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On the Analysis of Bandwidth Management for Hybrid Load Balancing Scheme in WLANs

Chutima Prommak, and Airisa Jantaweetip

Abstract**—**In wireless networks, bandwidth is scare resource and it is essential to utilize it effectively. This paper analyses effects of using different bandwidth management techniques on the network performances of the Wireless Local Area Networks (WLANs) that use hybrid load balancing scheme. In particular, we study three bandwidth management schemes, namely Complete Sharing (CS), Complete Partitioning (CP), and Partial Sharing (PS). Performances of these schemes are evaluated by simulation experiments in term of percentage of network association blocking. Our results show that the CS scheme can provide relatively low blocking percentage in various network traffic scenarios whereas the PS scheme can enhance quality of services of the multimedia traffic with rather small expenses on the blocking percentage of the best effort traffic.

Keywords**—**Bandwidth management, Load Balancing, WLANs.

I. Introduction

WIRELESS Local Area Networks (WLANs) deployments are experiencing tremendous growth due to inexpensive network equipments and availability of integrated WLAN cards in almost all laptops and handheld computers. It is projected that there will be more than 700 million WLAN users in the world by the end of 2008 [1]. As the number of WLAN users becomes larger, the demand for the network bandwidth usage has increased. However, the bandwidth capacity of each access point (AP) used in WLANs is limited. In order to provide a certain level of Quality of Service (QoS) for different applications in WLANs, efficient load balancing schemes and bandwidth management techniques are required.

Applications used in WLANs include the multimedia/real-time applications (such as Voice-over-IP (VoIP) and video conference) and the best effort services (such as file transfer and email). Such applications require the network to provide a certain QoS level. Measurement studies [2-4] show that in order to provide satisfied services to users, the network must be able to provide an average throughput of 380 Kbps and 100 Kbps for the multimedia applications and the best effort applications, respectively. The IEEE 802.11e Enhanced Distributed Channel Access (EDCA) was proposed to provide priority services for real-time applications such as video and voice but it still cannot provide strict QoS level for the real-time applications due to the limitation of AP capacity [5, 6]. Simulation study and measurement [2-4] show that the maximum capacity of AP, measured in term of the AP's average throughput, is about 60% of the maximum data rate capacity. In particular, the maximum throughput of the WLAN 802.11b and 802.11g is around 6 Mbps and 36 Mbps, respectively. Not only the AP capacity is limited but the average throughput of AP would reduce as the number of users associated to the AP increases [2-4]. For example, the average throughput of 802.11g AP is at 36 Mbps and 24 Mbps when the number of user associates to AP is one and two, respectively. The reason is that the IEEE 802.11 standard specifies a MAC protocol, called Carrier Send Multiple Access/ Collision Avoidance (CSMA/CA), to coordinate transmission of wireless users. This coordination is achieved by means of control information. This information is carried explicitly by control messages traveling in the medium (i.e. ACK messages). Control messages and message retransmission due to collisions consumes medium bandwidth. They are overhead required by the MAC protocol. According to the throughput analysis of the CSMA/CA protocol, the AP throughput varies depending on the number of users connecting with the AP [7]. As the number of users increases, the AP throughput decreases.

Recently research efforts on the load balancing schemes have been carried out to improve QoS in WLANs. [8] presented an algorithm to determine the user-AP associations that provide a max-min fair bandwidth allocation. [9] proposed load balancing schemes that use locations of users and APs to dynamically associate/ disassociate due to load changes. [10] proposed a distributed approach that considered the throughput to determine the load level at an AP. In another association control algorithm, [11] compared average load and handoff transaction of the user terminal and AP. The AP selection policy in [11] considered requirements and also the QoS improvement for each user. The overall target of the paper was to improve the users' experience in 802.11 WLANs, while keeping into account both load balanced a system and effective data rate for high priority traffic.

Although these previous works could distribute traffic load more evenly, they do not consider the consequences of different QoS requirements for different applications. The later work in [12] considered this issue and incorporated it in the load balancing scheme. The authors proposed a hybrid association control scheme of which the selection policy considers QoS requirements of each application and limit the

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load on the AP. Their main objective was to provide high level of QoS to multimedia applications while distributing load evenly among APs in the system.

Even though there have been several efforts on the improvement of the load balancing techniques, literature still lacks work on the AP bandwidth management. Thus, this paper aims at studying bandwidth management techniques for 802.11 APs. In particular, we analyze effects of using different bandwidth management techniques on the network performances of the WLANs that use the hybrid load balancing scheme. Specifically, we study three bandwidth management techniques, namely Complete Sharing (CS), Complete Partitioning (CP), and Partial Sharing (PS).

The rest of this paper is organized as follows. Section II describes three bandwidth management techniques studied in this paper. Section III explains the scenario of network used in the simulation study. Section IV presents numerical results and discussion. We conclude the paper in section V.

II. Bandwidth Management for Hybrid Load Balancing Scheme

To improve WLANs' performance, effective bandwidth management techniques must be used together with the hybrid load balancing scheme. In this section, we present mathematical models describing the operations of the three bandwidth management techniques. Table I. defines notations used in the models.

In [12], the hybrid load balancing scheme considers the priority of applications requesting connections before associating the connections with APs. In addition, it aims to balance load among APs in the system. For multimedia applications which mostly are delay sensitive applications, an incoming session will be associated with AP providing the highest signal strength in order to achieve the highest data rate. For the best effort applications which are not delay sensitive, a connection requests will be distributed to APs in the vicinity to maintain load balance in the system.

TABLE I
NOTATION

Notation	Definition
N_{max}	The maximum number of sessions that can be associated to each AP so that the WLAN can provide appropriate quality of services to the multimedia and best effort sessions
w_i	A weight that is associated with session *i*
s_{ij}	The signal strength that a user requesting session *i* connection receives from AP *j*
s_{th}	The received signal strength threshold
r_{ij}	The data rate that a user requesting session *i* connection can communicate with AP *j*
r_{max}	The maximum data rate that a user can communicate with AP
J	A set of access points (APs) in the system
I	A set of all incoming sessions in the system
I_1	A set of multimedia sessions
I_2	A set of best effort sessions
x_{ij}	A binary {0, 1} variable that equals 1 if the session *i* is associated to AP *j*; 0 otherwise

The hybrid load balancing scheme is written as a linear programming model that aims to maximize the sum of functions f_1 and f_2 where f_1 is a normalized function that measures a data rate level of multimedia sessions and f_2 is a normalized function that measures the number of best effort sessions that can be associated with APs in the system.

$$Maximize \quad f_1 + f_2 \tag{1}$$

where
$$f_1 = \left(\sum_{\substack{j \in J \\ j \neq 0}} \sum_{i \in I_1} \frac{x_{ij} r_{ij}}{r_{\max}} \right) \Big/ |I_1| \tag{2}$$

and
$$f_2 = \left(\sum_{\substack{j \in J \\ j \neq 0}} \sum_{i \in I_2} x_{ij} \right) \Big/ |I_2| \tag{3}$$

Subject to
$$x_{ij}\left(s_{ij} - s_{th}\right) \ \geq \ 0 \qquad , \forall i \in I, \forall j \in J, j \neq 0 \tag{4}$$
$$\sum_{j \in J} x_{ij} = 1 \qquad , \forall i \in I \tag{5}$$

Constraint (4) assesses the signal strength that the user of session *i* receives from AP *j*. It specifies that x_{ij} can be equal to one (i.e., the session *i* can connect to AP *j*) if the received signal strength from AP *j* is greater than the threshold s_{th}. Constraint (5) specifies that each connection can associate to one AP.

Besides constraint (4) and (5), the bandwidth management procedures impose additional constraints to the linear programming model as described in the following:

A. Complete Sharing: CS

This scheme permits an unrestricted sharing of the total bandwidth of APs such that an incoming session is accepted whenever sufficient bandwidth is available. Using CS, an additional constrain to above model is written as follows:

$$\sum_{i \in I} w_i x_{ij} \ \leq \ N_{\max} \qquad , \forall j \in J, j \neq 0 \tag{6}$$

Constraint (6) specifies the capacity limitation at each AP in order to guarantee quality of services to all connected sessions. Since different applications can be generated by users, each requesting session is associated with a weight w_i that depends on the service contract. The weight value of the best effort application, such as a file transfer and email, is set to 1 whereas that of the multimedia application, such as voice or video online, is set to 3.8 [4]. Constraint (6) computes the equivalent number of sessions that can be connected to AP which is limited by N_{max}. Note that incoming session that is dropped due to the capacity limitation specified in constraint (6) will be associated to AP *j*=0 (AP for dropped requests).

B. Complete Partitioning: CP

In this scheme, the AP bandwidth is permanently partitioned among the traffic types. Let b_1 denotes dedicated bandwidth for the multimedia traffic and b_2 denotes dedicated bandwidth for the best effort traffic. Using CP, additional constrains to the hybrid load balancing model are written as follows:

$$\sum_{i\in I_1} w_i x_{ij} \le b_1 \qquad ,\forall j\in J, j\neq 0 \qquad (7)$$

$$\sum_{i\in I_2} w_i x_{ij} \le b_2 \qquad ,\forall j\in J, j\neq 0 \qquad (8)$$

$$b_1 + b_2 \le N_{\max} \qquad (9)$$

C. Partial Sharing: PS

In this scheme, some bandwidth is shared among all traffic types whereas some bandwidth is reserved for traffic that requires higher quality of services. Let b_1 denotes dedicated bandwidth for the multimedia traffic and b_s denotes shared bandwidth that all traffic types can use.

$$\sum_{i\in I_1} w_i x_{ij} \le b_1 \qquad ,\forall j\in J, j\neq 0 \qquad (10)$$

$$\sum_{i\in I_1} w_i x_{ij} + \sum_{i\in I_2} w_i x_{ij} \le b_s \qquad ,\forall j\in J, j\neq 0 \qquad (11)$$

$$b_1 + b_s \le N_{\max} \qquad (12)$$

III. Description of Simulation Study

We conducted simulation studies using CSIM in order to compare the performance of the three bandwidth management techniques for the hybrid load balancing scheme. We considered a system of two APs locating in a 2-dimensional space with 75% cell overlapping area as shown in Fig. 1. The physical data rate at which the transceiver operates depends on the level of signal strength received from AP. The signal strength thresholds of -75/-79/-81/-84 dBm are used for data rate of 11/5.5/2/1 Mbps, respectively [4].

We considered wireless users generating both multimedia and best effort traffic in the cells. We assumed traffic arrival and service process are Poisson process. For the system offered load of 0.5, the mean interarrival time and the mean service time of both traffic types were set at 0.20 and 10, respectively. We ran simulation studies for different system offered load varying from 0.5 to 5.0. For the system offered load higher than 0.5, the mean interarrival time was decreased whereas the mean service time was kept the same. Furthermore, we assumed that locations of wireless users were uniform-randomly distributed in the cell areas.

In the simulation study, we considered that the multimedia traffic profile required an average throughput of 380Kbps (such as the video conference) and the best effort traffic required an average throughput of 100Kbps [4]. In order to satisfy the quality of services requirement of those applications, we set N_{max} = 60 (the maximum number of sessions that can be associated to each AP) and set the weight associated with the multimedia and the best effort traffic at 3.8 and 1, respectively [4].

We compared performance of the three bandwidth management techniques (CP, CS, and PS) described in the section II in term of the percentage of the user association blocking due to the overload at the AP.

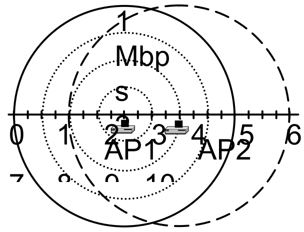

Fig. 1 System model for simulation studies

TABLE II
BANDWIDTH CONTROL SCHEME PARAMETERS

Scheme	Bandwidth dedicated for multimedia traffic (b_1)	Bandwidth dedicated for best effort traffic (b_2)	Shared bandwidth (b_S)
CS	-	-	100%
CP	70%	30%	-
PS	30%	-	70%

TABLE III
VARY PARAMETER VALUES

Experiment case	CP (b_1, b_2)	PS (b_1, b_S)
1	10%, 90%	10%, 90%
2	20%, 80%	20%, 80%
3	30%, 70%	30%, 70%
4	40%, 60%	40%, 60%
5	60%, 40%	60%, 40%

IV. Simulation Results and Analysis

The first experiment was conducted to study performance of different bandwidth management techniques. Particularly, we observed the effects of using each technique on the percentage of the association blocking in WLANs that used the hybrid load balancing scheme. We simulated the WLAN system carrying both the multimedia traffic and the best effort traffic. We simulated the case that 40% of overall traffic was multimedia traffic. The parameters of each bandwidth management technique were set as shown in Table II. The simulation results were graphed in Fig. 2. We can see that as the system offered load increases, the percentage of blocking increases, for all bandwidth control scheme. However, percentage of blocking of CP scheme is higher than those of the other two schemes. The reason is as follows. In the CP scheme, there is dedicated bandwidth for each traffic type. A new session entering the network cannot use free bandwidth dedicated for the different traffic type. PS scheme yields similar results as that of CS scheme but when the system offered load is higher than 2.0, the association blocking using PS scheme is greater than that of CS scheme because PS scheme reserves a portion of bandwidth that can serve only the multimedia traffic ($b_1 = 30\%$).

We conducted another set of experiments that we observed the effects of varying parameters of CP and PS scheme on the association blocking of the multimedia traffic and the best effort traffic and we compared the results with the case of using CS scheme. In these experiments, we studied five cases of the CP and PS. Each case we divided bandwidth for each traffic class as detailed in Table III in which for CP the dedicated bandwidth for best effort traffic decreases from 90% in case 1 to 40% in case 5 and for PS the shared bandwidth decreases from 90% in case 1 to 40% in case 5. We considered the system offered load at 1.5.

In the case of using CS scheme in which the bandwidth capacity was shared among all traffic types, the percentage of blocking of the multimedia sessions and the best effort session were at 55.77% and 7.57%, respectively.

The results of varying parameters of CP and PS scheme are shown in Fig. 3. We can see that when using the CP scheme, the percentage of blocking of the multimedia traffic from the experiment case 1 to 5 decreased linearly from 95% to 53% whereas that of the best effort traffic were about 0% in the experiment case 1 to 4 and it increased almost 20% in the experiment case 5. When using the PS scheme, the percentage of blocking of the multimedia traffic was lower than that of the CP scheme and it was constant at 55.77% in the experiment case 1 to 4; it slightly decreased to 50% in the experiment case 5. The results of the best effort traffic when using the PS scheme was that the percentage of blocking was little higher than that of the CP scheme; it was at 7.57% in the experiment case 1 to 3; it slightly increased to 10% in the experiment case 4 and increased to 22% in the experiment case 5.

Comparing with the CS scheme, we can see that PS scheme yields comparable results as those of CS scheme at a proper setting of the dedicated and shared bandwidth. In the experiment case 1 to 3, the blocking percentage of the multimedia traffic and the best effort traffic when using PS scheme was about the same as that using the CS scheme. In addition, we can observe that PS scheme can yield better results to the multimedia traffic at the expense of increasing blocking percentage to the best effort traffic. In the experiment case 4 and 5 when using the PS scheme in which the dedicated bandwidth for the multimedia traffic increases from 40% to 60%, the blocking percentage of the multimedia traffic decreases about 5% whereas the blocking percentage of the best effort traffic increases about 10%. For the CP scheme, we can see that it yields highest blocking percentage to the multimedia traffic in all cases of the bandwidth setting.

V. Conclusion

We have studied three bandwidth management techniques for WLANs that use a hybrid load balancing scheme. The experimental results indicate that the CS scheme is a simple and effective technique than can provide relatively low association blocking percentages to both multimedia and best effort traffic. However, if one wants to provide higher priority and better quality of services for the multimedia traffic, the PS scheme would be more effective because it reserves some portion of bandwidth especially for the multimedia traffic whereas the remaining bandwidth can be shared among different traffic types. For the best network performance, the bandwidth management technique must be able to flexibly adapt to the dynamic traffic environments by properly changing the ratio of dedicated and shared bandwidth. Our on-going researches are developing such dynamic bandwidth management algorithm.

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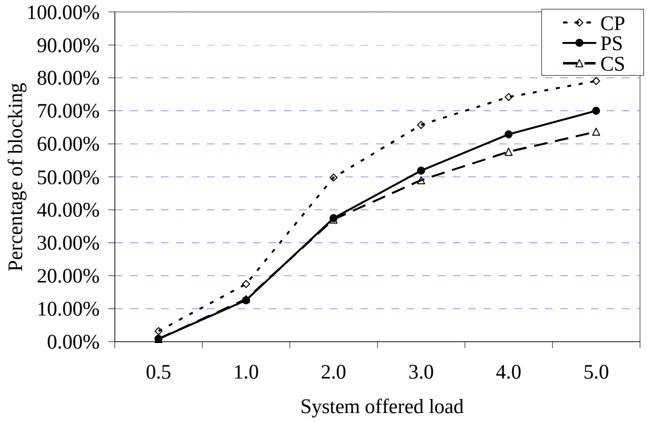

Fig. 2 Percentage of blocking at different system offered load

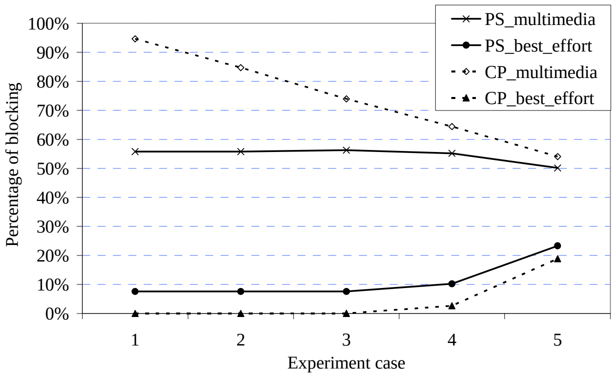

Fig. 3 Percentage of blocking when using CP and PS scheme

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