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Demo: WhiteHaul – White Space Spectrum Aggregation System for Backhaul

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ABSTRACT

Today almost half the world's population does not have Internet access. This is particularly the case in rural and undeserved regions where providing Internet access infrastructure is challenging and expensive. To this end, we present demonstration of WhiteHaul [5], a low-cost hybrid cross-layer aggregation system for TV White Space (TVWS) based backhaul. WhiteHaul features a custom-designed frequency conversion substrate that efficiently handles multiple non-contiguous chunks of TVWS spectrum using multiple low-cost COTS 802.11n/ac cards but with a single antenna. At the software layer, WhiteHaul uses MPTCP as a link-level tunnel abstraction to efficiently aggregate multiple chunks of the TVWS spectrum via a novel uncoupled, cross-layer congestion control algorithm. This demo illustrates the unique features of the WhiteHaul system based on a prototype implementation employing a modified version of MPTCP Linux Kernel and a custom-designed conversion substrate. Using this prototype, we highlight the performance of the WhiteHaul system under various configurations and network conditions.

KEYWORDS

Universal Internet access, Rural connectivity, Backhaul, TV white space spectrum, Spectrum aggregation, Multipath TCP

1 INTRODUCTION

Today, almost half the world's population is still unconnected to the Internet [3], and predictably a large fraction of it lives in rural and/or underserved areas. In the past decade, there have been a series of efforts to remedy this through community cellular networks, initially focused on voice and SMS services [3, 13] and more recently on LTE based mobile broadband Internet service [6, 11] leveraging the emergence of open-source software platforms. However, despite these developments, the backhual infrastructure is still limited and costly, and this remains a major roadblock [11, 12]. For example, common approaches for the backhaul connectivity rely on fiber, licensed microwave or satellite solutions have high CAPEX or OPEX costs [12].

A viable approach to overcome this barrier is to exploit spectrum white spaces, notably the TV white space (TVWS) spectrum — the portions of UHF TV bands unused by the incumbents. TVWS spectrum is attractive for backhaul connectivity in rural and developing regions for multiple reasons: (1) the low cost aspect (no spectrum licensing fees); (2) the ample spectrum availability in rural areas; and (3) the superior propagation characteristics of UHF TV spectrum compared to other higher frequency bands in terms of both range and non-line-of-sight (NLoS) propagation in presence of foliage and obstructions [2, 4, 8]. Despite the promise of TVWS spectrum for backhaul connectivity in rural regions, existing TVWS systems – both commercial solutions and research prototypes [1, 7, 9, 11] – fail to fully realize this promise as the throughput they can achieve is limited to a few tens of Mbps — insufficient for even a modest community of network users.

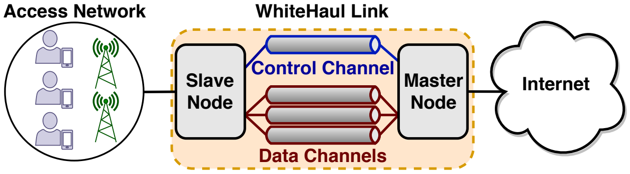

Figure 1: High-level schematic of WhiteHaul system in an end-to-end application scenario.

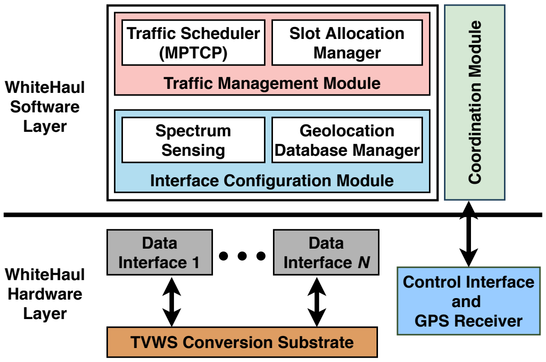

Figure 2: WhiteHaul node architecture.

In this work, we propose to demonstrate WhiteHaul [5], the first TVWS based spectrum aggregation system for backhaul that can deliver an order-of-magnitude higher throughput (nearly 600Mbps) than the state-of-the-art by addressing several significant challenges and constraints pertinent to the backhaul use case. First, individual TVWS channels are narrow (6/8MHz depending on the regulatory regime). Second, available channels may not be contiguous, making it imperative to aggregate multiple possibly non-contiguous TVWS spectrum chunks to realize high-speed TVWS backhaul connectivity. Third, TVWS spectrum exhibits a high degree of diversity in terms of chunk sizes, transmit power and interference levels. Fourth, cost and ease of deployability concerns make a single antenna system the preferred option. Lastly, backhaul traffic exhibits high degree of asymmetry and temporal fluctuations.

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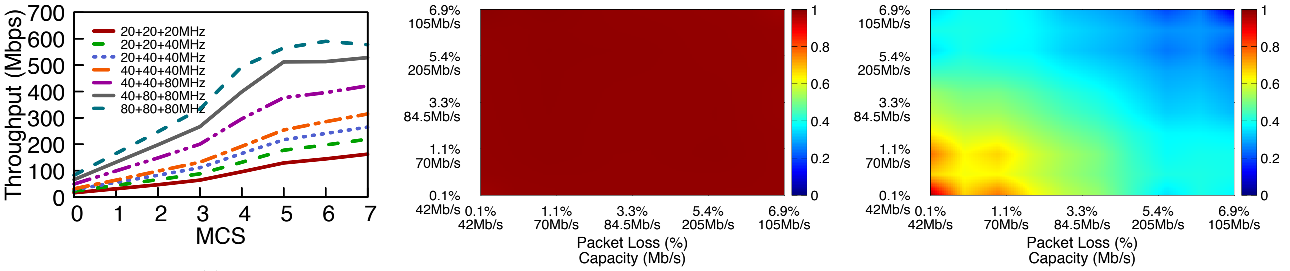

(a)

(b)

(c)

Figure 3: (a): WhiteHaul aggregate TCP throughput in a three interface scenario; (b) aggregation efficiency comparison between WhiteHaul MPTCP and (c) uncoupled MPTCP with CUBIC, in different conditions (as a heatmap – red is best).

In particular, the focus of this demo is on highlighting the unique features of the WhiteHaul system including: (i) the aggregation of multiple non-contiguous chunks of TVWS spectrum with a custom designed frequency conversion substrate; and (ii) the novel use of MPTCP as a link-level tunneling technique that enables efficient aggregation through a new cross-layer congestion control algorithm [5].

2 WHITEHAUL OVERVIEW

WhiteHaul is intended to realize point-to-point (PtP) TVWS based backhaul links, meaning a WhiteHaul node forms the endpoints of such a link. Fig. 1 shows a basic application scenario where a WhiteHaul link connects an access network (serving end-user devices) and the Internet. We do not make any assumptions on the nature of the access network, which could take several forms including a community cellular network (e.g., [11]). As shown in Fig. 1, we adopt a `Master-Slave` model in that one end of a WhiteHaul link acts as the `Master Node` and the other as the `Slave Node` with the former responsible for link configuration decisions (e.g., spectrum to use for interfaces on both sides). The `Master` and `Slave` coordinate over an *out-of-band control channel* while carrying user traffic over *multiple data channels that each operate on a separate TVWS spectrum chunk*. Fig. 2 provides the schematic of the WhiteHaul node architecture that consists of *Hardware Layer* and *Software Layer*.

Hardware Layer. This is designed based on the multi-radio architecture principle to combine the multiple non-contiguous TVWS spectrum chunks. Specifically, the hardware layer is composed of two types of physical wireless interfaces used for both control and data communication as well as the TVWS conversion substrate for the data interfaces. For the data interfaces, we use multiple low-cost COTS 802.11n/ac Wi-Fi cards operating in 5GHz band and design the conversion substrate to perform the frequency up/down conversion between available TVWS spectrum chunks and 5GHz Wi-Fi channels. These multiple Wi-Fi cards are combined together into a single antenna to avoid higher towers, which steeply increase the cost and deployment complexity. For the control interface, we use LoRa [10], a low-power wide area network technology.

Software Layer. This layer orchestrates the underlying interfaces to maximize the overall system performance. It is made up of three modules: (i) the *Coordination Module* facilitates communication between the `Master` and `Slave` nodes via the underlying LoRa control interface; (ii) the *Interface Configuration Module* configures the TVWS spectrum chunks and transmit power of data interfaces as decided by the `Master` node. These configurations are based on the TVWS spectrum availability information obtained from the geolocation database and local low-cost spectrum sensing from both ends of the WhiteHaul link; (iii) the *Traffic Management Module* performs two functions. One, by the *Slot Allocation Manager*, is to adapt the time allocation between `Master-Slave` (*forward*) and `Slave-Master` (*reverse*) directions, every *epoch*, depending on the effective capacity and traffic demand of forward and reverse links. The *Traffic Scheduler* is responsible for the other function to efficiently schedule the traffic among the underlying data interfaces using a modified variant of MPTCP, aided by signals from the *Slot Allocation Manager* (see [5] for more details).

3 DEMONSTRATION

The goal of this demonstration is twofold: (i) to demonstrate the capabilities of WhiteHaul system and show its performance under different configurations (e.g., using contiguous/non-contiguous TVWS spectrum chunks); (ii) to show how the new MPTCP cross-layer congestion control algorithm helps to achieve robust performance under various network conditions (e.g., packet losses).

We use a testbed setup similar to Fig. 1 where it consists of four Intel i7 machines (7567U processor at 3.5GHz, 8GB of RAM). The first node represents the access network side and it acts as a client in the local community network. Two other nodes represent both WhiteHaul `Slave` and `Master` nodes, and the last node acts as a local server that represents the Internet PoP. Both WhiteHaul `Slave` and `Master` nodes run our modified MPTCP Linux Kernel implementation, and is connected to a low-cost Pycom LoRa gateway, three Mikrotik 802.11ac Wi-Fi cards and the TVWS conversion substrate. The Wi-Fi cards and the conversion substrate are configured by the Interface Configuration Module in the software layer (See Fig. 2). We then use *iperf* to generate TCP traffic between the client and the local server nodes. That traffic is carried over 3 contiguous TVWS spectrum chunks with a total size of 240 MHz. Fig. 3a shows that WhiteHaul can provide maximum TCP throughput up to nearly 600Mbps in that given setup.

For the second part of the demonstration, we emulate the packet losses using Linux Network Emulator (NetEm) and real-world link loss values discussed in [5]. Figs. 3b, 3c display the results of WhiteHaul MPTCP compared to uncoupled MPTCP using CUBIC as heatmaps of efficiency, defined as the ratio of achieved throughput (in presence of losses) for a given MPTCP algorithm to the maximum achieved throughput (without losses). Overall WhiteHaul algorithm achieves superior performance, by an order of magnitude, compared to CUBIC, thanks to the periodic feedback from the underlying layers that helps to keep track of optimal congestion window size, and allows quick ramp up for the sending rate in case of random packet drops.

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