WhiteMesh: Leveraging White Spaces in Multihop Wireless Topologies

TBA

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Abstract—

I. INTRODUCTION

FCC adopted rules to allow unlicensed radio transmitters to operate in the white space freed from TV band since 2010 [1]. White space is popularly referred to unused portions of the UHF and VHF spectrum includes, but not limited to 54M-72MHz,76M-88MHz,174M-216MHz,470M-608MHz,and 614M-806MHz [2]. To use these band, FCC ruling requires white space devices(WSDs) to learn of spectrum availability at their respective locations from a database of incumbents. For example, in Dallas/Fort Worth, TX, 482M-488MHz band should be yielded for TV channels, in Chicago, IL 470M-482MHz band is reserved for TV channels. [3] These bands provides superior propagation and building penetration compared to licensed ISM Wifi bands like the 2.4 and 5GHz bands, holding rich potential for expanding broadband capacity and improving access for wireless users.

The advantages of white space equipment could be seen straight forward from using in *Wireless mesh network*. Wireless mesh network is able to provide broadband Internet access to large contiguous areas through less mesh nodes equipped with WSDs due to the propagation characteristic of ISM bands. White space mesh is an economic way to provide back-haul Internet service in rural area or other low density area employing the propagation characteristics. White space could also be used to improve the urban or high density area connectivity through lower interference channels.

Mesh deployment requires selecting the number and locations to place mesh nodes to cover the whole area and the nodes are inter-connected in order to access to Internet gateway points. Unfortunately, prior white space mesh placement research fails to address the compatibility of current existing devices, for instance, iPhone, Mac Laptop do not have white space radios to access white space gateway points. For a realistic mesh network, the end hop to the client need to be able to work in ISM Wifi band. So the practical way to employ white space could be creating Internet access backhual with less nodes or improve existing Wifi network by adding the frequency band, avoiding interference and reduce the hop relay among Wifi network. To appreciate the multiband mesh deployment problem, it is important to understand the differences between white spaces and the popular ISM bands where Wifi devices operate. First, in FCC rules, users in white space band have to yield primary users. Before enter a white space channel, users have to detect the channel occupation. Second, white space band may suffer some unknown interference such as wireless speakers. Such devices may turn on at anytime without warning. Third, white space is cleaner than ISM

bands since most of the TV stations have stopped using the bands. And also since in white space is in lower band, the coverage of these band is larger than higher frequency ISM band which could help to reduce the mesh nodes. According to these advantages and disadvantages, the balance between white space bands and ISM bands is possible to provide improvement of mesh network by reducing the construction cost or grabbing more capacity.

This work focus on minimize the mesh nodes when guarantee the coverage and connectivity of the network. We present FIXME mesh node placement algorithms so as to minimize the deployed nodes, guarantee the coverage, and mesh node inter-connectivity.

The main contributions of our work are as follows:

- We formulate the heterogeneous mesh node placement problem as a FIXME problem.
- We propose a methodology to leverage the influence of white space in mesh networks.
- We propose FIXME algorithms to minimize the number of deployed mesh nodes.
- We perform extensive outdoor experiments from multiple environments and simulations to evaluate the proposed algorithms.

II. WHITE SPACE MESH DEPLOYMENT

In this section, we first formulate the white mesh deployment problem with propagation, connectivity and QOS constraint of multiband scenarios. We then propose FIXME white mesh deployment algorithms for multiband multihop networks objectives. For comparison, we also propose FIXME baseline assignment methods based on existing solutions.

A. Problem Formulation

The objective of the mesh node placement problem in multiband scenario could either be to minimize the number of deployed mesh nodes and relay nodes with the constraint of fulfilling coverage of the target area and connectivity to the Internet existing users. or to maximize the capacity of existing mesh network topology with replacing ISM Wifi nodes to white space nodes.

The set of potential mesh node accessing to Internet locations, M, is assumed know. Discrete locations for mesh nodes follows naturally from practical constraints on deployment, such as the availability of wired connection store or other infrastructure for mesh node installation. The coverage area of the mesh network is discredited into small grid of coverage locations N. The center of each grid is the point output the received signal justifying the connection and channel capacity. Relay nodes R are defined as nodes do not have direct Internet

access but can connect to the mesh node and provide Wi-fi coverage of a number of grid. Relay nodes and mesh nodes could work in white space band and ISM Wifi band represented as bands set B. The vertex set of the input is defined as $O = M \cup N$, the union of coverage grid and the potential mesh nodes location. The solution of the problem could tell which mesh node will be built and where should a relay node be added. The set of chosen mesh nodes is represented as M_b. The output of the problem is the nodes location and number of wireless nodes $R \cup M_b$, the union of mesh nodes chosen from potential locations and the relay nodes.

B. Coverage Constraint

The connectivity graph represented as $G = (V, E)$ could indicate the existence of usable links. This formulation encodes the signal quality of each link independently can represent the link quality diversity across bands. The links set, E, from the coverage grids V to either relay nodes or mesh node O, corresponding to the estimated or measured signal strength is above a signal strength threshold. More formally, the connectivity graph where both target coverage locations and potential mesh node locations form a unified connectivity graph. The mesh network have to satisfy the coverage of each grid through an edge E from either a mesh node or a relay node O. Each coverage grid $v_i \in V$ has $E_{B_j}, B_j \in B$ valued $0, 1$, which represents the signal strength is below threshold as 0 or above threshold as 1 in band B_j. The sum of E in band is also valued $(0, 1)$, which means the grid has connection or not. According to the definition of E, mapping to the connectivity constraint, it should satisfy $\sum E \geq V$.

C. Mesh Network Capacity

Wireless bandwidth is shared among all clients and mesh nodes, as a result, it is usually desirable to limit the number of potential sharers of the scarce wireless spectrum. The link E II-B could guarantee the minimum bandwidth sharing for the client, however, it could not represent the quality of the service. Our formulation enforces this by imposing a maximum degree $b_v = f(E, P_{rB})$ on the connectivity of a mesh node, represented the down-link/up-link capacity of the mesh node to clients. More complete capacity of formulations in other research take into account on-demands and fairness [4], but we do not get into these scenarios in this paper.

Subject to the *Coverage Constraint* II-B, the capacity of mesh network is the sum of bandwidth assigned for each grid $\sum b_v$. If the metric would be the capacity of mesh network, as the ISM Wifi mesh network has capacity C_{ISM}, white space mesh network has capacity C_{ws}, the capacity gain could be noted as $C_{ws} - CISM$. The gain of minimize deployment mesh node could be noted as the nodes amount of ISM Wifi mesh network A_{ISM} minus the nodes amount of mesh network with white space nodes A_{ws}, $G_a = A_{ISM} - A_{ws}$.

To employ the propagation advantages brings a NP-hard problem to arrive the optimal solution [4]. To approach the optimal solution we have FIXME frameworks to solve part of the problem subject to time fairness of each node.

III. PROPAGATION IN MULTIBAND MESH NETWORK

In this section, we introduce the concept of propagation and the parameter of propagation.

The factors rule radio propagation are complex and diverse, and in most propagation models three basic propagation mechanisms: reflection, diffraction, and scattering

For wireless networks, the received signal power of a node is represented as $P_{dBm}(d) = P_{dBm} - 10\alpha log_{10}(\frac{d}{d_0}) + \epsilon$. Pathloss exponent α in outdoor environments range from 2 to 5, higher frequency has a heavier pathloss. [5]. The propagation of frequency becomes an important characteristic since the pathloss exponent varies with channel frequency. The propagation difference makes the performance of radios vary from band to band in the same location. Specifying each link individually enables us to encode propagation characteristics of different bands B. In other words, each grid can be covered by an arbitrary node through specific band. The propagation alternation brings the advantages of providing more possible path for multihop network without increase interference of their neighbors.

IV. PROPAGATION OF TYPICAL CITIES

To access to the white space usability, people should be careful of both the FCC rules in different cities and the different propagation characteristics of their environment. There are four kind of cities according to the combo of these two parameters: more white space band and lower propagation; less white space band and lower propagation; more white space band and higher propagation; less white space band and higher propagation. These are the scenarios we are going to deal with.

V. WHITE MESH ALGORITHMS

VI. EXPERIMENTAL ANALYSIS FOR PREDICTION ALGORITHMS

In this section, we introduce the experimental set up for *Multiband Mesh Network*. There are two set of experiments for characteristic leveraging of multiple scenarios presented **??**. One is the *local Multiband Measurement* grab propogation information across bands; the other is *WiEye* helps to find the propogation relationship of multiple cities. The methodology to process the data is also introduced.

A. Local Multiband Measurement

To discover the propagation diversity, we measure 4 different bands, 450MHz, 900MHz, 2.4GHz, and 5.8GHz on our off-shelf multiband platform. The measurement platform is made of Gateworks 2358 with GPS, Smartbridge 450MHz radio, Ubiquite XR2, XR5, and XR9 radios. The software on the platform is Linux based Openwrt with several third party applications such as Iperf, TCPdump. We bring 2 of this platform on cars and run Iperf at the transmitter with GPS records to generate traffic on the four bands simultaneously sending through the radios on the platform. The TCPdump running on the receiver side sniffs the packets and report the SNR with GPS information.

Comparing the GPS records on both side help to grab the distance between the transmitter and receiver with time

stamps. The SNR and distance could be synchronized according to the time stamps. The propagation relationship of four different bands could be found through the curve fitting.

B. WiEye Measurement

WiEye is an Android application help users to measure the *Access Point* signal strength provided by SMU *Wireless Networks Group* for free. It also help *Wireless Networks Group* collecting measurement data of signal strength to leverage the propogation characteristics on large scale [6]. Due to the hardware limitation, most of the cellphones can only work on 2.4GHz, most of the measurement data is on 2.4GHz. The data from WiEye helps to get the propogation of a city in 2.4GHz and according our 2.4GHz multiband measurements, we map the propogation in other bands of the cities.

An issue of the WiEye measurement is that the *Wifi Access Points* are unknown of the users. To overcome the issue, we propose a methodology to estimate the *Access Point* through multiple measurement. The *Path Loss Exponent* varies from 2 to 5 in different environment [5]. First we grab measurements in the same area, pull out their location information and signal strength information. Then, we assume the area have a small *Path Loss Exponent*. If there are *Access Points* at the location of the users, their connectivity circle click will cover the actual *Access Point*. The area covered by the most virtual click is believed to be the plane contain the *Access Point*. Third, we increase the *Pass Loss Exponent* to decrease the click of the virtual click getting close to the *Access Point* in the plane of the last step. We iteratively repeat the process to narrow the possible location of the *Access Point* till there are only two virtual click cover the same location in the previous step plane. Then the location is believed as the *Access Point*.

Base upon the estimation, the distance from the *Access Point* to the users could be calculated and mapping to the SNR for propagation estimation.

FIXMEAdd diagram to describe the process

VII. RELATED WORK

Since FCC ruling obviated mandatory spectrum sensing in whtie spaces networks, prior research in UHF white spaces has focused on accurate detecting the primary user [7]; assigning white spaces channels [8]. In [9], database is applied to detect white space channel. Employing the energy advantage of UHF bands is proposed to improve the performance for indoor networks [10].

In [11], a placement algorithm for wireless mesh networks is proposed for white space bands.

However, these works only focus on white space bands fails to connect the ISM bands and tons fo existing wireless devices for pratical application.

Tons of works have been done for multichannel multiradio.

Cognitive Radios

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