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A Fuzzy-Based Dynamic Bandwidth Allocation Approach for Campus Area Networks

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***Abstract* - A robust campus area network (CAN) with excellent connectivity to the internet is no longer a luxury to the educational institutions since the internet plays a vital role in education. With that, proper bandwidth allocation is needed so that the internet will be utilized for educational purposes. This study proposes a fuzzy based dynamic bandwidth allocation approach which can be used in CAN. The Mamdani fuzzy inference system was utilized along with the enhanced web usage mining (WUM) algorithm to achieve the proposed method. The improved WUM was employed to the weblog, captive portal log, and Shallalist file of the proxy server to identify the network users and the websites they accessed together with the website categories. Whereas the Mamdani FIS was used to decide the bandwidth that will be allocated to the users based on the rules provided. A prototype was developed and installed in a pfSense proxy server. The prototype was tested with several users connected to the proxy. The results showed that the prototype could dynamically allocate bandwidth to the computers and the bandwidth is based on the given rules. Further, this method is vital to the network administrators since the setting of the bandwidth can be done automatically.**

Index Terms – Bandwidth Control, Mamdani Fuzzy Inference System, pfSense, Shallalist, Web Usage Mining.

I. INTRODUCTION

As the technology evolves rapidly many applications have been created and developed which mostly require high bandwidth and low latency to maintain a reasonable quality of experiences (QoE) [1]. Because of that, bandwidth becomes one of the essential factors that is considered in many companies, organizations, and even educational institutions [2], [3] to come up with better user experience on web services [4]. However, upgrading the network bandwidth provides an extra cost or budget since it is expensive most especially for leased lines. In campus area networks (CAN), many researchers and experts which include IT managers designed and implemented some strategies to maximize the use of the existing bandwidth such as scheduling [5], and event-driven network control framework based on software-defined network (SDN) [6]. Also, a channel allocation mechanism [7], installation of squidGuard in many open-source firewall systems [8], and implementation of adaptive bandwidth management that can manipulate captive portal bandwidth settings [2] were employed in the CAN.

With all of these mentioned techniques in managing the bandwidth in the CAN, the challenge remains since it is a complex and evolving concern for most network operators around the globe [9]. Even the best network policy in network utilization has no value unless it is communicated and enforced which is also a very challenging task [10]. One of the concerns in many CANs is the utilization of the internet in educational purposes [2] since it was found out that most of the users misuse the bandwidth on low-priority, bandwidth-hungry websites, and applications such as pornographic and other useless websites and peer-to-peer applications [8], [11].

With that, this study aims to provide a dynamic bandwidth control in CAN which goal is to prioritize the setting of higher bandwidth to the users who utilize the internet for educational purposes while allocating a medium or low bandwidth to those who are not. The assigning of bandwidth can be done automatically as well. Also, the proposed approach can be implemented in many open-source firewalls which support the captive portal and RADIUS authentication protocol.

This study utilized web usage mining (WUM) which is an application of data processing techniques that discover usage patterns of users from the weblogs [12]. These weblogs contain possible information from the networks which can be used to determine usage patterns [13]. However, WUM has a problem in identifying the appropriate users to each record on the weblog [13]. Due to WUM's limitation, this study modified WUM's algorithm which will consider the utilization of Shallalist file and captive portal logs. The Shallalist file contains a collection of Uniform Resource Locators (URLs) and internet domains used by many internet filtering programs, and usually, URLs are categorized based on education, dating, finance, etc. [14], [15]. The captive portal log has records of all the users who log in or out from the network. The users need to enter their username and password before they can get access to the internet or CAN [16]. Usually, this authentication process is done through RADIUS protocol, and a database is needed for the authentication and the saving of each record every time a user tries to connect/disconnect to/from the network [11], [17].

Further, rules were set which will be the bases of the fuzzy inference system for allocating the bandwidth of each user. The Mamdani fuzzy inference system was employed in the study because it is perfect for the representation of human reasoning and useful analysis [18]. The Mamdani FIS can cope up with the vagueness that is existed in the web usage patterns of the network users. Fuzzy sets and fuzzy logic are powerful mathematical tools to model uncertain systems. Fuzzy models

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facilitate decision making by employing approximate reasoning and linguistic terms. Thus, it plays an important role when applied to complex phenomena not easily described by traditional mathematics [19]–[21].

The highlights of the study are the enhancement of the WUM algorithm that supports Shallalist file and captive portal logs which will be used in identifying the websites accessed by the users and the corresponding categories, the setting of rules for the fuzzy dynamic bandwidth allocation model, and the development and implementation of the prototype on top of the firewall's captive portal.

II. LITERATURE REVIEW

A. Bandwidth Allocation Approaches in Campus Area Networks (CAN)

Since managing the bandwidth in multi-service networks such as CAN remains a challenge and distributing it in an efficient and fair manner is a significant factor to be considered, many experts already came up with some solutions. One such solution is Procera [6] which is based on a software-defined network (SDN) and applied in VLANs. However, some schools do not implement VLANs, and Procera suffers from the inherent delay. Alam et al. [7] proposed the scheduling, and channel allocation mechanisms which give priority to delay sensitive real-time traffic flows and allocate channel dynamically.

Noughabi et al. [3] employed clustering and classification in allocating bandwidth based on priority. Its concept is to predict the behavioral patterns of the students. However, it still needs to be implemented.

Further, [2] developed a prototype which can dynamically set the bandwidth of the users based on their web usage patterns. However, it cannot deal with users' web usage pattern uncertainties. Also, [11] proposed a bandwidth allocation mechanism which classifies the users that are inclined to accessing more on educational websites and those who are not. The idea is those users who utilize the internet for educational purposes will be allocated with a higher bandwidth. The study of [11] is the same as [2] and the concept of this study. However, this study is more concern about dealing with uncertainties in bandwidth allocation.

B. Mamdani Fuzzy Inference Systems

The main idea of the Mamdani method is to describe process states using linguistic variables and to use these variables as inputs to control rules; the rules connect the input variables with the output variables and are based on the fuzzy state description that is obtained by the definition of the linguistic variables [22]. Its components are fuzzification, knowledge base with its inference system and defuzzification [21], [22]. Hence the Mamdani FIS is suitable in dealing with uncertainties, especially in decision support systems.

C. Web Usage Mining (WUM)

Web usage mining uses data mining process for the research of the usage pattern from data fetched from the web log files [23]. It applies to many real-world scenarios for discovering new user navigation method for updating of website design by composing additional theme or recommendations observing user or customer behavior [24]. However, its existing algorithm cannot identify the website category and the correct user who request for a particular website that is saved in the weblog. That is why in this study, the current algorithm was modified so that it overcomes those mentioned problems. The enhanced WUM algorithm can support the utilization of the Shallalist file and captive portal log to determine the website categories and the respective users appropriately.

III. METHODOLOGY

In this study, a prototype was developed using PHP and implemented in a pfSense proxy server which supports captive portal and RADIUS authentication protocol. The PC where the pfSense software was installed and the prototype was run has a processor of Intel® Core i7, 8GB RAM, and 3.6GHz speed. The prototype was tested by 20 concurrent users who were connected to the proxy server. The proxy server has a weblog, Shallalist file, and captive portal logs. Table 1 shows the attributes of a weblog.

TABLE I
ATTRIBUTES OF A WEBLOG

Attribute	Description
Timestamp	Date and time when the user requested to access specific URL or website
Client IP	IP address of the user's device
Client-server methods	Method or model of a request can be GET, POST, or HEAD
Client-server URL stream	Targeted default web page or domain that is accessed by the user.
Server IP	IP address of the web server
Server client status	Status code returned by server link
MIME	The standard way of classifying file types such as images, HTML, javascript, etc.

Figures 1 and 2 present the RADIUS database entity-relationship diagram and parts of the contents of a Shallalist file respectively.

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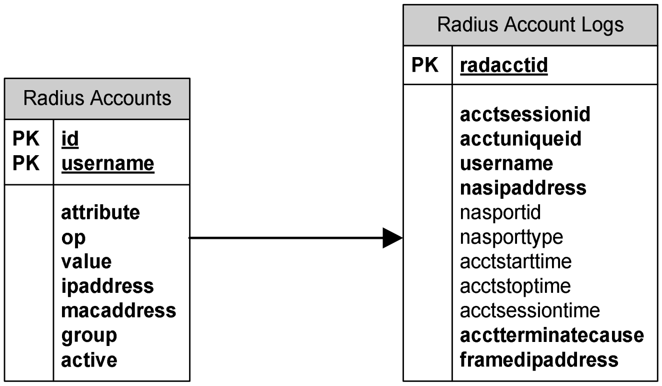

Fig. 1 RADIUS Entity-Relationship diagram.

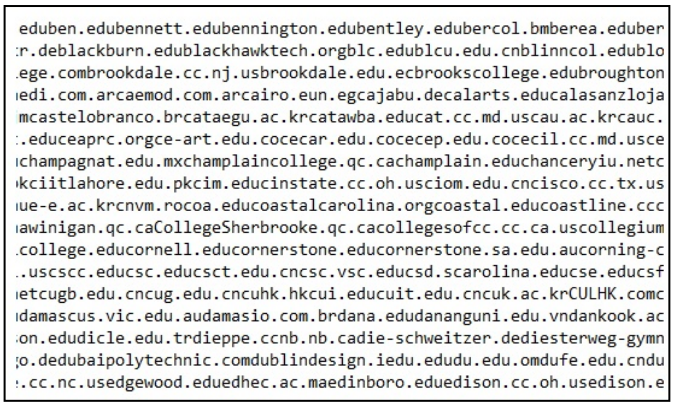

Fig. 2 Parts of Shallalist file content.

Figure 3 shows the architectural design of the study which composed of the clients, weblog, Shallalist file, dynamic bandwidth allocation controller, and the internet.

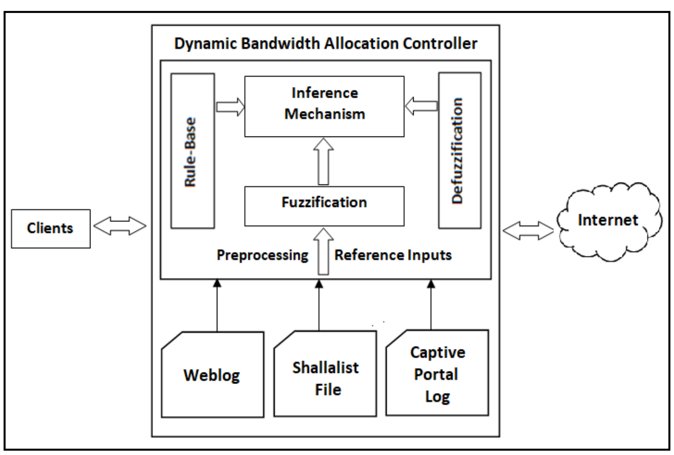

Fig. 3 The architectural design of the study.

A. Preprocessing

Before a user will be allocated with bandwidth, the weblog will undergo preprocessing where all the unnecessary records will be removed. This stage also involves the Shallalist file for the identification of the website category and the captive portal for determining the correct user who accesses each website saved in the weblog. Table 2 shows the enhanced web usage mining (WUM) algorithm for the preprocessing.

TABLE II
PREPROCESSING ALGORITHM

Algorithm**: Preprocessing Algorithm**

```
1.  Read log entry from weblog file
2.  if(weblog.mime="text/html" AND weblog.status=200 AND
    weblog.method="GET") {
3.  site=GetDomain(weblog.URL);
4.  user=GetUserAccountInCaptivePortal(weblog.IPAdd,
        weblog.TStamp);
5.  if(IsNewLogin(user, weblog.TStamp)=true) {
6.      if(GetSiteCategoryInShallalist(site)="Education") {
7.          num_educ=GetNumEduc(user)+1;
8.      }
9.      total_sites++;
10.     }
11.     UpdateSitesAccessed(user);
12. }
13. Repeat 1 and 2 until EOF encountered
14. Generalize all the users with respect to their number of
    educational and noneducational sites.
15. End the process
```

B. Dynamic Bandwidth Allocation Controller

The study used the Mamdani-style inference model for the process states mainly in the decision making about the allocation of the bandwidth to the individual user. Tables 3 and 4 present the fuzzy inference system input variables which are the number of educational websites and entire websites accessed by the users respectively. Table 5 shows the FIS output variable which is the bandwidth to be allocated to each user. Figures 4, 5, and 6 present the corresponding graphs of the FIS variables. The expert in network management provides these linguistic variables and degrees of membership.

TABLE IIIII
FIS INPUT VARIABLE: EDUCATIONAL WEBSITES

Membership Function	The Range of the Number of Educational Websites Accessed by the User
Low	0 – 3
Medium	2 – 5
High	3 – 15

TABLE IVV
FIS INPUT VARIABLE: TOTAL WEBSITES ACCESSED

Membership Function	The Range of the Total Number of Websites Accessed by the User
Low	0 – 4
Medium	3 – 7
High	6 – 15

TABLE V
FIS OUTPUT VARIABLE: BANDWIDTH ALLOCATION

Membership Function	Range of the bandwidth to be allocated to a user (Kbps)
Low	0 – 512
Medium	256 – 768
High	512 – 1024

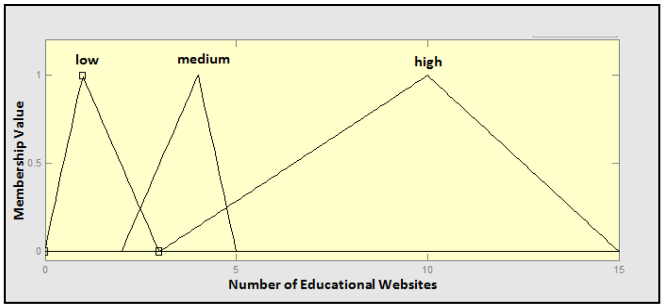

Fig. 4 Membership function for the number of educational websites

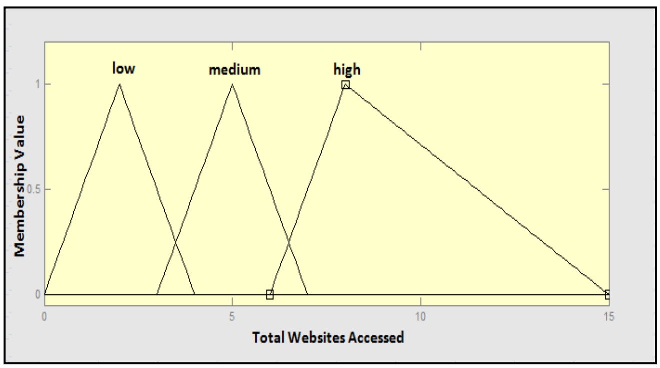

Fig. 5 Membership function for the total websites accessed

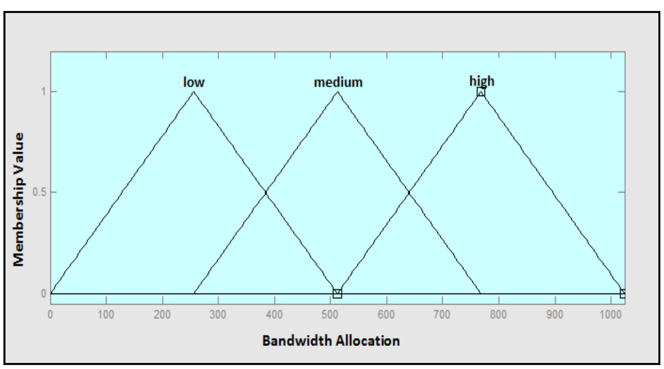

Fig. 6 Membership function for the bandwidth allocation

Along with the linguistic variables are the rules. Rules are necessary to connect the linguistic variables to come up with the specific bandwidth allocation for each user. The expert or the network administrator also give the rules. Table 6 presents the rules. To visualize further, figure 7 depicts the fuzzy inference system of the study.

TABLE VI
RULES FOR THE BANDWIDTH ALLOCATION

No. of Educational Websites being Accessed	Total Websites being Accessed by the User	Bandwidth
Low	Low	High
Low	Medium	Low
Low	High	Low
Medium	Low	High
Medium	Medium	Medium
Medium	High	Medium
High	Low	High
High	Medium	Medium
High	High	Medium

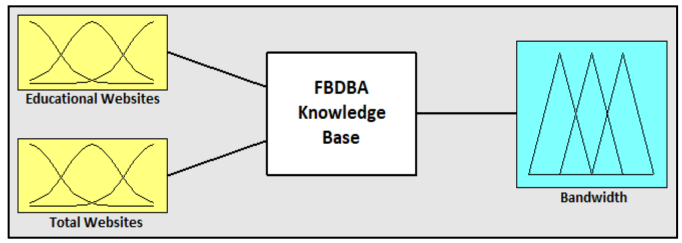

Fig. 7 The general structure of the fuzzy model for the fuzzy-based dynamic bandwidth allocation.

IV. RESULTS AND DISCUSSION

Figure 8 visualizes the three-dimensional mapping from the educational websites and total websites to the bandwidth allocation. It shows the expected bandwidth to be allocated to the users based on what they are browsing. It is noticeable that users may have a typical bandwidth allocation of 512Kbps, and the highest bandwidth that can be set to the user's device is more than 700Kbps.

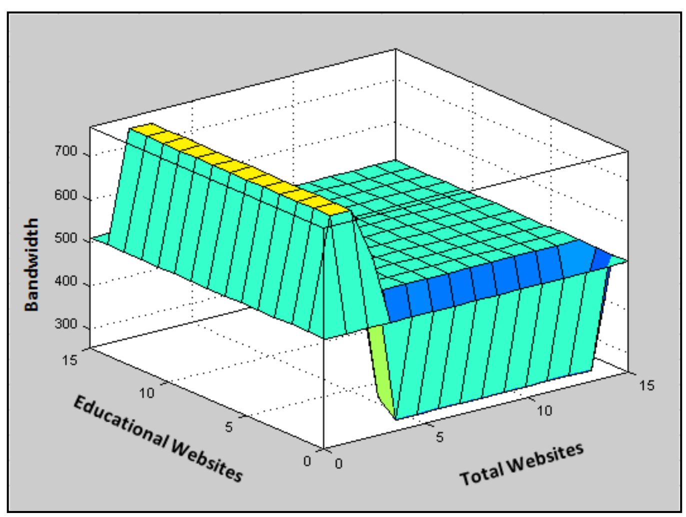

Fig. 8 Three dimensional plot as a reference for the bandwidth allocation.

The user interface of the prototype can be seen in figure 9. The prototype continues to run as a background process and remains to update the bandwidth of the users by modifying the captive portal configuration file of the pfSense software. A waiting time of approximately six seconds is expected before the bandwidth of the computer will be changed. Every time there is a change of bandwidth, the prototype automatically logs the activity.

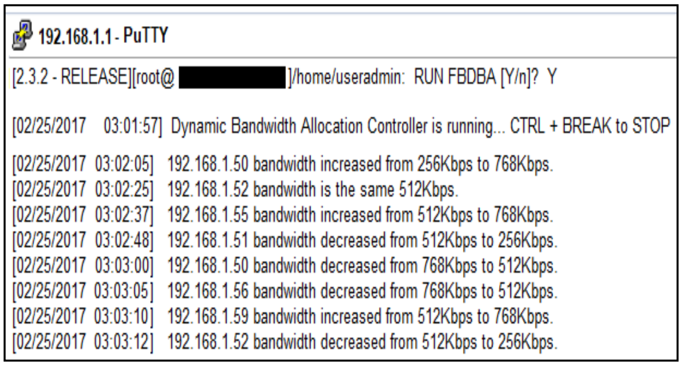

Fig. 9 The user interface of the prototype for the dynamic bandwidth allocation controller.

Table 7 presents some parts of the activities done by the prototype regarding the bandwidth allocation of the users. To test if the bandwidth is already changed, the user of the computer checks his/her bandwidth by browsing the speedtest tool [25]. It is noticeable that the bandwidth obtained from speedtest tool differs a little to the bandwidth assigned by the prototype. The small difference of both bandwidths is insignificant because some factors might affect the transmission to or from the speedtest server [2].

TABLE VII
PARTS OF THE RECORDS FROM THE BANDWIDTH ALLOCATION LOGS

User's IP	Educ. Sites	Total Sites	CBw (Kbps)	BwP (Kbps)	BwS (Kbps)
192.168.1.50	1	2	256	768	761
192.168.1.51	1	8	512	256	232
192.168.1.52	3	4	512	512	499
192.168.1.53	5	15	256	512	505
192.168.1.54	3	10	768	512	520
192.168.1.55	3	3	256	768	766
192.168.1.56	10	15	768	512	526
192.168.1.57	2	8	512	256	270
192.168.1.58	10	10	768	512	507
192.168.1.59	1	1	512	768	771
192.168.1.60	1	7	512	256	286

CBw – Current Bandwidth, BwP – Bandwidth assigned by the Prototyped, BwS – Bandwidth upon checking speedtest tool

V. CONCLUSIONS, LIMITATIONS, AND FUTURE WORK

This study introduced an approach for allocating the bandwidth of the network users using the enhanced web usage mining and Mamdani fuzzy inference system which was applied to the proxy server's weblog, captive portal log, and Shallalist file. This technique can also be implemented in many open-source firewalling systems that support the captive portal and RADIUS authentication protocol. The results obtained from the prototype showed that the proposed mechanism could dynamically allocate bandwidth to the users in the campus area network (CAN) based on the given rules. This proposed method will help the IT managers or those who manage the CAN because the manual way of assigning bandwidth of each user will be eliminated since the proposed technique will automatically do it. Further, results showed that if a user browses more on noneducational websites, his/her computer's bandwidth becomes low.

However, this study has a limitation because the experts provided a maximum of 15 websites in the rules. Therefore, the prototype may not perform or give proper bandwidth value if the total number of sites is more than 15. Because of that, the rules provided in this study should be refined in the future. Furthermore, other techniques can be integrated into the existing method for enhancement purposes.

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