A

Seminar report

On

Wireless Mesh Networks

Submitted in partial fulfillment of the requirement for the award of degree
of Bachelor of Technology in Computer Science

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Preface

I have made this report file on the topic **Wireless Mesh Networks**; I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to ……..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

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INTRODUCTION

Mobile (multihop) ad hoc networks (MANETs) are collections of mobile nodes connected together over a wireless medium. These nodes can freely and dynamically self-organize into arbitrary and temporary ad hoc network topologies, allowing people and devices to seamlessly internetwork in areas with no preexisting communication infrastructure (e.g., disaster recovery and battlefield environments).

After almost a decade of research into ad hoc networking, MANET technology has not yet affected our way of using wireless networks. A common answer is emerging: most of the ongoing research on mobile ad hoc networks is driven by either Department of Defense (DoD) requirements(large-scale military applications with thousands of ad hoc nodes) or specialized civilian applications (disaster recovery, planetary exploration, etc). DoD generated a research agenda and requirements that are far from real users' requirements. Indeed, military and specialized civilian applications require lack of infrastructure and instant deployment. They are tailored to very specialized missions, and their cost is typically not a main issue. On the other hand, from the users' standpoint, scenarios consisting of a limited number of people wanting to form an ad hoc network for sharing some information or access to the Internet are much more interesting. In this case, users are looking for multipurpose networking platforms in which cost is an issue and Internet access is a must.

To turn MANETs into a commodity, we move to a more pragmatic "opportunistic ad hoc networking" in which multihop ad hoc networks are not isolate self-configured networks, but networks coexisting with them. Indeed, a new class of networks is emerging from this view: *Mesh networks*.

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MESH NETWORKS

Mesh networks are built on a mix of fixed and mobile nodes interconnected via wireless links to form a multihop ad hoc network. As in MANETs, users' devices are an active part of the mesh. They dynamically join the network, acting as both user terminals and routers for other devices, consequently further extending network coverage. Mesh networks thus inherit many results from MANET research but have civilian applications as the main target. Furthermore, while the MANET development approach was mainly simulation-based, from the beginning mesh networks have been associated with real testbeds. Even though mesh networks are quite recent, they have already shown great potential in the wireless market. Indeed, we can subdivide mesh networks into two main classes: off-the-shelf and proprietary solutions.

This promising networking technology recently received a further boost when IEEE 802 creating Task Group 802.11s aimed at defining medium access control (MAC) and PHY layers for mesh networks to improve wireless LAN (WLAN) coverage with no single point of failure. In such networks, 802.11 access points relay information from one to another, hop by hop, in router-like fashion. As users and access points are added, capacity is added. In addition to802.11s, other IEEE Working Groups are currently working to provide mesh networking extensions to their standards (e.g., 802.15.5,802.16a, and 802.20). Same system is also expected to be used to address and alleviate transportation congestion problems, control pollution, and improve transportation safety and security.

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SYSTEM AND NETWORK ARCHITECTURES FOR WIRELESS MESH NETWORKS

A wireless mesh network is a fully wireless network that employs multihop communications to forward traffic en route to and from wired Internet entry points. Different from flat ad hoc networks, a mesh network introduces a hierarchy in the network architecture with the implementation of dedicated nodes (called wireless routers) communicating among each other and providing wireless transport services to data traveling from users to either other users or access points (access points are special wireless routers with a high-bandwidth wired connection to the Internet backbone). The network of wireless routers forms a wireless backbone (tightly integrated into the mesh network), which provides multihop connectivity between nomadic users and wired gateways. The meshing among wireless routers and access points creates a wireless *backhaul* communication system, which provides each mobile user with a low-cost, high-bandwidth, and seamless multihop interconnection service with a limited number of Internet entry points and with other wireless mobile users. Specifically in the mesh case, the traffic is originated in the users' devices, traverses the wireless backbone, and is distributed over the Internet network. To summarize, Fig. 3.1 illustrates the mesh network architecture, highlighting the different components and system layers.

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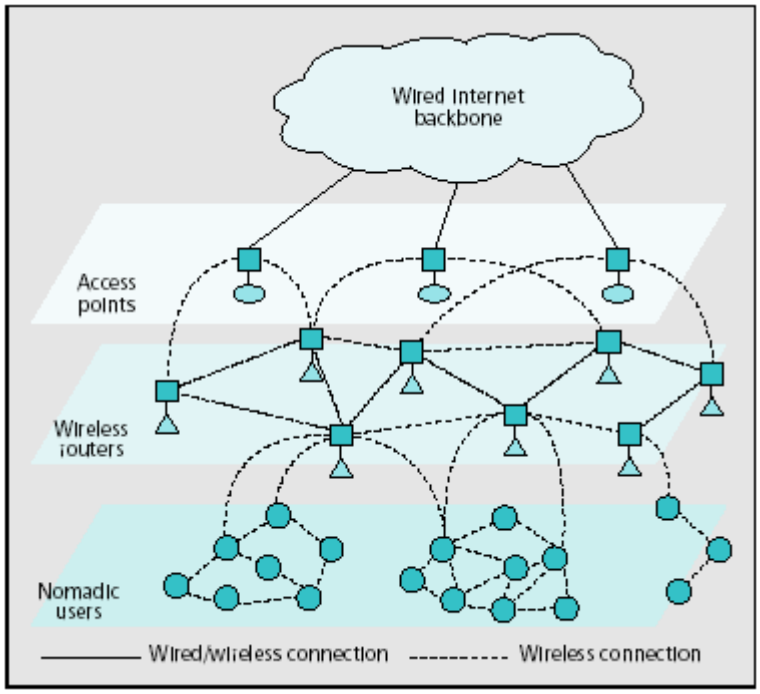

Fig. 3.1: A three-tier architecture for wireless mesh networks.

OFF-THE-SHELF SOLUTIONS FOR BUILDING MESH NETWORKS

An example of this class are so-called community network built (mainly) on 802.11 technology and aimed at providing Internet access to a community of users that can share the same Internet access link wireless backbone enormously reduces the Community networks are systems that allow neighbors to connect their home networks together. Again, wireless mesh could be the technological driver to realize this vision. Nevertheless, the commercial deployment of community networks is still in its infancy. Nowadays , the majority of community network implementations are experimental and non-commercial trials funded and operated by government agencies, non-profit organizations, municipalities, and research institutions, and are based on nonproprietary off-the-shelf technologies.

Roofnet is an experimental and independent multihop 802.11b mesh network consisting of about 50 houses located in Cambridge. The network participants are volunteers who accept

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hosting in their apartments the equipment required to implement a mesh node. One of the main objectives pursued during the design of the Roofnet network has been to employ only open source software and to maintain reasonably low costs. Consequently, IEEE 802.11 is the radio technology used in the Roofnet community, because cheap network cards operating in unlicensed bands are available. Moreover, many commercial mesh networks rely on directional antennas for increased range, but Roofnet nodes use mainly omni directional antennas to reduce the per-node costs. Only the gateways are equipped with directional antennas to provide extended coverage. The Roofnet user node is a computer working as a wireless router, equipped with open source software. Both wireless and wired network cards are mounted on the Roofnet node. A multihop routing protocol optimized to find paths with links of good quality is used to route traffic within the mesh. Each Roofnet node also runs a Web server, a network address translator(NAT), and a Dynamic Host Configuration Protocol (DHCP) server on its wired Ethernet port.

PROPRIETARY SOLUTIONS FOR BUILDING MESH NETWORKS

The growing interest in wireless mesh applications has boosted industrial efforts to develop solutions to makes wireless mesh networks a reality. Several companies and manufactures are now selling proprietary solutions for both indoor and outdoor environments. These solutions adopt radically different approaches and protocols, making these systems incompatible. For instance, Tropos' outdoor systems are cellular Wi-Fi networks where each Wi-Fi cell behaves as a wireless routed LAN. The company has developed its own wireless routing protocol, called Predictive Wireless Routing Protocol (PWRP), that does not rely only on hop count to detect transmission paths, but compares packet error rates and other network conditions to determine the best path at a given moment.

Several other vendors like Radiant and Mesh-Network are manufacturing solutions based on proprietary radio technologies. The motivation behind this design choice is that the 802.11 technology has been developed to provide very high data rates over short distances to stationary computers using a very low-cost low-power radio. Consequently, the 802.11 radio technology is not optimized to support mobile and wide-range applications. For this reason, the Mesh Network company has developed a proprietary radio platform, called quadrature-division multiple access

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(QDMA™), that includes capabilities such as multitap rake receivers (commonly found in cell phones) and real-time equalization algorithms to compensate for the rapidly varying RF conditions typically encountered in real-world mobile environments. The Mesh Network company has also developed a proprietary hybrid ad hoc routing protocol that combines both proactive and reactive routing algorithms, called Mesh Networks Scalable Routing (MSR™).

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OPEN STANDARDSIMPLEMENTING WIRELESS MESH NETWORKING TECHNIQUES

Open standard radio technologies are essential for industry because they enable economies of scale, which bring down the cost of equipment and ensure interoperability. For these reason several IEEE standard groups are actively working to define specifications for wireless mesh networking techniques.

IEEE 802.15.5

The IEEE 802.15 project is devoted to the definition of PHY and MAC specifications for establishing short-range wireless connectivity for small groups of fixed, portable, and moving computing devices, such as PCs, PDAs, peripherals, cell phones, pagers, and consumer electronics. Employing mesh-like multihopping communications increases the coverage of WPANs and allows shorter links to be used, providing both higher throughputs and fewer retransmissions. Indeed, meshing capabilities are particularly important when using ultra wideband (UWB) communications, because the bandwidth of UWB wireless links decreases very rapidly (the indoor channel rolls off as the third power of distance). In this case, using shorter links significantly increases the throughput.

IEEE 802.11S

The IEEE 802.11 Working Group is an umbrella that contains several standards committees developing technologies for the WLAN environment. It provides higher speeds (more than 100 Mb/s), quality of service (QoS) support, faster handoffs, and several additional capabilities. Relevant to the mesh-networking paradigm is the extension underdevelopment by the P802.11s ESS Mesh Networking Task Group. The scope of this TG is to extend the IEEE 802.11 architecture and protocol for providing the functionality of an extended service set (ESS) mesh (i.e., access points capable of establishing wireless links among each other to enable automatic topology learning and
dynamic path configuration). The idea behind this proposed amendment is to extend the IEEE802.11 MAC protocol to create an IEEE 802.11wireless distribution system that supports

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both broadcast/multicast and unicast delivery at the MAC layer using radio-aware metrics over self configuring multihop topologies

IEEE 802.16A

In 1999 the 802.16 Working Group was established to address the “first-mile/last-mile” connection in WMANs, working toward local multipoint distribution system (LMDS)-type architectures for broadband wireless access. The WMAN network, as specified in the 802.16 standard , employs a point-to-multipoint (PMP) architecture where each base station (BS) serves a number of subscriber stations (SSs) in a particular area. At the high frequencies (> 10 GHz) used in802.16 systems, line-of-sight (LOS) communications are needed because the system can tolerate a limited amount of multipath interference. The need for reliable non-LOS (NLOS) operations, together with the opportunity to expand the system scope to license-exempt bands, has led to the development of the IEEE 802.16a standard. The adoption of NLOS operations allowed 802.16astandard mesh extensions to be included in the standard. In mesh mode all SSs may have direct links with other SSs, and the data traffic can be routed through other SSs and occur directly between SSs. Communications in the direct links can be controlled by either a centralized or distributed algorithm.

IEEE 802.20

Recently, several IEEE working groups have turned their attention to mobile broadband. In December 2002 the establishment of IEEE802.20, the Mobile Broadband Wireless Access (MBWA) Working Group, was approved. 802.20systems are intended to provide ubiquitous mobile broadband wireless access in a cellular architecture (e.g., macro/micro/picocells), supporting the mesh-networking paradigm (i.e., NLOS communications) in both indoor and outdoor scenarios. 802.20 aims for operation in licensed bands below 3.5 GHz.802.20addresses high-speed mobility issues (speeds up to 250 km/h).

Although the above standards target different network environments, these technologies are not complementary and overlap as far as many proposed functionalities. Consequently,

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network operators that want to deploy solutions for the last-mile broadband wireless Internet access can take advantage, for instance, of both emerging 802.11s and 802.11a products. Nowadays, Wi-Fi based solutions appear advantageous because they are already established and operate in unlicensed cost-free frequency bands. Nevertheless, it is feasible to envision integration between WiMAX and Wi-Fi, particularly considering that the 802.16a MAC and PHY layers are optimized for long-distance wireless links. In Fig. 6.1 we show a wireless mesh that fully exploits the advantages of the WiMAX technology, implementing both wireless PMP communications between the wireless routers and the Internet backbone, and mesh based communications among the wireless routers. Once a wireless mesh network based on Wi-Fi products is installed, the integration of WiMAX will be straightforward. Indeed, 802.16wireless links can easily be added to the existing network to either expand the network or introduce additional capacity in the wireless backbone. Consequently, WiMAX products can offer low-cost flexible alternatives for building the wireless backbone in outdoor scenarios.

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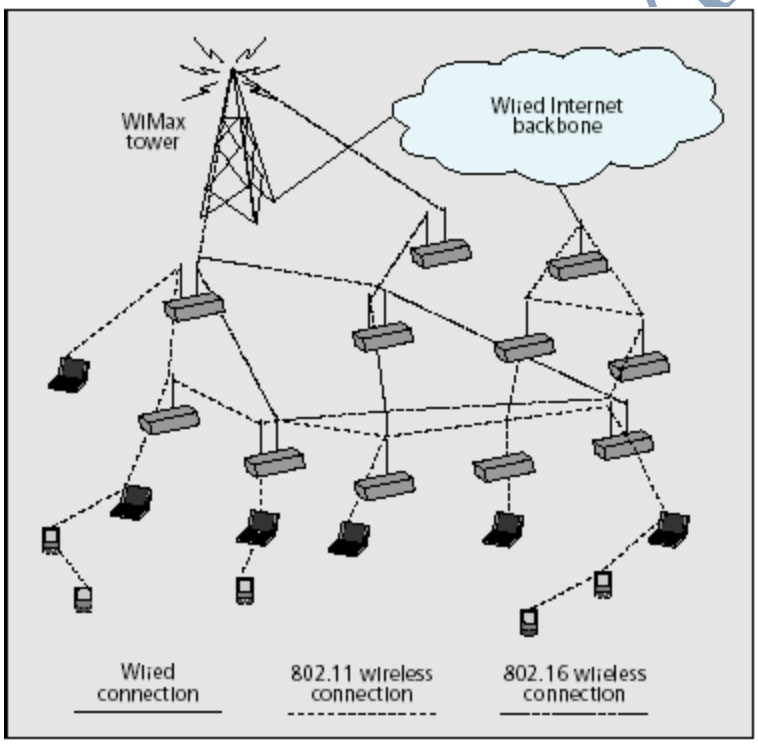

Fig 6.1: Integration of WiMAX and Wi-Fi technologies in large-scale Wireless mesh networks.

ADVANTAGES OF MESH NETWORKS

Reduction of installation costs

Currently, one of the major efforts to provide wireless Internet beyond the boundaries of indoor WLANs is through the deployment of Wi-Fi hotspots. Basically, a hot spot is an area that is served by a single WLAN or a network of WLANs, where wireless clients access the Internet through an 802.11-based access point. To ensure almost ubiquitous coverage in a metro scale area, it is necessary to deploy a large number of access points due to the limited distance covered by the 802.11 signal. The downside of this solution is an unacceptable increase in the infrastructure costs because a cabled connection to the wired backbone is needed for every access point. Installing the necessary cabling infrastructure not only slows down hot spot implementation, but also significantly increases installation costs. As a consequence, the hot spot architecture is costly, unscalable, and slow to deploy. On the other hand, building a mesh wireless backbone enormously reduces the infrastructural costs because the mesh network needs only a few points of connection to the wired backbone.

Large-scale deployment

In recently standardized WLAN technologies (i.e., 802.11a and802.11g), increased data rates have been achieved by using more spectrally efficient modulation schemes. However, for a specific transmit power, shifting toward more efficient modulation techniques reduces coverage (i.e., the further from the access point, the lower the data rate available). Moreover, for a fixed total coverage area, more access points should be installed to cover small-size (e.g., pico) cells .Obviously, this picocellularization of WLANs further hinders the scalability of this technology, especially in outdoor environments. On the other hand, multihop communications offers long distance communications via hopping through intermediate nodes. Since intermediate links are short, these transmissions could be at high data rates, resulting in increased throughput compared to direct communications.

Reliability

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The wireless backbone provides redundant paths between each pair of endpoints, significantly increasing communications reliability, eliminating single points of failure and potential bottleneck links within the mesh. Network resilience and robustness against potential problems (e.g., node failures, and path failures due to temporary obstacles or external radio interference) is also ensured by the existence of multiple possible destinations (i.e., any of the egress points toward the wired Internet) and alternative routes to these destinations.

Self-management

The adoption of peer-to-peer networking to build a wireless distribution system provides all the advantages of ad hoc networking, such as self-configuration and self-healingness. Consequently, network setup is automatic and transparent to users. For instance, when adding additional nodes in the mesh, these nodes use their meshing functionalities to automatically discover all possible wireless routers and determine the optimal paths to the wired network. In addition, the existing wireless routers reorganize, taking into account the new available routes. Thus, the network can easily be expanded, because the network self-reconfigures to assimilate the new elements.

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POPULAR COMMERCIAL APPLICATIONS FOR WIRELESS MESH NETWORKS

Intelligent transportation systems

Several public transportation companies, government agencies, and research organizations are looking for viable solutions to realize *intelligent transport systems* (i.e., integrated public transportation systems that are built to be safe, cost effective, efficient, and secure). Wireless mesh could be the flexible solution to implement the information delivery system required to control transportation services, as depicted in Fig. 8.1.An example for this application scenario is the Portsmouth Real-Time Travel Information System (PORTAL), a system that, as part of a city wide public transportation communications network, aims at providing real-time travel information to passengers. This system is realized by equipping more than 300 buses with mesh technology provided by Mesh Networks Inc. The wireless mesh network allows anybody to display, at more than 40 locations throughout the city , real-time information on transportation services, such as where his/her bus is, its ultimate destination, and when it is scheduled to arrive. The same system is also expected to be used to address and alleviate transportation congestion problems, control pollution, and improve transportation safety and security.

Public safety

The 9/11 events have dramatically increased interest in *public safety* (police, fire departments, first responders, and emergency services), creating additional demand and urgency for wireless network connectivity to provide mobility support, reliability, flexibility, and high bandwidth. For years, solutions based on cellular technologies have been used, but they have proved to be unsatisfactory in many aspects. In particular, cellular data networks promise near ubiquitous coverage limited, even lower than a typical dialup connection, and the network infrastructure is extremely costly. Wireless mesh networks appear to be the natural solution to

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address the needs of law enforcement agencies and city governments. Currently, several mesh networks are operating to provide public safety applications. For instance, the San Matteo Police Department in the San Francisco Bay Area has equipped all its patrol cars with laptops, and motorcycle and bicycle patrols with PDAs, employing standard 802.11b/gwireless cards for communications.

Public internet access

Internet service providers (ISPs) are avidly seeking integrated solutions to implement *public Internet access*, which could simultaneously target the markets of residential, business, and travel. A growing number of both small and big ISPs are deploying solutions based on Wi-Fi technologies to provide broadband wireless Internet access. The wireless mesh networks are the ideal solution to provide both indoor and outdoor broadband wireless connectivity in urban, suburban, and rural environments without the need for extremely costly wired network infrastructure. An example of this is the metro-scale broadband city network activated on April 2004 in the city of Cerritos, California, operated by Aiirmesh Communications Inc., a wireless ISP (WISP) company. This network is built up with Tropos based mesh technology and covers a city area as large as eight square miles using more than 130 outdoor access points, less than 20 percent of them directly connected to a wired backhaul network. This significant reduction of network installation costs ensures rapid deployment of a metropolitan broadband network that is cost effective even with a limited potential subscriber base, as found in rural or scarcely populated urban areas

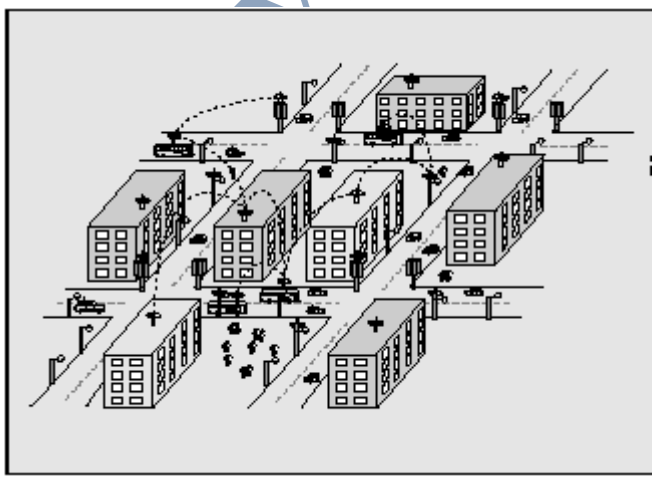

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Fig.8.1 Intelligent transportation system

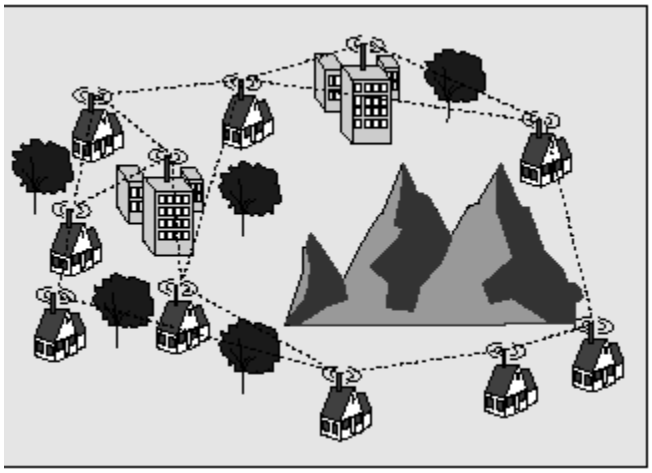

Fig 8.2: residential broadband access for hard to reach and/or scarcely populated areas.

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KEY RESEARCH CHALLENGES

The wireless infrastructure meshing formed through multihop communications among wireless routers and access points (Fig. 1.1) cannot be treated simply as a large multihop ad hoc network, because the structure and functionalities of such a network are radically different from those of a general ad hoc network. In practice, this simplification will undoubtedly lead to the well-known scalability limits of ad hoc networks due to the dramatic degradation of throughput and delay performance as the network diameter increases. Consequently, one of the major problems to address while building a multihop wireless backhaul network is the *scalability* of both the network architecture and protocols. Hence, in the following sections we discuss the most relevant and promising research activities, focusing on the design and development of a scalable and high-performance wireless backbone for mesh networks.

High-capacity and reliable radio interfaces for the wireless backbone

Currently, there are several research efforts to improve the capacity of wireless mesh networks by exploiting such alternative approaches as multipleradio interfaces, multiple-input multiple-output (MIMO) techniques, beamforming antennas, and opportunistic channel selection. Multiplechannels and/or radio interfaces could increase network capacity by exploiting the independent fading across different frequencies or the orthogonality of frequency bands. Similarly, systems employing multiple antennas for both transmitting and receiving (generally called MIMO systems) improve the capacity and reliability of wireless backbones by exploiting antenna diversity and spatial multiplexing. Diversity provides the receiver with several (ideally independent) replicas of the transmitted signal and is therefore a powerful technique to combat fading and interference. On the other side, spatial multiplexing divides the channel into multiple “spatial channels” through which independent data streams or signals can be coded and transmitted simultaneously. As a consequence, diversity techniques make the channel less fading, which is of fundamental importance for wireless backbones, where deep fades can occur and the channel changes slowly, causing fades to persist over a long period of time.

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To cope with interference, smart antennas or adaptive array processing can be utilized to enhance both the energy efficiency and multiple access interference rejection capability of the high-throughput wireless backbone. The key idea is to exploit the beamforming capability of the transmit/receive antenna arrays. Beamforming creates an effective antenna pattern at the receiver with high gain in the direction of the desired signal and low gain in all other directions.

Designing scalable and opportunistic networking functions

It is well known that as the number of users increases, random MAC protocols suffer from increased contention in the network. Moreover, users' traffic traversing the wireless backbone does not have a unique fixed destination, but rather can be delivered to any wired access point. In addition, several paths may exist at the same time to reach a given access point; path capacity and channel bandwidth could be highly variable. As a result, new scalable and distributed scheduling, MAC, and routing protocols have to be designed to efficiently manage data traffic. These algorithms exploits *multi-user* diversity, that is, the condition when, in a system with many users, different users experience peaks in their channel quality at different time instants network capacity by exploiting the independent fading across different frequencies or the orthogonality of frequency bands. Similarly, systems employing multiple antennas for both transmitting and receiving (generally called MIMO systems) wireless backbones by exploiting antenna diversity and spatial multiplexing. Diversity provides the receiver with several replicas of the transmitted signal and is therefore a powerful technique to combat fading and interference. On the other side, spatial multiplexing divides the channel into multiple "spatial channels" through which independent data streams or signals can be coded and transmitted simultaneously. The mesh network environment adds further degrees of freedom in the scheduling process, because the scheduling policies could exploit additional types of diversity such as spatial diversity (spatial channels opened by a multi-antenna wireless backbone implemented at the PHY layer) and frequency diversity (radio technologies using multiple frequency channels) to enhance throughput. Opportunistic selection of the high-quality channel cannot be performed locally in the single wireless router, but should be coordinated among all the wireless routers forming the backbone network.

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To fully exploit the potential capacity improvement ensured by the adoption of optimized transmission and antenna technologies, it is fundamental that the routing protocol discovers high-quality routes by explicitly considering the current network conditions. Moreover, users' traffic traversing the wireless backbone does not have a unique fixed destination, but rather can be delivered to any wired access point. In addition, several paths may exist at the same time to reach a given access point; path capacity and channel bandwidth could be highly variable. Consequently, new scalable and several research efforts are devoted to the definition of novel routing metrics that correctly account for the loss rate and channel bandwidth of each link forming the path . Moreover, the routing protocol for a wireless backbone needs to be redesigned not only to deal with the path diversity, but also to address the distinct nature of the wireless backbone network with respect to a general ad hoc network. In particular, the user traffic to the Internet does not need to follow the same path, but could be forwarded to any of the Internet egress points in the multihop wireless backhaul network. Consequently, the routing protocol should opportunistically select the "best wire" toward any wired access point. Finally, the routing protocol could effectively benefit from the existence of nonmobile powered wireless infrastructure to exploit hybrid ad hoc routing that combines both proactive and reactive techniques.

7

System-wide resource management

The wireless backbone forming the core of a mesh network provides a backhaul communication service. End users' traffic is transparently routed to and from the wired Internet employing a multihop wireless path traversing the wireless backbone. It is an essential requirement for the backhaul network to ensure that all users in the network achieve a *fair* share of system resources. Unfortunately, current networking protocols are not appropriate for multihop wireless backbone networks, usually inducing severe unfairness and scarce performance to users located far from the available Internet egress points. Hence, a coordinated multihop resource management algorithm must be developed to achieve high performance while preserving a system-wide notion of fairness .In a novel fairness model has been proposed that addresses the requirements of multihop aggregated flows, aimed at eliminating the spatial bias by

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ensuring that each user receives the same fair share of resources independent of how far it is from the Internet entry point (i.e., independent of its spatial location).

Coordinated resource management is required not only to tackle the issue of providing system wide fairness and to exploit spatial reuse in the wireless backbone, but also to provide a prompt reaction to variations in system capacity due to changes in traffic patterns, channel conditions, and contention. Considering the intrinsic large-scale nature of the wireless backbone, to achieve system-wide performance objectives the resource management algorithm must be distributed. However, careful design of network control has to be employed to trade off the additional overhead of increased protocol information required to perform more precise control and the benefits derived by opportunistic exploitation of this information. Consequently, analysis of system
capacity and scalability should incorporate the impact of protocol overheads and operations.

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CONCLUSION

The mesh network architecture addresses the emerging market requirements for building wireless networks that are highly scalable and cost effective, offering a solution for the easy deployment of high-speed ubiquitous wireless Internet. In addition to802.11s, other IEEE Working Groups are currently working to provide mesh-networking extensions to their standards (e.g., 802.15.5,802.16a, and 802.20).

Finally, it is worth pointing out that mesh networking, as a special case of ad hoc networking, should fully implement self-management, self-configuration, and self-healing features in all key research challenge is also to ensure that the scalable and opportunistic networking functions designed specifically for the mesh networks effectively fulfill the requirements of the peer-to peer networking paradigm adopted in the wireless backbone.

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