WhiteMesh: Leveraging White Spaces in Multihop Wireless Topologies

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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 spactrum 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 poetntial for expanding broadband capacity and improving access for wireless users.

Wireless mesh network is able to provide broadband Internet access to large contiguous areas through less mesh nodes equipped with WSD due to the propagation characteristic of ISM bands. White space mesh is an economic way to provide backhaul 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. 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 Mic. 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 imporvement of mesh network.

This work focus on minimize the mesh nodes when gurantee 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 hetergeneous mesh node placement problem as a FIXME problem.
- We propose a methodology to leverage the infulence of white space in mesh networks.
- We propose FIXME algorithms to minimize the numberof deployed mesh nodes.
- We perform extensive outdoor experiments from multiple environments and simulations to evaluate the proposed algorithms.

II. Multiband Adaptation

In this section, we first formulate the multiband multihop problem in multiband networks and introduce the context information that we use. We then propose FIXME multiband channel assignment algorithms for multihop networks. For comparison, we also propose FIXME baseline assignment methods based on existing solutions.

A. Problem Formulation

Consider a network make of $\{1, 2, \ldots, m\}$ nodes equipped radios of n frequency bands, represented by an index set $\{1, 2, \ldots, n\}$. Each node will share a frequency band with neighborhood nodes in time $T_s mn$, means a node can use this part of the time slot for transmitting. Each node in the network has the right to share the wireless resource with its neighbors, if a number of nodes in the same click of a band, they should share the channel of the band equally in time occupancy. For instance, if in a click there are 3 nodes all fully backlogged, each of them should have one third time sharing of this band. The time fairness is what we hold for all nodes in channel assignment. We assume the source nodes are fully backlogged. The objective of the work is to achieve higher thoughput through assigning the bands to the nodes subject to fair time sharing, $T_s best$, In a network, the throughput r_m of a node m depends on several factors, such as in a single band i, the received signal power P_R^{mi}, noise power $P_N^m i$, the activity/occupancy level B^i, the time sharing of a band, and other factors such as location and contextual information. This relationship is represented in general as $r_m = \sum_n f(P_R^i, P_N^i, B^i, context - information)$. The objective can be stated as

$$T_s\{best\} = \arg\max_{T_s} r_m \tag{1}$$

For a multiband wireless network, The received signal power 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. [4]. The propagation of frequency becomes an important characteristic since the pathloss exponent varies with the wavelength. The propagation difference makes the performance of radios vary from band to band in the same location. The propagation alternation brings the advantages of providing more possible path for multihop network without increase interference of their neighbors. However, to employ the propagation advantages also bring a NP-hard problem to arrive the optimal solution [5]. To approach the optimal solution we have FIXME frameworks to solve part of the problem subject to time fairness of each node.

The framework allows us to separate the interference from other nodes using the same technology via the busy time and the interference from nodes using other technologies in the same and via the noise level P_N^i. For instance, an 802.11 node can observe the packets of other 802.11 nodes but only the increase noise levels from other Zigbee/Bluetooth nodes. The existing pattern embedded in the historical data connecting the performance of different bands and collected context information e.g., B^i, P_N^i, P_R^i could be extracted and help make decisions for multiband adaptation in a similar context [6].

To represent the utilization level of the channel, we define *busy time*, B, as the percentage of time when the channel is occupied by all competing sources $x_j (j = 1, 2, 3, ...)$ other than the intended transmitter y. For 802.11-based transmissions, the busy time on band i is defined as:

$$B^i = \frac{\sum_j \sum_k \frac{L_k^{x_j}}{R_k^{x_j}}}{\sum_k \frac{L_k^y}{R_k^y} + \sum_j \sum_k \frac{L_k^{x_j}}{R_k^{x_j}} + S\sigma} \tag{2}$$

where $L_k^{x_j}$ and $R_k^{x_j}$ represent, respectively, the packet length in bits and the data rate at which that packet is transmitted, for external sources x_j; S and σ are the idle slots and the slot duration. When considering the activity level of non-802.11 users (e.g., the bands currently licensed to TV and other non-802.11 devices), we use the received signal level from non-802.11 interference sources P_N^i on band i as an input to our algorithms.

B. Multiband Channel Assignment Algorithms

In order to evaluate the proposed multiband adaptation algorithms, we construct two baseline multiband channel assignment methods: (1) We assign the time sharing randomly to the nodes. (2) For each node, we try to transmit in all the time without considering the interferance of the networks:

III. 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

References

[1] FCC, “White space,” http://www.fcc.gov/topic/white-space, 2012.

[2] Wiki, “White space(radio),” http://en.wikipedia.org/wiki/White_spaces_(radio)#United_ 2013.

[3] B. W. Consulting, “Tv white space,” http://www.broadband-mapping.com/tv-white-spaces.html, 2013.

[4] J. Camp, J. Robinson, C. Steger, and E. Knightly, “Measurement driven deployment of a two-tier urban mesh access network,” in *Proceedings of the 4th international conference on Mobile systems, applications and services*. ACM, 2006, pp. 96–109.

[5] S. Arkoulis, E. Anifantis, V. Karyotis, S. Papavassiliou, and N. Mitrou, “On the optimal, fair and channel-aware cognitive radio network reconfiguration,” *Computer Networks*, 2013.

[6] R. Meikle and J. Camp, “A global measurement study of context-based propagation and user mobility,” in *Proceedings of the 4th ACM international workshop on Hot topics in planet-scale measurement*. ACM, 2012, pp. 21–26.

[7] H. Kim and K. G. Shin, “Fast discovery of spectrum opportunities in cognitive radio networks,” in *New Frontiers in Dynamic Spectrum Access Networks, 2008. DySPAN 2008. 3rd IEEE Symposium on*. IEEE, 2008, pp. 1–12.

[8] P. Bahl, R. Chandra, T. Moscibroda, R. Murty, and M. Welsh, “White space networking with wi-fi like connectivity,” *ACM SIGCOMM Computer Communication Review*, vol. 39, no. 4, pp. 27–38, 2009.

[9] R. Murty, R. Chandra, T. Moscibroda, and P. Bahl, “Senseless: A database-driven white spaces network,” *Mobile Computing, IEEE Transactions on*, vol. 11, no. 2, pp. 189–203, 2012.

[10] B. Radunovic, D. Gunawardena, P. Key, A. Proutiere, N. Singh, V. Balan, and G. Dejean, “Rethinking indoor wireless mesh design: Low power, low frequency, full-duplex,” in *Wireless Mesh Networks (WIMESH 2010), 2010 Fifth IEEE Workshop on*. IEEE, 2010, pp. 1–6.

[11] J. Robinson, M. Singh, R. Swaminathan, and E. Knightly, “Deploying mesh nodes under non-uniform propagation,” in *INFOCOM, 2010 Proceedings IEEE*. IEEE, 2010, pp. 1–9.