SPECTRUM ADAPTATION ACROSS LINK AND NETWORK

Approved by:

Dr. Dr. Joseph Camp

Dr. Dinesh Rajan

Dr. Eli Olinick

Dr. TBA1

Dr. TBA2

SPECTRUM ADAPTATION ACROSS LINK AND NETWORK

A Dissertation Presented to the Graduate Faculty of the

Bobby B. Lyle School of Engineering

Southern Methodist University

in

Partial Fulfillment of the Requirements

for the degree of

Doctor of Philosophy

with a

Major in Electrical Engineering

by

Pengfei Cui

(B.S., Beijing Institute of Technology, 2007)
(M.S., University of Chinese Academy of Sciences, 2010)

TBA

ACKNOWLEDGMENTS

TBA

Cui , Pengfei B.S., Beijing Institute of Technology, 2007
M.S., University of Chinese Academy of Sciences, 2010

Spectrum Adaptation across Link and Network

Advisor: Professor Dr. Joseph Camp

Doctor of Philosophy degree conferred TBA

Dissertation completed TBA

Due to the convenience of deployment and utility, wireless devices and network has become the dominant tools for telecommunication. However, the spectrum resource is limited in natural and has to be approved for accessibility, there is a huge challenge for individual devices and infrastructure to efficiently exploit the licensed frequency. In 2009, the FCC has approved the use of broadband services in the white space of UHF TV bands, which were formerly exclusively licensed to television broadcasters. These white space bands are now available for unlicensed public use, offerring new opportunities for new design of device and network with better performance in throughput and economy cost. In this work, we investigate multiband adaptation in both link communication and network deployment. Furthermore, we design algorithms with in-field measurement to improve the link and network performance. First, since wireless propagation largely depends on the environment in operation, a historical understanding of the frequency bands' performance in a given environment could expedite band selection as vehicles transition across diverse scenarios. In this paper, we leverage knowledge of in-situ operation across frequency bands with real-time measurements of the activity level to select the the band with the highest throughput. To do so, we perform a number of experiments in typical vehicular topologies. With two models based on machine learning algorithms and an in-situ training set, we predict the throughput based on: (*i.*) prior performance for similar context information (*e.g.*, SNR, GPS, relative speed, and link distance), and

(*ii.*) real-time activity level and relative channel quality per band. In the field, we show that training on a repeatable route with these machine learning techniques can yield vast performance improvements from prior schemes. While many metropolitan areas sought to deploy city-wide WiFi networks, the densest urban areas were not able to broadly leverage the technology for large-scale Internet access. Ultimately, the small spatial separation required for effective 802.11 links in these areas resulted in prohibitively large up-front costs. The FCC has reapportioned spectrum from TV white spaces for the purposes of large-scale Internet connectivity via wireless topologies of all kinds. The far greater range of these lower carrier frequencies are especially critical in rural areas, where high levels of aggregation could dramatically lower the cost of deployment and is in direct contrast to dense urban areas in which networks are built to maximize spatial reuse. Thus, leveraging a broad range of spectrum across diverse population densities becomes a critical issue for the deployment of data networks with WiFi and white space bands. In this paper, we measure the spectrum utility in the Dallas-Fort Worth metropolitan and surrounding areas and propose a measurement-driven band selection framework, Multiband Access Point Estimation (MAPE). In particular, we study the white space and WiFi bands with in-field spectrum utility measurements, revealing the number of access points required for an area with channels in multiple bands. In doing so, we find that networks with white space bands reduce the number of access points by up to 1650% in sparse rural areas over similar WiFi-only solutions. In more populated rural areas and sparse urban areas, we find an access point reduction of 660% and 412%, respectively. However, due to the heavy use of white space bands in dense urban areas, the cost reductions invert (an increase in required access points of 6%). Finally, we numerically analyze band combinations in typical rural and urban areas and show the critical factor that leads to cost reduction: considering the same total number of channels, as more channels

are available in the white space bands, less access points are required for a given area. Wireless mesh networks were previously thought to be an ideal solution for large-scale Internet connectivity in metropolitan areas. However, in-field trials revealed that the node spacing required for WiFi propagation induced a prohibitive cost model for network carriers to deploy. The digitization of TV channels and new FCC regulations have reapportioned spectrum for data networks with far greater range than WiFi due to lower carrier frequencies. In this work, we consider how these white space bands can be leveraged in large-scale wireless mesh network deployments. In particular, we present an integer linear programming model to leverage diverse prop- agation characteristics of white space and WiFi bands to deploy optimal WhiteMesh networks. Since such optimization is known to be NP-hard, we design a heuristic algorithm, Band-based Path Selection (BPS), which we show approaches the performance of the optimal solution with reduced complexity. We additionally compare the performance of BPS against two well-known multi- channel, multi-radio deployment algorithms across a range of scenarios spanning those typical for rural areas to urban areas. In doing so, we achieve between 3 to 6 times the gateway goodput of these existing multi-channel, multi-radio algorithms, which are agnostic to diverse propagation characteristics across bands. Moreover, we show that, with similar channel resources and bandwidth, the joint use of WiFi and white space bands can achieve a served user demand of 170% that of mesh networks with only WiFi bands or white space bands, respectively.

TABLE OF CONTENTS

Write something here. I dedicate this thesis to someone important to me.

Chapter 1

Introduction

Chapter 2

Background

Chapter 3

Spectrum Adapatation in Access Tier Network

[2] testsf

3.1. Introduction

The FCC has approved the use of broadband services in the white spaces of UHF TV bands, which were formerly exclusively licensed to television broadcasters. These white space bands are now available for unlicensed public use, enabling the deployment of wireless access networks across a broad range of scenarios from sparse rural areas (one of the key applications identified by the FCC) to dense urban areas [4]. The white space bands operate in available channels from 54-806 MHz, having a far greater propagation range than WiFi bands for similar transmission power [1].

Specific to rural areas, the lack of user density and corresponding traffic demand per unit area as compared to dense urban areas allows greater levels of spatial aggregation to reduce the total number of required access points, lowering network deployment costs. In densely populated urban areas, the greater concentration of users and higher levels of traffic demand can be served by maximizing the spatial reuse. While many works have worked to address multihop wireless network deployment in terms of maximizing served user demand and/or minimizing network costs, the unique propagation characteristics and the interference from coexisting activities in white space bands have either not been jointly studied or assumed to have certain characteristics without explicit measurement [6]. Specifically, previous work has investigated wireless network deployment in terms of gateway placement, channel assignment, and routing [3, 5]. However, each of these works focus on the deployment in WiFi bands without considering the white space bands. Moreover, the assumption of idle channels held in these models fails to match the in-field spectrum utility, which could degrade the performance of a wireless network. These two issues are critical for designing an optimal network deployment and providing commercial wireless services to clients in any location.

Thus, the new opportunities created by white spaces motivate the following questions for wireless Internet carriers, which have yet to be addressed: *(i) To what degree can white space bands reduce the network deployment cost of sparsely populated rural areas as opposed to comparable WiFi-only solutions?* and *(ii) Where along the continuum of user population densities do the white space bands no longer offer cost savings for wireless network deployments?* In this paper, we perform a measurement study which considers the propagation characteristics and observed in-field spectrum availability of white space and WiFi channels to find the total number of access points required to serve a given user demand. Across varying population densities in representative rural and metropolitan areas, we compare the cost savings (defined in terms of number of access points reduced) when white space bands are not used. To do so, we first define the metric to quantify the spectrum utility in a given measurement location. With the in-field measured spectrum utility data in metropolitan and surrounding areas of Dallas-Fort Worth (DFW), we calculate the activity level in WiFi and white space bands. Second, we propose a measurement-driven framework to find the number of access points required for areas with differing population densities according to our measurement locations and census data. We then evaluate our measurement-driven framework, showing the band selection across downtown, residential and university settings in urban and rural areas and analyze the impact of white space and WiFi channel combinations on a wireless deployment in these representative scenarios.

The main contributions of our work are as follows:

- We perform in-field measurements of spectrum utilization in various representative scenarios across the DFW metroplex, ranging from sparse rural to dense urban areas and consider the environmental setting (e.g., downtown, residential, or university campus).

- We develop a measurement-driven Multi-band Access Point Estimation (MAPE) framework to jointly leverage propagation and spectrum availability of white space and WiFi bands for wireless access networks across settings.

- We analyze our framework under capacity and coverage constraints to show that, with white space bands, the number of access points can be greatly reduced from WiFi-only deployments by up to 1650% in rural areas.

- We quantify the impact of white space and WiFi channel combinations to understand the tradeoffs involved in choosing the optimal channel setting, given a certain number of available channels from multiple bands.

Chapter 4

Spectrum Adapatation in Backhual Tier Network

Chapter 5

Proposed Work

REFERENCES

[1] Balanis, C. A. *Antenna theory: analysis and design.* John Wiley & Sons, 2012.

[2] Friis, H. T. A note on a simple transmission formula. 254–256.

[3] He, B., Xie, B., and Agrawal, D. P. Optimizing deployment of internet gateway in wireless mesh networks. *Computer Communications 31*, 7 (2008), 1259–1275.

[4] Inc., C. Fcc certifies carlson wireless technologies tv white space radio. `http://www.carlsonwireless.com/rural-connect-press-release.html`, 2014.

[5] Marina, M. K., Das, S. R., and Subramanian, A. P. A topology control approach for utilizing multiple channels in multi-radio wireless mesh networks. *Computer Networks 54*, 2 (2010), 241–256.

[6] Si, W., Selvakennedy, S., and Zomaya, A. Y. An overview of channel assignment methods for multi-radio multi-channel wireless mesh networks. *Journal of Parallel and Distributed Computing 70*, 5 (2010), 505–524.