Design of a High-Capacity Multihop Wireless LAN

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1. Introduction

The IEEE 802.11-based wireless LAN is currently a primary enabling technology for ubiquitous data access to data networks with a reasonably high bandwidth. Traditionally, 802.11-based wirelesses LANs are deployed in the *infrastructure mode.* Here, access points (AP) are deployed to cover a region and they are connected to a backbone distribution system (DS). A client device, such as a laptop or palmtop with an 802.11 interface, associates itself to an AP. APs connect to an infrastructure network (e.g., the Internet or an intranet) via the distribution system. The distribution system is usually a wired network, even though options exist in the standards for provisioning a *wireless distribution system* or WDS, where the APs are connected via wireless links.

Use of WDS opens up significant opportunities for wireless LAN deployment. Wiring APs to form a wired DS is often an expensive, time-consuming and labor-intensive process. WDS makes WLANs easy to deploy, particularly for hard-to-wire scenarios such as large, old buildings, factory floors and hazard areas. Maintenance also becomes easier. This also opens up opportunities for community-wide wireless mesh networks. However, several technical challenges need to be addressed for making WDS widely deployable and usable. The goal of our work is to design and implement a wireless router architecture (called *Stony Brook Wireless Router*) that addresses these challenges, and does not require any special hardware or software set up or configuration on the clients. Such transparency is a driving force in our design.

2. Technical Challenges

We describe the challenges in this section.

Multihop routing: In a WDS, APs (nodes in the network) should also act as routers so that multihop paths can be formed between APs. This enables the clients to access the infrastructure network via a gateway node, or communicate with other clients at large distances. Such multihop routing can be somewhat similar to routing in an ad hoc network of 802.11 radios. The only significant difference is that in the latter case the wireless interfaces are operated in the so-called *ad hoc* mode, where the clients directly communicate among themselves to form an amorphous network without any involvement of any AP. In this case, the clients need to be configured with appropriate routing software. However, in a wireless network of APs using WDS, the clients can be completely unaware of the underlying wireless multihop backbone. The routing protocol operates only on the APs. The protocol choices are likely to differ as well. The network of APs is mostly stationary. However, the clients could be mobile, changing their associations to APs that would trigger route changes. We are currently developing a link state-based routing protocol to achieve this functionality.

***Multiple radios*:** Current 802.11 radios are capable of operating only in one channel at any time, and they cannot transmit and receive at the same time. Thus, if only one radio interface is used (as in most commercial APs) a relaying node automatically operates at about half the available bandwidth. Provisioning multiple radio interfaces is an obvious solution [1]. However, still the “incoming” and “outgoing” interfaces should be set to different channels so that they do not interfere. Extending this technique a little further, the choice of the channel on an interface can be done carefully so that overall interference is minimized. Spatial reuse can be exploited such that the same channel is reused on nodes at large physical distances.

802.11b can operate at 2.4 GHz band with a maximum of 11 Mbps data rate and 3 non-overlapping channels; and 802.11a can operate at 5 GHz band with a maximum of 54 Mbps data rate and 12 non-overlapping channels (8 in most commonly available hardware). Given the decreasing cost of 802.11 interfaces and availability of single-chip solutions, provisioning multiple interfaces at an AP, set to different channels, are certainly viable options. Such APs have already started to appear in the commercial market, but in a very limited form [2]. It is also possible to have a *heterogeneous* network where a node has multiple 802.11 interfaces that use different channels on different bands – thus mixing 802.11a and 802.11b. The commercial market has already started seeing “programmable” 802.11 hardware that can work in multiple bands [3]. This can make the multi-radio AP platform very flexible indeed.

***Channel assignment and topology control**:* Operating different interfaces on different bands/channels, however, must be done carefully. First, assignment of channels (and bands) to interfaces impact the interference between neighboring transmissions. Second, it also defines the network topology that in turn influences routing. This is because a link can be formed between two neighboring nodes, only if each of them has at least one interface running on a common channel. Careful attention must thus be paid to assigning interfaces to channels to maximize network throughput. It will depend not only on the physical locations of the nodes, but also on the traffic pattern. The problem can be viewed as a joint optimization problem for routing and channel assignment. We are presently designing efficient, distributed heuristics for channel assignment that works in unison with a routing protocol.

Note that channel assignment techniques can take different forms if 802.11 interfaces are capable of operating in multiple channels. Even simple abilities, such as simultaneous power measurements on a given set of channels, open up opportunities for *dynamic channel selection* on a per packet basis. For example, for each transmission, the clearest channel can be selected for transmission. This, of course, requires that the interface(s) at the receiver's end is(are) able to receive on any one of the channels. The commercial sector is developing such multi-channel 802.11 interfaces [4]. However, currently our work does not assume availability of such specialized hardware. We also assume that channel switching has a long latency (several hundred milli-seconds in our experiments with off-the-shelf 802.11 cards). Thus, channel "re"assignment will be done only at a much slower time-scale than packet transmissions, such as the timescale of new flow arrivals.

Switching bands as well bit rates in the same band can change the effective radio range. Thus, routing protocols must also factor in the "topology creation" aspect of the band assignment and bit rate selection.

3. Router Testbed and Initial Performance Evaluation

The *Stony Brook Wireless Router* is a flexible AP-cum-router platform to support the above "multi-radio, multi-channel, multi-hop" wireless backbone network to connect multiple APs. Our goal is to use off-the-shelf 802.11-based radios so that an experimental testbed can be easily built. So far, we have used two hardware platforms to experiment with. One is the Eumitcom WL11000SA-N boards by US Robotics that were reprogrammed to run embedded Linux with the openAP driver [5]. This platform, however, provides us with only one wireless interface. However, two or more such APs can be connected via the Ethernet interface to form one "single" node. The second platform uses small form-factor processor boards manufactured by Soekris [6] with up to three possible wireless interfaces – two PC card-based and one miniPCI-based. It is capable of running both Linux and FreeBSD. Many other similar small form factor board options are possible that are capable of running open source operating systems and device drivers.

We ran some simple experiments to evaluate the impact of channel assignment for multihop forwarding using a mixture of different platforms available in our laboratory. They included US Robotics-based openAP and Soekris platforms operating as AP-cum-routers and laptops operating as client devices. We have used 802.11b radio interfaces from various manufacturers – all based on the Intersil's Prism chipset with various firmware versions. We have performed experiments with 2 and 3 wireless hops using different channels on each hop. The results are in Figure 1. Note that because of a heterogeneous platform used, absolute throughput numbers are not particularly important, as performance indeed varies across interface cards from different manufacturer and with different firmware versions. The important thing to note that with channel diversity a tremendous performance boost is possible, with the improvement increasing with more wireless hops. We expect that a further boost is possible with larger number of hops.

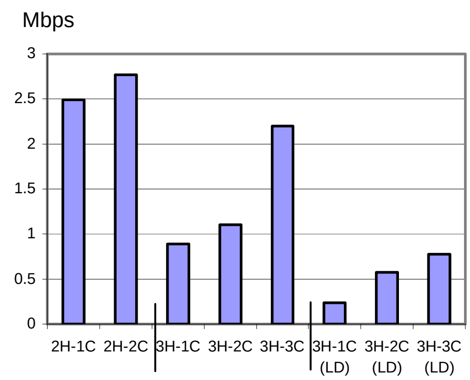

Figure 1. Maximum UDP throughput in Mbps for multihop forwarding with multiple APs with different channel assignments. There are three sets of experiments. *x*H denotes *x* hops and *n*C denotes *n* non-overlapping channels. The first two sets of experiments have all nodes in close proximity. In the third, they are at large distances (denoted by LD) causing a slower bit rate.

References

1. Atul Adya, Paramvir Bahl, Jitendra Padhye, Alec Wolman, Lidong Zhou, "A Multi-Radio Unification Protocol for IEEE 802.11 Wireless Networks," Tech. Report, Microsoft Research, MSR-TR-2003-44, July 2003.
2. Firetide, "Wireless Instant Networks," http://www.firetide.com.
3. Atheros, "Atheros AR5004 WLAN Solutions," http://www.atheros.com.
4. Engim, Inc, "Wideband Multichannel Wireless LAN Chipsets for Next Generation Access Points," http://www.engim.com.
5. OpenAP, http://opensource.instant802.com/.
6. Soekris Engineering, Soekris PC-Based Advanced Communication Computers, http://www.sokeris.com.