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Towards Centralized Management for Video Streaming Over Enterprise Wireless LANs

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***Abstract*—To satisfy the need for ubiquitous connectivity of their customers, many enterprises (e.g., hotels, cafes and commercial centers) deploy EWLAN (Enterprise WLAN). In these networks, video streaming is both one of the most popular and challenging applications. To improve the overall users QoE in EWLAN, we propose to address simultaneously the resource bottlenecks that can occur on wireless links as well as the lack of overall bandwidth that can be experienced on the Internet access link. We propose a dynamic video Streaming Management based on software defined enterprIse wireLEss LANs (SMILE), an SDN framework which *dynamically* allocates the bandwidth among different access points based on their workloads and on the available bandwidth. We evaluate SMILE over several adaptive video streaming performance metrics: instability, rebuffering, and average video quality. The results demonstrate an improvement for these parameters with different adaptation logic's when SMILE is in use.**

I. INTRODUCTION

To satisfy the raising need for ubiquitous connectivity, many companies or institutional organizations deploy small cells infrastructures often relying on WiFi technology. Many WiFi hotspots can now be found in restaurants, transportation hubs, hotels, commercial centers and even in cities all around the world [1]. A recent visual networking index report from Cisco Systems [2] confirms this vision and it predicts the Internet access through Wi-Fi will reach 52.6% of the total Internet traffic by 2021. The same report expects the total Internet video traffic to reach 82% of all Internet traffic by 2021. This huge increase in Wi-Fi demands for Internet access brings new challenges for multimedia traffic, especially regarding Internet video streaming.

Dynamic Adaptive Streaming over HTTP (DASH) protocol proposes to provide high quality video delivery and to increase end user Quality of Experience (QoE). In DASH adaptive video streaming, the video is encoded into different bitrates and segmented into multiple segments of fixed durations. Issues may raise when two or more DASH players compete for a limited bandwidth. As the network conditions evolve dynamically and the adaptation logic of each player reacts independently, instability, unfairness among the players requested bitrates can occur as well as network bandwidth underutilization [3].

Dense wireless local area networks (WLANs) are deployed to provide wireless Internet access for wide coverage area. Therefore Enterprise WLANs (EWLANs) can gather a large set of access points often managed through a wireless controller [4]. Thus typical in EWLAN architectures, the wireless device connects to one of the available access point. Access points are then interconnected through wired link to a single gateway which provides the entry point to the Internet. In such architectures, bottlenecks could appear in the wired access link (between the gateway and ISP Network) due to a bandwidth congestion or in the wireless links due to wireless access limitation (e.g, too many clients or neighboring wireless networks, interference with non-WiFi devices and the wireless channel fading). In addition, the DASH protocol runs over HTTP which uses TCP as a transport layer. The weak TCP performance over WiFi (IEEE 802.11) networks is a well known problem. When multiple TCP flows share the same access point, TCP fairness issue leads to an underutilization of the available bandwidth [5]. Furthermore, the TCP congestion control is run by the server while DASH adaptation logic is performed by the client, thus leading to mismatch between the two protocols behavior [6]. When multiple DASH clients stream videos over HTTP with different wireless channel qualities (some with poorer quality) the overall TCP performance declines, as it has been identified and described in [7], [8]. Further, the Internet gateway often has a limited bandwidth to the Internet, which all clients will compete for. Consequently, bottlenecks could be either in the access link or on the wireless links.

In this paper we propose and evaluate SMILE, an SDN based framework that improves adaptive video streaming in Enterprise Wireless LANs. SMILE dynamically allocates the bandwidth among clients according to the available bandwidth, number of users and access points loads. In addition, it shares fairly the bandwidth between the access points based on the clients link qualities.

The rest of the paper is organized as follows. Related work are presented in Section II. In Section III we explain SMILE. The performance evaluation is presented in section IV. Finally, the conclusion and future work is discussed in Section V.

II. RELATED WORK

Traffic shaping is a well known mechanism often used to reduce competition among scarce resources. In [9] , the authors introduced static traffic shaping for DASH clients to eliminate the competition between video flows. This technique could be implemented in EWLANs controller. However, in EWLANs static traffic shaping could lead to undesirable performance due to network dynamic and the wireless link instability. In [10], the authors proposed a centralized control plane to provide video quality fairness between different video flows sharing a common bottleneck. However, the authors do not consider the wireless link variations and their instability.

Airtime fairness [11] was proposed as a solution for IEEE 802.11 performance anomaly. This technique resolves the anomaly problem for uplink traffic but in adaptive video streaming, most of the traffic is downlink. The authors in [12] proposed a scheduler in the Access Point (AP) that selects a subset of clients to be served during instant period. This technique isn't suitable for delay sensitive applications such as adaptive video streaming where the delay causes buffer starvation and decreases the users QoE. Chiariotti et al [13], proposed a centralized QoE aware bitrate streaming. A proxy-based solution was proposed in [14]. The proxy fetches segments and redirects the requests based on wireless channel prediction. In [15], the authors developed Internet video control service to predict the optimal bitrate for the clients every 30 seconds. This technique is more suitable for stable links (wired connection) which is not the case in EWLANs. In our previous work [16], we proposed a solution in wireless home context when the bottleneck is in the wireless link. However, in this work we consider EWLAN and when the bottleneck could be either in wireless and access link.

Centralized management for EWLANs was proposed as solution for network management [17]. The authors used a centralized controller to manage the clients associations, dynamic channel assignments and load balancing between different access points. Shrivastava et al [18] proposed a centralized scheduler for EWLANs to reduce the packet loss due to hidden and exposed terminal problems. However, in these frameworks the HTTP Adaptive video Streaming (HAS) issues were not taken into account.

SDN based centralized management for wireless networks were proposed by many researchers. Schulz-Zander et al [19] proposed an SDN based architecture for Wi-Fi networks. The authors designed a new protocol to support wireless datapath control. Sen et al [20] proposed an SDN framework for EWLANs to bring the network programmability. In [21], the authors designed an SDN based dense Wi-Fi network. The results show the ability of SDN architecture to manage EWLANs and it opened the road for new SDN services. SMILE uses the standard functions supported by OpenFlow and OpenvSwitch. Therefore, SMILE is compatible with any software defined EWLANs. In the next section we will describe the architecture of SMILE framework.

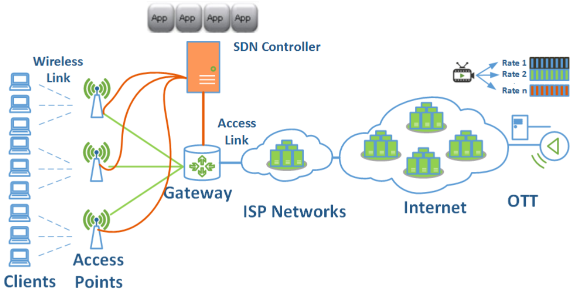

Fig. 1: Dynamic adaptive video streaming management in EWLANs using SDN architecture.

III. THE SMILE FRAMEWORK

SMILE is an SDN based framework which manages HTTP adaptive video streaming traffic in EWLANs. SMILE's objective is to address the bottleneck problem occurring in the access or wireless links. SMILE takes into account the variation of links quality among different clients and fairly shapes the video streams to account for the available bandwidth of access links. Henceforth, SMILE improves the end users QoE by increasing the TCP throughput and the streaming rates while reducing the competition between different adaptive video flows.

Figure 1 shows the proposed architecture to manage adaptive video streaming in EWLANs. Note that SDN control is performed with in-band signaling and not out-of-band as the representation of Figure 1 may suggest. The access points and the gateway are managed by one or several SDN controller(s). Videos are available in the Over The Top (OTT) content servers. Channel quality for each client-access point link differs. SMILE is run on top of the SDN controller as an application in order to improve users QoE and smooth the competition between DASH players. Note that this paper doesn't address the position of the SDN controller within architecture. Although Figure 1 places the controller within the EWLANs, we consider it could as well be into the cloud.

SMILE has been designed as a modular framework and represents a subset of the potential SDN controller functions for EWLAN management. A SDN controller could host other services such as load balance services or routing optimization. Our main objective is to simplify integration of SMILE with other potential future SDN controller services.

SMILE framework consists of four modules, each one designed for a specific function that will be introduced

TABLE I: Summary of Notations

Notation	Meaning
Z	Set of access points in the EWLAN
z	Element of Z
N	Set of clients attached to an access point
n	Element of N
i	Index of the modulation/coding scheme
m_i	Physical transmission rate of index i
E_{nz}	Wireless effective rate for client n
P_{nz}	Total number of packets for client n
s_{nzi}	Successfully received packets for client n
LE_{nz}	Link experience for client n
$Wittnz$	WiFi TCP throughput for client n
a	Airtime utilization from non-WiFi source
c	Local contention
C	DASH protocol overhead
R_{min}	Minimum bitrate in the available video bitrates
$B_{W_{Gz}}$	Bandwidth from gateway to access point z
AB_{W_z}	Aggregate bandwidth for access point z
BW	Total available bandwidth in the EWLAN
B_{nz}	Bandwidth assigned for client n attached to access point z

in the next subsections. For convenience, we summarize the used notations in Table I.

A. Traffic Monitoring Module

The traffic monitoring module is in charge of flows classification and traffic monitoring. In an SDN architecture, when a new traffic flow starts the first packet reaching the access point (forwarding element) is forwarded to the SDN controller for processing. Then, the controller classifies the traffic flows (e.g, using DNS based classification [22] or Deep Packet Inspection (DPI) [23]) before installing the new flow route in the access point. Furthermore, an access point periodically sends statistics about each traffic flow to the controller. When the SDN controller stops receiving traffic flow statistics for a certain period of time (for this paper 10 seconds), this flow is then considered inactive.

According to [24], the data plane could be extended to report the wireless effective rate for each client. Such metric reflects the link quality and the packet losses percentage. When a link quality between a client and its access point is good, the effective wireless rate is high and vice versa. The wireless effective rate for client n attached to access point z is defined as :

$$E_{nz} = \frac{1}{p_{nz}} \sum_{1}^{i} s_{nzi}\, m_i \tag{1}$$

Where p_{nz} is the number of packets for the n^{th} client attached to the access point z. i the index of the modulation/coding scheme used on the link between the client and its access point (e.g., for 802.11g 8 modulations/codings are defined therefore $1 \leq i \leq 8$). s_{nzi} is the number packets received successfully for the client n and m_i is the physical transmission rate for physical transmission rate index i. In subsection III-C, we will show how the effective wireless rate is used to estimate the fair TCP throughput for the clients.

B. MPD Analyzer Module

This module is used to analyze the Media Presentation Description (MPD) file. The MPD is downloaded from the Over The Top content server by the DASH player at the beginning of the streaming session and it contains metadata about the video. In the SMILE framework, when the MPD file reaches the gateway, a copy is forwarded to the SDN controller [25][1]. The MPD file contains the video length, the number of chunks, the available bitrates and the chunks URLs. The flow traffic statistics and the MPD files metadata will be used by the QoE optimizer to allocate bandwidth for the clients.

C. QoE Optimizer Module

In EWLANs multiple clients are connected to the access points with unstable wireless links. When the clients stream videos using DASH protocol from OTT content servers, the bottleneck causes competition between the DASH players which leads to instability among the players and impacts the users QoE. To solve this problem we introduce dynamic traffic shaping in the access points. Such functions is widely supported by modern access points [26], [27]. The main objective of QoE optimizer module is to fairly allocate the bandwidth between clients and prevent a bottleneck. Among the various models that exist in the literature to estimate the TCP throughput over IEEE 802.11 networks, we chose the one presented in [24]. It uses the wireless effective rate to estimate the TCP throughput using Link Experience (LE). The authors found a maximum value of the correlation coefficient between the link experience and the TCP throughput over many other metrics. The link experience for client n attached to access point z is defined as:

$$LE_{nz} = (1-a)(1-c)E_{nz} \tag{2}$$

Where a is the airtime utilization from non-Wi-Fi source [24][2], c is the local contention. We need to reduce the contention between clients to maximize the aggregate TCP throughput. Since we have N clients attached to the access point z, we need the clients to have the same contention probability and airtime utilization, for that we assign $c = \frac{1}{N}$. Hence, the new expression for link experience with the equal contention probability and the airtime utilization for the clients becomes:

$$LE_{nz} = (1-a) \times (1-\frac{1}{N}) \times E_{nz} \tag{3}$$

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[1] Another technique to do this consists in using the OTT open API such as YouTube API to get the video metadata.

[2] we assign the value 0.1 for a [28].

From [24] the Wi-Fi TCP throughput ($Witt$) for client n is calculated from the link experience as:

$$Witt_{nz} = \beta_1 LE_{nz} + \beta_0 \tag{4}$$

Where β_1 and β_0 are constants, their values depend on the IEEE 802.11 standard (e.g., for IEEE 802.11g they are 0.422 and 0.167 [24]). The SDN controller calculates the $Witt$ for each client to evaluate the fair TCP throughput that should be allocated in the access point. Also we need to make sure the assigned $Witt_{nz}$ is greater than the minimum video bitrate available in the server (the goal is to eliminate the starvation by assigning bandwidth to each client at least greater than the minimum available video bitrate) so the new equation for Witt is:

$$Witt_{nz} = \begin{cases} Witt_{nz} & \text{if } Witt_{nz} > (1+C)R_{min}. \\ (1+C)R_{min} & \text{otherwise.} \end{cases} \tag{5}$$

Where C is the DASH protocol overhead[3], R_{min} is the minimum video bitrate available at the server and is extracted by the MDP analyzer module. In EWLANs, there are Z access points connected to the gateway (aggregate switch). The aggregate bandwidth needed for each access could be determined by:

$$AB_{W_z} = \sum_{n=1}^{N} Witt_{nz} \tag{6}$$

However, the total bandwidth available at the Gateway could be lower than the sum of aggregate bandwidths for all access points which is common in EWLANs (access link bottleneck). In this case our algorithm propose to assign the available bandwidth proportionally to the aggregate bandwidths of each access point. We formulate the fair bandwidth allocation between different access points as a linear programming problem as shown below [4] :

$$\begin{aligned} &\textbf{Problem 1:} \text{ maximize} \sum_{z=1}^{Z} B_{W_{Gz}} \\ &\text{subject to} \sum_{z=1}^{Z} B_{W_{Gz}} \leq BW \\ &B_{W_{Gz}} \geq \frac{AB_{W_z}}{\sum_{z=1}^{Z} AB_{W_z}} \times BW \end{aligned} \tag{7}$$

Where BW is the total available access link bandwidth in the EWLAN. AB_{W_z} is the aggregate bandwidth expected on the wireless links of access point z (equation 6) and $B_{W_{Gz}}$ is the bandwidth that should be assigned for access point z. The objective function of **Problem 1** is to maximize the bandwidth assigned to each access point subject to the constraints (1) the sum of bandwidth that is assigned for all the access points is lower than the total available bandwidth and (2) the bandwidth that is assigned for each access point is proportionally fair to the the access point load (aggregate bandwidths). After solving **Problem 1** we get the values that should be allocated to each access point. Now we have the fair bandwidth allocation that should assigned to each access point. Therefore, the QoE optimizer will send these values to the traffic shaping module to enforce it. The traffic shaping module will be discussed in the next subsection.

The competition between video flows in the access link will be reduced due to the fair allocation of bandwidth between the access points. However, the contention between clients connected to the same access point is still an issue due to the performance anomaly of IEEE 802.11 based networks and of TCP fairness problem. Consequently, The video flows will face bottleneck in the wireless links which can lead to under-utilization of the aggregate bandwidth allocated to the access point, instability of the DASH players, and unfairness between different clients. Therefore, we need to fairly allocate the bandwidth between the clients of a same access point. We formulate this problem as a linear programming problem which should be solved individually for each access point as follows:

$$\begin{aligned} &\textbf{Problem 2:} \text{ maximize} \sum_{n=1}^{N} B_{nz} \\ &\text{subject to} \sum_{n=1}^{N} B_{nz} \leq B_{W_{Gz}} \\ &Bnz \geq X \end{aligned} \tag{8}$$

Where X is:

$$X = \begin{cases} Witt_{nz} & if AB_{W_z} \leq B_{W_{Gz}}. \\ \frac{Witt_{nz}}{\sum_{n=1}^{N} Witt_{nz}} \times B_{W_{Gz}} & \text{otherwise.} \end{cases} \tag{9}$$

B_{nz} is the bandwidth that should be allocated for a client n which belongs to an access point z. The objective of **Problem 2** is to evaluate the maximum bandwidth that should be allocated for each client taking into account the available bandwidth (P2P bandwidth) for each access point and the links qualities for the clients. When the available bandwidth for access point z ($B_{W_{Gz}}$) is greater than the needed bandwidth ($AB_{W_{Gz}}$)

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[3] When a client streams video at bitrate R it needs a bandwidth $(1+C)R$ due to the protocol overhead. In our evaluation we used C = 0.3 which is the average value in multiple DASH experiments [29].

[4] We choose to model the problem as a linear programming problem because it is solvable in polynomial time.

then each client should get in minimum $(Witt_{nz})$. Otherwise, the total bandwidth of the Wi-Fi cell is shared among the clients in proportion to their link quality. The same process is applied for every access point z of the EWLAN. Then the QoE optimizer module will c this value to be applied by the traffic shaping module.

The objective from the two problems formulation it to solve different issues for video streaming within EWLAN. Equation 7 aims to allocate the aggregate bandwidth for each access point proportionally to its load compare to the other access point. In equation 8 we aim to allocate bandwidth for each client within the same access point based on the allocated bandwidth for the access point (solution of **Problem 1**) and the number of clients and their links qualities within the same access point. We model the two problems as linear programming equations because its complexity is P so it could be solved in a polynomial time. Therefore, we could quickly find for such dynamic network where the users numbers and locations vary in time.

D. Traffic Shaping Module

This module shapes the traffic at the gateway and the access points based on solutions of both equations 7 and 8. The bandwidth allocated to the clients is proportional to their links qualities, available bandwidth and the load of different access points . In the next section we will explain the performance evaluation of our framework.

IV. PERFORMANCE EVALUATION

This section is divided into two subsections. First we will discuss the performance metrics that used to evaluate SMILE. Then, we will evaluate the overall performance using the video streaming performance metrics.

A. Video Streaming Performance Metrics

The adaptive video streaming is delay and bandwidth sensitive application. There are many adaptive video streaming performance metrics proposed by researchers. We chose three metrics widely used in the literature reflects the end user QoE within the streaming session.

1) Average Video Quality (AVQ): There is a relation between the video quality and its bitrate [30]. In general, the video quality metrics such as the Structural SIMilarity (SSIM) increases as the bitrate increases [19]. The Average Video Quality (AVQ) is defined as:

$$\text{Average Video Quality} = \frac{1}{G}\sum_{g=1}^{G}\sum_{h_g=1}^{H_g}\frac{R_{h_g}}{H_g} \tag{10}$$

Where H_g is the number of streamed chunks by the adaptive video flow g, G is the total number of adaptive video streaming flows, Rh_g is the bitrate chosen by the adaptation logic of flow g to stream chunk h_g.

TABLE II: Simulation Parameters

Simulation Parameters	Value
Access Bandwidth	40 Mbps
Number of Access Points	3
WiFi Standard	IEEE 802.11g
WiFi Rate Adaptation Algorithm	Minstrel
DASH Player Buffer Size	120 Seconds
Chunk Duration	4 Seconds
Simulation Time	300 Seconds

2) Average Instability: The QoE of DASH based video streams impacted by the bitrate switches [31], [32], [33]. The instability of DASH player is defined as follow:

$$\text{Average Instability} = \sum_{g=1}^{G}\frac{S_g}{G} \tag{11}$$

Where S_g is the number of switches in bitrate for adaptive video streaming flow g. G is the total number of adaptive video streaming flows. Smaller instability reflects better end user QoE and vice versa.

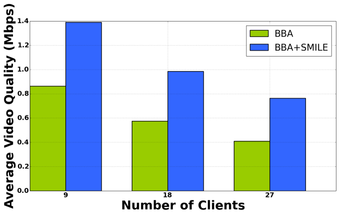
3) Average Rebuffering: This metric reflects the average rebuffering duration for all video streams [32], [33].

$$\text{Average Rebuffering} = \sum_{g=1}^{G}\frac{RB_g}{G} \tag{12}$$

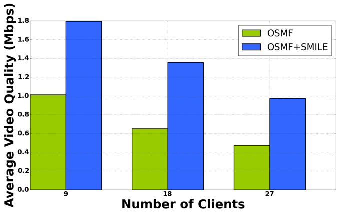
Where RB_g is the rebuffering duration for adaptive video streaming flow g. Rebuffering is one of the most important metric for video streaming QoE. Low rebuffering means better user QoE and vice versa.

B. Performance Evaluation

To evaluate SMILE framework, NS-3 simulator [34] has been configured with simulation parameters listed in table II. A new NS-3 module has been added to include DASH video streaming and Big Buck Bunny [35] an open-source film widely used in DASH research has been encoded with FFmpeg open-source encoder [36] at the same bitrates Netflix [31] uses. The file has then been segmented into chunks of 4 seconds using GPAC multimedia framework [37]. The chunks were streamed over the simulated EWLAN. The EWLAN consists from three access points connected to the gateway. In addition, the Internet access bandwidth of the Gateway has been limited to 40 Mbps to generate a potential bottleneck. We use an minimal model for the SDN controller to evaluate SMILE performance . To make the experiment more realistic some background traffic has been added, thus each access point handles an extra FTP download from one of its clients. Different clients load were simulated ranging from 3 to 9 clients per access point. Clients are distributed over the access points coverage area and each experienced a different channel quality[5]. SMILE allocates the bandwidth at the gateway level by solving **Problem 1** and per access point by solving **Problem 2**. SMILE keeps the OTT content server and the client side (DASH player) without modification. We evaluate the performance of video streaming with and without our SMILE framework using the adaptive video streaming performance metrics presented in subsection IV-A with different adaptation logics (Buffer Based Algorithm [38] and Open Source Media Framework [39]).



(a) BBA.

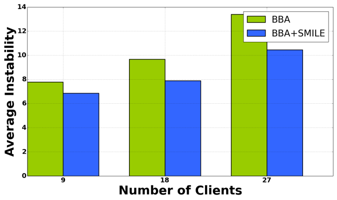


(b) OSMF.

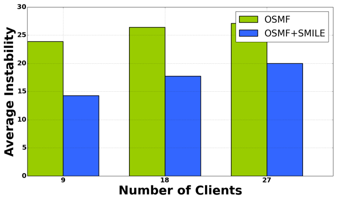
Fig. 2: Average video quality vs Number of clients

Figure 2 shows the average video quality for the benchmark algorithms with and without SMILE framework. OSMF streams at higher bitrate compared to BBA. As shown in subfigure 2-a, SMILE increases the average video quality for BBA adaptation logic because it eliminates the anomaly behaviour of the IEEE 802.11 which leads to fill the clients buffers faster and reduce the access link congestion. Subfigure 2-b shows that SMILE increases the average video quality for OSMF of up to 80% over different access points load. We can conclude that SMILE increases the average video quality for the benchmark algorithms between 57% and 100%.

Figure 3 shows the average instability for the benchmark algorithms with and without SMILE framework. As shown in Subfigure 3-a SMILE increases the average stability for BBA adaptation logic over different access points load. SMILE eliminates the anomaly behaviour of the IEEE 802.11 which leads to faster fill the clients buffers and to reduce the access link congestion. In addition, SMILE eliminates the competition between different DASH players which improve TCP performance. Subfigure 3-b shows that SMILE enhances the stability for OSMF adaptation logic. We can conclude that SMILE improves the stability for the benchmark algorithms between 15% and 60%.



(a) BBA.



(b) OSMF.

Fig. 3: Average Instability vs Number of clients.

TABLE III: Average Rebuffering vs Number of Clients

Scenario	**Number Of Clients**		
	9	**18**	**27**
BBA	0	1.16	3.07
BBA+SMILE	0	0.31	0.94
OSMF	0.77	1.88	3.94
OSMF+SMILE	0	1.05	1.37

SMILE aims to improve the TCP performance. It allocates the bandwidth between different clients proportionally to their links quality and eliminates the performance anomaly of IEEE 802.11 networks. Table III shows the number of rebuffering for different adaptation logic. When the number of clients is small (3 per access points) the number of rebuffering for is zero with and without the proposed framework. In addition, the proposed framework reduces the average rebuffering for OSMF. When the number of clients increase the rebuffering duration increases due to the competition between different player and the bandwidth starvation.

V. Conclusion and Future Work

We proposed a new framework SMILE to improve adaptive video streaming in EWLANs. SMILE dynamically allocates the available bandwidth based on the access points loads. In addition, it shares fairly the bandwidth between the access points based on the clients link qualities. SMILE improve the performance of different DASH adaptation logics over different adaptive video streaming performance metrics. Our work will continue in the following directions. First, the simulation results motivate us to implement SMILE over large scale EWLAN (e.g, university campus WiFi network). Sec-

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[5] We divided the access point capacity into three regions (poor, medium and high link quality). Poor link quality includes the rate indexes 1, 2 and 3. Medium link quality includes the rate indexes 4 and 5. High link quality includes the rate indexes 6,7 and 8.

ond, we will address the new direction in DASH video streaming where Server and Network-assisted DASH (SAND) could be used to allow bidirectional communication between the DASH client and the network [40].

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