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Wireless Mesh Networks : Design, Opportunities and Challenges

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ABSTRACT

Wireless mesh networks (WMNs) have recently evoked much research attention as a novel technology for last-mile broadband Internet access. It provides wireless local area network coverage and network connectivity for stationary or mobile hosts at low costs both for network operators and customers. The core technology involves a network of wireless routers relaying each other's packets in a multihop fashion. Many variations on targeted applications and implementation choices offer different opportunities to emerging companies in this emerging area. In this article, we will present an introduction to wireless mesh networks, architecture of WMNs and present both the benefits enabled by this technology and the main hurdles that have to overcome.

Keywords : Wireless Mesh Networks, Architecture, Multihop

I. INTRODUCTION

Wireless communication is without a doubt a very desirable service as emphasized by the tremendous growth in both cellular and wireless local area networks (WLANs) (primarily, the ones that are compliant with the IEEE802.11 family of standards, popularly known as Wi-Fi). However, these two radically different technologies address only a narrow range of connectivity needs, and there are numerous other applications that can obtain benefits from wireless connectivity. The cellular networks offer wide area coverage, but the service is relatively expensive and offers low data rates: even the third generation of cellular networks (3G) offers (at best) low data rates (_2Mbps) compared to WLANs (>50Mbps for IEEE 802.11a and 802.11g and _100Mbps for proprietary solutions at the time of this writing). On the other hand, the WLANs have rather limited coverage (and the associated reduced mobility).

Furthermore, in order to increase the coverage of WLANs, a wired backbone connecting multiple access points is required. Wireless metropolitan area networks (WMANs) (e.g., the family of IEEE 802.16 standards), partially bridges this gap, offering high data rates with guaranteed quality of service to a potentially large customer base (up to tens of miles from the base station). The main drawback of WMANs is their (current) lack of mobility support and the line of sight (LOS) requirement: if a customer does not have a clear LOS to the WMAN base station, it is unlikely that he can receive service. In communities with a high density of obstructions (high-rise buildings or trees), more than half of the customers cannot be served due to the LOS requirement. Furthermore, the base stations tend to be complex and expensive. Wireless mesh networks (WMNs) have the potential to eliminate many of these disadvantages by offering low cost, wireless broadband Internet access both for fixed and mobile users.

The main drawback of WMNs is their complexity: it is relatively easy to design and build a line of products that will form a WMN and will forward packets to and from the destinations; however, it is very difficult to achieve optimum (or near-optimum) performance of this network while ensuring security and robustness.

II. OVERVIEW OF THE TECHNOLOGY

In its most general form (see Figure 1), a wireless mesh network (WMN) interconnects stationary and/or mobile clients and optionally provides access to the Internet. The defining characteristic of a WMN is that the nodes at the core of the network are forwarding the data to and from the clients in a multihop fashion, thus forming a (mobile) ad hoc network (MANET). Beyond the multihop requirement, there are no other restrictions on the design of a WMN, resulting in considerable flexibility and versatility. This versatility allowed many players to enter the mesh-networking arena with different products and applications. For example, the Internet access link in Figure 1 can be wired (e.g., T1, Ethernet, etc.), wireless (point to point or point to multipoint), or be absent [1]. Some WMN technologies are designed for high-speed mobility (100mph) [2], some for casual roaming in a building, while others are only meant to be used by stationary clients.

The wireless links used to connect the mobile clients can be of the same type as the intra-mesh wireless links[2] or can be a completely different technology [1]. (They can also be missing altogether) Many implementations allow mobile nodes to connect to the WMN while in its range; their packets are forwarded in the same multihop manner as the ones of the stationary nodes (and in their turn, although not always preferable, the mobile nodes can forward packets on behalf of other nodes). Not all nodes have to support client nodes; the service provider can employ several relay nodes to increase the coverage of the network (or to improve its performance, as the relays can allow some clients to reach their destinations in fewer hops). Figure 1 is intentionally vague on the application scenario; both indoor and outdoor (even mixed scenarios) are specifically targeted by different companies.

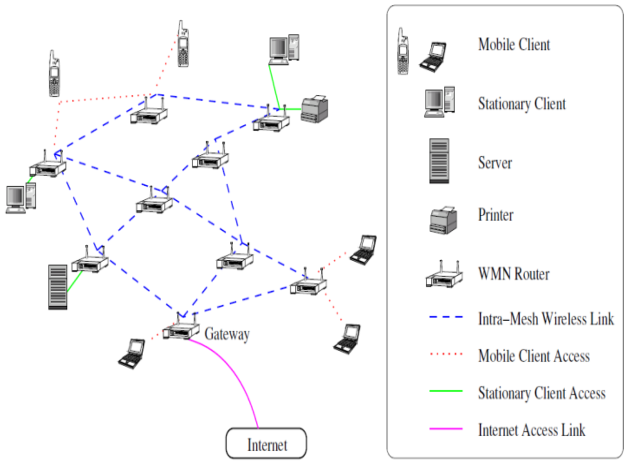

Figure 1. A wireless mesh network interconnecting stationary and mobile clients

III. DESIGN

With the proliferation of Internet, Wireless Mesh Networks (WMNs) have become a practical wireless solution for providing community broadband Internet access services. These networks exhibit characteristics that are novel in the wireless context, and in many ways more similar to traditional wired networks. In Infrastructure WMNs, Access Points (APs) provide internet access to Mesh Clients (MCs) by forwarding aggregated traffic to Mesh Routers (MRs), known as relays, in a multi-hop fashion until a Mesh Gateway (MG) is reached. MGs act as bridges between the wireless infrastructure and the Internet.

Figure 2 illustrates a typical WMN infrastructure. In such networks, it is possible to equip each infrastructure node with multiple radios, and each radio is capable of accessing multiple orthogonal channels, referred as Multi-Radio Multi-Channel transmissions.

Figure 3 depicts the case of multiple radios routers where each router is equipped with two radio interfaces for the backside communications and one radio interface for the client side communications. In a Multi-Radio Multi-channel network, simultaneous communications are possible by using non-interfering channels, which have the potential of significantly increasing the network capacity WMNs can provide large coverage area, lower costs of backhaul connections, prolong end-user battery life, and more importantly provide no LOS (Line Of Sight) connectivity among users without direct LOS links. Recent commercial and academic deployments of WMNs in real world are beginning to demonstrate some of these advantages.

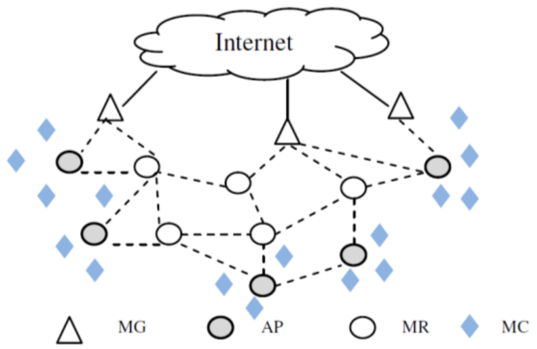

Figure 2. Wireless mesh network infrastructure

However, several challenges remain so that a WMN performance in terms of throughput and delays match the performance of a wired network. Furthermore, earlier deployments of WMNs have been linked to a number of problems mainly related to connectivity problems (such as lack of coverage, dead spots or obstructions) and performance problems (low throughput and/or high latency).

Due to the scarce nature of wireless channel resources, network performance is highly impacted by wireless interference and congestion causing considerable frame losses and higher delays. Figure 4 depicts situations where some communicating nodes are within the interference range *ri*. The most noticeable sources of performance degradation in WMNs, e.g., low throughput or high latency, are mainly due to poorly planned wireless networks. According to interviews and discussions conducted with network administrators and operations engineers of Microsoft's IT department, performance problems occur for many reasons: multi-path interference, traffic slow down due to congestion, large co-channel interference due to poor network planning, or due to poorly configured client/AP.

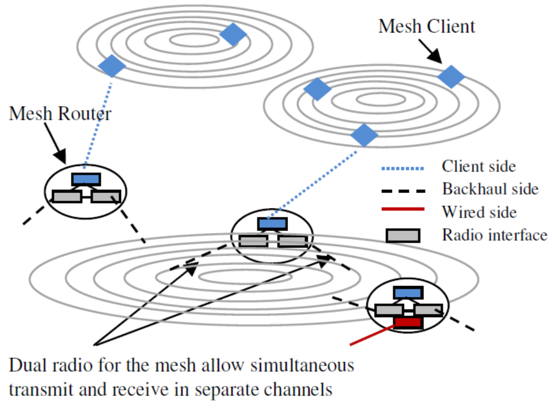

Figure 3. Multi-radio Mesh Routers.
Simultaneous communications are possible by using non-interfering channels.

The cause of the problems of wireless network performance can be traced back to the original design assumptions. Moreover, as individual protocols are typically specified with different assumptions in mind, the end-to-end performance of these protocols stacks in deployed wireless networks has not been always satisfactory. We believe that a well planned and optimized wireless network can often provide extra capacity with the same infrastructure cost; for instance, this may result in more efficient use of radio frequencies (considered as scarce resources). In this survey, we focus on multi-channel WMNs most widely adopted techniques.

Specifically, topology-aware MAC and routing protocols can significantly improve the performance of WMNs. Also, to increase the capacity and flexibility of wireless systems, approaches based on radio techniques have been proposed, the most noteworthy being directional and smart antenna, MIMO systems, and multi-radio/multi-channel systems. To date, many contributions in the context of WMNs performance improvement have been proposed. Depending on what and how to optimize, we can classify these contributions into two broad classes, namely *fixed-topologies* and *unfixed-topologies* (as shown in Figure 5). Fixed-topologies based approaches aim at better exploiting and utilizing the network resources; they improve the channel spatial or temporal reuse and/or routing protocols/metrics together with possible admission control mechanisms. However, they assume a given topology, i.e., the position and the type of all mesh nodes are decided beforehand. On the other hand, unfixed-topologies based approaches are subdivided into two groups.

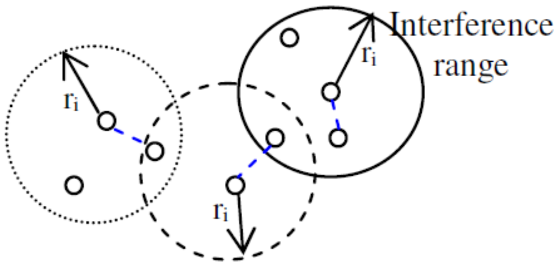

Figure 4. Simultaneous communications interfere with each other.

The first group (partial design) encompasses all approaches that attempt to optimize the network performance by optimally selecting the position and type of each mesh node (either MR or MG) given a different set of pre-deployed nodes.

The second group is more generic and uses more complex techniques to build a network from scratch; it requires the consideration of many factors prior to network deployment. Some of these factors are clients' coverage, optimal placement of MGs (for better throughput and less delay/congestion), and an optimal number of channels/radio per node.

Because of the new and inventive applications WMNs can offer, most industries, unfortunately, introduced premature and not optimized solutions to avoid losing their market share. Furthermore, the solutions were not standardized, and each network offered different incentives for a particular application [13]. To optimize WMNs, a literature search already yields several design issues and solutions, but further research is still needed. The present article surveys existing WMNs performance improvement studies in a comprehensive taxonomy of WMN design approaches according to the categorization shown in Figure 5. More specifically, for each category, we explore the most representative set of approaches and discuss the corresponding fundamental characteristics.

IV. APPLICATIONS OF WIRELESS MESH NETWORKS

Due to their versatility, WMNs can efficiently satisfy the needs of multiple applications. In this section, we will survey some of the most commonly encountered applications of WMNs. It is likely that other applications will emerge as the technology matures.

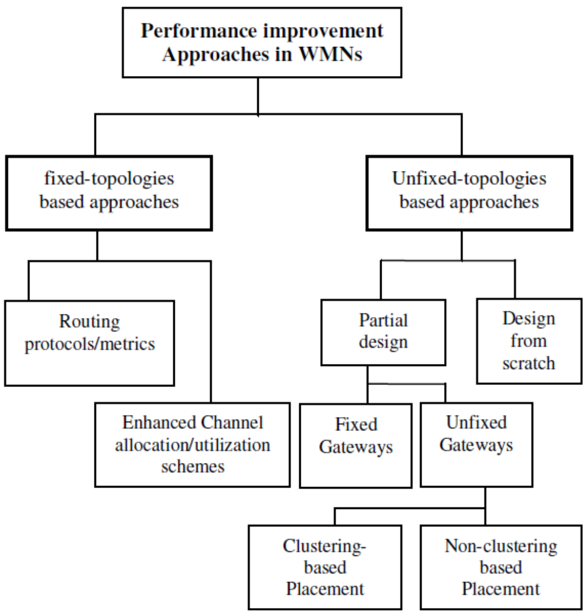

Figure 5. Classification of approaches for WMN performance improvement

A. Broadband Internet Access

Today, most of the Internet broadband connections rely either on cable or digital subscriber lines (DSL) (satellite being a distant third). Unfortunately, a large percentage of the population (especially in rural environments, but also in large cities, even in developed countries) do not have the necessary broadband infrastructure (either TV cable or a good quality phone cable) to connect to the Internet. Furthermore, installing the required infrastructure (in particular, installing new cables) is prohibitively expensive for all but the largest Internet Service Providers (ISPs). Several companies realized the potential of WMNs as an Internet access solution and produced a broad range of related products. WMNs offer considerable advantages as an Internet broadband access technology [3]:

Low Upfront Investments: Since there are no cables to install, the significant upfront investments typically associated with cable and DSL are largely bypassed. A bare-bones WMN providing minimal coverage can be used to service the first customers (an operation commonly known as "seeding"); as the number of customers increases, the network can be upgraded incrementally.

Customer Coverage: Due to its multihop routing ability, line of sight to a single base station is not required; as long as a client has connectivity to any other client, it can obtain Internet access. It was shown [4] that, especially for scenarios with significant obstructions (trees or high-rise buildings), a WMN can significantly improve the coverage in comparison with a point-to-multipoint (e.g., IEEE 802.16) solution.

Fast Deployment: Adding a new client to an existing WMN can take several hours instead of several months, the typical delay for installing new wires for cable or DSL.

Reliability: Especially if multiple gateways are used, all single point-of-failures are eliminated. A responsive routing protocol can quickly route around failed links or nodes; and, in the case of a gateway failure, it can redistribute the orphaned nodes to nearby gateways.

Interestingly enough, Metricom's Richochet's WMN [5], one of the first commercial wireless mesh networks, started as a wireless sensor network used to read parking meters and later evolved into an Internet access network.

B. Indoor WLAN Coverage

The popularity of IEEE 802.11 compatible WLANs exposed one of the most unpleasant aspects of the technology: in order to provide coverage of any but the smallest buildings, multiple access points (APs) are required. All of these access points have to be connected to a distribution system (a wired network), commonly an Ethernet network. Several companies leveraged the multihop capabilities of WMNs to eliminate the need for cables. In such a deployment, at least one of the WMN routers is connected to the external network and, hence, becomes a gateway. All of the other WMN routers double as APs and forward the data from (and to) the wireless clients to the gateway. Another form of WMN is formed by using the bridging features of some models of access points that can forward each others' packets.

The main disadvantage of these products is the potentially larger number of required APs: the APs have to be in the wireless range of each other. Furthermore, because all of the APs have to be on the same channel (to be able to forward each other's data) and, due to forwarding induced inefficiencies, the resulting network capacity can be several times smaller than the capacity of a traditional WLAN.

To mitigate these problems, Belair Networks proposed to replace the numerous wired APs with only a few larger, more powerful APs placed at the *exterior* of the building. To increase its network capacity, Belair's wireless routers have several directional antennas (increasing signal power and reducing interference) and multiple radios, being thus able to efficiently utilize the entire 2.4 GHz ISM band.

C. Mobile User Access

The third generation of cellular systems, commonly known as 3G, can offer relatively high-speed connections (up to 2Mbps for stationary users and 144kbps for highly mobile users in macro cells). However, full deployment of 3G will take several years. In the mean time, most mobile users seeking connectivity outside the sparse coverage of WLAN hot spots have to settle for the slow and expensive 19.2kbps cellular digital packet data (CDPD) or, more recently, for GPRS (usually 20-30kbps - theoretical maximum 171.2kbps).

Properly designed WMNs can easily deliver higher bandwidth than the best 3G technology. Mesh Networks [2] was one of the first companies to demonstrate connectivity and seamless handovers at highway speeds. Thus, all of the promises of 3G (bandwidth, mobility, voice quality) can be accommodated by WMNs with lower upfront investments (and possibly without expensive spectrum licenses), making WMNs a serious competitor to 3G cellular systems. Currently, the main customers for such systems are small governmental agencies (e.g., fire and/or police departments) in small- to medium-sized towns, which can improve the access data rates while significantly reducing their monthly bill. The US Department of Defense (DoD) may also benefit from such a mobile and versatile network for data and voice communications on future battlefields.

D. Connectivity

Sometimes, providing network connectivity can be cumbersome, expensive, time consuming or unsightly. Firetide [1] constructs WMNs specifically geared toward providing connectivity. Each of the Firetide WMN routers have an available Ethernet port; all WMN routers form a wireless “cloud” that can be seen from outside as one big Ethernet switch. In the Firetide design, the Internet access and mobile user access are optional (IEEE 802.11 APs can be connected to the WMN nodes if WLAN coverage is desired). The main advantages of the Firetide products, when compared with traditional Ethernet wiring are:

Fast Deployment: If fast deployment is required (e.g., conferences, shows, etc.), plugging WMN routers in the power sockets in the appropriate places is all that is needed to obtain network connectivity. Furthermore, even if fast deployment is not required, many businesses cannot afford to shut down for wires to be installed (e.g., an airport).

Pleasing Aesthetics: There are many settings that can benefit from the lack of unsightly wires associated with Ethernet networks (e.g., hotel lobbies, show halls, airports, etc.). Moreover, in some buildings (e.g., historic), drilling holes for the networking cables is not allowed altogether.

V. CHALLENGES

In this section we outline the major research issues related to WMNs. We follow a bottom-up layered approach and emphasize the less obvious issues at each layer.

A. Physical Layer

WMN technology is theoretically “radio agnostic” [2] (i.e., independent of the physical layer); however, as for all networking technologies, the characteristics of the physical layer are reflected in the performance of the WMN. The challenges of the physical layer of WMNs are not fundamentally different from other wireless technologies. As a minimum, the physical layer of a WMN should be reliable. The undesirable effects of fading and interference are well understood and several (typically spread spectrum) solutions (Frequency Hopping Spread Spectrum (FHSS), Code

Division Multiple Access (CDMA), Orthogonal Frequency Division Multiplexing (OFDM) and Ultra-Wide Band (UWB)) are routinely employed to increase the reliability of the radio transmission.

Since the MAC protocol of WMNs is commonly contention based, resistance to interference is more important than in the case of cellular systems and 802.16 that enjoy practically collision free MAC protocols. Beyond basic reliability requirement, several other characteristics can make a significant difference for the performance
of WMNs:

Mobility: For WMNs capable of supporting user mobility, it is necessary for the physical layer to support the shift in frequency and adapt to the fast fading conditions commonly associated with mobile users.

Link Adaptation: When transmission conditions are less than ideal (i.e., most of the time), a more robust modulation or error-correcting codes should be employed to restore the reliability of a link (at the expense of the bandwidth). Many current technologies (cellular systems, WLANs, WMANs) currently employ such a link adaptation.

Variable Transmission Power: Being able to vary the power of the wireless transmitter can be seen as an extra degree of freedom for the link adaptation algorithm. However, the “optimal” transmission power can be determined only using information from the upper layers (depending on the goal any of the following objectives can be optimized: minimize interference, minimize delay, maximize network capacity, etc.).

Multiple Transceivers: If multiple communication channels are available (i.e., multiple frequency channels, different orthogonal codes for CDMA, UWB, etc.) it is conceivable that a well designed MAC protocol can take advantage of having multiple transceivers to simultaneously transmit and/or receive on different channels.

Directional Antennas: Omni-directional antennas are inexpensive and simple to build and use; however, directional antennas allow WMNs to reduce the interference between simultaneous transmissions to improve the link budget and range and/or to reduce the transmission power. However, using directional antennas can significantly complicate the design of the upper layers.

Link Quality Feedback: It is currently well recognized that, for wireless networks, link quality information can be effectively used in the higher layers for detecting handover imminence, routing decision, capacity optimization, etc. The availability of this information can significantly improve the efficiency of the upper layers.

Transceiver Performance: Finally, the transceivers should be able to switch quickly between the available channels, between transmitter and receiver mode and be able to quickly acquire synchronization. The efficiency of the transmission can be significantly lowered if preambles and inter-frame spacing are long, especially for short packets [6].

B. Data Link Layer

At the data link layer, the design of the MAC protocol is the most likely challenge in WMN. Despite the existence of a centralized entity (the gateway), it is unlikely that the gateway can efficiently coordinate the MAC layers of nodes several hops away. There are a significant number of MAC protocols designed for MANETs. It is likely that many of those layers will work reasonably well in WMNs. In particular MACAW, (the RTS/CTS option standardized in IEEE 802.11 [7]) is particularly useful in preventing the effects of the hidden terminal problem. An interesting problem in WMNs (and ad hoc networks in general) is how to efficiently utilize multiple physical channels (if supported by the physical layer).

Channel Assignment:

Figure 6 shows two possible channel assignments for a WMN with C = 3 channels and M = 1 transceivers in each router. Which of the two assignments maximizes the capacity of the network depends on the offered load at each node in the network. Potentially, there can be a very large difference in network capacity between the two channel assignments. The problem is further complicated by an increase in the number of transceivers M > 1 and/or the flexibility afforded by some technologies (CDMA, UWB) in choosing a channel capacity: in CDMA and UWB by choosing different code lengths, different rates can be assigned to different transmitters.

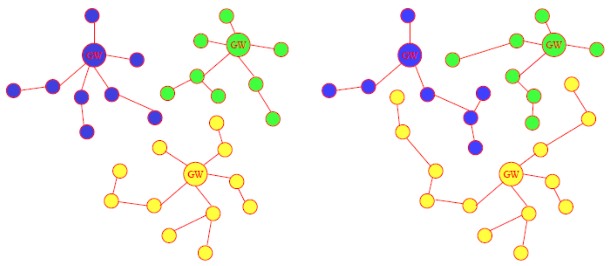

Figure 6. Two different channel assignments for a network with three channels, three gateways, and 29 WMN routers.

Multichannel MAC Layer:

In the previous section no specialized MAC protocol was assumed; a standard 802.11 transceiver with the possibility of controlling the transmission/reception channel will suffice. If, however, a new MAC protocol is used (or, alternatively, it is possible to finely and efficiently control the behaviour of a standard MAC from a higher layer).

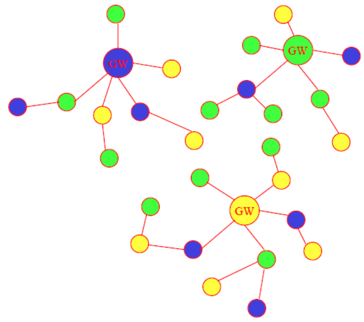

Figure 7. Channel assignment with a specially designed MAC protocol.

With a MAC capable of changing the channels, and multiple transceiver nodes, it is possible to transmit and receive simultaneously or to use more than one channel for one transmission. This freedom can lead to an increase of the overall performance at the expense of a more complex MAC layer and a costlier physical layer.

MAC Layer for Smart Antennas:

Smart antennas (software steerable directional antennas) are part of the 3G standards. Their advantages are very similar to those of traditional directional antennas (increased link budget, larger transmission range, reduced transmission power, increased reliability, etc.) with the added advantage that they can change the direction of the antenna and thus switch between different neighbors and track mobile users.

Designing efficient MAC protocols for smart antennas is far from trivial, requiring good coordination between the antennas of the transmitter and receiver (in space and time), as well as provisions for new nodes to join. The problem is especially difficult for WMNs supporting mobile nodes.

C. Network Layer

The main function of the networking layer is to transfer the packets from the source to the destination over multiple hops. In this respect, WMNs are radically different from 3G systems, WLANs and WMANs. All these technologies use a single wireless link, and hence have no need for a network layer. In contrast, for WMNs and MANETs the source and the destination can be several wireless hops away from each other, and hence the packets have to be routed and forwarded in the wireless network itself.

1) Routing:

The routing protocol is an important factor in any network, but in WMNs it can mean the difference between failure and success. Several of the advantages of WMNs over competing technologies are enabled by the routing protocol alone:

- **Scalability/Efficiency:** If the routing protocol has a high overhead and requires global information, it will be impossible to scale it to a large number of nodes.
- **Reliability:** The routing protocol should be able to reroute fast around failed nodes, broken links, and upon the failure of a gateway it should be able to redistribute the orphaned clients among neighbouring gateways. For this property, fast reconfiguration and support of multiple gateways is essential.
- **Mobile User Connectivity:** To ensure seamless mobileuser connectivity, the routing protocol should enable fast hand-offs.
- **Flexibility:** The routing protocol should be flexible and adapt to different network topologies.
- **QoS:** In addition to support from the MAC layer and/or the forwarding engine, selecting the best routes for different traffic classes is an essential ingredient for QoS support.

In addition, the entire performance of a WMN is affected by its routing protocol. Load balancing, avoiding congested routes, and taking into account interference patterns existent in a WMN are just some of the factors that directly affect the performance of WMNs. A considerable number of routing protocols were developed for MANETs. Most of these protocols work well for MANETs. However, in MANETs, the traffic is assumed to be flowing between arbitrary pairs of nodes while in WMNs, most of the traffic flows between the gateway and client nodes. Furthermore, while the mobility of MANET nodes is usually similar, in WMNs, the nodes can be distinctly classified as either mobile or stationary. It is thus likely that for WMNs a custom routing protocol can significantly outperform general MANET protocols.

2) Forwarding: Fairness and QoS

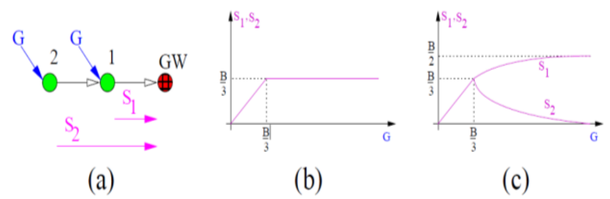

Figure 8. (a) Fairness study of a two-node network forwarding packets to a gateway GW. The deal (b) and real (c) throughputs of nodes 1 and 2 as a function of the offered load G.

Once the routes are established, data packets have to be forwarded between the clients and the gateway. All classical forwarding problems still apply for WMN (minus the need to scale to hundreds of thousands of flows). The fact that the WMN routers have a single wireless interface that handles its own flows as well as forwarding on behalf of other nodes introduces additional problems.

Even in the simplest case (depicted in Figure 8) with two users (1 and 2) forwarding data to a gateway, user 1 can completely starve user 2 just by sending its own data [8]. This unfair effect occurs in all implementations using a single-forwarding queue. An obvious extension of the fairness problem is providing QoS in the form of multiple classes of service for the clients (e.g., residential/business or silver/gold/platinum class).

D. Transport Layer

TCP is currently the most widely-used transport protocol on the Internet. Unfortunately, TCP was designed and finetuned for wired networks where most packet losses are due to buffer overflows in the routers. This assumption is simply not true in WMNs where most losses are due to poor wireless links, medium access contention, and user mobility.

It is well known that even in single-hop wireless networks, TCP performs poorly (unnecessarily reducing its transmission rate in response to transmission errors and delays). In a multihop environment such as a WMN, TCP will perform significantly worse as there are significantly more chances to lose a packet (several wireless transmissions for each packet, mobility of intermediate routers, etc.) than in the single-hop wireless networks.

Furthermore, even for relatively simple scenarios, TCP is unfair favoring some links at the expense of others. The unfair behaviour is, in some instances, inherited from the networking layer, while, in other cases, it is induced by TCP mechanisms.

E. Other Challenges

In this section we will present several other challenges that span multiple layers of the OSI stack.

1) Provisioning:

Provisioning WLANs in multi access point deployments is far from trivial. In WMNs, the problem is considerably more difficult. Usually, the main provisioning problem is to determine how much bandwidth each subscriber can receive, given a WMN topology and the offered loads. Preliminary results with simplified network models and assumptions (e.g. single communication channel, omni-directional antennas) have been recently published [9], [10]. The problem with a more realistic model and for a more general physical and MAC layers is yet to be solved.

The capacity of a WMN is decreasing with the number of clients connected to each gateway [10]. At some point, the ISP (operator) should upgrade the infrastructure by adding one or more gateways. In this case the problem is to determine the location of the additional gateways that maximizes the network capacity.

Another interesting problem is determining where to "seed" (install gateways and repeaters) a neighbourhood (given a list of potential clients, or a list of subscribed clients and potential clients).

2) Security:

Unfortunately, security is sometimes an after-thought. For any commercial wireless product, however, security should be one of the first problems to be solved. For WMNs, there are at least several security issues to be considered:

- **Authentication:** Before allowing a user to join the network, each client (stationary or mobile) should be authenticated. This can prevent access by unauthorized (sometimes malicious) users or those that simply are not willing to pay for the service.
- **Privacy:** Especially in WMNs, where user data travels through multiple wireless hops, the clients will be concerned with the privacy of their information. User data should be secured both from sniffing by occasional eavesdroppers while transmitted between WMN routers and from being read by other network users at intermediate hops. An end-to-end (at least client to gateway) encryption scheme is likely necessary.
- **Reliability:** In addition to user data it is imperative to protect the control data (routing, monitoring, etc.). If the control data is unprotected, it will be

relatively easy for an attacker to disable a WMN (or alter its behavior at his or her will).

3) Transmission Power Level:

The choice of transmission power in MANETs is a prolific research area. Clearly the transmission power should be higher or equal to a lower bound that ensures network connectivity. The transmission power is also bounded from above by technology and regulatory limits. An algorithm that maximizes the network capacity by varying the transmission power between the two limits is needed. Many other parameters (error rates, delay, etc.) are influenced by the transmission power.

VI. CONCLUSION

Wireless mesh networks leaped from the drawing boards into reality. Numerous start-up companies are pursuing the technology and use it to satisfy the needs of numerous application, providing broadband Internet access, WLAN coverage and connectivity. The technology has the potential to successfully compete with several traditional technologies (3G systems, WLANs and WMANs). The main drawback of the technology is its complexity. The main source of this complexity is a combination between wireless technology (with its flexibility and drawbacks) and the unusual role of each wireless node (as simultaneously router and host). The challenges are in large part unique to WMNs and considerable research has yet to be completed before WMNs can reach their full potential.

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