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ABSTRACT

As mobile devices become common in mainstream computing, it becomes imperative to effectively design computing architectures that seamlessly and effectively integrate them. Rapid advancements in wireless technology has made it possible to build efficient wireless local area networks (WLANs). Designing WLANs presents some unique challenges. Some heuristics are available for WLAN design, but they represent piecemeal solutions, focusing on a limited set of issues. This paper provides a more comprehensive approach to WLAN design, by providing support for additional tasks in the design process, as well as by providing the designer the option of examining multiple competing options. The approach is developed in modular fashion, thereby permitting the easy substitution of alternative models in any phase of the process. We believe the approach to be useful for WLAN designers, and it provides an apt illustration of design science in information systems research.

Keywords:

WLAN design, Network infrastructure, Wireless networking, Mobile computing.

INTRODUCTION

Wireless networking has the potential to provide users unprecedented flexibility in accessing and modifying information. It is estimated that in near future, about 40% of the e-commerce transactions will be initiated through a mobile device or involve some form of wireless networking (Varshney and Vetter, 2002). Wireless networks come in many forms, though it is convenient to classify them in terms of their range (Agarwal et. al., 2003). These include personal area networks, wireless local area networks, wireless metropolitan area networks, and wireless wide area networks. This paper addresses wireless local area networks (WLANs) only. WLANs are the drivers behind the widespread availability of hotspots that offer wireless connectivity to the Internet. With a wide variety of hardware, software, security, and protocol choices available, the design and implementation of WLANs could be challenging and confusing (Varshney, 2003). Several heuristic approaches to WLAN design are available. However, they represent piecemeal solutions. This paper attempts to provide a more comprehensive approach to WLAN design to assist and guide potential WLAN designers through the multifaceted decisions that constitute the process. It presents a design framework that allows WLAN designers to assemble alternative designs, evaluate these alternatives, and assist in the selection of a preferred design.

CURRENT APPROACHES TO WIRELESS LAN DESIGN

A number of different approaches have been proposed for WLAN design, including vendor whitepapers, design guidelines, and solution techniques for specific issues. Wireless network throughput represents an important aspect of WLAN design. The theoretical maximum throughput under alternative security protocols is discussed in (Jun et al., 2003). A similar analysis is provided in (Cisco, 2003a). Placement of wireless access points is another aspect of WLAN design that has received attention. Lee et. al. (2003) develop a integer programming solution strategy for optimal placement to achieve load balancing given user traffic demands. Security in WLANs is an area that has been the subject of design guidelines. Convery et. al. (2003) provide a detailed discussion on WLAN security. Edney and Arbaugh (2004) provide detailed discussions on security protocols for WLAN design, and suggest the use of a security architecture. Performance modeling for networks is also relevant to WLAN design, with models for resource utilization and response time presented in (Menasce and Almeida, 2003).

Several authors acknowledge the need for a more comprehensive approach. Gast (2002) proposes the incorporation of network topology, project planning, and site surveys as part of WLAN design, without addressing the core tasks in WLAN design. Roshan and Leary (2003) suggest the use of quality of service measures, deployment, and security, though no clear solution strategy is presented. Perhaps the most comprehensive approach is presented in (Cisco, 2003b). It discusses hardware selection (pp 3-11 – 3-15), security considerations (pp 4-11 – 4-14), quality of service measures (pp 6-17 – 6-18), and roaming considerations (pp 7-9 – 7-10), as fundamental issues in WLAN design. Though the presentation is slanted towards Cisco products, the discussions are useful and can be adapted for a more universal treatment.

However, none of these approaches provide a truly holistic solution. Rather, they represent piecemeal attempts to address various facets of WLAN design. This paper adopts the view that WLAN designers could benefit from a more comprehensive approach, that addresses these issues, while also factoring in cost and performance considerations.

WIRELESS LAN DESIGN FRAMEWORK

For the purposes of this paper, a WLAN is viewed as consisting of wireless devices, hotspots, hotspot controllers, and access points. Several different topologies are possible. A number of protocols and standards for supporting different forms of wireless communication are also available. The design approach advocated here assumes the following:

- Wireless devices are not addressed.
- WLAN topologies are also not addressed.
- Only wireless networks that employ the IEEE 802.11 technical specification are addressed.

WLAN Design is a multidimensional problem. It involves decisions that address very different aspects, but are in some manner related. This paper adopts a modular approach to WLAN design. This permits working on different aspects of the design in independent manner, as well as the easy swap of one component, should the underlying technologies change, or should alternative designer preferences dictate so. We have identified four related modules for WLAN design, viz. infrastructure design, security design, cost estimation, and performance modeling. These components are inexorably linked, but can be addressed in somewhat independent manner. It is not the intent that the framework produces a single WLAN design recommendation. Rather, it is expected that multiple competing designs are possible, characterized by different cost, performance, and security measures. Allowing the designer to trade off between these objects is a necessary part of the design framework. The basic structure of the proposed WLAN design framework is presented in Figure 1. External inputs will shape the design of individual components. Relationships between various design components are also highlighted.

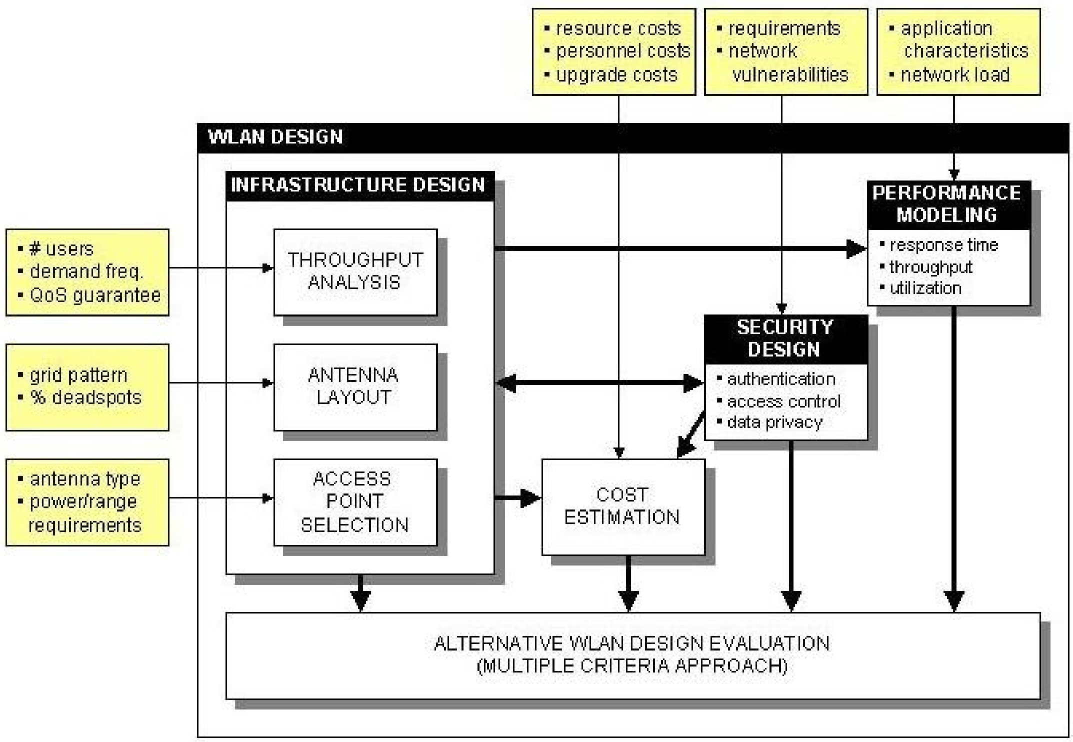

Figure 1. Wireless LAN Design

Infrastructure Design

Specifying the architectural components for a WLAN requires estimation of network throughput, selection of access points, and layout to meet specific objectives. These are related decisions, and must be performed in tandem. Selection of access point devices will affect the layout, and subsequent cost of the WLAN. Likewise, throughput will be affected by access point selection and layout, and will in turn affect the performance.

Network Throughput Analysis

WLAN throughput requirements can be computed is several ways. One approach is based on users and their individual requirements. This is a data intensive strategy that requires identification of all users, estimation of their requirements, including frequency of access, and specification of the resource requirements at the server for each requirement. Network throughput WT_{est} is estimated as

$$WT_{est} = \sum_p \sum_q f_{pq} \times D_q \times 8192 \times (1 + OH)$$

where f_{pq} represents the frequency of access of application q by user p, D_q the data returned by application q, 8192 converts bytes to Kilobits, and OH represents the wireless protocol overhead (approximately 0.8 to 1).

Since this involves tedious data collection, and potentially suspect data based on user perceptions of frequencies, an analysis of server logs may yield a more accurate picture, based on the service demand for different types of requests. Using this approach, network throughput can be estimated as

$$WT_{est} = \sum_i sd_i \times R_i \times 8192 \times (1 + OH)$$

where sd_i represents the service demand for request type i, and R_i the volume of data returned by request type i.

The designer can select either approach, or employ both to estimate throughput. Actual throughput is a function of bandwidth, error performance, congestion, and other factors. Throughput is also moderated by quality of service guarantees. A simple estimate of network throughput is given by

$$WT = \frac{B \log_2 (1 + S/N)}{1 + dR/lv}$$

where B is the bandwidth, S/N represents the signal to noise ratio, d the distance traversed, R the data transfer rate, l the frame length, and v the transmission velocity. Accordingly, the signal strength S can be estimated, for a given signal to noise ratio.

Access Point Selection

The access point characteristics are specified in terms of the type, power, and range of the antenna selected. Clearly, the larger the range, the fewer the number of devices needed. This also has implications for throughput and costs.

Antenna Layout

The layout model of the access points will depend on the grid pattern or the way the access points will be placed (hexagonal versus tiled), the percentage area of deadspots and the access point characteristics. Deadspots can be computed as

$4d^2 - 4\pi r^2$ for a tiled layout, or

$1.5\sqrt{3}d^2 - 3\pi r^2$ for a hexagonal layout,

where d represents the distance between access points, and r is the range for the antenna. Based on this, the percentage of deadspots for a non-overlapping regular layout is 21.5% for tiled, and 9.3% for hexagonal patterns. Deadspots can be eliminated by shrinking d, and this condition is achieved for $d=1.77r$ for a tiled pattern, and $d=1.90r$ for a hexagonal pattern. Selecting values of d less than this provides no additional benefit, and increases overlap. In the layout model, the designer can select an appropriate configuration and distance between antennae, trading off overlap and deadspots.

Security Design

This component enables a designer to specify security requirements, including specification of security protocols used, user authentication policy, and user access policy. At the WLAN layer, it is important to ensure that the integrity of the data is not compromised, and protocols for encryption need to be selected. Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA) based on Temporal Key Integrity Protocol (TKIP), Robust Security Networks (RSN) represent options for the designer to select.

At the access control layer, the aim is to ensure that only data from authorized users enters the WLAN. Protocols that can be used to implement access control in WPA and in RSN include IEEE 802.1X, Extensible Authentication Protocol (EAP), and Remote Authentication Dial-In User Service.

The authentication layer establishes user identity, and the policy decisions are made at this layer. Protocols available at this stage include Transport Layer Security (TLS) [the default for WPA], Kerberos V5, and Protected Extensible Authentication Protocol (PEAP).

Given the multiplicity of goals for security design, no single solution approach can be universally recommended. Instead, a prescriptive system using a rule-based strategy is recommended.

Cost Estimation

The cost incurred for installing and operating a WLAN is easily computed. Initial setup costs include hardware, software, installation and configuration costs. Operating and maintenance costs include personnel costs, and upgrade costs. In an effort to maintain comparability between the initial and ongoing costs, the ongoing costs will be computed for a period of two years, as rapid technology advancement would render the design obsolete. To facilitate equal treatment of vendor costs, suggested list prices will be employed for all hardware, software, and upgrade costs. All cost information will be stored in a database for easy computation and update

Performance Modeling

Several different measures of network performance have been recommended, such as response time, throughput, availability, and cost among others (Menasce and Almeida 2002). This approach to WLAN design will focus on network utilization, response time, and throughput, as performance relevant metrics.

Utilization can be easily estimated for each resource in the WLAN. Utilization for a resource j is simply estimated as

$$U_j = \sum_i sd_{ij} \times ST_{ij}$$

where sd_{ij} represents the service demand for request type i at resource j, and ST_{ij} is the service time for request type i at resource j. Clearly, utilization cannot exceed 1. An average value of utilization across resources is not meaningful, and instead, the maximum value, representing the bottleneck resource, is suggested.

Response time is estimated using a queuing model where service time and wait time at each resource needed by a request are estimated. This is estimated as:

$$\textit{Average response time} = \sum_i f_i \times RT_i = \sum_i f_i \times \left(\sum_{j^*} \frac{ST_{ij}}{(1 - U_j)} \right)$$

where f_i represents the relative frequency of request type i as a fraction, RT_i is the estimated response time for request type i, and U_j is the utilization of resource j. Note that the computation includes only those resources that are needed for this request.

Throughput can be estimated in a variety of ways. While it is tempting to examine it from a resource perspective, e.g. number of requests serviced by resource, it is more meaningful to estimate it from a user perspective, particularly in the case of lost connections, dropped messages, and request timeouts. Accordingly, throughput is estimated as:

$$T_{est} = \sum_i \left(sd_i \middle| RT_i \le RT_{\max} \right)$$

where RT_{max} represents the response timeout for requests.

WLAN Design Evaluation

The design process outlined will permit the WLAN designer to generate several different WLAN designs, each of which is characterized by several dimensions, including deadspot percentage, cost, security considerations met, network utilization, response time, and throughput. These metrics employ different units, making comparability difficult. It is recommended that a multiple criteria approach be adopted for alternative design evaluation, given that the importance accorded to different criteria will vary. An intuitively appealing approach is the use of the Analytic Hierarchy Process (Saaty, 1980). It permits decision makers to trade off among diverse criteria without having to perform explicit tradeoffs. Additionally, it provides for a hierarchical analysis of the problem, permitting the designer to examine related criteria when evaluating solutions. Another alternative is a neighborhood search of a promising solution. After generating several alternative designs, the designer can select a preferred solution, and search in close proximity of this solution. Yet another approach would involve the use of an ideal solution, and the use of multidimensional scaling to select a solution that is the closest to this ideal. Traditional multiple criteria decision making methods like multi-objective linear programming are not recommended given the nature of the functions.

FUTURE RESEARCH

Implementation of the design modules and integration into a cohesive system represents the next logical step. The use of a variety of solution approaches, e.g. algorithmic (infrastructure design, cost estimation), rule-based (security design), probabilistic (performance modeling), and interactive iterative (design evaluation), coupled with the need for a separate database on product characteristics, introduces the need for interoperability between modules, and the assembly of a robust physical architecture of the design components. Creation, calibration, and testing of the models will entail some simulation to validate performance under a variety of design scenarios. Application to real world design problems would then be undertaken. This includes application to new design problems, as well as identification of alternative designs for currently wired facilities.

CONCLUSIONS

This paper discusses an approach to WLAN design that is more comprehensive than the current heuristic approaches. Support is provided for infrastructure design, security design, and performance estimation. Several mechanisms are proposed for the evaluation of competing designs. The use of a modular approach permits easy replacement of one component of the design with relatively little effect on the rest of the design. Upgrades to the framework, to accommodate new technologies or alternative considerations, are also facilitated. Clearly there are other considerations that have not been included in the design framework. Likewise, some assumptions for the estimation procedures can be challenged. Nonetheless, it represents a good starting point for WLAN design. It provides a designer with a set of meaningful measures to evaluate alternative designs, thereby leading to a more informed decision, and presumably a better design.

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