Analysis of Distributed Resource Management in Wireless LANs that Support Fault Tolerance

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Abstract. Deploying wireless LANs (WLAN) at large scale is mainly affected by reliability, availability, and performance. These parameters will be a concern for most of managers who wanted to deploy WLANs. In order to address these concerns, new radio resource management techniques with fault tolerance can be used in a new generation of wireless LAN equipment. These techniques would include distributed dynamic channel assignment, sharing load among Access Points (AP), and supporting fault tolerance. Changing from the relatively static radio resource management techniques generally in use today to dynamic methods has been addressed in previous research article using centralized management, but it suffer from network availability problem. In [10] a new distributed management for dynamic channel assignment has been suggested. In this paper the idea has been extended to support fault tolerance, which improves the network availability and reliability compared to centralized management techniques. In addition, it will help in increasing network capacities and improve its performance especially in large-scale WLANs. The new system has been analyzed and according to binomial distribution results showed improvement of network performance compared to static load distribution.

1 Introduction

WLAN technology is rapidly becoming a crucial component of computer networks that widely used in the past few years. Wireless LAN technology evolved gradually during the 1990s, and the IEEE 802.11 standard was adopted in 1997 [1]. Companies and organizations are investing in wireless networks at a higher rate to take advantage of mobile, real-time access to information.

Enterprise managers want to deploy wireless networks with several important qualities. These include; high security, highly reliable and available WLANs with very little downtime, and high performance. The ideal wireless network is to have reliability, availability, and performance criteria to be similar of wired enterprise networks. In addition, it should be possible to deploy wireless networks very quickly and without the need for extensive and time-consuming site surveys. Furthermore, the networks should have the flexibility needed to support load balance and changes in the radio environment. Radio resource management (RRM) forms the basis of quality

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of service (QoS) provisioning for wireless networks [2]. It is an intense research area due to the wireless medium's inherent limitations and the increasing demand for better and cheaper services. Improving the mobility management has been addressed in [3] based on dividing the location management into two levels, intra and inter mobility. This will reduce the amount of signaling traffic, but still didn't address the problem of reliability and availability. Supporting security, reliability and QoS in dynamic environment has been discussed in [4] using modified routing protocol OSPF-MCDS over WLANs.

In WLANs, when AP is called on to serve a high number of users, it is likely to become overloaded, and the resulting congestion may significantly degrade the service received by users dependent on that AP. Overhead bits dramatically reduce the effective data rate available as described in [1, 5, 6]. Congestion further reduces the throughput experienced by a user because AP and the mobile computers it serves share a single radio channel. All stations using an IEEE 802.11 AP share the same bandwidth resource, and congestion is likely to be particularly severe in areas of high user density [5, 7]. It is highly desirable for wireless LAN equipment to include provisions to mitigate this problem and try to eliminate or reduce the effect of congestion.

The design of WLAN is usually based on signal strength measurements and on consideration of radio propagation issues. This is challenging because the building is a three-dimensional space, and an AP located on one floor of the building may provide signal coverage to adjacent floors of the same building and perhaps to other buildings, as well [5, 7]. Firstly, selection of AP location should be done to provide complete coverage of the target space without undue coverage overlap. Consideration of the characteristics of the radio propagation environment in which the wireless LAN is being deployed can be difficult but is important in a WLAN design [6].

In [8], centralized management architecture has addressed the above issues to improve reliability, availability, performance, and deployment effectiveness in enterprise and other large-scale wireless LANs. These improvements arise from the radio resource management algorithms contained in the software running on the intelligent switches that control APs. In this approach, the software controlling the APs attempts to optimize performance without having any direct control over client behavior, and this limits the effectiveness of the approach. The above article discussed how radio resource management is beginning to be used to mitigate some of the problems in enterprise wireless LANs. However, centralized management still suffer form availability problem if the centralized node failed. Gandhi [12] has addressed the network availability by focusing on tolerating access-points failures, where it detects fault based on signal-to-noise ratio. A solution to network availability has been addressed in [10] using distributed network management that has the same benefit described in [8] (reliability, availability, performance and deployment effectiveness in enterprise and other large-scale WLANs). In this paper the distribution network management has extended to the one described in [10], but with higher network availability and fault tolerance as would be described in the following sections.

2 Distributed WLAN Network Management Architecture with Fault Tolerance

In order to reduce the congestion at the AP and at the same time maintain high network availability, distributed dynamic network management with fault tolerance across multiple APs has been suggested in this paper as described in Figure 1. As shown in Figure 1, the dotted circle indicating the coverage of a particular AP. This coverage might overlap with adjacent AP, where interference is caused if both APs are running at the same channel radio frequency. At the same time mobile terminal falling within the overlapped region would have the choice to have association with either AP. Each AP has 2 coverage areas; low coverage as shown in the dotted circle for AP-2, Ap-4, and AP-5, and high coverage as shown in the blue solid circle of AP-1, and in the grey solid circle of AP-7. The AP-1 and AP-7 have also low coverage area as shown in the dark grey solid circle, and pink solid circle for AP-1 and AP-7 consecutively. The solid circle for AP-3, with dashed pattern indicates a failed AP, where its coverage has been substituted by the high coverage area of AP-1 and AP-7. This architecture *improves the WLAN performance by reducing the interference* through assigning different channel radio frequency to adjacent as described in section 2.1. This architecture also *improves the performance in load balancing as well as reducing the congestion* by dividing The coverage region of every AP is divided in 2 regions, left hemisphere and right hemisphere, where mobile terminal would choose to associate with one AP according to its location in the left or right hemisphere of the AP as described in the subsection 2.2. It also *improve the WLAN performance by providing high network availability and fault tolerance* through broadcasting 2 coverage levels by every AP to substitute for the failing AP coverage area to allow mobile terminal falling within the failed AP to use the WLAN as described in subsection 2.3.

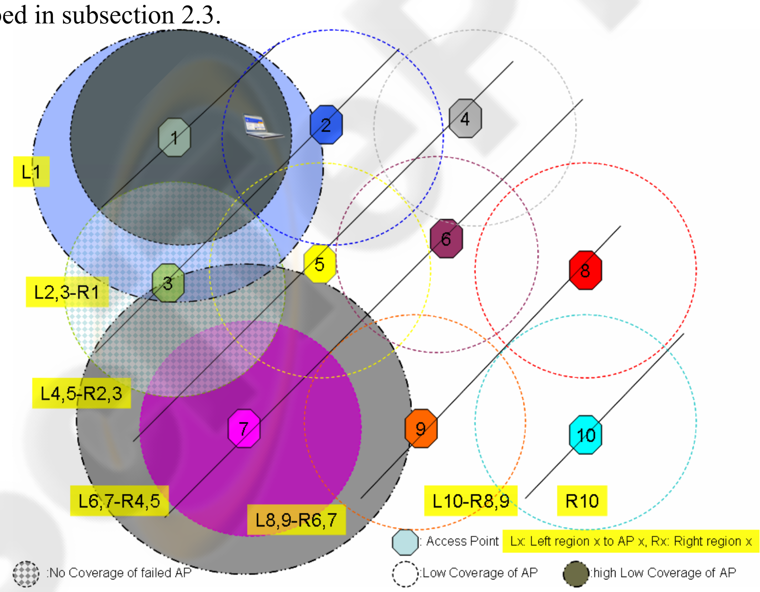

Fig. 1. Distributed APs Management Techniques with Fault Tolerance.

2.1 Distributed Dynamic Channel Assignment

The performance of a network depends, in part, on the assignment of radio channels to APs. This assignment is often done using a manual process in which the designer attempts to assign the channels in a way that minimizes co-channel overlap. The coverage areas, and therefore the channel assignments, are dependent on among other things such as the radio propagation environment. Since the radio propagation environment changes, so one cannot be sure that the channel assignments valid at the time the network was designed will continue to be valid. However, distributing channel assignment between APs according to its channel frequency that minimize the overlap between these frequencies would reduce the interference between these channels as described in [10] where the assignment of channel frequency to adjacent APs, are spread from minimum frequency to maximum which cause less interference between these APs. Example Adjacent APs 1, 2, 3 are assigned channel number 1, 6, 11 consecutively, and APs 4, 5, 6 are assigned channel number 2, 7, 10 consecutively. Distributed Dynamic Channel Assignment would add extra flexibility to assign a proper channel number to different AP dynamically according to AP index number. This dynamic assignment would help in replacing failed AP with another one using the same index number. Each AP requires having an index number that can be set at the initialization stage.

2.2 Load Balancing and Terminal Association

Since an AP and its associated clients share a limited bandwidth resource, APs can become overloaded, leading to congestion and poor network performance. WLAN equipment with this capability can enhance network performance considerably. Association between a client and an AP begins with an association request that is initiated by the client. This association request is normally preceded by the client's transmitting one or more probe requests on channels it selects. In each of these probe requests, the client asks for a response from all APs operating on that channel and able to receive the client request. This tells the client which APs are within radio range, and the signal strengths received from the APs give an indication of which APs will be able to provide higher-quality service. Before sending an association request, a client should also have previously sent an authentication request that has been granted. The method by which a client decides with which AP to request association is not specified in the IEEE 802.11 standard.

However, the association between mobile terminals in distributed dynamic management can be controlled not only according to signal strength which cause network congestion at some AP, *but also according to its location in the right or left hemisphere of the AP [9]*. This management technique works according to distributing the load between adjacent APs where mobile terminal fall within the overlapped region would be associated only with one AP located to its right hemisphere. If mobile terminal located within the overlapped region, the signal strength would not be used to determine to which AP it will associate with. In fact, the mobile terminal location would be used to distributed load to different AP, where it will associate with AP that is located at the right hemisphere of itself. As shown in

Figure 1, if mobile terminal located anywhere within the region of AP-1 without overlapping with other AP, it always associate with this AP-1. However, if it locates within the overlapped region of AP-1, and AP-2, it will associate with AP-2 where the terminal is located at the left hemisphere of AP-2.

2.3 WLAN with Fault Tolerance

WLAN with multiple AP suffer from network unavailability when one or more AP failed. This will cause some mobile terminals falling within the area of the failed AP to lose connection and become unable to use the network. The distributed architecture suggested previously in section 2 has the advantage of providing fault tolerance. This is done by increasing the broadcasting power of the adjacent APs of the failed one to high coverage to cover the area of the failed AP. In order for this architecture to work, each AP should operate in 2 level of coverage power. Each AP would also detect the failed neighbor AP through continuous broadcast management signal that occurs at specific interval of time, where each AP will broadcast its available network table for all adjacent APs that have sensitive antenna to detect it. The available network table would be updated by each AP when it receive broadcast from neighboring APs, where after few broadcast the table would contain a list of all operating AP that belong to the same network as explained in the following sequence diagram. Assume in this diagram that AP-1 has joined the WLAN and broadcasted its own availability network table (that contains list of known AP {1}) to neighboring APs (AP-2, and AP-3). AP-1 also receives broadcast from AP-2 and AP-3. The management signal received from AP-2 would contain a list of all APs (2, 4*, and 5*) that are neighbor to AP-2, where *4* is the list of APs for AP-4* that had been received previously at AP-2 from AP-4. The list 4* indicating another list of AP-4 that contains the list of APs that are neighbor of AP-4 which are AP-5 and list of AP-7 (7*). Also list from AP-5 (5*) would contain the list of AP-5 that are neighbor of AP-5 which are (3, 4, 6, 7, 8). At the same time the list received from AP-7 would contain the list of APs that are neighbor to AP-7 which are (4, 5, 8, 9). Eventually, the availability table at AP-1 would contain a list of all APs that are belonging to the same network. The other APs would also update their availability table which also would include the list of all APs of the same network. If one of the AP failed (example Ap-3) as shown in figure 1, all of its neighbor APs (AP-1, and AP-7) would not receive a regular broadcast from it. If AP-1 and AP-7 didn't receive broadcast management signal from its neighbor AP-3, they will assume a failure on AP-3 and adjust their coverage power to operate at high level. This will allow AP-1, and AP-7 to cover the area of the failed AP-3 as shown in figure 1 (blue solid circle, and grey solid circle).

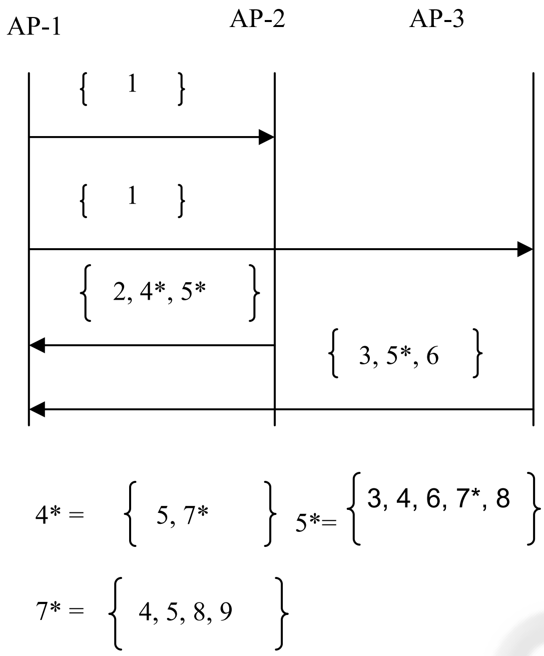

Fig. 2. Sequence of broadcast management at AP.

3 Analysis Results

The binomial distribution gives the discrete probability distribution $P_p(n/N)$ of obtaining exactly *n* successes (terminal falling only within a particular AP range eg. AP-5) out of *N* Bernoulli trials or terminals falling within the coverage of a particular AP and its neighbors APs (where the result of each Bernoulli trial is true with probability p and false with probability $q = 1 - p$). The binomial distribution is therefore given by:

$$P_p(n|N) = \binom{N}{n} p^n q^{N-n} \quad (1)$$

$$= \frac{N!}{n!(N-n)!} p^n (1-p)^{N-n}, \quad (2)$$

where $\binom{N}{n}$ is a binomial coefficient.

Assume that the desired probability of terminals falling within one Access Point (eg. AP-5) only is $p = 0.8$. Therefore the probability of failure is $q = 1 - p = 0.2$. The total number of terminals (trials) is $N = 50$. According to binomial distribution of formula 2, the probability of at least up to i terminals is falling within only one AP (eg. AP-5) is:

$$p(x \le i) = \sum_{k=0}^{i} \frac{n!}{(n-k!)k!} p^k (1-p)^{n-k} \qquad (3) \qquad (3)$$

The probability that more than i terminals are falling within the same AP is given by:

$$p(x > i) = 1 - p(x \le i) = 1 - \sum_{k=0}^{i} \frac{n!}{(n-k!)k!} p^k (1-p)^{n-k} \qquad (4) \qquad (4)$$

Using formula 4, we can obtain the probability for more than i terminals are falling within AP-5 according to different value of i {i=20 to 48} as shown in Figure 3. As shown in this figure, the probability would reach one when desired probability is 0.8 if the number of terminals is 32. The number of terminals would increase to 42 if the desired probability increases to 0.95.

According to distributed management and using binomial distribution, the total number of terminals that are only falling within AP-5 can be obtained by the following formula as shown in figure 4:

$$T = i \times p(x > i) \qquad (5)$$

Using signal strength terminal management the total number of terminals that are falling within AP-5 is N. Hence the advantage of using distributed management is reducing the number of terminals associated with a particular AP (eg. AP-5) by:

$$N - T = N - i \times p(x > i) \qquad (6)$$

If AP failed and its load distributed equally among 3 neighbor APs then extra load would be added to its neighbor AP in addition to formula 4 as follow:

$$p(x > i) + p(x \le i)/3 = 1 - 2\left(\sum_{k=0}^{i} \frac{n!}{(n-k!)k!} p^k (1-p)^{n-k} \right) \Big/ 3 \qquad (7)$$

As shown in figure 4, the maximum total number of terminals depends on the desired probability. When the desired probability is 0.95, the maximum number is 43 terminals. This number drops to 32 when the desired probability is reduced to 0,8. Using signal strength terminal management the total number of terminals that are falling within AP-5 is N.

As shown in figure 5, the total number of terminals falling within the same access points using signal strength is N (50 terminals) independent of the desired probability. The total number of terminals using distributed management depends on the desired probability, where the total number would be 32 at desired probability of 0.8, and it increases to 43 when the desired probability increases to 0.95. Hence, the total number of terminals falling within the same AP using distributed management drops by 1-32/50 (35%). This would allow terminals to have better bandwidth allocation using the distributed management scheme.

Using formula 7, figure 6 shows that at desired probability of 0.8, the probability of 40 terminals joins one AP when there is a failed AP is 0.6 higher than 0.4 when there is no AP failure. This increases of terminals associating with one AP is caused by the failure of neighbor AP where its terminals re-associate with other AP that fallen within its range after increasing its power coverage. Figure 7 shows similar effect of adding extra load to AP caused by terminals were associated with the failure AP and re-associated with neighbor AP after the failure.

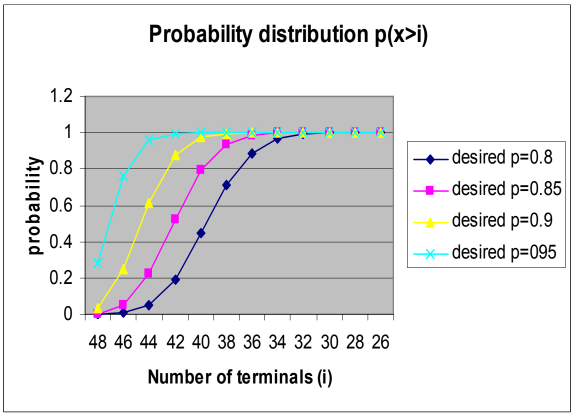

Fig. 3. Binomial Probability Distribution.

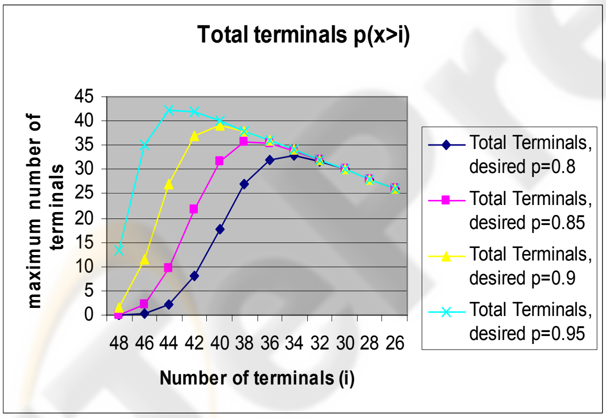

Fig. 4. Total number of terminals.

4 Conclusion

The architecture that has been described has the potential to improve performance, and deployment effectiveness in enterprise and other large-scale wireless LANs, and at the same time maintain a high network availability and reliability through network fault tolerance that is based on dynamic power coverage assignment. These improvements arise from the distributed dynamic resource management deployed in mobile terminals and APs.

The suggested technique assists the APs to optimize its performance by dynamically allocating different frequency to adjacent AP in order to reduce the signal interference. In addition, the association between mobile terminals and AP are distributed to different APs according to their location in the left or right hemisphere of the AP. Furthermore, fault tolerance has been provided through the dynamic power coverage assignment. The effect of fault tolerance improves the network availability, but it increases loads on APs. This increase of load would be temporarily until the failed AP has been replaced by working one.

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