Journal of Advances in Computer Research
Quarterly pISSN: 2345-606x eISSN: 2345-6078
Sari Branch, Islamic Azad University, Sari, I.R.Iran
(Vol. 9, No. 2, May 2018), Pages: 21-36
www.jacr.iausari.ac.ir

Network Resource Management for Improving Users QoE in SDN by WFPN Method

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Received: 2017/04/18; Accepted: 2014/06/04

Abstract

The rapid rise in popularity of multimedia applications, such as VoIP, IPTV and Video Conferencing, intensifies the need to consider resource management for user satisfaction. Furthermore, improving Quality of Experience (QoE) in Software Defined Networks (SDNs) services is one of the important issues to be addressed by provisioning optimum resource management. In this paper, resource allocation in SDN is considered to improve user perceived quality. To this end, an intelligent learning is presented based on Weighted Fuzzy Petri Net decision algorithm for SDN resource management based on QoE assessment. The efficiency of the proposed system is evaluated through simulations. The results show that, through the control plane supervision, the proposed algorithm, improves Quality of Experience by decreasing delay and jitter while preserving throughput in the network.

Keywords: *Quality of Experience (QoE), Resource Management, Software Defined Network (SDN), Weighted Fuzzy Petri Net (WFPN)*

1. Introduction

In recent years, novel real-time applications such as video conferencing, distant learning, Internet calls, and Internet TV have soared in popularity over best-effort networks. For instance, over 51 percent of internet traffic in 2011 was used for video applications and the figure is expected to reach 70-80 percent by 2017 [1]. Globally, IP video traffic will be 82 percent of all consumer Internet traffic by 2020, up from 70 percent in 2015, and IP video traffic will grow threefold from 2015 to 2020 [2]. Furthermore, experts predict that, in the next decade, the Internet will effectively become a playground for multimedia content, where the web's traffic will be entirely used for multimedia purposes [3]. Therefore, by significant increase in the number of such applications with high quality requirements; managing resources at the network level for different users and applications is essential for service providers.

Network service providers have attempted to offer multimedia applications by meeting standards (such as Quality of Service (QoS) methods) of network developers and other standard institutions. However, due to the ineffectiveness of these measures user satisfaction was not improved and, in some cases, network resources were wasted [4]. Therefore, Network developers needed another mechanism to predict and improve the quality of multimedia applications on the Internet.

Since, Quality of Service lacks a critical criterion for describing video and multimedia streams, i.e. user's emotions [5], network developers aim to describe multimedia streams in terms of Quality of Experience (QoE) [6]. By allowing end-users to adjust quality parameters, QoE creates a way for them to express their level of satisfaction with the provided service. In return, by knowing QoE evaluations, network developers are able to manage their resources with more efficiency and accuracy, to match user needs [7, 8].

In recent years, most studies on networking have been devoted to the software-defined network (SDN) [9], a new network paradigm, came from the campus and enterprise network environments with the invention of the Openflow concept [10]. The main achievements of SDN include the separation of the control data plane, and a programmable network. SDN facilitates network configuration and management by pushing all control tasks to a centralized controller. In SDN, the control plane is separated from network hardware, which enables dynamic control and the ability to allocate resources at any given moment to best effect [11]. Moreover, SDN speeds the deployment of new innovations or services and reduces operational costs through programmable interfaces (e.g., Openflow [12], ForCES [13], and PCEP [14]) in the controller. Therefore, with the development of SDN, there is a need for mechanisms that can be implemented and used in these networks. In this study, we use SDN such that the controller is connected to the client-side video streaming application and to the Openflow switches, so the controller can perform resource allocation based on the QoE-state parameters of the clients.

The main purpose of this paper is to present an appropriate SDN approach for resource management to improve QoE. We consider management of resources and their improved usage. Thus, a learning-based decision-making algorithm is proposed, which improves resource management and QoE. In the proposed model, control features of SDN are used to obtain several QoS parameters including bandwidth, jitter, and packet loss. Using network-level information in combination with the feedback from measuring QoE on the user-side, fuzzy decision-making algorithms [15] are utilized to manage resources more accurately. The algorithm in this paper is a Weighted Fuzzy Petri Net (WFPN) [16], which is an extension of Fuzzy sets, possessing a new additional attribute function i.e. non membership. The intuitionist index takes into account a stronger expression ability to allow inferences to be made on the knowledge base using FPN inference algorithms, even on imprecise information.

The remainder of the paper is organized as follows. Section 2 highlights the related work followed by Section 3, which provides the details of the policy in the WFPN algorithm. In Section 4 we describe the simulation setup and provide analysis of the numerical results. We finally present conclusions and specify future work in Section 5.

2. Research Background

SDN presents such architecture to overcome the current problems caused by complex protocols and extensive use of equipment [17]. But most SDN methods take advantage of QoS parameters to improve quality of user experience. However, in many cases, variations in these parameters will not significantly impact quality and leads to loss of resources. In the remainder of this section, some of the most important attempts to improve QoE in the context of SDN are reviewed.

In [18], perceived QoE for home users of optic fiber services is improved by allocating appropriate bandwidth. The paper aims to present an appropriate SDN architecture for allocation of bandwidth and access to sweet points for improving QoE. Minimal and maximal bandwidths are determined using two methods as follows:

- Broadband Remote Access Server (BRAS) allocates the necessary bandwidth to an application by imposing restrictions on others. This is an indirect method.
- Based on the available bandwidth, BRAS assigns the highest priority to a particular application i.e. it controls and restricts the maximum bandwidth necessary for each application.

This approach allows resources, especially the bandwidth allocated to an application, to be controlled through the minimum and maximum bandwidth required for each application. As a result, QoE for users can be improved. However, as the number of users and requests increases several issues arise.

An investigation of QoE based on path optimization for multimedia services using SDN is presented in [19]. Since most streams toward a destination travel the same path, it is possible to exploit resources and impact QoE. Thus, the paper uses a Q-POINT model to optimize paths and improve perceived QoE by selecting the best path. Furthermore, a linear combinatory mathematical model is presented which creates a mapping between QoS and QoE parameters to determine the best path and improve end-user satisfaction.

[20] Studies video streams and aims to design an SDN application for monitoring network conditions and dynamically choosing paths using MPLS. In this mechanism, during congestion, the optimal paths are changed dynamically, to avoid congested paths for transmitting user data.

Many users often request the same data; thus, in order to prevent the creation of multiple similar streams, [21] proposes a caching mechanism, to improve adjustability, efficiency, and transparency of transmissions. Also, this architecture reduces response time for repetitive requests and ultimately improves QoE. However, the placement of the caching node in the network is critical in this approach as inappropriate placement may result in data inconsistency and system management issues. Furthermore, the paper fails to discuss data types in terms cache ability, in full detail.

[22] Takes advantage of SDN features to optimize video quality over HTTP. In addition to enhancing extendibility and network awareness, SDN optimizes and adjusts the network in the control layer. Therefore, the operation decreases path length and processing time, ultimately leading to adequate video quality. Interestingly, SDN does not intervene in policies regarding the transmission of video and special-purpose data by default. Note that, by default, SDN is not involved in the policy used for the transmission of video and special-purpose data. Therefore it cannot be sufficient for improving QoE.

A policy-based QoE-aware content delivery mechanism is proposed in [23], which is based on the Q-learning algorithm. It uses optimal transmission parameters to deliver in-use content. Analysis of the algorithm reveals that, compared to TCP content delivery, packet loss in buffer is reduced. Moreover, the Q-learning algorithm achieves good optimization for services and data flows of each type of data. However, the mechanism is only implemented in the application layer, which restricts its applicability. Under circumstances with scarce resources (e.g. low bandwidth) a scheduling algorithm cannot be very effective in improving QoE.

Due to the unprecedented growth of video traffic and the increasing demand for bandwidth in fiber optic networks, it is critical to solve the issue of competition over bandwidth. In order to tackle this problem, [24] proposes an Application-aware software-defined Passive Optical Network (EPON) architecture. In this approach, to achieve a better client-and service-level differentiation, application-level feedback from the client side (for video users) to the network is used. The authors apply application-aware SDN-Enabled resource allocation (AASRA) to manage bandwidth or network resources. Optical line terminal (OLT) is responsible for scheduling packet queues according to the weights (i.e. significance of each packet in the queue) and queue length. OLT is able to communicate with SDN controller, once QoE for a user decreases to adjust the weights in an attempt to improve QoE. However, as the number of users and consequently the number of requests grow, the controller is faced with more efficiency drops.

Video based applications have strict requirements such as high bandwidth, low delay, and relatively low packet loss. Therefore, [25] uses Edge as a Service (EASS) as an appropriate approach to improve quality. In order to manage resources and increase efficiency, this approach takes advantage of network virtualization and SDN. The paper proposes a framework for managing Virtual Network Resources (VNR), based on the characteristics of multimedia applications and network requirements. Furthermore, a study is conducted to use the relationship between QoE and availability of VNR as a basic mechanism in resource allocation. Thus, in order to deal with different traffic demands in different applications, the paper presents the Multimedia-aware virtual resource management (MAREM) framework, which employs VNR to adjust available resources according to the characteristics of the applications. However, since the approach uses only VNR virtualization for resource management and QoE is measured in virtual switches, achieving efficiency with increased number of users and network complexity appears to be a formidable task.

To the best of our knowledge, none of the previous works aimed to present an appropriate decision-making method for resource management and QoE improvement based on the requirements of applications and users. In this paper, we use the WFPN decision-making algorithm to improve allocation efficiency and users' QoE provisioning.

3. WFPN-Based Decision-Making Algorithm

3.1 Weighted Fuzzy Petri Net

A Petri net, also known as a place/transition net, is a mathematical method for the description and analysis of systems. It is a directed bipartite graph whose nods and edges are called places and transitions, respectively. In each transition, the connection from one or more places to other places is described under a transition policy. The lifecycle of a Petri net begins when a number of tokens enter one or several nods to enable them. Once all input nods of a transition are enabled, the transition policy is fired and the tokens are transferred to the destination of the policy [15].

Regular Petri nets cannot be used to represent fuzzy information. With the combination of Petri nets and fuzzy logic, different types of Fuzzy Petri Nets (FPN) are created to represent and infer fuzzy knowledge [16, 26]. A classification of various FPNs and their applications is presented in [27]. In basic FPNs, the Boolean tokens are replaced with fuzzy values and each policy is associated with a Certainty Factor (CF), which represents the probability of transition.

Fuzzy decision-making systems constitute major applications of FPNs [15]. FPNs can be used for both modeling the knowledge base using fuzzy rules and making inferences on the knowledge base. FPN inference algorithms are employed as fuzzy inference engines in fuzzy expert systems which allow us to work with imprecise information. Weighted FPNs offer good decision-making capabilities and enable modeling and inference on a weighted fuzzy rules-base. A weighted fuzzy rule can be expressed in the following form [28]:

$$if\ P_{11}(\lambda_1)\ and\ P_{12}(\lambda_2)\ and \ldots then_\tau =_t\ P_{o1}(\mu_1) P_{o2}(\mu_2) \ldots \tag{1}$$

Where P_{ij} represents primary bearers and λ_i is the importance of each predicate. Similarly, μ_j indicates the CF value in the transition to the j^{th} proposition. In this rule τ denotes the firing threshold or Fuzzy truth value of the rule. Therefore, in WPPN, in addition to a degree of confidence, the rules have firing thresholds. Furthermore, the fuzzy tokens are transferred in a weighted manner i.e. the fuzzy value of each input token has a certain weight in the generation of new tokens (in destination nodes) [15]. In order to select the best method for generating improvements or managing resources, WFPN is used with the following distinct features:

1. Decision parameters used in selecting the best method and the significance of each one.
2. Preferences in the form of the importance of decision parameter.
3. A list of switches, the available states, and parameter values.

These features are consistent with the structure of a weighted fuzzy rule. Here, the decision parameters and the extent to which a program needs each, form the primary bearers of the rule. The priority of the parameters determines the weights of primary bearers. The set of switches and candidate operations create the obverses of the rules, for each of which the CF is based on the initial parameters. The objective of inference on a WFPN composed of a number of such rules is to obtain fuzzy values expressing the score of each method and the transition from one state to another for selection. The policy of the proposed decision-making model can be defined as the following tuple [28]:

$$\{FC\}, <P,LL,HL>, <P,W>, <PS,SW>, T_L,\ T_H \tag{2}$$

Where FC represents a set of conditions for constraining the policy to special situations; $<P, LL, HL>$ denotes a vector of upper (HL) and lower thresholds for a number of parameters; $<P,W>$ is a vector of parameter-value pairs presenting the weights of the considered context parameters in the policy; $<PS, PW>$ represents a vector of candidate state identifiers along with the ability of each one to satisfy requirements; and finally, T_L and T_H are thresholds which determine, according to the certainty of input requirements, when the rule based on this policy is fired.

The $\{FC\}$ section is intended to select appropriate policies upon decision request for improving or managing resources. In other words, according to this field, the appropriate policy for each request is selected from the policy repository. Each improvement or resource management request contains several parameters that determine the decision-making context and can be used to choose the best policy accordingly. {FC} may include the following:

1. Service type, equipment, and user mental characteristics, which are used to determine the appropriate policy.
2. Current state of services: in order to assign an appropriate policy to each user.
3. Network and equipment type: This information is used in cases when the user requests quality improvement or resources are wasted so that a new policy can be selected.

It can be argued that, in order to select a policy, not all the above items are needed. Furthermore, with fewer items to consider, the policy can have a more significant impact on decision-making.

Each $<P,LL,HL>$ vector specifies the possible range of each decision-making parameter (P).For instance, in a multimedia traffic policy, delay can be expressed as $<Delay\,,\ 1ms,\ 5ms>$. In other words, the traffic must not be delayed longer that 5ms but it is not sensitive to delays of shorter than 1ms. Thus, network resources must be managed accordingly. The vector is used to fuzzy values of the decision parameters (WFPN inputs) for user requests. The range is also used to filter possible solutions based on available capabilities.

3.2 Policy Based Evaluation

In this subsection, the decision-making part of the mechanism, which is responsible for assessing the requests from the QoE measurement unit and the SDN controller, is explained. Upon receiving a request for improving QoE or managing requests, the following steps are taken:

1. Policy selection: As soon as a request is received, policies are filtered according to request specifications. Request specifications include user identifier, service type, and network status.
2. WFPN construction: Each selected policy in the previous step expresses one of the weighted fuzzy rules, which are combined to form a WFPN. Note that the policies include the common parameters; however, the certainty of each parameter, in the input generation stage (fuzzy state), is dependent on its defined range. Therefore, different places are required in the WFPN.
3. Input application: In this step, the extent to which each QoE improvement or resource management request requires each decision parameter is given as a fuzzy input (a number between 0 and 1) to the WFPN inference algorithm. The extent of certainty for each useful parameter, such as bandwidth for which higher values are preferred, is calculated the following Expressions [29]:

$$p_i = \frac{req_i - l_i}{u_i - l_i} \ \ if\ l_i < req_i < u_i$$

$$p_i = 1\ if\ req_i \geq u_i\ \ or\ l_i = u_i \tag{3}$$

$p_i = 0 \; if \; req_i \le l_i$

However, the extent of certainty for cost parameters, such as delay for which lower values are preferred, is calculated the set of equations (4) [29]:

$$p_i = 1 - \frac{req_i - l_i}{u_i - l_i} \; if \; l_i < req_i < u_i$$

$$p_i = 1 \; if \; req_i \le l_i \; or \, l_i = u_i \qquad (4)$$

$$p_i = 0 \; if \; req_i \ge u_i$$

Where req_i denotes the extent of the action to be taken (a non-fuzzy value). Furthermore, l_i and u_i represent the lower and upper bounds, respectively. Finally, p_i shows the fuzzy value of the requirement.

4. Generation the output: Following the application of fuzzy inputs to the constructed WFPN, the output of the inference algorithm specifies fuzzy values for certainty of selecting each alternative. The values demonstrate the benefit of executing each choice. Once calculated, they are transmitted to the SDN controller so that the final commands can be issued at the network level.

4. Evaluation

In this section, simulations and numerical analyses are used to evaluate the proposed method and compare it to similar algorithms in the literature. All simulations are conducted using the NS3 Simulator. Therefore, different capabilities of the proposed method are compared to similar works in subsection as below.

4.1 Simulation Scenario

The objective of simulation is to evaluate the ability of the WFPN decision-making algorithm in preventing loss of QoE and network resources (leading to reduced costs and increased network efficiency) by taking data streams and network parameters into account. The simulation includes a set of video streams along with some streams of data such as FTP, email, and database. The simulated environment is shown in Figure 1. The simulated environment has servers and clients receiving various services such as Email, FTP, Video, and Database (DB). The servers and the clients are connected through the Internet, which transfers a multitude of packets between different servers and clients. The network also includes Openflow switches connected through 10Mbps links. By increasing the Email, FTP, and DB traffic, the overall traffic of the network is multiplied so that the links become busy. Additionally, an SDN controller is included in the scenario, which is directly connected to the clients (for whom QoE is calculated) and the Openflow switches to send the necessary commands.

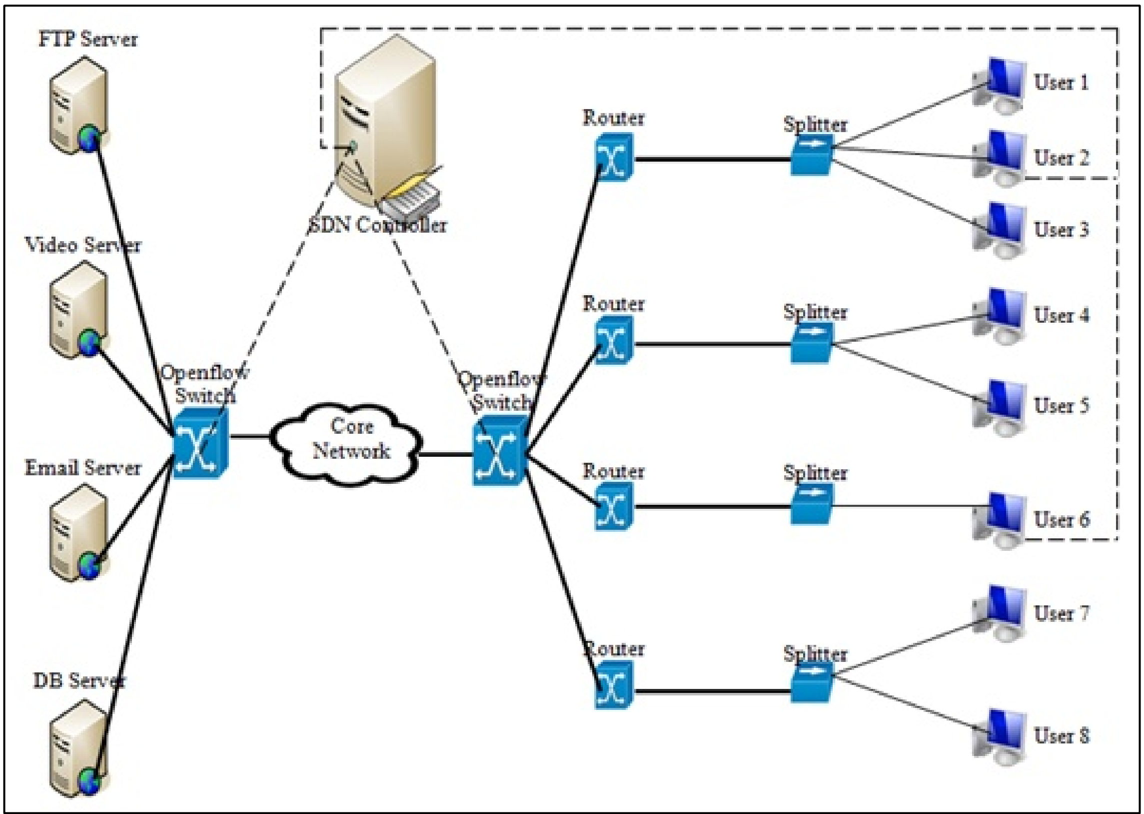

Figure 1. Simulation scenario [25]

The WFPN algorithm employs the functions discussed in Subsection 3.2. It is compared to the MAREM resource allocation method [25]. Two aspects are highlighted in simulation: 1) the quality received by the user (i.e. QoE) and 2) loss of resources. In the simulation, the video receivers are the main clients whose QoE is measured and improved. The QoE measurement unit aims to use an objective method to transmit Peak Signal-to-Noise Ratio (PSNR) [30] value to the controller so that resource management and user satisfaction can be improved. Although the measurements are neither perfect nor sufficient for real users, the purpose of the simulated scenario is to illustrate the importance of measurements and resource management under different circumstance, in addition to quick decision making upon user request. The clients receive MPEG [31] video streams and relay their requests through Openflow switches to the servers. The specifications of the MPEG videos stream are shown in Table 1. Parameter values for other applications in the simulation as well as simulation time can be in Table 2. During the simulation, different video streams with different frame counts are sent to the clients. PSNR is calculated according to [32, 33]. To obtain comparison values, minimal and maximal PSNR values are set to 34dB and 38dB respectively. The value of PSNR is measured for the user receiving the video stream. If the measured value is smaller than 34dB, then the received video does not have adequate quality. This means that the decision-making algorithm must take action to improve the quality. However, a value of greater than the maximum (i.e. 38dB) indicates sufficient quality, yet, resources are likely to be wasted. In this situation, the controller uses the WFPN algorithm to prevent waste of resources.

Table 1. Video database information [25]

Video	Bit rate (Kbps)	Frame Per Second	Resolution
CrowndRun	10900	50	HD 1080p
DanceKiss	10500	50	HD 1080p
ParkJoy	10300	50	HD 1080p
Flagshoot	7700	25	HD 1080p
Libertadores-2012	3000	25	HD 720p
Puskas-2013	2500	30	HD 720p
Fifa-2014	2400	30	HD 720p
Crew	770	30	4CIF
Harbour	710	30	4CIF
Soccer	660	30	4CIF
City	550	30	4CIF
Foreman	150	30	CIF
Paris	120	30	CIF
News	90	30	CIF
Akiyo	70	30	CIF

Table 2. Simulation scenario specifications

Parameters	Simulation Time	FTP Type	Email Traffic Type	Date Base Traffic Type
Value	1200 sec.	High Load	High Load	High Load

4.2 Analysis of the Results

Using SDN and Openflow switches, it is possible to separate traffic flows. Moreover, by applying the WFPN algorithm, network resources can be managed more efficiently and user satisfaction can be improved as well. In order to demonstrate these outcomes, a scenario based on the one in [24] is created to allow numerous video and data streams (Figure 1) to be transferred.

Figure 2 depicts traffic volume during the course of simulation, including the total bit rate for video and other types of data. As shown, the maximum amount of traffic equals 10 Mbps, which indicates the available bandwidth during the experiment.

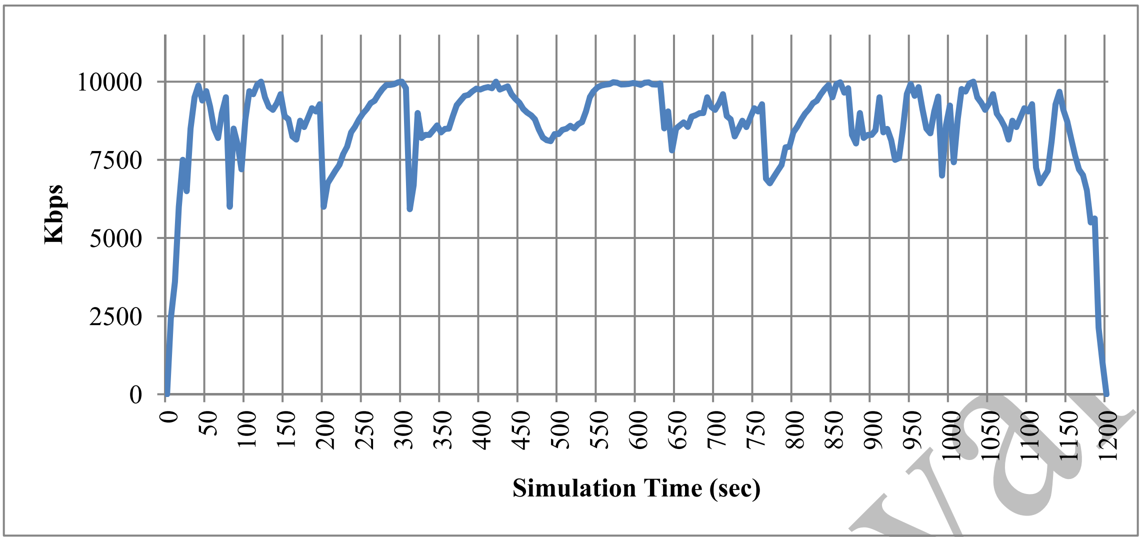

Figure 2. Traffic volume in the experiment

Figure 3 shows PSNR values for the two video streams. PSNR of the proposed method approximately falls between 35 dB and 39 dB. In Table 3, the PSNR values obtained by comparing the original and received video streams are converted to Mean Opinion Score (MOS) (is a measure used in the domain of Quality of Experience, representing overall quality of a stimulus or system) values [34]. According to Table 3, the WFPN algorithm generally provides adequate (31<PSNR<37) and in some cases excellent quality (PSNR>37) [32]. MOS values for the received videos can be seen in Figure 4 As evident, the values are always superior in comparison to MAREM. However, in the other method, the decrease in the PSNR level persists for a long time.

Table 3. Convert PSNR to MOS [32]

PSNR [dB]	MOS
>37	(Excellent) 5
31 - 37	(Good) 4
25 - 31	(Fair) 3
20 - 25	(Poor) 2
<20	(Bad) 1

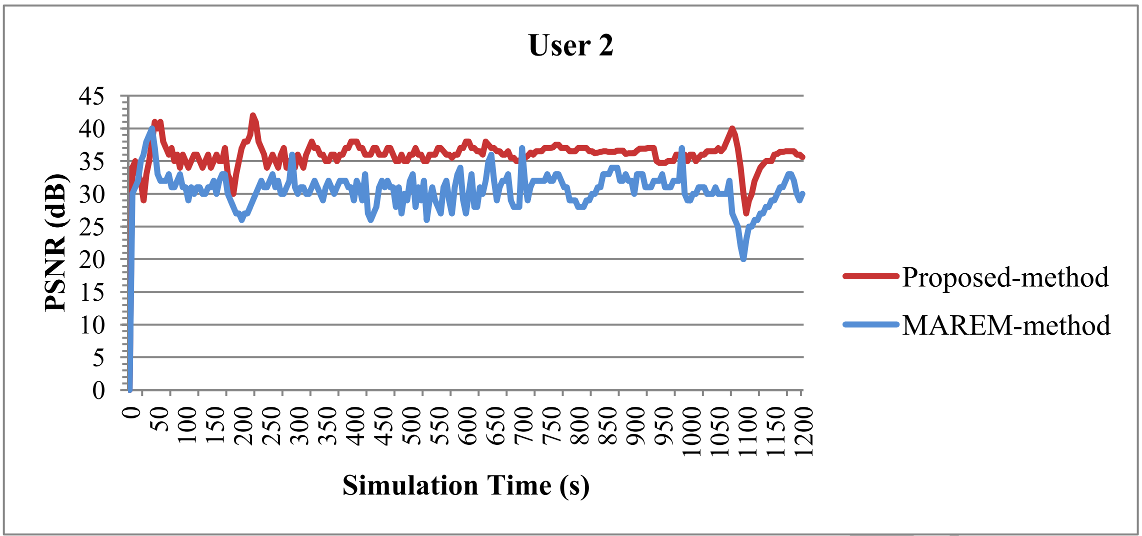

Figure 3(a). Comparison of PSNR levels of received videos on two methods for user 2

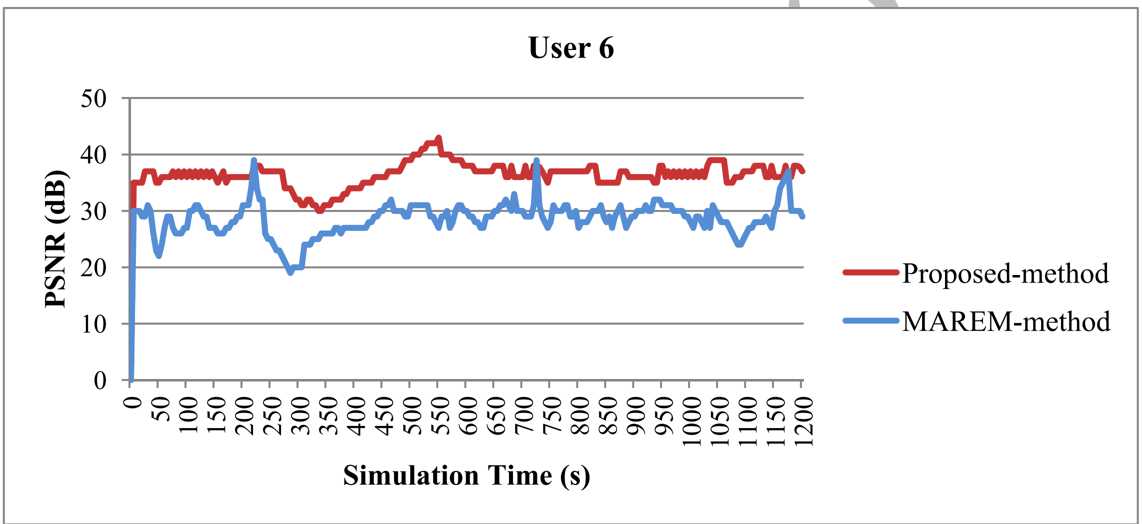

Figure 3(b). Comparison of PSNR levels of received videos based on two methods for user 6

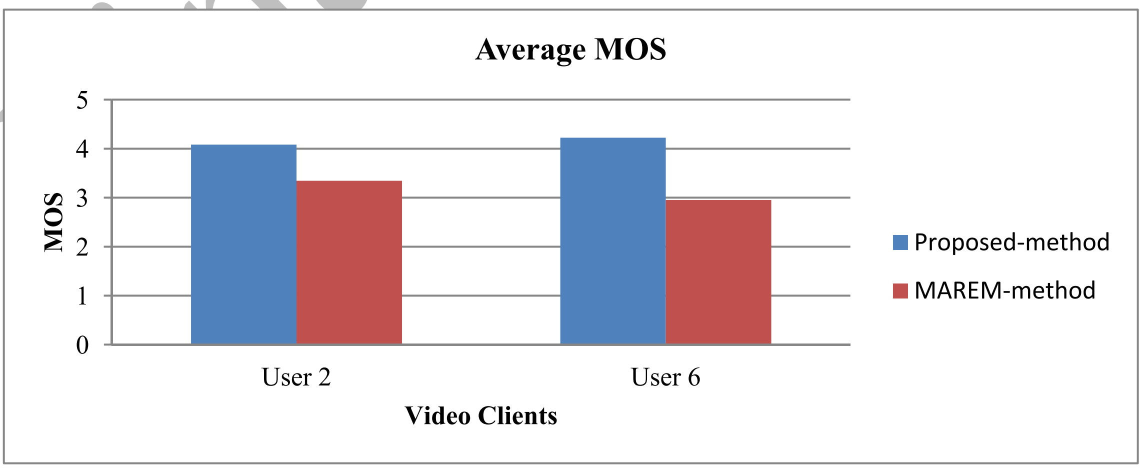

Figure 4. MOS results

Comparisons regarding resource management are carried out using measurements of delay, jitter, and throughput. As shown in Figure 5, average delay values of the proposed method for different users are smaller to those of MAREM. However, the difference is not significant in many cases. Since network and stream parameters remain constant for both methods, the differences in delay values can be attributed to the way network resources are managed and allocated. In comparison, the proposed method provides superior performance.

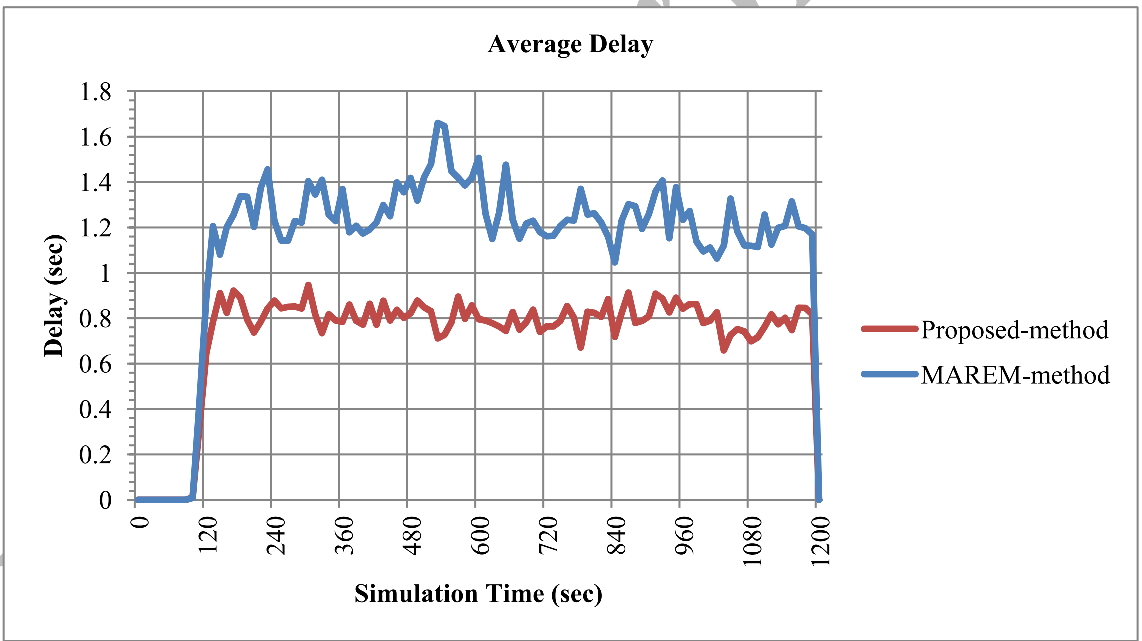

Figure 5. Comparison of delay

A comparison of jitter for the two methods can be seen in Figure 6. According to the diagram, the MAREM method experiences more significant delay variations, although this is also true for the proposed algorithm at some times. Higher jitter in packet transmission can be translated to lack of proper resource management in the network, particularly in the SDN controller. Delay variations are caused when the packets are routed, processed, and prioritized regardless of previous and future information, and it is calculated based on sending and receiving time stamps of consecutive packets sent out.

However, as the proposed algorithm employs WFPN decision-making to manage resource at the network layer, the experience jitter remains minimal, which is indicative of proper resource allocation to different services according to priority, importance, and QoE. Since our proposed SDN controller shares the load among network paths, it tends to decrease traffic congestion, which consequently leads to a reduction in delay and jitter. Second, we propose WFPN decision-making algorithm that optimizes the distribution of flows among the various redundant paths inside the network to reduce the delay and jitter experienced by users.

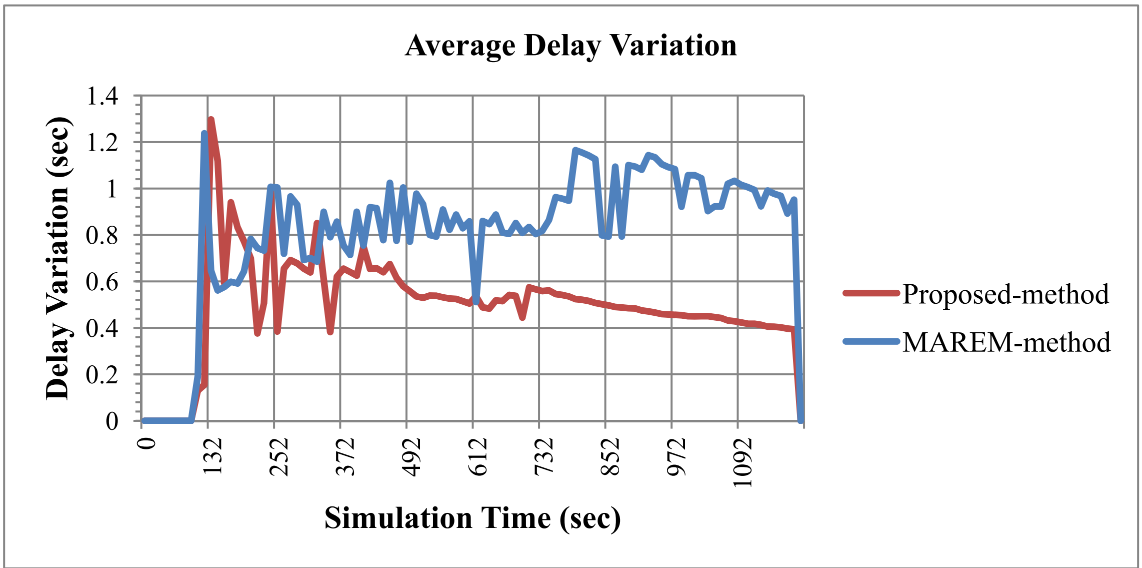

Figure 6. Comparison of jitter values

Finally, the efficiency of the methods with regard to the number of fulfilled user requests is compared in Figure 7. Throughput values for both algorithms are shown in this figure. Since network parameters remained unchanged, the obtained improvement can be attributed to the only variation between the scenarios i.e. resource allocation and management mechanism. The proposed method offers superior performance in assigning resources to flows.

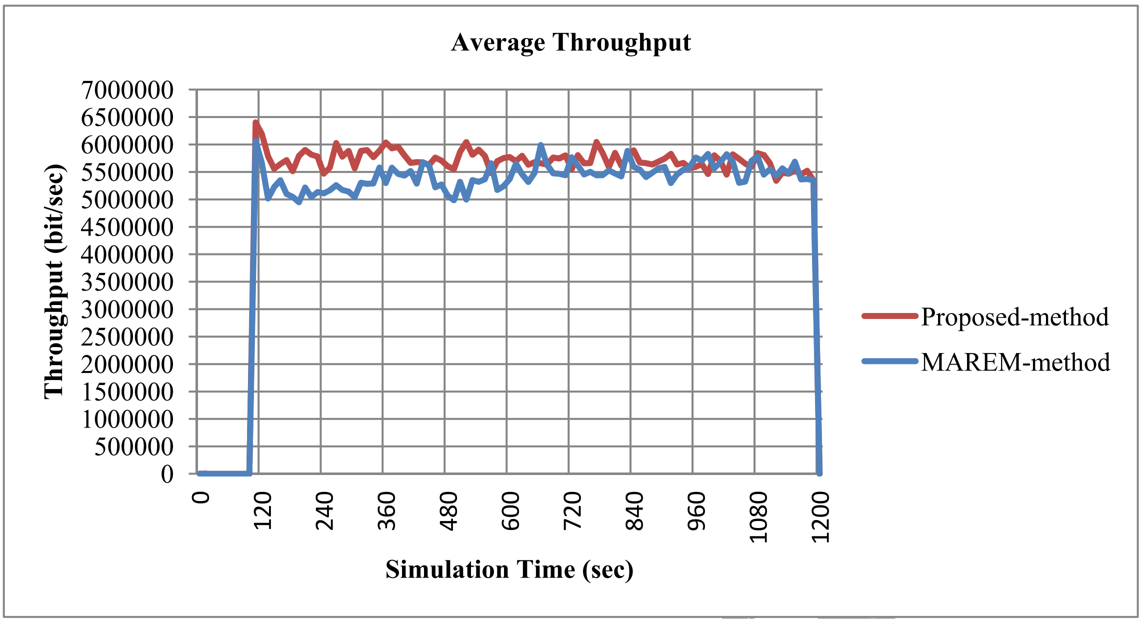

Figure 7. Comparison of throughput values

According to the simulations, the WFPN algorithm outperforms MAREM in terms of efficiency because it prevents loss of QoE and waste of resources. Thus, the proposed method leads to improved user satisfaction (alternatively QoE) while preventing waste of network resources.

5. Conclusion

In this paper, a learning and policy-based decision-making algorithm was proposed where its objective was to improve resource management of multimedia traffic in SDN for QoE enhancement. The proposed method used QoS parameters, output traffic flows, PSNR values, and user equipment specifications to improve user satisfaction. The algorithm, which takes advantage of client-side PSNR measurements, uses a fuzzy WFPN decision-making algorithm to determine network parameters and allocate resources to a user. A typical scenario, with video as source traffic, was simulated which demonstrated the efficiency of the proposed method compared to a conventional method. The method was analyzed in terms of parameters such as client-side QoE (measured through PSNR), delay, jitter, and throughput. The results showed overall improvements in the network.

The proposed method can be employed as an intelligent mechanism to improve QoE as the number of users increase. The application of the proposed method for further improvement of QoE in more complex scenarios, where mental and psychological states are also considered, is suggested for future studies.

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