WiFi Related Problems in Mobile Computing

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Executive Summary

This thesis summarizes recent results in the larger area of mobile computing and includes work on channel assignment for wireless meshes, usage of WiFi compatible protocols in white spaces, optimization of WiFi networks with movement at the level of the antenna, or at the level of the entire node, robotics driven WiFi, interaction between TCP and VoIP in WiFi meshes, and interactions between WiFi and the emerging standard of Multipath TCP.

Since the inception of the first IEEE 802.11 standard in 1997, networks using unlicensed bands have been growing in popularity and surpassed all initial estimates of adoption. Their success enabled some new mobile computing applications, but also spawned a host of new problems for the research community. While expecting new applications and functionality from the new wireless LAN (WLAN), users also expected the network to behave as the conventional LAN, but this was not the case. The thesis reproduces results recently published in our work [1, 2, 3, 4, 5, 6], and shows that 802.11 based networks (informally named WiFi) are difficult to operate under high density conditions because of complex patterns of interference. These require some form of channel allocation, differential treatment of mixed traffic (TCP and VoIP). At the same time, we investigate how WiFi is blending with newer technologies at the upper layers, such as MPTCP, or at the lower layers, such as spectrum mobility.

The newly emerging standard of MPTCP aims to allow applications to use several network interfaces for a given TCP flow. This fits particularly well with WiFi, as it is used used together with other wireless technologies (3G, 4G, Bluetooth, NFC) in recent mobile devices. In chapter 1 we identify a number of classical problems related to mobile computing that can be solved with MPTCP: vertical handoff between different technologies (3G - WiFi), horizontal handoff between WiFi access points, savings in energy, and seamless connectivity. We present some simulated cases, showing the projected benefits in terms of throughput and battery savings.

When supporting both voice and TCP in a wireless multihop network, there are two conflicting goals: to protect the VoIP traffic, and to completely utilize the remaining capacity for TCP. In chapter 2, we investigate the interaction between these two popular categories of traffic and find that conventional solution approaches, such as enhanced TCP variants, priority queues, bandwidth limitation, and traffic shaping do not always achieve the goals. TCP and VoIP traffic do not easily coexist because of TCP aggressiveness and data burstiness, and the (self-) interference nature of multihop traffic. We found that enhanced TCP variants (Reno, Vegas, C-TCP, CUBIC, Westwood) fail to coexist with VoIP in the wireless multihop scenarios. Surprisingly, even priority schemes, including those built into the MAC such as RTS/CTS or 802.11e, generally can not protect voice, as they do not account for the interference outside communication range. We present VAGP (Voice Adaptive Gateway Pacer) - an adaptive bandwidth control algorithm at the access gateway that dynamically paces wired-to-wireless TCP data flows based on VoIP traffic status. VAGP continuously monitors the quality of VoIP flows at the gateway and controls the bandwidth used by TCP flows before entering the wireless multihop. To also maintain utilization and TCP performance, VAGP employs TCP specific mechanisms that suppress certain retransmissions across the wireless multihop. Compared to previous proposals for improving TCP over wireless multihop, we show that VAGP retains the end-to-end semantics of TCP, does not require modifications of endpoints, and works in a variety of conditions: different TCP variants, multiple flows, Internet delays, different patterns of interference, different multihop topologies, different traffic patterns.

Multi-hop wireless relays can provide instant network connectivity over extended areas. However, due to the spatial dependency of wireless links, the deployment of relay nodes requires extensive and hence expensive measurement and management efforts. In chapter 3, we present Mobile Autonomous Router System (MARS), through which a relay router autonomously seeks and adjusts the best "reception" position for itself and cooperatively forms a multi-hop relay network with other neighboring routers. Specifically, MARS consists of a novel measurement technique that accurately characterizes spatial link-quality; a spatial probing algorithm that effectively reduces probing space for the optimal position; and a positioning system that provides error-tolerant position information for each node. MARS has been prototyped with a commodity mobile robot and a wireless router with WiFi cards. Our evaluation of the MARS prototype shows that it achieves on average 95% accuracy on spatial measurement, and reduces measurement efforts by two-thirds over exhaustive spatial probing.

Judiciously assigning channels to a wireless mesh network can substantially enhance capacity of the network. One particular flavor of mesh network is that with a tree topology, which has the property that all traffic passes through one central point. Usually the allocation problem is linked to problems of routing, load, and measurements of interference. In chapter 4, we take advantage of the restrictions on the routing, and on potential load imposed by the topology, to present a channel allocation algorithm that is tailored for wireless trees. Using the connection characteristics of the topology, we define a conflict graph over which a coloring heuristic can provide better performance by not having to focus on connectivity/routing/interference. We show that the algorithm has a low complexity (quadratic in the number of nodes), and in simulation shows significant gains in performance when compared to simpler solutions.

In chapter 5, we explore possibilities of using white spectrum for WiFi. WLANs equipped with dynamic spectrum access DSA-capable nodes for secondary users can opportunistically utilize licensed channels when they are unused by their primary users. During such unlicensed usage, it is critical to ensure safe (low-interference) communication of PUs while ensuring high channel-use efficiency of SUs for achieving good coexistence. We propose a dual-mode MAC operation called SpeCWiFi, where secondary users try to recognize the pattern of ON/OFF behavior from the primaries and use either an Aggressive Mode once such a pattern is found, while they stay in a Safe Mode otherwise. SpeCWiFi has been implemented in software using the MadWifi driver for Atheros chipsets, and its experimental evaluation demonstrates the effectiveness of the proposed mechanisms.

Finally, in chapter III, we present a few possible research directions, some continuing research described below, and some branching out into other areas of mobile computing.

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