Wireless Mesh Networks

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ABSTRACT

Wireless mesh networks (WMNs) consist of mesh routers and mesh clients, where mesh routers have minimal mobility and form the backbone of WMNs. They provide network access for both mesh and conventional clients. The integration of WMNs with other networks such as the Internet, cellular, IEEE 802.11, IEEE 802.15, IEEE 802.16, sensor networks, etc., can be accomplished through the gateway and bridging functions in the mesh routers. Mesh clients can be either stationary or mobile, and can form a client mesh network among themselves and with mesh routers. WMNs are anticipated to resolve the limitations and to significantly improve the performance of ad hoc networks, wireless local area networks (WLANs), wireless personal area networks (WPANs), and wireless metropolitan area networks (WMANs). They are undergoing rapid progress and inspiring numerous deployments. WMNs will deliver wireless services for a large variety of applications in personal, local, campus, and metropolitan areas. Despite recent advances in wireless mesh networking, many research challenges remain in all protocol layers. This project presents a detailed study on recent advances and open research issues in WMNs. System architectures and applications of WMNs are described, followed by discussing the critical factors influencing protocol design. Theoretical network capacity and the state-of the-art protocols for WMNs are explored with an objective to point out a number of open research issues. Finally, testbeds, industrial practice, and current standard activities related to WMNs are highlighted.

KEYWORDS

Wireless mesh networks; Ad hoc networks; Physical layer Network layer

INTRODUCTION

As various wireless networks evolve into the next generation to provide better services, a key technology, wireless mesh networks (WMNs), has emerged recently. In WMNs, nodes are comprised of mesh routers and mesh clients. Each node operates not only as a host but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations. A WMN is dynamically self organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves (creating, in effect, an ad hoc network). This feature brings many advantages to WMNs such as low up-front cost, easy network maintenance, robustness, and reliable service coverage.

Conventional nodes (e.g., desktops, laptops, PDAs, PocketPCs, phones, etc.) equipped with wireless network interface cards (NICs) can connect directly to wireless mesh routers. Customers without wireless NICs can access WMNs by connecting to wireless mesh routers through, for example, Ethernet. Thus, WMNs will greatly help the users to be always-on-line anywhere anytime.

Moreover, the gateway/bridge functionalities in mesh routers enable the integration of WMNs with various existing wireless networks such as cellular, wireless sensor, wireless-fidelity (Wi-Fi) [11], worldwide inter-operability for microwave access (WiMAX) [7], WiMedia [8] networks. Consequently, through an integrated WMN, the users of existing network can be provided with otherwise impossible services of these networks. WMN is a promising wireless technology for numerous applications [3], e.g., broadband home networking, community and neighborhood networks, enterprise networking, building automation, etc. It is gaining significant attention as a possible way for cash strapped Internet service providers (ISPs), carriers, and others to roll out robust and reliable wireless broadband service access in a way that needs minimal up-front investments. With the capability of self-organization and selfconfiguration, WMNs can be deployed incrementally, one node at a time, as needed. As more nodes are installed, the reliability and connectivity for the users increase accordingly. Deploying a WMN is not too difficult, because all the required components are already available in the form of ad hoc network routing protocols, IEEE 802.11 MAC protocol, wired equivalent privacy (WEP) security, etc. Several companies have already realized the potential of this technology and offer wireless mesh networking products. A few testbeds have been established in university research labs. However, to make a WMN be all it can be, considerable research efforts are still needed. For example, the available MAC and routing protocols applied to WMNs do not have enough scalability; the throughput drops significantly as the number of nodes or hops in a WMN increases. Similar problems exist in other networking protocols. Consequently, all existing protocols from the application layer to transport, network MAC, and physical layers need to be enhanced or re-invented. Researchers have started to revisit the protocol design of existing wireless networks, especially of IEEE 802.11 networks, ad hoc networks, and wireless sensor networks, from the perspective of WMNs. Industrial standards groups are also actively working on new specifications for mesh networking. For example, IEEE 802.11 [6], IEEE 802.15 [8], and IEEE 802.16 [5] all have established sub-working groups to focus on new standards for WMNs. The remainder of the paper is organized as follows, we present possible system architectures of WMNs. The characteristics of WMNs are summarized , where a comparison between WMNs and ad hoc networks is also conducted. There is different application scenarios of WMNs are addressed. Critical factors influencing protocol design.

Characteristics

The characteristics of WMNs are explained as follows:

- Multi-hop wireless network. An objective to develop WMNs is to extend the coverage range of current wireless networks without sacrificing the channel capacity. Another objective is to provide non-line-of-sight (NLOS) connectivity among the users without direct line-of-sight (LOS) links. To meet these requirements, the mesh-style multi-hopping is indispensable [5], which achieves higher throughput without sacrificing effective radio range via shorter link distances, less interference between the nodes, and more efficient frequency re-use.
- Support for ad hoc networking, and capability of self-forming, self-healing, and self-organization. WMNs enhance network performance, because of flexible network architecture, easy deployment and configuration, fault tolerance, and mesh connectivity, i.e., multipoint-to-multipoint communications [10]. Due to these features, WMNs have low upfront investment requirement, and the network can grow gradually as needed.
- Mobility dependence on the type of mesh nodes. Mesh routers usually have minimal mobility, while mesh clients can be stationary or mobile nodes.
- Multiple types of network access. In WMNs, both backhaul access to the Internet and peer-to-peer (P2P) communications are supported [5]. In addition, the

integration of WMNs with other wireless networks and providing services to end-users of these networks can be accomplished through WMNs.

• Dependence of power-consumption constraints on the type of mesh nodes. Mesh routers usually do not have strict constraints on power consumption. However, mesh clients may require power efficient protocols. As an example, a mesh-capable sensor [1,11] requires its communication protocols to be power efficient. Thus, the MAC or routing protocols optimized for mesh routers may not be appropriate for mesh clients such as sensors, because power efficiency is the primary concern for wireless sensor networks [8,9].

• Compatibility and interoperability with existing wireless networks. For example, WMNs built based on IEEE 802.11 technologies [3,9] must be compatible with IEEE 802.11 standards in the sense of supporting both meshcapable and conventional Wi-Fi clients. Such WMNs also need to be inter-operable with other wireless networks such as WiMAX, Zig- Bee [8], and cellular networks. Based on their characteristics, WMNs are generally considered as a type of ad-hoc networks due to the lack of wired infrastructure that exists in cellular or Wi-Fi networks through deployment of base stations or access points. While ad hoc networking techniques are required by WMNs, the additional capabilities necessitate more sophisticated algorithms and design principles for the realization of WMNs. More specifically, instead of being a type of ad-hoc networking, WMNs aim to diversify the capabilities of ad hoc networks. Consequently, ad hoc networks can actually be considered as a subset of WMNs. To illustrate this point, the differences between WMNs and ad hoc networks are outlined below. In this comparison, the hybrid architecture is considered, since it comprises all the advantages of WMNs.

• Wireless infrastructure/backbone. As discussed before, WMNs consist of a wireless backbone with mesh routers. The wireless backbone provides large coverage, connectivity, and robustness in the wireless domain. However, the connectivity in ad hoc networks depends on the individual contributions of end-users which may not be reliable.

• Integration. WMNs support conventional clients that use the same radio technologies as a mesh router. This is accomplished through a host-routing function available in mesh routers. WMNs also enable integration of various existing networks such as Wi-Fi, the Internet, cellular and sensor networks through gateway/ bridge functionalities in the mesh routers. Consequently, users in one network are provided with services in other networks, through the use of the wireless infrastructure. The integrated wireless networks through WMNs resembles the Internet backbone, since the physical location of network nodes becomes less important than the capacity and network topology.

• Dedicated routing and configuration. In ad hoc networks, end-user devices also perform routing and configuration functionalities for all other nodes. However, WMNs contain mesh routers for these functionalities. Hence, the load on end-user devices is significantly decreased, which provides lower energy consumption and high-end application capabilities to possibly mobile and energy constrained end-users. Moreover, the end-user requirements are limited which decreases the cost of devices that can be used in WMNs.

• Multiple radios. As discussed before, mesh routers can be equipped with multiple radios to perform routing and access functionalities. This enables separation of two main types of traffic in the wireless domain. While routing and configuration are performed between mesh routers, the access to the network by end users can be carried out on a different radio. This significantly improves the capacity of the network. On the other hand, in ad hoc networks, these functionalities are performed in the same channel, and as a result, the performance decreases.

• Mobility. Since ad hoc networks provide routing using the end-user devices, the network topology and connectivity depend on the movement of users. This imposes additional challenges on routing protocols as well as on network configuration and deployment.

Physical layer

Advanced physical layer techniques

Physical layer techniques advance fast as RF and circuit design for wireless communications evolve. Most of existing wireless radios are able to support multiple transmission rates by a combination of different modulation and coding rates [7,8]. With such modes, adaptive error resilience can be provided through link adaptation [11,3,2]. It should be noted that under a frequency selective fading environment, a link adaptation algorithm cannot take signal-to-noise ratio (SNR) or carrier-to-interference ratio (CIR) as a single input from the physical layer, because SNR or CIR alone does not adequately describe the channel quality [8]. In order to increase the capacity of wireless networks, various high-speed physical techniques have been invented. For example, orthogonal frequency multiple access (OFDM) has significantly increased the speed of IEEE 802.11 from 11 Mbps to 54 Mbps. A much higher transmission rate can be achieved through ultra-wide band (UWB) techniques. However, UWB is only applicable to short-distance applications such as wireless personal area networks (WPANs). If a transmission speed as high as that of UWB is desired in a wider area network such as WLANs or WMANs, new physical layer techniques are needed. In order to further increase capacity and mitigate the impairment by fading, delay-spread, and co-channel interference, multiple-antenna systems have been used for wireless communication [10,2]. This techniques such as antenna diversity and adaptive/smart antennas can be used for a multiantenna system. They have been proposed for point-to-multipoint one-hop cellular networks. Antenna diversity is based on the fact that signals received from uncorrelated antennas have independent fading. Thus, it has high probability that at least one good signal can be received at the receiver.

Antenna uncorrelation is usually achieved through space, polarization, or pattern diversity, and the processing technologies for diversity include switch diversity, equal gain, and maximum ratio combining [4]. When strong interference is present, diversity processing alone is insufficient to receive signals with high quality. To resolve this issue, adaptive antenna array processing is used to shape the antenna beamform so as to enhance the desired signals while to nullify the interfering signals. The technique for adaptive antenna processing is called optimum combining. It assumes that part information of the desired signal can be acquired through a training sequence. Antenna diversity and smart antenna techniques are also applicable to WMNs and other ad hoc networks. However, their performance in WMNs or any other ad hoc networks needs more evaluation. Examples of analyzing smart antenna systems for MANETs are reported in [1,11]. Due to complexity and cost, a fully adaptive smart antenna system is only used in base stations of cellular networks. On-going research and development efforts are still needed to implement fully adaptive smart antenna system in a mobile terminal.

For WMNs, low-cost is a challenging issue. As a consequence, directional antennas have been actively researched in the area of ad hoc networks. A mechanically or electronically steerable or switched directional antenna system can be tuned to a certain direction. By using directional transmission, interference between network nodes can be mitigated and thus, network capacity can be improved [4,8]. Directional antenna can also improve energy efficiency [3]. However, directional antennas bring challenges to the MAC protocol design [4,10,8,6]. If multiple antennas are in the transmitter and single antenna in the receiver, i.e., N = 1 , L = 1 and either K > 1 or M > 1, antenna diversity or smart antenna cannot be applied unless the channel state information (CSI) is available. However, usually partial information of channel state is available at the transmitter. To achieve diversity under this situation, a commonly used technique is space–time coding (STC) [11], where signals transmitted at different antennas in different symbol periods are processed with a certain coding technique. The received signals are then combined at the receiver through an appropriate algorithm such as maximum likelihood detection (MLD).

STC is a promising technique that achieves second order diversity without bandwidth expansion [4]. To date, if CSI is not available, no solution has been developed yet for smart antennas at a transmitter. Schemes such as [35] still assume that CSI is perfectly known. If multiple antennas are in both the transmitter and the receiver, i.e., M > 1 ,L > 1 or K > 1 ,N > 1 , the multiple-antenna system is an MIMO system, where both diversity and simultaneous transmissions exist. Thus, MIMO can potentially increase the system capacity by three times or even more [4]. Currently MIMO is being adopted into IEEE 802.11n [6]. Depending on where the MIMO processing is placed, MIMO systems can be categorized into three types: receiver processing only, transmitter processing only, and both transmitter and receiver processing MIMO systems. The processing techniques can be based on maximum likelihood detection (MLD), vertical Bell Lab Layered Space–Time (V-BLAST) [5], singular value decomposition (SVD) [10], and space–time coding. So far only few results have been reported on the research of applying STC and MIMO to WMNs as well as other ad hoc networks. Since multiple channels are usually available in the frequency band of a wireless radio, they can be used to increase the capacity. A single-transceiver radio can use different channels by channel switching on the time axis according to the needs of higher layer protocols. For a multi-transceiver radio, simultaneous transmissions in different channels can be supported. Multiple transceivers can be easily implemented in a base station of cellular networks. However, with the concern of cost and system complexity, a wireless radio with multiple transceivers has not become a mature technique yet, although IEEE 802.11 chipsets with multiple transceivers are already available [4]. In some situations, the system capacity of a network node can be improved by using multiple radios each with single or multiple channels. Since each radio contains both MAC and physical layers, in order to make a multi-radio network work as a single node, a virtual MAC protocol is usually required to coordinate the communication in all radios [3]. For a wireless network, the frequency band is a very precious resource. However, many of existing allocated frequency bands (both licensed and unlicensed) have not been utilized efficiently. Measurements by the FCC show that around 70% of allocated spectrum is not utilized [5,9]. In addition, the time scale of spectrum occupancy can vary from milliseconds to hours [5]. Therefore, abundant spectrum is still available for wireless communication. Furthermore, in a large scale ad hoc network, the complexity is beyond human planning, and thus, conventional static frequency planning becomes impossible [9]. To achieve much better spectrum utilization and viable frequency planning, frequency agile [7] or cognitive radios [9] are being developed to dynamically capture this unoccupied spectrum. The FCC has recognized the promising future of this technique and pushes to enable it to a full realization. In order to implement cognitive radios, software defined radio (SDR) is one of the most convenient platforms [4] because programmability exists in all components of a radio such as programmable RF bands, channel access modes, and channel modulations [10]. SDR is not a mature technique yet, although testbeds are available now [1].

However, for the long term, SDR will be a key technique for wireless communications. It cannot only realize the cognitive radios, but can also easily implement all other advanced physical techniques such as adaptive modulation and coding, MIMO system [9], controller for smart and directional antennas, multi-channel radio, and multi-radio systems.

Open research issues

Open issues in the physical layer are twofold. First, it is necessary to further improve the transmission rate and the performance of physical layer techniques. New wideband transmission schemes other than OFDM or UWB are needed in order to achieve higher transmission rate in a larger area network. Multiple-antenna systems have been researched for years. However, their complexity and cost are still too high to be widely accepted for WMNs. An example of low-cost directional antenna implementation is reported in [6]. Frequency agile techniques are still in the early phase. Many challenging issues need to be resolved before they can be accepted for commercial use [9]. 460 I.F. Akyildiz et al. / Computer Networks 47 (2005) 445–487 Second, to best utilize the advanced features provided by physical layer, higher layer protocols, especially MAC protocols, need to be carefully designed. Otherwise, the advantages brought by such physical layer techniques will be significantly compromised. For directional and smart antennas, many MAC protocols have been proposed for ad hoc networks [4,5,2,6]. A MAC protocol for MIMO systems is studied in [10]. However, for multi-antenna systems, an efficient MAC protocol to achieve significant throughput improvement is still needed. Communication protocols for cognitive radios remain an open issue. Significant research efforts are needed to make cognitive-radio based WMNs become practical.

Network layer

WMNs will be tightly integrated with the Internet, and IP has been accepted as a network layer protocol for many wireless networks including WMNs. However, routing protocols for WMNs are different from those in wired networks and cellular networks. Therefore, we focus our study on routing protocols in this section. Since WMNs share common features with ad hoc networks, the routing protocols developed for ad hoc networks can be applied to WMNs. For example, mesh routers of Firetide Networks [7] are based on topology broadcast based on reverse-path forwarding (TBRPF) protocol [10], Microsoft mesh networks [10] are built based on dynamic source routing (DSR) [7], and many other companies [8] are using ad hoc on-demand distance vector (AODV) routing [9].

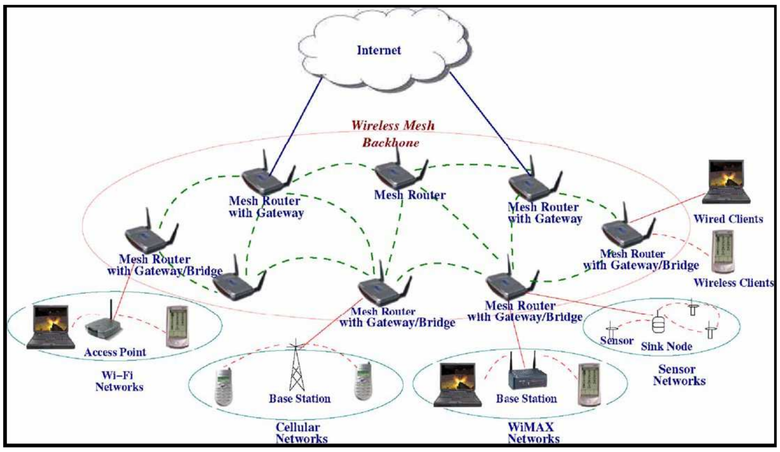
Despite the availability of several routing protocols for ad hoc networks, the design of routing protocols for WMNs is still an active research area for several reasons. First of all, new performance metrics need to be discovered and utilized to improve the performance of routing protocols. In addition, existing routing protocols still have limited scalability. Moreover, the existing routing protocols treat the underlying MAC protocol as a transparent layer. However, the cross-layer interaction must be considered to improve the performance of the routing protocols in WMNs. More importantly, the requirements on power efficiency and mobility are much different between WMNs and ad hoc networks. In a WMN, nodes (mesh routers) in the backbone have minimal mobility and no constraint on power consumption, while mesh client nodes usually desire the support of mobility and a power efficient routing protocol.

Such differences imply that the routing protocols designed for ad hoc networks may not be appropriate for WMNs. Based on the performance of the existing routing protocols for ad hoc networks and the specific requirements of WMNs, we believe that an optimal routing protocol for WMNs must capture the following features:

- Performance metrics. Many existing routing protocols use minimum hop-count as a performance metric to select the routing path. This has been demonstrated not to be valid in many situations. Suppose a link on the minimum hopcount path between two nodes has bad quality. If the minimum hop count is used as the performance metric, then the throughput between these two nodes will be very low. To solve this problem, performance metrics related to link quality are needed. If congestion occurs, then the minimum-hop count will not be an accurate performance metric either. Usually Round trip time (RTT) is used as an additional performance metric. The bottomline is that a routing path must be selected by considering multiple performance metrics.
- Fault tolerance with link failures. One of the objectives to deploy WMNs is to ensure robustness in link failures. If a link breaks, the routing protocol should be able to quickly select another path to avoid service disruption.
- Load balancing. One of the objectives of WMNs is to share the network resources among many users. When a part of a WMN experiences congestion, new traffic flows should not be routed through that part. Performance metrics such as RTT help to achieve load balancing, but are not always effective, because RTT may be impacted by link quality.
- Scalability. Setting up a routing path in a very large wireless network may take a long time, and the end-to-end delay can become large. Furthermore, even when the path is established, the node states on the path may change. Thus, the scalability of a routing protocol is critical in WMNs.
- Adaptive Support of Both Mesh Routers and Clients. Considering the minimal mobility and no I.F. Akyildiz et al. / Computer Networks 47 (2005) 445–487 465 constraint of power consumption in mesh routers, a much simpler routing protocol can be developed for mesh routers than existing ad hoc routing protocols. However, for mesh clients, the routing protocol must have the full functions of ad hoc routing protocols. Consequently, it is necessary to design an efficient routing protocol for WMNs that can adaptively support both mesh routers and mesh clients. In the rest of this section, we discuss various routing protocols applicable to WMNs and emphasize the open research issues.

Marketing challenges & Implications of WMN

This paper used in the application of the internet wireless system ,so the computers , laptops will connect to the Access Point through wireless LAN card .



Infrastructure/backbone WMNs.

The figure above shows that the terminals connect to the Internet gateway through the sub gateway (Access point) .

The signal will delver through this gates according the MAC of the terminal devices .

In the big markets we connect this Access point to the main gateway so as to create a Wi-Fi system.

CONCLUSION

The capability of self-organization in WMNs reduces the complexity of network deployment and maintenance, and thus, requires minimal upfront investment. The backbone of WMNs provides a viable solution for users to access the Internet anywhere anytime. It can also enhance the reliability of the mobile ad hoc network of mesh clients. WMNs enable the integration of multiple wireless networks. WMNs can be built up based on existing technologies. Some companies already have products for sale, while other companies have started to deploy WMNs in various application scenarios. However, field trials and experiments with existing WMNs prove that the performance of WMNs is still far below what they are expected to be. As explained throughout this paper, many open research issues need to be resolved:

- Scalability. Based on existing MAC, routing, and transport protocols, the network performance, indexed by throughput, end-to-end delay, and fairness, is not scalable with either the number of nodes or the number of hops in I.F. Akyildiz et al. / Computer Networks 47 (2005) 445–487 481 the network. This problem can be alleviated by increasing the capacity of network nodes. Typical approaches include applying multiple channels/ radios per node or developing wireless radios with higher transmission speed. However, these approaches do not truly enhance the scalability of WMNs, because the relative performance over the increased network capacity is not actually improved. Therefore, in order to achieve scalability, it is essential to develop new MAC, routing, and transport protocols for WMNs.
- Self-organization and self-configuration. Self organization and self-configuration require all protocols in WMNs to be distributive and collaborative.

Otherwise, WMNs will lose the autonomic feature. However, current WMNs
can only partially realize this objective.

- Security. Due to wireless ad hoc architecture, WMNs are vulnerable to security attacks in various protocol layers. However, current security approaches may be effective to a particular attack in a specific protocol layer, but lack a comprehensive mechanism to prevent or counter attacks in different protocol layers.
- Network integration. Current WMNs have very limited capabilities of integrating heterogeneous wireless networks. Integrating multiple heterogeneous wireless networks is still an on-going task for WMNs, due to the difficulty in building multiple wireless interfaces and the corresponding gateway/bridge functions in the same mesh router. Software radios may be the ultimate solution to this problem. Protocol improvement relying on single layer cannot entirely solve all the existing problems. All protocols ranging from physical to application layers need to be improved or re-invented, and the cross-layer design among these protocols is needed in order to reach the optimal performance. WMNs are a promising technology for next generation wireless networking. Many application scenarios are stimulating its rapid development. However, to strengthen the market penetration and secure the success of WMNs, more research is needed.

FUTURE SCOPE

In this paper ther is a study of wireless mesh network so the implementation of it in NS2 software, the TCL file will process so as to show the graphs of sending and receiving signals.

The implementation of WiMAX will used to send and receive signals in big city , high building , high distortion

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