Dynamic Load Balancing and Channel Allocation in Indoor Wireless Local Area Networks

A Thesis Proposal Presented

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1. Introduction

Wireless communications is one of the most active areas of technology development of our time. Over the recent years it has rapidly emerged in the market providing users with network mobility, scalability and connectivity. Wireless Local Area Networks (WLANs) have been developed to provide users in a limited geographical area with high bandwidth and similar services supported by the wired Local Area Network (LAN) [1].

The IEEE (Institute of Electrical and Electronics Engineers) 802.11 standards offer performance nearly comparable to that of Ethernet. In addition, they provide scalability, mobility, flexibility and relative ease of integration of wireless access. Unlike wired networks, WLANs, which uses IEEE 802.11 standards, transmit and receive radio waves through the air medium between a wireless client and an Access Point (AP), as well as among two or more wireless clients within a certain range of each other [2]. Radio wave signals propagate through walls, ceilings, and even cement structures.

A WLAN is a flexible data communications system that can either replace or extend a wired LAN where cost is an issue or running cables between floors or different rooms on the same floor is not feasible [3]. Examples of structures that are difficult to wire are warehouses, historic buildings, and manufacturing facilities. A WLAN basically consists of one or more wireless devices connected to each others in a peer-to-peer manner or through APs, which in turn are connected to the backbone network providing wireless connectivity to the covered area. Fig.1 shows a typical layout of a WLAN with two APs [4].

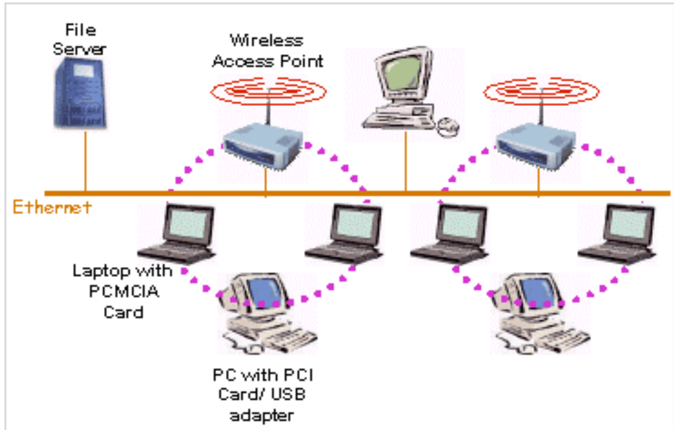

Fig. 1: WLAN with two APs

A WLAN can be configured in two basic modes:

- Peer-to-peer (ad hoc mode)- This mode consists of two or more PCs equipped with wireless adapter cards, but with no connection to a wired network, as shown in Figure 2 [5]. It is usually used to quickly and easily set up a WLAN where no infrastructure is available, such as a convention center or offsite meeting location.
- Client/Server (infrastructure networking)- This mode consists of multiple stations (Laptops, PDAs, PCs) linked to a central hub that acts as a bridge to the resources of the wired network, as shown in Figure 3 [6], offering fully distributed data connectivity

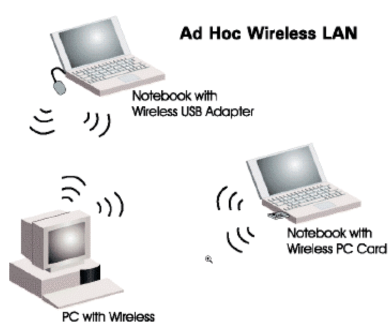

Fig. 2: Peer-to-Peer Wireless Configuration

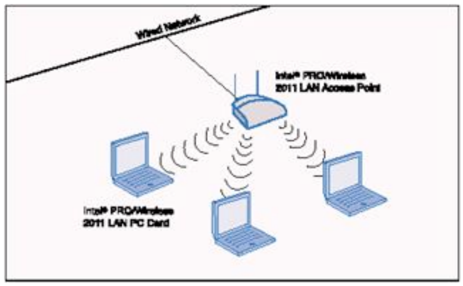

Fig. 3: Client/Server Wireless Configuration

In many situations, the deployment of a single AP is not enough to provide the required connectivity. As an example, large facilities, such as an office complex, a university campus, hospitals, large buildings or warehouses generally require many cooperating APs in order to provide the required services to the end users.

Services in the WLAN environment should be designed in order to achieve maximum coverage and throughput. AP placement, channel assignment and load balancing should be carefully examined to maximize coverage and throughput. Optimizing APs' placements and channel allocations result in improvement in Signal-to-Interference ratio (S/I), better bandwidth utilization for the whole network and higher throughput [7].

A major challenge when deploying WLANs is the channel allocation problem. The 802.11 wireless LANs operate in the unlicensed Industrial, Scientific and Medical (ISM) frequency of 2.4 GHz. This introduces interference from other electronic devices, such as microwave ovens and wireless phones. There are two types of interference in WLANs: adjacent channel interference and co-channel interference. Adjacent channel interference takes place between adjacent APs due to the fact that APs may share the same frequency bandwidth. On the other hand, co-channel interference takes place between APs using the same frequency channels [8].

The 802.11 standard specifies three techniques for data transmission in the physical (PHY) layer for lower data rates: Infrared (IR), frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS) [9]. Infrared technology, which is seldom used in WLANs, uses diffused (or reflected) transmission that does require line-of-sight and is limited to small areas due to the fact that IR, like light cannot penetrate opaque objects. However, most 802.11 systems of lower data rates use spread-spectrum technology. There are two spread spectrum techniques used in 802.11 that use short range radio waves operating in the unlicensed ISM band at 2.4 GHz: DSSS and FHSS. DSSS generates a chipping code (redundant bit pattern) for each bit to be transmitted. Due to this redundancy in transmission if one or more bits are damaged, the receiver can still recover the original data without the need for retransmission. To the unintended receiver, DSSS appears as low-power noise and is rejected. Of course, the drawback of this technique is the need for more bandwidth which is a limited resource in IEEE 802.11. On the other hand, FHSS uses a narrowband carrier (1 MHz), with 79 channels which begins at 2.412 GHz in the U.S. [7], which changes frequency in a pattern known to both transmitter and receiver. This technique provides good security since a user who does not know the hopping sequence of channels, cannot eavesdrop. FHSS appears as a short duration impulse noise to the unintended receiver. The main disadvantage of DSSS and FHSS is the low data rate (1 Mbps or 2 Mbps).

Two new techniques were introduced in 1999 for higher data rates [10, 11]. The two techniques are: Orthogonal Frequency Division Multiplexing (OFDM) and high range direct sequence spread spectrum (HR-DSSS). OFDM splits the data over multiple narrowband carriers (frequencies) to transmit simultaneously. The advantage of OFDM is the efficient use of the spectrum, better immunity to narrow band interference and lower multi-path distortion [12]. OFDM is used by 802.11a in the 5 GHz band and 802.11g in the 2.4 GHz. On the other hand, HR-DSSS spread spectrum, which is used by 802.11b, is the same as DSSS spread spectrum but uses 11 x 10^6 chips per second to achieve 11 Mbps data rate in the 2.4 GHz ISM band. However, HR-DSSS does support and is compatible with lower data rates of 1, 2, 5.5 and 11 Mbps.

2. Problem Statement and Scope of Thesis

This section summarizes the research the author plans to perform in order to complete the dissertation. Details of the techniques as well as plan of action are detailed later in this proposal.

Statement of Intent *The author plans to optimize AP selection by dynamically balancing traffic load and minimizing channel interferences by assigning optimal channels to the access points of an indoor WLAN.*

In wireless communications, there is always a demand for more bandwidth, increased coverage or range, increased data rate, decreased interference, and lower costs. Today, most AP based WLANs are inefficient in the sense they associate with new comers on the basis of power instead of user density. Therefore, they end up providing far less total throughput than they should [13].

Designing 802.11 WLANs include two major components: placement of APs in the service areas and assignment of radio frequencies to each AP. Coverage and capacity are some key issues when placing APs in a service area. APs need to cover all users. According to [7], "a user is considered to be covered if power received from its corresponding AP is greater than a given threshold.” Moreover, from a capacity point of view, APs need to provide certain minimum data rate to users located in the coverage area.

The first challenge resides in selecting APs positions in an optimal way to achieve maximum coverage and throughput. In other words, APs should be placed to achieve maximum coverage possible with the least number of APs.

According to [14], the number of APs needed to support the load of a given coverage area is determined using the following equation

$$N_{AP} = (bw_{user} * N_{user} * \%activity) / (\%effeciency*rate_{association}) \quad (1)$$

where N_{AP} is the number of APs needed to provide the required capacity, bw_{user} is the bandwidth required per user, N_{user} is the number of users in the area, *%activity* is the fraction of time the users are active, *%efficiency* is the channel efficiency defined as the ratio of actual-rate over association-rate which is $rate_{association}$. Equation (1) is used for large coverage areas that require high bandwidth with uniformly distributed users. If a small amount of bandwidth is needed for a large coverage area, then the number of APs cane be determined by the following equation [14],

$$N_{AP} = C_{total} / C_{AP}, \quad (2)$$

where C_{total} is the total area to be covered, and C_{AP} is the coverage area of a single AP based on maximum power.

The second challenge is to assign channels to the APs in a manner that achieves minimum co-channel and adjacent cell interferences.

The last and greatest challenge of all is to dynamically keep the network at optimum performance. In other words, every node that connects to or disconnects from an AP should be updated into the WLAN network database through a centralized station. The WLAN network in turn reconfigures the association and dissociation of nodes with their respective APs in order to maintain the best level of performance i.e. maximum coverage and minimum interference. Node mobility can be looked at as dynamic traffic decreasing with the dissociation and increasing with the association of nodes. Few techniques have been proposed to cover the first two challenges for fixed or static load [7, 8], where the distribution of demand clusters and service areas are known before hand.

The author plans to add the dynamic feature in conjunction with optimal AP placement and channel assignment to improve the overall network performance and throughput through minimizing cost, in terms of number of APs, and maximizing bandwidth utilization.

3. Literature Review

There are various similarities between WLANs and cellular networks. Several deployment problems have been extensively studied in the context of cellular networks [14]. The problem of optimizing the selection of APs can be traced back to the cellular communication industry where the authors in [15, 16] stated that "one of the most important problems in the design phase of a cellular radio network is where to locate and how to configure base stations." The objective was to serve the most traffic while the amount of interference is kept small. In [15] the authors provided analytical optimization problems where each problem was formalized as an Integer Linear Program (ILP) and was solved for relevant examples of realistic problem size. However, in [16] the authors used a different optimization algorithm called Divide-and-Conquer to select the BSs. The algorithm divides the total serviced area into equal sized grids and then the problem is solved in each of these grids by exhaustive search. The authors in [17] developed an analytical framework for the analysis of dynamic load balancing schemes with multiple traffic types (voice and video). Moreover, theoretical expressions were developed to study the call blocking probability performance of voice and video traffic cellular networks which employ dynamic load balancing schemes. Results showed that with proper amount of load balancing capability (load balancing channels) and proper amount of relay station coverage, the call blocking probability for all traffic types can be reduced significantly up to 60% in hot (congested) cells.

In [7] and [8], the authors proposed an approach to optimize AP placement and channel assignment in WLANs by formulating an optimal ILP. The optimization objective in [7, 8] is to minimize the maximum channel utilization on a data network, which quantitatively represents congestion at the hot spot in WLAN service areas. By using a simple model of demand point to construct various amounts of traffic by users and channel assignment graphs, the WLAN service design process can be easily performed. The proposed method finds the best set of AP locations for load balancing by considering user traffic demands (constant bandwidth is provided by a channel at an AP regardless of the number of active users and connection bit rates). From simulation results, it is shown that the maximum channel utilization or the number of selected APs is minimized. The authors in [8] considered dynamic load balancing traffic but did not provide the reconfiguration of demand clusters in the network. Traffic disruption, caused by the association and dissociation of demand clusters to and from their respective APs, is minimized

In [18], the authors reported experimental and analytical results to address the problem of designing high capacity WLANs based on 802.11b technology. The authors studied the impact of hidden and exposed terminal on the capacity increase in a layout of APs in a WLAN. The hidden terminal problem occurs when two or more stations outside the "hearing" range of each other transmit to one station that is within the hearing range of both, causing a collision. Figure 4 shows the hidden terminal problem [19].

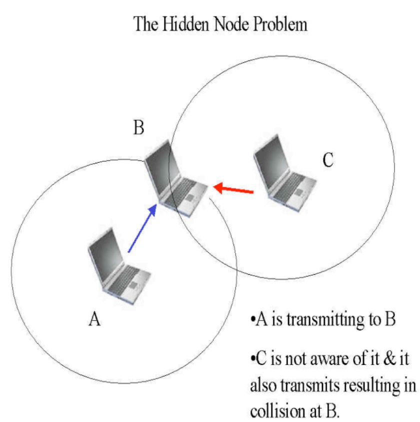

Fig. 4: Hidden terminal phenomenon

The exposed terminal phenomenon, shown in Figure 5 [20], occurs when station A is transmitting to Station B and station X wants to transmit to station Y but cannot do so since it is in the hearing range of station A, so it must defer its own transmission. However, if both stations A and X transmit at the same time, all frames would be successfully received. Hence, the large transmission range of station A has prevented other stations from sending and receiving, while they can do so without colliding. Therefore, in the design of high density WLANs, particular attention must be paid to the means by which the effects of exposed terminals in the network can be reduced since there is limited control over transmission ranges of wireless devices.

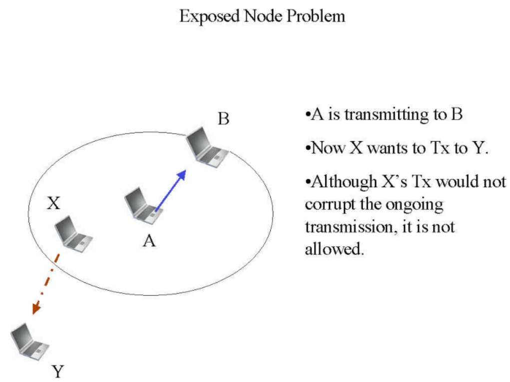

Figure 5: Exposed Terminal Phenomena

In conclusion, without proper consideration of cell locations and cell sizes in the design phase, deployment of high-density WLANs using current 802.11b/g technology carries significant risk of poor performance.

In [14], the authors showed how the current deployment processes use ad-hoc and manual measures to optimize coverage and capacity throughout enterprises. Moreover, the authors described various tools and techniques that can perform on-going coverage optimizations of the network and addressed some of these issues. Three of the core problems, namely RF propagation modeling, AP positioning and channel allocation, and their respective solutions during a large-scale deployment were discussed in detail throughout the paper. Finally, the authors discussed how the number of channels per AP, transmitted power and mode of operation could be intelligently tuned to adapt the network capacity according to traffic patterns. Even though dynamic load balancing, dynamic channel allocation and dynamic transmit power control for capacity provisioning were discussed in [14], the authors did mention that the algorithms of these dynamic optimization techniques were not made public.

It should be noted that moving objects or obstacles would cause unpredictable fluctuations in the received signal strength. Therefore, the authors in [21] investigated the influence of moving obstacles, such as people, on indoor radio wave propagation and the effect on received signal quality in WLAN. It was shown that the presence of moving obstacles seriously affects the performance of the system by introducing large variations in the received signal strength due to fast fading and small area shadowing. The authors proposed a model for WLAN channel parameter prediction incorporating the effects of moving objects on performance of an IEEE 802.11 WLAN.

4. Goals and Objectives

The proposed research is based on needs that have been identified based on a comprehensive review of the current state of the art knowledge in the field of deploying APs and dynamic traffic load balancing in WLANs. The goals of this research can be summarized as follows:

1. Optimal AP selection and traffic allocation: Formulate an optimal access point placement by balancing present traffic load.
2. Optimal dynamic channel allocation: Formulate a dynamic optimal channel assignment by minimizing interference between APs in WLANs.
3. Dynamic reconfiguration of AP assignments: Formulate a dynamic optimal reconfiguration assignment of newly associating/dissociating nodes by keeping channel interference between APs at a minimum.

The simulation of the various components of the research will be done using a variety of computer packages including, but not limited to, LINear and General Optimization (LINGO) [22], Wireless InSite [23], and OPtimized Network Engineering Tools (OPNET) [24]. In addition to these tools, programming using C++ and Matlab will be utilized. The emphasis of the simulations will focus on evaluating the performance of the system:

- Under a variety of signal-to-interference ratios,
- On a varying traffic load with time,
- With various propagation models, and
- With realistic models of buildings and floors.

5. Originality and Relation to Other Work

Little work has been done on the optimization of AP placements and channel allocations. Previous research considered static optimization where the number of demand clusters was fixed and assumed not to change with time.

The work reported by [7] and [8] dealt with load balancing techniques performed only at association time. In other words, the models presented so far are not realistic, for they do not support time varying loads. A dynamic load balancing scheme should be able to:

- Continuously balance the traffic load on APs,
- Dynamically allocate non-overlapping channels to newly associated clients and,
- Allocate non-occupied non-overlapping channels from newly dissociating clients to congested hot spots on the network.

For instance, if a client joins the network, the scheme will associate the client with the least loaded access point or channel available in the neighborhood. However, the traffic patterns of clients can change over time making the associated channel non-optimal. Therefore, a dynamic load-balancing scheme is proposed in this research, whereby newly joining clients are re-associated with a less loaded channel on the AP and newly not used channels are assigned to congested APs to optimize the load traffic and channel allocation on the network for coverage and capacity provisioning satisfying the co-channel and adjacent channel interference constraints.

6. Research Implementation Plan

The research is planned to be executed in three phases. Phase one, or the preparatory phase, has already been started and is in progress. Phase two and three will be executed independently except for some tasks that could be done concurrently.

6.1 Phase One

The work described in this subsection has been started and is in progress. This phase includes literature review and getting familiar with the available software packages-OPNET [24] and Wireless InSite [23]. Some simulations have been already conducted using these two software packages. For instance, in Wireless InSite, an outdoor simulation tutorial of propagation paths and models have been conducted in the city of Rosslyn, VA. Figure 6 shows the top view of Rosslyn, VA. Although this simulation is not directly related to the indoor environment, it does help achieve the basic understanding of the software features and its capabilities that will assist in simulating future indoor models. The software is capable of displaying propagation results, visual paths traced between receiver and transmitter, signal degradations and strengths with distance taking into consideration moving objects and materials of objects of interest. Another tutorial based on an indoor environment was simulated using the design proposed in [25] taking into consideration the material of the walls, doors, windows, ceiling and floor. Figure 7 shows the different colors of walls which implies different kind of materials.

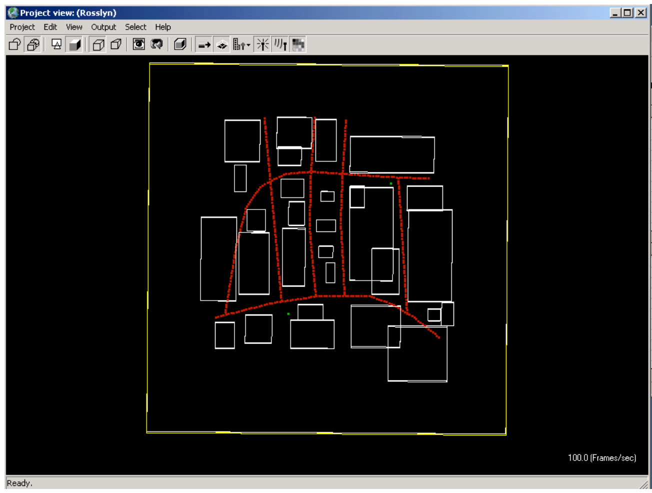

Fig. 6: Rosslyn, VA with designated Receiver Routes (red lines) and Transmitter points (green dots)

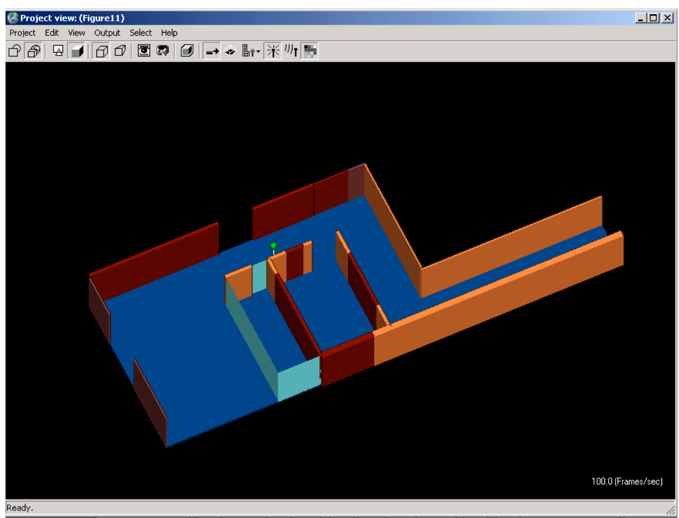

Fig. 7: Indoor example with Transmitter point (green dot)

On the other hand, the author of this proposal is facing some challenges in modeling WLAN environments using OPNET but is working on resolving them in a few weeks once the wireless license is received.

At the end of this phase, the author would have developed sufficient amount of simulations on realistic indoor environments that should aid in formulating the optimization problem with the properly defined constraints. This phase will provide realistic modeling scenarios for the indoor environments.

6.2 Phase Two

Phase two involves formulating the optimization problem. This phase runs concurrently with phase one where the author is attending a graduate course on optimization offered by Dr. Yupo Chan in order to help in formulating the ILP algorithm. At the end of this phase, a static optimization formulation should be available to provide results for the initial configuration of APs placements and assignment of non-overlapping channels to present demand clusters. The results will be validated by comparison with other configurations published in the literature.

6.3 Phase Three

In the final phase, the dynamic feature will be added to the optimization techniques that will allow continuous reconfiguration of the network with time as clients join or leave the network based on the traffic load on APs and other constraints, such as S/I and power control. A mobility model based on Poisson distribution will be simulated to represent the dynamic feature. This will be presented in terms of a statistical distribution that will provide realistic mobility of the traffic. Several simulations will be carried out under different scenarios and constraints such as, different propagation models, different configuration of nodes and various signal-to-noise ratio threshold values. Also, results will be presented and compared to the models reported in [7] and [8].

7. Expected Outcome

In this research a study of new concepts will be developed to efficiently utilize the channel and improve the capacity and coverage area in a WLAN. At the end of this research, formulation and results achieved will be presented. The applicability of the model presented in the research will be tested and compared to realistic models. It is expected that the proposed dynamic traffic load-balancing scheme will lead in utilizing the channel (capacity) and coverage more efficiently.

8. Conclusion

The demand for more capacity and better coverage in a WLAN environment has been increasing steadily for the last few years [26]. However, the assigned channels in the IEEE 802.11 WLAN are fixed (14 frequency channels, 1 through 11 are used in USA). Researchers have been actively investigating how to efficiently utilize the available channels by implementing different techniques and algorithms such as, better placement algorithms for APs, load-balancing on APs, and assigning non-overlapping channels (frequencies) to adjacent APs to minimize interference. Dynamic load balancing is a technique that improves coverage areas of APs and capacity provisioning in a WLAN environment. Unlike other load balancing techniques, the proposed approach strives to give the optimal performance as time progresses.

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