 55]$ in Fig.6. This indicates that profitable bandwidth is available to accommodate more traffic. As is defined before, continuous growth of $Min(t)$ above mos_{th} in the whole interval TI indicates good condition of the network. Once this condition is satisfied, the base station will resume one CBR connection to make profit from the available bandwidth.

The simulation results for the mos_{th}-halt scheme and the degradation one with resuming are demonstrated in Fig.7 and Fig.8, respectively. By comparing these two figures, it can be found that the mos_{th}-halt scheme has a larger variation of the number of supporting CBR connections, and thus imposes more operation loads on the base station.

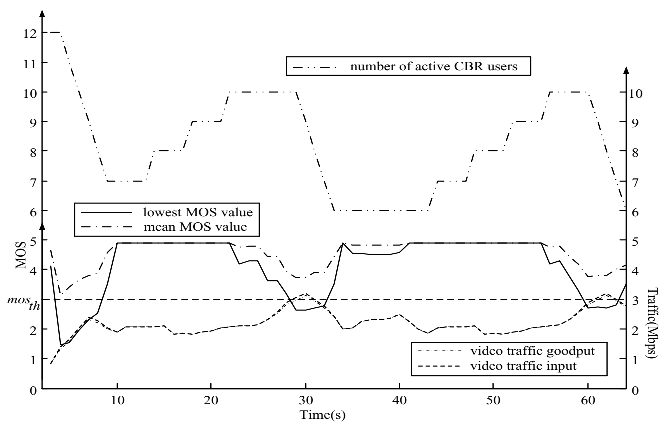

Fig. 7. Network performance with CBR resumed(mos_{th}-halt).

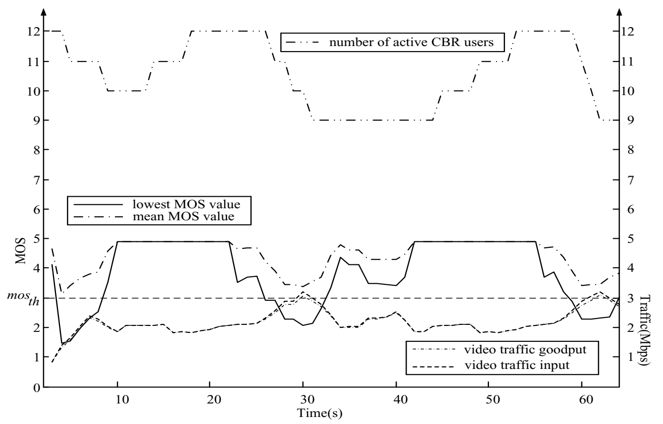

Fig. 8. Network performance with CBR resumed (degradation-halt).

Table 1. Comparison of schemes to control CBR traffic

Scheme	$\overline{MOS}_{min}$	Goodput	$\overline{CBR}$
mos_{th}-halt	4.57	2.191	7.32
degradation-halt	4.13	2.186	9
mos_{th}-halt & resume	4.10	2.184	8.24
degradation-halt & resume	3.82	2.166	10.55
bandwidth allocation	3.58	2.163	10.2
no control	3.33	2.150	12

The proposed schemes are further compared with the bandwidth allocation scheme. The critical bandwidth (CB) is defined as the mean bandwidth consumed by all the traffic, i.e., $CB = \overline{r}_v n_v + \overline{r}_c n_c$, where n_v and n_c are the numbers of video clients and CBR users, respectively. The criterion for control is the remaining bandwidth, which is defined as CB minus the transient consumed bandwidth. The base station can halt one CBR traffic once the remaining bandwidth is less than 0; and resume one CBR traffic when the remaining bandwidth can accommodate one.

Table 1 demonstrates some statistics of the proposed schemes and the bandwidth-allocation scheme. $\overline{MOS}_{min}$ is the minimum MOS value averaged over the whole simulation time, which reflects the overall quality of the video streams. $\overline{CBR}$ is time-averaged number of supporting CBR users, which indicates the bandwidth utilization. The tradeoff between the MOS value and the bandwidth utilization can be clearly observed from Table 1. The quality enhancement of video streams is owing to allocation of larger amount of bandwidth resources to video clients. Consequently, less resources are allocated to CBR connects. Moreover, it can be seen from Table 1 that the bandwidth allocation scheme brings marginal benefits on the video quality and cannot realize better tradeoff compared to the proposed schemes, since it does not employ the MOS value as a direct feedback. The proposed *degradation-halt* scheme supports more CBR connections with acceptable sacrifice of MOS value. If it is necessary, background CBR traffic can be squeezed by using the resuming scheme. In summary, the proposed method guarantees service requirement of video clients, and in the meanwhile seeks to make more profit from varied available bandwidth. Therefore, our method can realizes a good tradeoff between video quality and link bandwidth.

4. CONCLUSIONS

In this paper, we have shown the necessity to apply control on ongoing background traffic when the resource requirement by video streams changes over time. With this regard, the schemes that dynamically halt and resume the background traffic are proposed. The crucial feedback parameter for control is the minimum MOS value of all the video clients, which can be obtained by the base station in real time. By halting some connections when the minimum MOS value drops down below the threshold mos_{th}, the quality of remaining video connections can recover quickly to meet the service requirement. Moreover, halted background traffic can be resumed once the link condition becomes good. Good tradeoff between video quality and bandwidth utilization can be realized by proposed schemes. Furthermore, the advantage of the proposed method is that the subjective experience of end users can be improved directly, since QoE is utilized as the evaluation method and the feedback for control. Solid improvement of QoE brought by proposed control schemes is validated by extensive simulations. Note that IEEE 802.11e also provides mechanisms to provide QoS. It would be interesting to implement the proposed schemes in the architecture of IEEE 802.11e networks, which can be regarded as part of the future work.

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