IEEE 802.11s Wireless Mesh Networks: Challenges and Perspectives

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Abstract. A promising solution for wireless environments is the wireless mesh technology that envisages supplementing wired infrastructure with a wireless backbone for providing Internet connectivity to mobile nodes (MNs) or users in residential areas and offices. The IEEE 802.11 TGs has started to work in developing a mesh standard for local area wireless networks. Although a lot of progress has been made and a few new drafts have been released recently, there exist many issues that demand enhanced or even new solutions to 802.11s mesh networking. This paper aims to overview the latest version of the IEEE 802.11s protocol (Draft 2.02), especially the MAC and routing layers, and to point out the challenges that these networks have to overcome in these layers.

Keywords: Wireless mesh network, IEEE 802.11s, routing, MAC, power management.

1 Introduction

The IEEE 802.11 protocol family has become the dominant solution for Wireless Local Area Networks (WLANs), due to its high performance, the low cost and its easiness in deployment. However, the increasing demand for wireless broadband access and high speed rates create new challenges for local area wireless networking, due to the fact that in order to increase the data rate the Access Points (APs) of the WLANs ought to decrease their transmission range in order to support a range of innovative services and access to the mobile users. Although, the interconnection of WLANs with a fixed infrastructure could be a solution, the cost is an inhibitory factor for this implementation.

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A promising solution for wireless environments is the wireless mesh technology that envisages supplementing wired infrastructure with a wireless backbone for providing Internet connectivity to mobile nodes (MNs) or users in residential areas and offices, and could be called the Web-in-the-sky [1]. A Wireless Mesh Network (WMN) consists of mesh routers and mesh clients [1]. Mesh routers have minimal mobility and form the mesh backbone for mesh clients. Furthermore, in order to further improve the flexibility of mesh networking, a mesh router is usually equipped with multiple wireless interfaces built on either the same or different wireless access technologies. A comprehensive survey regarding the mesh technology can be found in [2].

In order to provide wireless Internet connectivity at lower cost than the classic Wireless Fidelity (WiFi) networks, several companies are developing their proprietary WMN solutions, such as Motorola [9] with "MOTOMESH" and Proxim Wireless Corporation [10] with "ORiNOCO". Also, in order to develop a mesh standard for local area wireless networks the *Extended Service Set (ESS)* Mesh Networking Study Group (SG), authorized by IEEE 802.11 Working Group (WG), has been established in 2003. Its main task was the definition of the Project Authorization Request (PAR) and Five Criteria (5C), which are needed to request formation of a new Task Group (TG). From July 2004, "Mesh Networking" became TG "s".

A call for proposals was issued in May 2005, which resulted in the submission of 15 proposals submitted to a vote in July 2005. After a series of eliminations and mergers, the proposals dwindled to two (the "SEE-Mesh" and "Wi-Mesh" proposals), which became a joint proposal in January 2006. This merged proposal was accepted as draft version D0.01 after a unanimous confirmation vote in March 2006. Although a lot of progress has been made and a few new drafts have been released recently, there exist many issues that demand enhanced or even new solutions to 802.11s mesh networking [8]. As of September 2008 the draft is at version D2.02 [3].

Since the standardization of the 802.11s in an ongoing recent work, many changes have made from the one draft version to the other. The scope of this paper is to give an overview of the IEEE 802.11s draft (version 2.02), and especially of the MAC and routing layers, as well as, to point out the challenges that these networks have to be overcome in these layers. It should noticed that in this paper we follow the latest terminology for the 802.11s mesh networking, the one defined in draft (version 2.01) [4].

The rest of the paper is organized as follows: The new key terms of the IEEE 802.11s mesh networks are defined in Section 2. In Section 3 and 4 the proposed IEEE 802.11s MAC and routing layer enhancements are presented, respectively. Section 5 discusses challenging research issues that still exist in the current 802.11 standard at MAC and routing layer. Finally, Section 6 concludes the paper.

2 Terms and Definitions

In the IEEE 802.11s standard, all the devices that have mesh functionalities are called Mesh Stations (Mesh STAs or MSTAs). The term "mesh capabilities" means that the device can participate in the mesh routing protocol and forward data on behalf of other mesh points according to the proposed 802.11s amendment [1]. A set of Mesh STAs consist a Mesh Basic Service Set (MBSS) that may be used as a distribution system (DS). Each mesh STA is a member of exactly one MBSS.

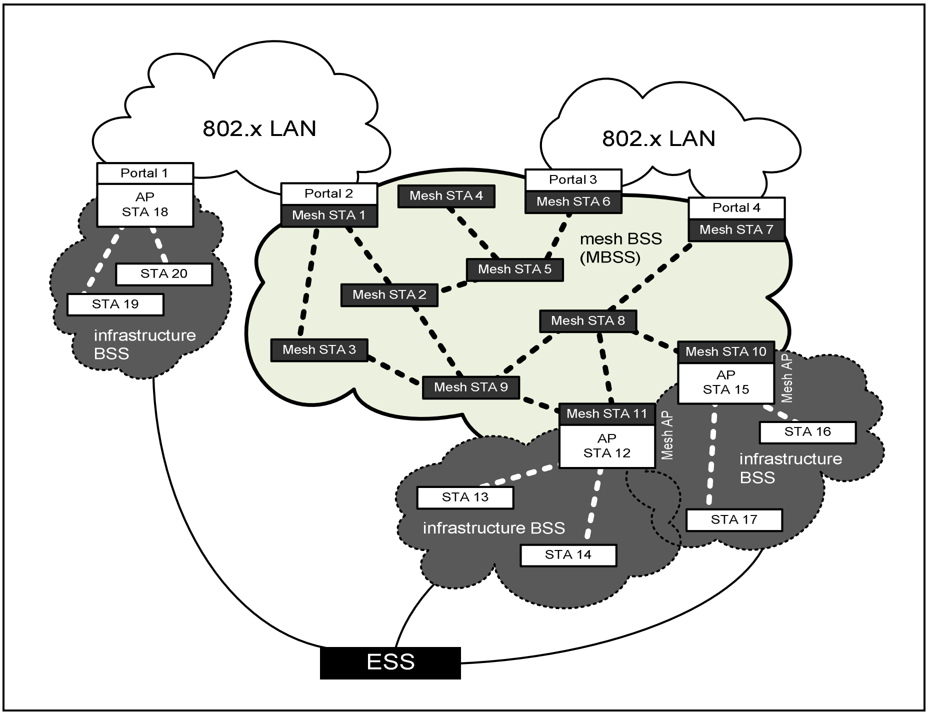

Fig. 1. The ESS 802.11s Network Architecture

Also, Mesh STAs that have additionally access point functionality are called *mesh access points (mesh APs)*. IEEE 802.11 stations that do not have mesh capabilities can connect to mesh APs in order to send data over the mesh network.

A Mesh STA that has a connection to a wired network and can bridge data between the mesh network and the wired network is called *Portal*. Therefore, in order to uniquely identify a Mesh STA in an IEEE 802.11s, a Mesh BSSID is assigned to each Mesh STA, similar to the use of Service Set IDentifier (SSID) to represent an ESS in legacy 802.11 networks [6].

An IEEE 802.11s network architecture is illustrated in Fig. 1.

3 Medium Access Control

The IEEE 802.11s employs the EDCA specified in IEEE 802.11e [7]. It also provides an optional Coordination Function (CF) that is called Mesh Deterministic Access (MDA) that allows supporting Mesh STAs that support MDA to access a certain period with lower contention, called MDA OPportunity (MDAOP). To use the MDA method for access, supporting Mesh STAs must be synchronized to each other. MDA capable Mesh STA negotiates with their neighbor Mesh STAs on the reservation of multiples of 32 μs time slots. Once accepted, the transmitter is referred to as the owner of the MDAOP.

During an MDAOP period, the owner of the MDAOP and the receiver follow a different procedure: The owner of MDAOP that has highest priority for medium access, attempts to use Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with new backoff parameters to set up a Transmission Opportunity (TXOP), while the non owner of MDAOP has to defer its access by setting its Network Allocation Vector (NAV) to the end of the MDOAP or by using a carrier sensing scheme.

The proposed MAC mechanisms facilitate also synchronization, beacon collision avoidance, congestion control, and power saving.

3.1 Beaconing and Synchronization

Synchronization is an optional feature for Mesh STAs. With synchronization, each Mesh STA updates its timers with time stamp and offset information received in beacons and probe responses from other Mesh STAs. Thereby a common Time Synchronization Function (TSF) timer is maintained, called Mesh TSF timer.

In 802.11s also beaconing procedures are defined not only for synchronized Mesh STAs but also and for unsynchronized Mesh STAs. More specifically, the standard also specifies a beacon collision avoidance mechanism, called Mesh Beacon Collision Avoidance (MBCA) mechanism. MBCA mechanism is utilized to detect and mitigate the contiguous collisions among beacon frames transmitted from hidden nodes.

In contrast, unsynchronized Mesh STAs transmit their beacons as APs in BSS networks, each maintaining independent TSF timer and Target Beacon Transmission Times (TBTTs).

3.2 Intra-mesh Congestion Control

In an IEEE 802.11s network intra-Mesh congestion control is achieved by implementing the following three main mechanisms: Local congestion monitoring and congestion detection, congestion control signaling, and local rate control.

Although Mesh STAs may support multiple congestion control protocols, as stated in 802.11s (draft version 2.0), there is only one congestion control protocol active in a particular mesh network at a time. The default congestion control protocol specifies only congestion control signalling. Specific algorithms for local congestion monitoring and congestion detection, as wells as, local rate control algorithms are beyond the scope of the default congestion control protocol.

3.3 Power Management

All Mesh STAs have the capability to operate in power save mode. More specifically, two different power states are considered:

- *Awake:* the Mesh STA is able to transmit or receive frames and is fully powered.
- *Doze:* the Mesh STA is not able to transmit or receive and consumes very low power.

The manner in which an Mesh STA transitions between these two power states is determined by the Power Management mode of Mesh STA. These include:

- *Active mode:* the Mesh STA shall be in the Awake state all the time.
- *Power save mode:* the Mesh STA alternates between Awake and Doze states, as determined by the frame transmission and reception rules. The Mesh STA in Power Save mode can either operate in light sleep or in deep sleep mode.

4 Routing in WMNs

In the IEEE 802.11s, the default hybrid wireless mesh protocol (HWMP) combines the flexibility of reactive on-demand route discovery and the efficiency of proactive routing. Specifically, the reactive on-demand mode in HWMP is based on the Radio-Metric Ad hoc On-demand Distance Vector (RM-AODV) protocol, while the proactive mode is implemented by the tree-based routing. Such a combination in HWMP can achieve the optimal and efficient path selection. The draft standard (1.0) also defines an optional Radio Aware-Optimized Link State Routing (RAOLSR) that uses multipoint relays, a subset of nodes that flood a radio aware link metric, thereby, reducing control overhead of the routing protocol [5]. However, starting from draft 1.07, the optional routing protocol is removed from the 802.11s [6].

All modes of the HWMP operation utilize common processing rules and primitives. HWMP information elements are the Path Request (PREQ), Path Reply (PREP), Path Error (PERR) and Root Announcement (RANN). The metric cost of the links determines which paths HWMP builds. In order to propagate the metric information between Mesh STAs, a metric field is used in the PREQ, PREP and RANN elements.

The HWMP can support various radio metrics in the path selection, such as throughput, QoS, load balancing, power-aware, etc. The default metric is the airtime cost metric, which considers the PHY and MAC protocol overhead, frame payload, and the packet error rate to reflect the radio link condition. The airtime cost at each link c_a is given by

$$c_a = \left[O + \frac{B_t}{r} \right] \frac{1}{1 - e_f} \tag{1}$$

where O and B_t are constants for each 802.11 modulation type (see Table 1), and the parameters r and e_f are the data rate in Mb/s and the frame error rate for the test frame with size B_t respectively. The rate r represents the data rate at which the Mesh STA would transmit a frame of standard size B_t, based on current conditions and its estimation is dependent on local implementation of rate adaptation. The frame error rate e_f is the probability that when a frame of standard size B_t is transmitted at the current transmission bit rate r, the frame is corrupted due to transmission error; its estimation is a local implementation choice. Frame drops due to exceeding Time-To-Live (TTL) should not be included in this estimation as they are not correlated with link performance.

Table 1. Airtime Link Metric Constants

Parameter	Recommended Value	Description
O	varies depending on PHY	Channel access overhead, which includes frame headers, training sequences, access protocol frames, etc.
B_t	8192	Number of bits in test frame

5 Challenging Issues in WMNs

Although several standard drafts have been released by 802.11s, many issues still remain to be resolved. The following of this section discusses and points out challenges, especially at the MAC layer and routing layer (Table 2).

5.1 Medium Access Control

The medium access protocols, which are currently used in mesh networks, were initially designed for single-hop networks. Therefore, these protocols do not work well in IEEE 802.11s WMNs, since data transmission and reception at a node is not only affected by nodes within one hop, but within two or more hops away and also from the fact that a mesh STA MAC is usually equipped with multiple wireless interfaces built on either the same or different wireless access technologies. Therefore, there exist several major challenging issues that ought to be addressed, these include:

- **Multi-channel Operation:** Although a Mesh STA can have multi- radio interfaces, however, no multi-channel mechanism has been specified in 802.11s. In 802.11 draft (version 0.04), the concept of Common Channel Framework (CCF) was introduced in order to deal with multi-channel operation. However, because of many problems that were not resolved effectively, the proposal was removed from the draft [6]. Therefore, multi-channel operation is still an open issue.
- **Scalable MAC:** Scalability is an important factor for the performance of a mesh network. However, this issue has not been studied in depth in the 802.11 standard. In order to really achieve spectrum efficiency and improve the per-channel throughput, the scalable MAC protocol needs to consider the overall performance improvement in multiple channels [12]. Therefore, new distributed and collaborative MAC schemes must be proposed to ensure that network performance (e.g., throughput and even QoS parameters, such as delay and delay jitter) will not degrade as network size increases [12].
- **Network Integration:** In WMNs, mesh routers can operate in various wireless technologies, such as IEEE 802.11 and IEEE 802.15.4, and IEEE 802.16. Hence, in the MAC layer, advanced bridging functions should be designed. In this way, different wireless technologies can work together seamlessly [11], [12].

- **Adaptivity to Network Configuration Change:** In WMNs, new nodes can be joined and some nodes can be left from the network dynamically. Hence, the MAC layer and the associated channel assignment schemes need to be adaptive to these network configuration changes [11].
- **QoS:** Support for different QoS levels in a multiradio multi-channel architecture using IEEE 802.11e should be investigated [1].

5.2 Routing

Although the standard defines the HWMP as the default routing protocol, HWMP has several shortcomings. Scalability in this protocol is limited and it cannot support route optimization between two mesh STAs [6]. Also, more routing metrics are needed for multi-channel operation, as well as, interaction with MAC layer since HWMP is considered as a module at the MAC layer [6]. Therefore, there still exist several major challenging issues that ought to be addressed, these include:

- **Load balancing and QoS:** Most applications of WMNs are broadband services with heterogeneous QoS requirements. Therefore, routing algorithms are needed to provide QoS guaranteed paths or at least some support for QoS provisioning. Also, the proposed routing algorithms need to perform load balancing and to ensure that a router does not become a bottleneck node [2].
- **Integrated Routing/MAC Design:** In WMNs, the routing layer needs to work interactively with the MAC layer in order to maximize its performance. Integrating adaptive performance metrics from layer-2 into routing protocols or merging certain operations of MAC and routing protocols can be promising approaches [11].
- **Routing Metrics:** Although the airtime cost metric considers the PHY and MAC protocol overhead, frame payload, and the packet error rate to reflect the radio link condition and other factors, such as the power saving feature, the mobility, the multi-channel operation s may need to be devised in order to take into account the peculiarities of multi-channel multi-radio wireless mesh networks [11].

Table 2. 802.11s Challenging Issues

Layer	Issues
MAC	Multi-Channel Operation Scalable MAC Network Integration Scalability Adaptivity QoS
Routing	Load balancing & QoS Cross Layer Routing Routing Metrics

6 Conclusions

A promising solution for wireless environments in order to provide wireless Internet connectivity at lower cost than the classic Wireless Fidelity (WiFi) networks is the wireless mesh technology. A Wireless Mesh Network (WMN) consists of mesh routers and mesh clients. Mesh routers have minimal mobility and form the mesh backbone for mesh clients. Furthermore, in order to further improve the flexibility of mesh networking, a mesh router is usually equipped with multiple wireless interfaces built on either the same or different wireless access technologies.

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References

1. Nandiraju, N., Nandiraju, D., Santhanam, L., He, B., Wang, J., Agrawal, D.P.: Wireless Mesh Networks: Current Challenges and Future Directions of Web-In-The-Sky. IEEE Wireless Communications 14(4), 79–89 (2007)
2. Akyildiz, I.F., Wang, X.: A survey on wireless mesh networks. IEEE Communications Magazine 9(43), 23–30 (2005)
3. Draft Standard for Information Technology - Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Amendment: ESS Mesh Networking, IEEE Unapproved draft P802.11s/D2.02 (September 2008)
4. Draft Standard for Information Technology - Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Amendment: ESS Mesh Networking, IEEE Unapproved draft P802.11s/D2.01 (July 2008)
5. Camp, J.D., Knightly, E.W.: The IEEE 802.11s Extended Service Set Mesh Networking Standard. IEEE Communications Magazine 46(8), 120–126 (2008)
6. Wang, X., Lim, A.O.: IEEE 802.11s wireless mesh networks: Framework and challenges. Ad Hoc Networks 6, 970–984 (2008)

7. IEEE P802.11e/D13.0, Amendment: Medium Access Control (MAC) Quality of Service (QoS) Enhancements (January 2005)
8. Hiertz, G.R., Max, S., Zhao, R., Denteneer, D., Berlemann, L.: Principles of IEEE 802.11s. In: 16th IEEE International Conference Computer Communications and Networks, Honolulu, Hawaii, USA, pp. 1002–1007 (2007)
9. MOTOMESH Duo by Motorola Company, `http://www.motorola.com/statichtml/MOTOMESH_Duo.html`
10. ORiNOCO Wi-Fi Mesh Series by Proxim Wireless Corporation, `http://www.orinocowireless.com/products/wifi_mesh/index.html`
11. Hossain, E., Leung, K.: Wireless Mesh Networks Architectures and Protocols. Springer, Heidelberg (2008)
12. Akyildiz, I.F., Wang, X., Wang, W.: A Survey on Wireless Mesh Networks. Computer Networks 47(4), 445–487 (2005)