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Indoor deployment of IEEE 802.11s mesh networks: Lessons and guidelines

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ABSTRACT

Emerging wireless mesh networks (WMNs) are known for their fast and low cost deployment. Conventional mesh deployment focuses on the outdoor environment, which regards the WMNs as backbone networks. This study deploys and measures indoor IEEE 802.11s mesh networks to extend WLAN capabilities with extensive experiment configurations. The testbed is constructed in a laboratory and a field crossing three floors of a building. Disagreeing with previous research, the results of this study indicate that RTS/CTS can improve throughput by up to 87.5%. Moreover, compared with the IEEE 802.11b/g, 802.11n achieves better fairness for multi-stream or multi-hop communications. Experimental results also suggest that a longer beacon interval, e.g. 500 ms, can improve channel efficiency for a denser deployment. On the other hand, sparser deployments should use a shorter beacon interval, e.g. 100 ms, to enhance link stability.

1. Introduction

IEEE 802.11s wireless mesh networks (WMNs) [1] have generated extensive research and commercial interest in recent years. Unlike ad hoc networks and sensor networks, which are primarily motivated by military, crisis, or environmental applications, WMNs show potential for commercial applications such as last-mile wireless access or home wireless networking. WMNs can largely reduce the wiring cost and complexity of network deployment by *multi-hop relaying*. As illustrated in Fig. 1, devices in the service range of an 802.11s WMN consists of mesh stations (MSTAs), mesh portals (MPPs), mesh access points (MAPs), and non-mesh wireless stations (STAs). Mesh devices, including MSTAs, MPPs, and MAPs, form a wireless backhaul by connecting with neighboring devices via the wireless medium and relaying traffic for each other. In addition, an MPP bridges the traffic between a WMN and external networks, such as a wired LAN. An MAP provides the functionalities of IEEE 802.11 access point (AP). A conventional IEEE 802.11 STA connecting to a nearby MAP can then communicate with other STAs or access the Internet.

1.1. Lab and field testbeds

Many WMN testbeds have been developed for academic research purposes and commercial trials [2–8]. There are generally two categories of testbeds built by previous work. The first category is implemented in a well-controlled laboratory environment, such as a shielding room. One of the most well-known lab testbeds is the ORBIT project [9]. The benefit of this category is that the strictly-controlled environment reduces the unexpected effect from external error sources, like the wireless signal generated by the widespread wireless devices and noise emitted by microwave ovens [10,11]. However, the disadvantage of this approach is that the scale of experiments, constrained by time and laboratory space, is usually quite small. Therefore, the results from lab testbeds can indeed validate an idea under the clean environment, but are not general enough to be applied to all configurations in real-world deployment.

The second category of WMN testbed is the field trial. Most previous studies on this category build the testbed

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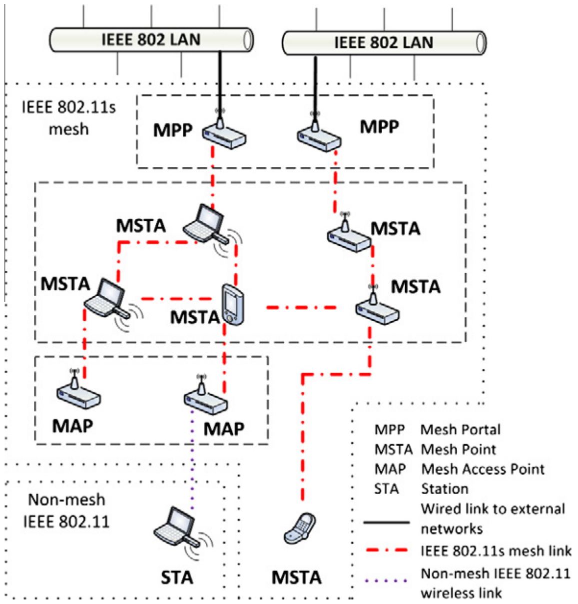

Fig. 1. IEEE 802.11s mesh network architecture.

outdoors, e.g., in an urban or rural area. The devices used in an outdoor environment are usually commercial products [4,5,8] because they must sustain harsh open-air conditions for extended periods of time. The advantage of this approach is that the results collected from a *large-scale* outdoor testbed are undoubtedly a good reference to real-world outdoor deployment. The disadvantage is that the results can vary greatly with highly changeable channel conditions and traffic loading. Meanwhile, the outdoor results might not be applicable to *indoor*, *small-scale* WMNs. Outdoor WMNs typically aim to provide last-mile or community wireless access, and hence need to deploy dozens to hundreds of MSTAs. To guarantee link capacity and signal quality, neighboring MSTAs should be within *line-of-sight* and equipped with *directional* antennas. Unlike outdoor WMNs, however, indoor WMNs provide wireless access coverage to a single building, especially important for old buildings without Internet facilities. The scale of an indoor WMN is much smaller, and its devices are much cheaper, e.g., plastic case without waterproof consideration. In addition, signal decay is more serious in indoor WMNs due to non-line-of-sight deployment. Noise sources are also different from the ones in outdoor environment [11]. As a result, deployment guidelines obtained from outdoor testbeds could not be applied to indoor WMNs.

1.2. Indoor field deployment benchmarked by lab tests

Indoor and outdoor WMNs possess distinguishable attributes and limitations. To the best of our knowledge, only a little previous work focuses on indoor WMNs [3,4]. Therefore, this study combines the deployment methodologies of laboratory and field testbeds to make observations and provide guidelines for indoor IEEE 802.11s WMN deployment. Specifically, 802.11s mesh entities of this study are implemented on a chipset complying with IEEE 802.11n [12]. First, we constructed a *laboratory* testbed. The experimental results of this testbed provide a basic benchmark for field deployment. Then, we deployed a testbed in a three-floor *field* environment, and conducted numerous experiments to investigate the effect of different configurations on complex channel conditions.

The rest of this article is organized as follows. Section 2 reviews previous studies and summarizes the differences of key findings among those literals. Section 3 describes the IEEE 802.11s testbed and experiment methodology. Section 4 presents experiment results. Then, Section 5 summarizes the lessons and guidelines learned. Finally, Section 6 concludes the work.

2. Related work: Effect of RTS/CTS and rate adaptation

Researchers have recently built a number of WMN testbeds to evaluate the performance characteristics of WMNs in real environments. Koutsonikolas et al. [3] reported on the configurations of the TCP maximum window size and other two important MAC parameters, i.e., Request-to-Send/Clear-to-Send (RTS/CTS) and data rates, in the indoor WMN (named MAP) deployed at Purdue University. According to their observation, RTS/CTS and auto-rate adaptation (operating at 2 and 5.5 Mbps) should be enabled for 4-hop flows, and disabled for 1-hop and 2-hop flows. Sun et al. [4] also studied the impact of different MAC configurations of RTS/CTS and auto-rate adaptation (for 802.11b/g) on an indoor WMN testbed called UCSB MeshNet. Their study focuses on performance evaluation in terms of latency and loss rate for video and voice traffic. They recommended that RTS/CTS should *not* be used for multimedia traffic, and that the auto-rate adaptation does *not* always lead to capacity improvement in bursty traffic.

In addition to studies on indoor WMN testbeds, several researchers have examined outdoor WMN testbeds. DGP [5] and FRACTEL [6] are 802.11b outdoor WMNs deployed to determine the performance of wireless networks in rural and semi-urban areas, respectively. Both of these studies indicate that external interference, generated by non-WiFi sources or from WiFi sources in adjacent channels, significantly increases the packet error rate of 802.11b long-distance links. As a result, [5,6] believed that RTS/CTS may *not* really help in such situations. Camp et al. [7] investigated a measurement study of an 802.11b outdoor WMN testbed (named TFA) and highlighted the importance of measurements in accurately planning mesh networks. They also demonstrated that the RTS/CTS scheme has an overall *negative* effect on per-node throughput with minimal gains in fairness, while a *static* rate limiting scheme yields a fair multi-hop throughput distribution even with heavily loaded traffic. In addition, Arjona et al. [8] evaluated the feasibility of singe-radio mesh technology and its competitiveness with cellular networks on an 802.11g outdoor WMN (called Google WiFi) for urban deployment built by Google. Like [7], they concluded that rate limitations for each user could improve the fairness of multi-hop transmissions. Their study also shows that *disabling* the RTS/CTS scheme might improve overall performance at the