Dynamic Load Balance Algorithm (DLBA) for IEEE 802.11 Wireless LAN

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Abstract

In an infrastructure wireless LAN, the access point (AP) is responsible for connecting mobile stations (STA) and wired stations. Each access point is assigned on one channel. Traditionally, one station selects AP to connect is based on the received signal strength indicator (RSSI). This approach may cause all active mobile stations to connect to few APs and lots of contentions/collisions will occur by the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) protocol. Consequently, the total network throughput will be degraded. Contrarily, if all STAs can be equally distributed to all APs and the signal strength of any pair of STA and connected AP is still kept in an acceptable range, the spare bandwidth in wireless LAN (WLAN) will be utilized in a more efficient way. In this paper, a novel dynamic load balance algorithm is proposed for WLAN. Simulation results show the proposed algorithm has the ability to fairly distribute all STAs among APs. Moreover, it also maximizes the average RSSI between AP and connected STAs.

Key words: AP, CSMA/CA, Infrastructure, RSSI, STA, WLAN.

1. Introduction

The IEEE organization has approved the 802.11 standard for Wireless Local Area Networks (WLAN) [3]. IEEE 802.11 defines two types of wireless networks. One is called as IBSS (Independent Basic Service Set) or *ad hoc* WLAN. An *ad hoc* WLAN is limited in its range. That is, all stations need to 'see' or 'hear' each other. Within an *ad hoc* WLAN, there is no fixed wired infrastructure to provide STAs to communicate each other. A collection of STAs with wireless network interface may form a network immediately without the aid of any established infrastructure or centralized administration. The other type is the ESS (Extended Service Set) or infrastructure WLAN. Infrastructure WLAN connects the wireless stations to a wired network through access point (AP). An Infrastructure WLAN extends a wireless network to support STAs roaming within a larger coverage range.

The fundamental access method of the IEEE 802.11 MAC is known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The CSMA/CA protocol works by a "listen before talk“ scheme. This means that a station wishing to transmit must first sense the radio channel. If the medium is not busy, the transmission may proceed. The CSMA/CA scheme defines a minimum time gap between two consecutive frames. Once a frame has been sent from a station, this station must wait until the time gap is up. Once the time gap has passed, each active station selects a random amount of time (within a backoff interval) to wait. After passing the backoff interval, station is allowed to transmit. If collision occurs, involved stations will select another random amount of time (with a larger backoff window) and wait again. This process is repeated until station transmits successfully. This type of multiple access ensures judicious channel sharing while avoiding collisions. However, such access method will degrade the network throughput especially when too many stations share bandwidth [1]. Because wireless network provides much lower bandwidth than traditional wired networks (e.g., 1-2Mbps vs.

10-150Mbps) [4], the designed protocol needs to pay more attention on the bandwidth consumption.

In the traditional approach, a new station chooses an access point to connect is following two steps. At first, it scans all available channels to find attachable APs and records the corresponding RSSI value for each one. After then, it will select the best AP (with the maximum RSSI value) to connect. Based on this approach, it will result in a serious problem : there may be too many stations connected to only few APs and the other APs are idle. Considering Fig. 1 for example, there are twelve STAs and four APs in WLAN. For simplicity to demonstrate, suppose the RSSI value is proportional to the distance between STA and AP. There are eight STAs will attach to AP_a and four STAs will select AP_c. Since the traffic load of a mobile station is unpredictable, we assume the traffic load of station is the same in this paper. As a result, the shared bandwidth of station is not equal and the load among all APs are also quite unbalance. In this scenario, the network throughput of the entire network becomes poor (only one-half network capacity is utilized). A better station assignment is shown in Fig. 2. In this case, each AP is responsible for three STAs equally.

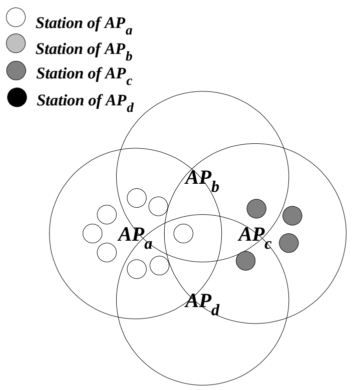


Figure 1. The stations' assignment in the traditional approach.

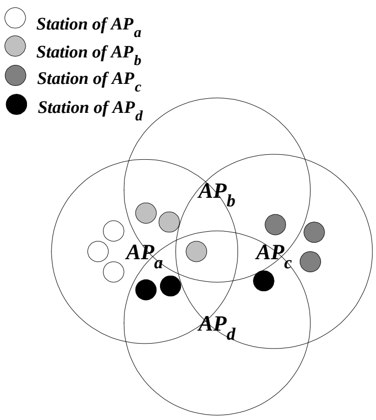


Figure 2. The stations' assignment in the load balance approach.

In this paper, we will propose a new approach, namely Dynamic Load Balance Algorithm (DLBA), for wireless networks. The proposed DLBA is able to distribute mobile stations among all APs and the signal strengths between stations and access points are also being maximized at the same time. Therefore, a wireless network with DLBA will perform much better than the traditional approach. The rest of the paper is organized as follows. In Section 2, the problem of load balancing is addressed. In Section 3, the efficient DLBA for wireless networks is described. In Section 4, the simulation models and simulation results are reported and compared. Finally, some concluding remarks are given in Section 5.

2. Problem Description

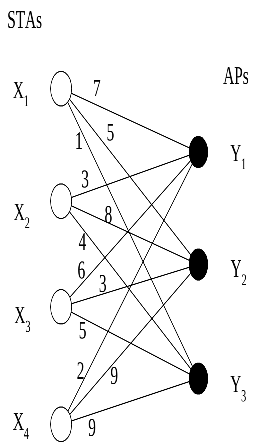
In this section, the station assignment problem is addressed. Assume that a wireless network consists of *M* STAs and *N* APs. Each AP/STA can access one channel at a time. A STA can only select an AP to attach and each AP is capable of supporting at least *M* STAs. Let S_x denote a set of STAs which connect to AP_x and let $R_x(y)$ denote the corresponding RSSI value when AP_x receives packets issued from STA_y. The average RSSI value of set S_x (denoted as AR_x) is defined as the average RSSI value between any STA and AP_x in set S_x. That is, $AR_x = \Sigma_{y\in Sx} R_x(y)/SN_x$, where SN_x is the number of stations in set S_x.

We note that the RSSI is not necessarily a reliable indication of performance due to many effects such as multipath fading or the present of other constructive or destructive sources of interference. Actually, a good estimation method should include the quality of transmission which is often measured by the frame error rate (FER). To precisely collect the quality information, the join process may take a considerable time. This may degrade the network efficiency. In this paper, we only consider the RSSI value and assume that a higher RSSI value indicates a better transmission condition.

Let *VAR* and *VSN* denote the variances of *ARs* and *SNs*, respectively. The *Dynamic Load Balancing Problem* (*DLBP*) on a wireless network can be defined as follows.

Dynamic Load Balancing Problem : Given a wireless network which consists of a number of STAs and APs, each station will select an access point to connect. The dynamic load balancing problem is to find a scheme such that 1) the average RSSI in WLAN is maximized and 2) both *VAR* and *VSN* are minimized.

The DLBP can be simply represented as the following bipartite graph except that it is a dynamic assignment problem. Consider Fig. 3 for example, there are four stations (X_1, X_2, X_3, X_4) needed to assign to three APs (Y_1, Y_2, Y_3). The RSSI value between station and AP is shown on edge. The problem is to find a matching for which the average RSSI value in each set Y is maximum and the station numbers in three sets are as equal as possible. To solve the basic assignment problem, some static algorithms, such as Hungarian Algorithm [2], have been proposed. However, such algorithms are not well suitable for DLBP. The DLBP is more complicated because that the process of STAs to join/leave WLAN is dynamic and unpredictable. That is, it is very difficult to obtain all information in advance and assign them at a time. Also, it is impractical to rearrange all stations' assignment when a new station joins or leaves. Therefore, it is desirable to design an algorithm to solve the dynamic problem. In this paper, we will propose a simple and efficient heuristic algorithm which has the ability to obtain the near optimal result.



STAs	APs Y_1	Y_2	Y_3
X_1	7	5	1
X_2	3	8	4
X_3	6	3	5
X_4	2	9	9

Figure 3. Bipartite graph.

It is clear that any scheme solves the DLBP implies that the network bandwidth is maximized and the fairness criteria is also achieved. In the next section, a dynamic load balancing algorithm (DLBA) based on the concept of dynamic station assignment is introduced.

3. Dynamic Load Balance Algorithm (DLBA)

Before describing the operations of the LBA, we first define some useful parameters as follows:

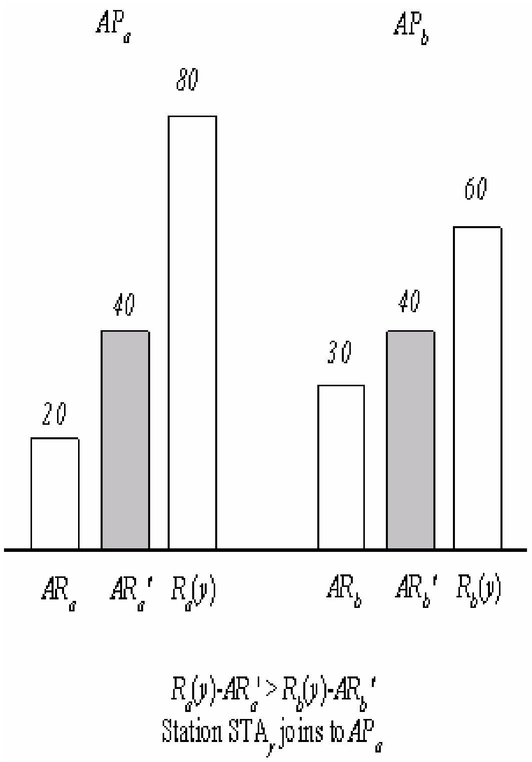
- SN_x : denotes the number of STAs which connect to AP_x.
- $R_x(y)$: denotes the RSSI value between AP_x and STA_y.
- AR_x : denotes the average RSSI value in set S_x.
- $R_{\max}$:denotes the normalized maximum RSSI value which can be received and estimated by WLAN adapter.

In traditional approach, a new joining station (say STA_y) will scan all channels in WLAN to find out all available APs. To do this, STA_y will send a probe request onto each channel. (This is referred as active scanning approach.) When an AP receives the probe request, it will send a probe response with the information of current AP. As STA_y receives the response frame from AP_x, it will record the received $R_x(y)$. After STA_y scans all channels, it will choose the AP with the maximum RSSI to join. As mentioned before, this approach may cause serious unbalance. To solve this potential unbalance problem, an access point responses STA_y with two extra information. One is the new average RSSI value (AR_x') which is calculated by temporarily including STA_y into set S_x. That is,

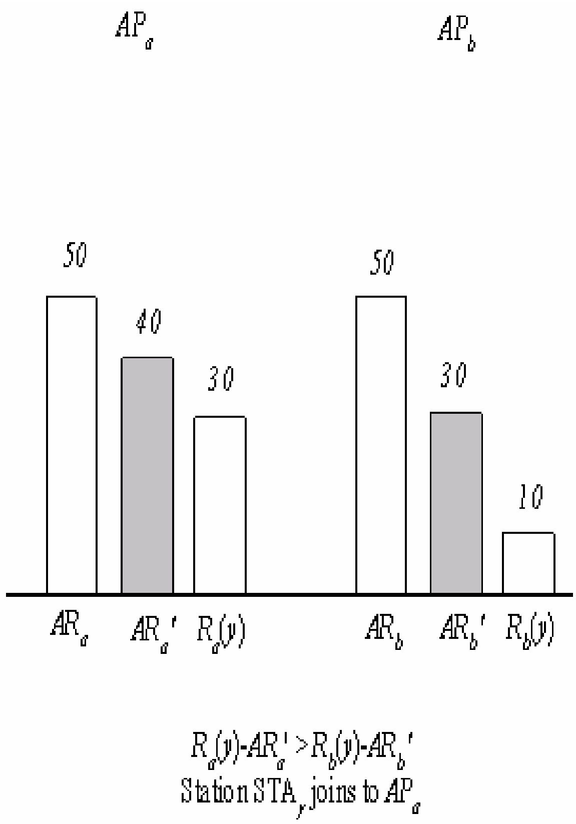
$$AR_x' = (\Sigma_{z \in Sx} R_x(z) + R_x(y))/(SN_x+1).$$

The other is the detected RSSI value $R_x(y)$ when AP_x receives the probe request from STA_y. These two values are used to evaluate the affect if this station joins into this set. According to the relation of these two values, a STA will select the best AP to join. The way to determine the best AP is described as follows.

The difference between $R_x(y)$ and AR_x' is the major reference value in proposed DLBA. If $R_x(y)$ is greater than AR_x', this implies that STA_y has a positive contribution to set S_x. On the contrary, if $R_x(y) \le AR_x'$, adding the STA_y into set S_x will degrade the average RSSI value in set S_x. Therefore, let $D_x(y)$ denote the difference between $R_x(y)$ and AR_x' , we have $D_x(y) = R_x(y) - AR_x'$. The STA_y prefers selecting the AP which has the maximum $D(y)$ among all APs. This is quite different from traditional approach. Consider Fig. 4 for example. In Fig. 4(a), station STA_y will select AP_a to join because the AR_a will be improved more than AR_b (i.e., $D_a(y) > D_b(y)$). Similarly, Fig. 4(b) illustrates the case of $R_x(y) \le AR_x'$, STA_y will select AP_a since its joining affects AR_a is less than AR_b (i.e., $D_a(y) > D_b(y)$). Based on this concept, the average RSSI in sets may perform still very close to the traditional approach. However, this method still does not guarantee that all stations are equally distributed to different sets. In other words, it is still possible that lots of stations select a same AP to connect. To solve this problem, all stations whose RSSI values are less than the new average RSSI *AR'* are forced to change into another set with a better transmission condition. Obviously, the handoff process will decrease network performance. To minimize the overhead, each station needs a holding counter *HC*. Each time a new station joins, other stations in this set will listen the probe request and compare its RSSI value with the new average RSSI. If its RSSI value is lower than average RSSI, its *HC* is incremented by one. Once its *HC* equals to a threshold *MH*, it may leave the current set and become a new station to perform joining process as described above. Meanwhile, its *HC* is reset to zero. It is obvious that this progress is a recursive process for many stations. Since the handoff process happens only when station's *HC* reaches *MH*, this progress will be terminated consequently. As a result, all stations will be rearranged into a relative better condition in WLAN. Obviously, a smaller MH is given, a higher level thrashing will occur and a better load balance will obtain.



(a)



(b)

Figure 4. Two examples of a station selects AP to join according to $D(y)$ in the proposed DLBA.

Beyond expectation, if a new station only considers the difference between $R(y)$ and AR', it may choose a worse AP. Fig. 5 illustrates two interesting cases of $D_a(y) < D_b(y)$ in which the station selects the AP_a may better than AP_b. For example, in Fig. 5(a), if STA_y selects AP_a to join, not only the average RSSI in set S_a is improved but also some stations with worse RSSI values in set S_a have a chance to change into a better condition. To do this, the proposed DLBA should take the AR' value into consideration. A simple proportional weighted function $P(y)$ is defined as follows:

$$P_x(y) = \begin{cases} 1 + \dfrac{AR_x'}{R_{max}}, & if\ D_x(y) \geq 0. \\ 1 - \dfrac{AR_x'}{R_{max}}, & if\ D_x(y) < 0. \end{cases}$$

The weight of station STA_y connects to AP_x is now defined as

$$W_x(y) = D_x(y) \times P_x(y).$$

When a station wants to join a WLAN, it calculates all weights of APs to find the best AP that has the maximum weight. Therefore, if

$D_a(y)<D_b(y)$, station STA_y still has a chance to select AP_a only when $W_a(y)>W_b(y)$. That is,

$$D_a(y)\times P_a(y) > D_b(y)\times P_b(y).$$

Thus, we have

$$\frac{D_a(y)}{D_b(y)} > \frac{P_b(y)}{P_a(y)} ,$$

Replacing these two variables, we derive

$$\frac{R_a(y)-AR_a'}{R_b(y)-AR_b'} > \frac{R_{\max}+AR_b'}{R_{\max}+AR_a'} .$$

The detailed flowchart of an AP is shown in Fig. 6. The flowchart of a new STA to choose an AP is shown in Fig. 7.

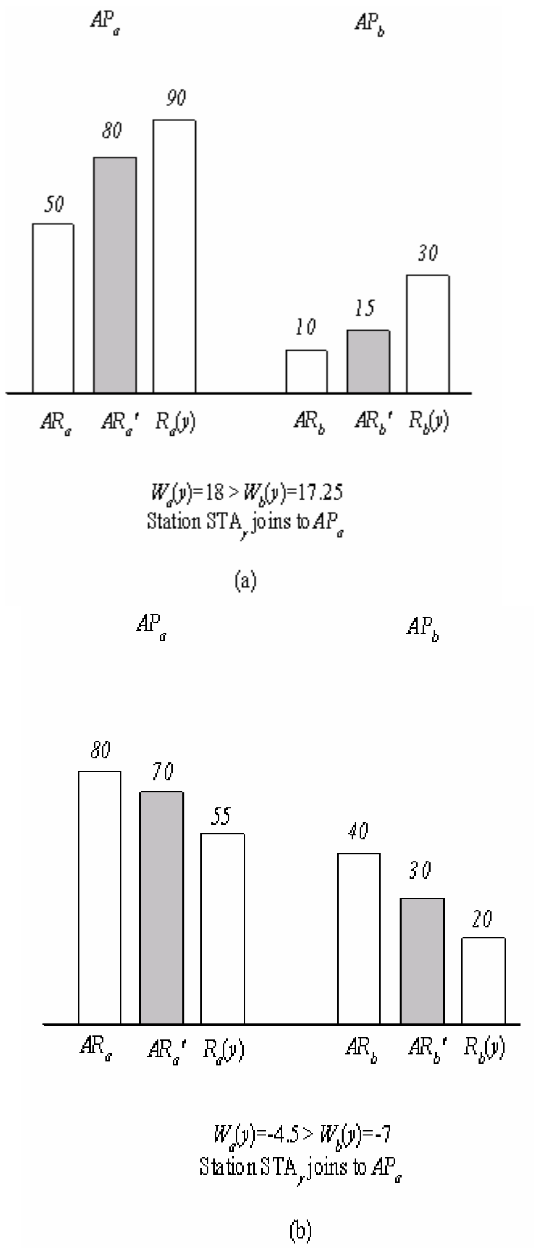


Figure 5. Two examples of a station selects AP to join according to $W(y)$ in the proposed DLBA.

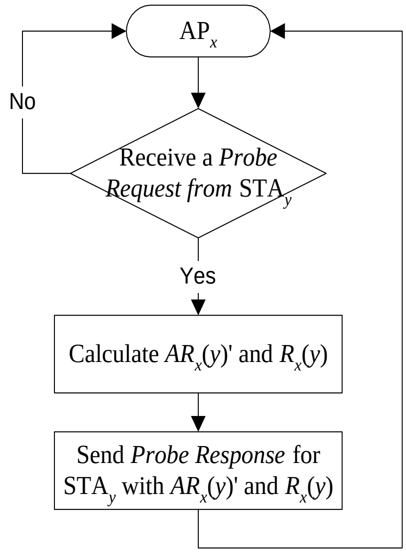


Figure 6. The flowchart of the AP.

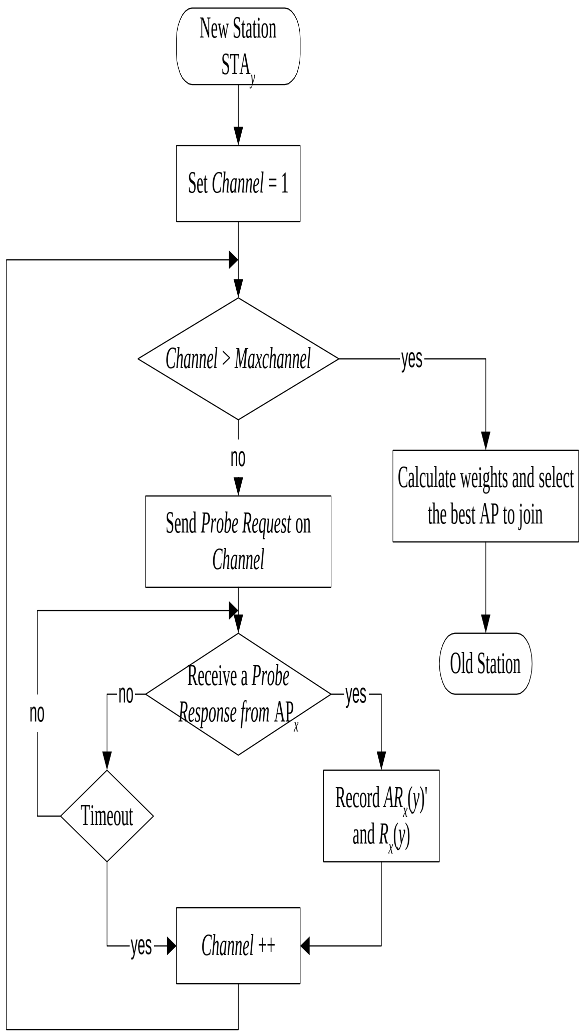


Figure 7. The flowchart of the new station.

4. Performance Measurement and Simulation Models

4.1 Performance Measurement

The performance of the DLBA is evaluated in terms of the following three measurements : the Variation of *SN*s (*VSN*), Variation of *AR*s among different sets(*VAR*), and Average RSSI in WLAN (*ARW*). A high load balanced network should have a low *VSN*. Under this condition, only a high *ARW* and a low *VAR* can provide high network throughput. When both *VSN* and *VAR* are high, the network fairness will be violated due to the unfair traffic loading in different sets. Let *M* and *N* denote the number of STAs and the number of APs in WLAN, respectively. We say that an algorithm is *load balancing* if all APs have the same number of members $\lfloor M/N \rfloor$ and the average RSSI in WLAN is maximized.

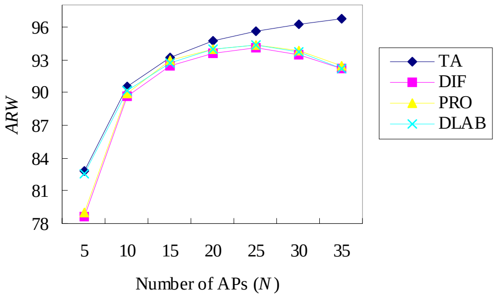
4.2 Simulation Models

The proposed dynamic load balancing algorithm is implemented by the C language. For simplicity, we assume R_{max}=100 and the RSSI value between a pair of station and AP is randomly generated in the range [0, R_{max}]. We also assume that the joining process of all stations is sequential. In the simulation, two simulation models are investigated. In these two simulation models, we compare the degree of load balancing of the proposed DLBA (DLBA) and traditional approach (TA). To precisely investigate the performance of proposed DLBA, two different approaches are considered :. the approach only considers the distance $D(y)$ is denoted as DIF scheme and the approach only considers the proportional weight $P(y)$ is denoted as PRO. The first simulation model investigates how the number of AP (*N*) affects *VSN*, *VAR*, and *ARW* when the number of stations is fixed (*M*=50). The second simulation model considers the performance of proposed strategy under different network sizes when the number of APs is 5 (N=5). For simplicity to observe, the processes of dynamic joining and leaving are not considered here. That is, all simulation results are calculated when all stations are joining completely.

4.2 Simulation Results

Fig. 8 shows the results obtained by the first simulation in which the *VSN*, *VAR*, and *ARW* of WLAN under different numbers of APs. Fig. 8(a) shows the *ARW* obtained by four different approaches. We can easily see that TA performs better than proposed strategies. We also note that the *ARW* obtained by proposed strategies are almost equivalent under different numbers of APs. Moreover, the derived *ARWs* by proposed strategies are very close to the maximal *ARW* which obtained by TA when *M*<25. This is because that proposed algorithms will force the later joining stations to select the idle APs even when the RSSI is not the maximal. Fig. 8(b) shows the *VSN* obtained by four different approaches. We can see that the *VSN* in traditional approach is quite unbalance due to the TA only considers the strength of received signal. It seems that more APs allocated in WLAN will result in a lower degree of load balance in TA. This is undesirable since the total network throughput can not be fully utilized. Contrarily, the proposed DLBA and DIF strategies will distribute 50 stations into every AP as fair as possible. In fact, when the number of APs is greater than 25, the member size of each AP should not excess 2 to provide the load balancing. Fig. 8(c) illustrates the *VAR* results obtained by four strategies. We can see that the proposed strategies significantly improve the fairness on average RSSI in WLAN.

The results obtained by the second simulation are illustrated as follows. In Fig. 9(a), we can see that the TA still obtains the highest *ARW*. The *ARW* of DLBA is slightly higher than the other two simple strategies (DIF and PRO) under different network sizes *M*. Figures 9(b) and 9(c) show that DLBA and DIF obtain the lowest *VSN* and *VAR*, respectively. We can see that in Fig. 9(b), the *VSN* increases as the number of STAs increases. But we can find that the *VSN* of traditional approach is still much higher than that of DLBA. The degree of unbalance will become much serious when the number of stations becomes large. However, both *VSN* and *VAR* obtained by DLBA are very small. We conclude that although the average RSSI value in DLBA is not as high as in TA, the load of APs with DLBA is more balanced. Besides, the *VSN* (*VAR*) of each proposed strategy is slightly increase (decrease) as the network size increases. This implies that the proposed DLBA has the ability to fairly distribute stations into all APs and guarantee near optimal average RSSI in WLAN no matter how many stations existing in WLAN.



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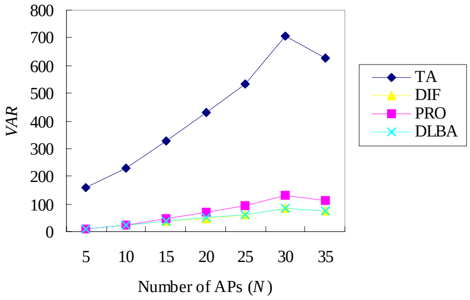

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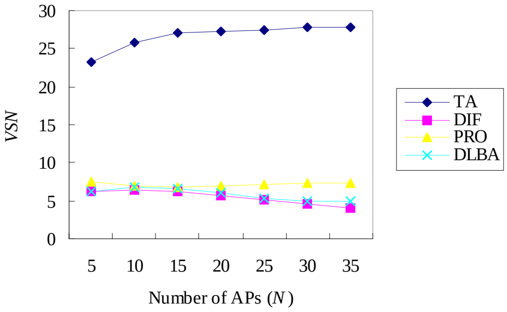
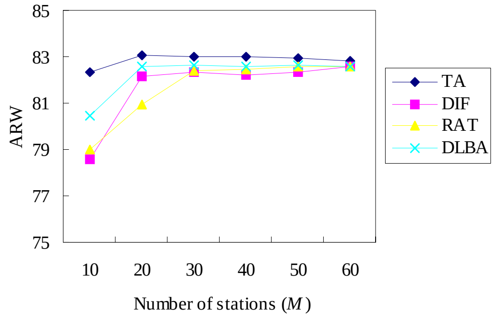


(c)

Figure 8. The *VSN*, *ARW*, *VAR* derived by three different strategies and the traditional approach under different numbers of APs.



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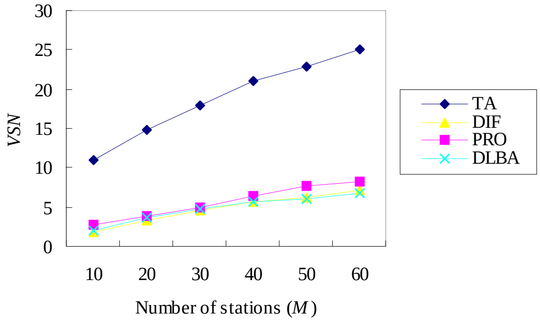

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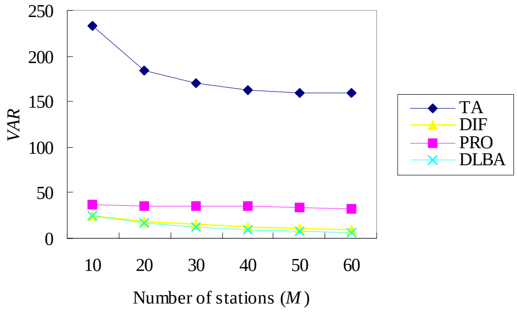

(c)

Figure 9. The *VSN*, *ARW*, *VAR* derived by three different strategies and the traditional approach under different numbers of STAs.

5. Conclusion

In this paper, we defined the dynamic load balance problem in the infrastructure WLAN. A simple dynamic load balancing algorithm (DLBA) was also proposed to fairly distribute STAs into all APs to derive the maximal total network throughput. Simulations shows that the proposed DLBA have the following benefits (1) All STAs are near uniform distributed to all AP. The load of AP is more balanced than traditional approach and the performance is much better than tradition approach. (2) The derived average RSSI value between AP and STA is very close to that in TA. (3) The performance of DLBA is almost independent of the network size in WLAN. (4) The proposed algorithm is very simple and the required calculating time is very small.

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