Perspective: White Space Networking with Wi-Fi like Connectivity

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ABSTRACT

This paper, titled White Space Networking with Wi-Fi like Connectivity [8], received the best paper award at ACM SIGCOMM 2009. Since then, it has led to new research, a new IEEE standard, new governmental regulations, and a new industry. The work also laid the foundation for new rural connectivity initiatives, connecting rural schools, hospitals, and libraries in Africa, Asia, and America.

CCS CONCEPTS

• **Networks** → **Routing protocols**; **Wireless Access Protocols**;

KEYWORDS

TV White Spaces, Dynamic Spectrum Access

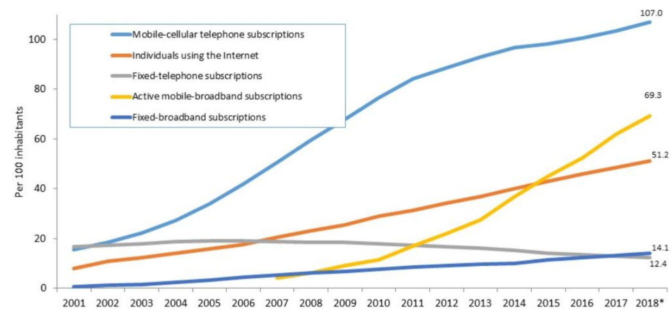

Figure 1: ITU estimates that 48.8% of the world's population was not connected to the Internet at the end of 2018 [5].

1 INTRODUCTION

Nearly half of the world's population is not connected to the Internet, and a large portion of those who are connected do not have access to broadband 1. This *digital divide* is particularly stark in places such as sub-Saharan Africa, and one of its primary reasons is the lack of affordable Internet.

One promising technology to make Internet access affordable is the use of TV White Spaces [15]. TV White Spaces refers to spectrum that has been reserved for wireless television stations, but that is currently unused. This TV spectrum has excellent propagation characteristics (both in terms of signal propagation range as well as penetration of obstacles such as buildings), and is substantially under-utilized outside of cities. If this unused TV spectrum can be utilized without interfering with the TV reception in adjacent channels, then an operator can set up a network at a fraction of the cost without purchasing the exclusive use of this spectrum.

The WhiteFi paper [8] published at SIGCOMM 2009 was the first to show how a Wi-Fi like protocol can operate opportunistically in the TV White Space spectrum, without interfering with TV transmissions in adjacent channels, using a concept called spectrum sharing. It presented a hardware design capable of transmitting and receiving Wi-Fi signals in this spectrum [13], and proposed a protocol using which these devices would not interfere with primary users, i.e., transmissions in the TV Spectrum. It also proposed an algorithm to select the best channel, and to handle disconnections when the primary user returned to the TV channel. The SIGCOMM WhiteFi paper built on a rich body of work on Cognitive Radios [11], crucially extending it to demonstrate how these radios can be used to form a TV white space *network*, without interfering with the transmissions of primary users.

Given the proliferation of wireless devices, there is a dramatic need for more freely accessible wireless spectrum of good quality to support the demands of these new devices. However, the fact is that essentially the entire spectrum from 30 MHz to 100 GHz has already been exclusively reserved for different entities. Therefore, safe and non-interfering spectrum sharing techniques (also known as Dynamic Spectrum Access (DSA)) that leverage the concepts proposed in the WhiteFi paper are the premier way to make more spectrum accessible, while ensuring primary users have continued access to their reserved spectrum. While TV White Spaces was the initial use case for DSA, the same paradigm has since been used for the Citizen Band Radio Service (CBRS) portion of the spectrum as well, which is also being used for Private LTE [1].

2 CONTINUING RESEARCH

Several research teams in both academia and industry, have continued research on WhiteFi and dynamic spectrum access to efficiently utilize TV White Spaces (TVWS), and use it to bridge the digital divide. Our own work [6] has further developed WhiteFi into several directions, including:

Databases for Dynamic Spectrum Access: WhiteFi uses spectrum sensing to determine the available TV channels. In [12], we enhanced the WhiteFi design, and proposed the world's first system that used a database instead of wireless sensing to enable TVWS networks. The design of CBRS systems is based on a similar principles. There has been multiple follow-up papers on the efficient design of spectrum databases.

Deploying Real TVWS networks: We built the world's first urban WhiteFi network on Microsoft campus [10], and demonstrated it to spectrum regulators from all over the world. Visitors included the FCC Chairman Genachowski in 2010, the TRAI Chairman from India in 2009, and others. In another work, researchers at University of Wisconsin deployed a TVWS network in buses in Madison [18]. Researchers at Rice deployed these networks around Houston [7]. We also deployed these networks in various countries in Africa [15].

Cognitive Radio Networking: There is a large body of research on networking cognitive radios, which improve the WhiteFi algorithms for channel selection, routing, and efficiency. This work also addresses additional issues in TVWS networks, such as transmit power asymmetry [14], mobility, and others.

Precision Agriculture: [16] We have leveraged the WhiteFi work to connect farms, and have used it to collect data and build accurate Precision Maps of farms. These maps can be used to determine how much water, and nutrients to apply in different parts of the farm. Microsoft FarmBeats uses WhiteFi technology as an integral part [3].

Yet, the concept of dynamic spectrum access is still in its infancy, and there remain many hard research problems before achieving the full potential of dynamic spectrum access in the TVWS, CBRS, and other bands. First, most existing deployments use a web service-based spectrum database, instead of spectrum sensing, to determine the available frequencies at a given location. As has been shown in prior work [17], the model-based approach used by spectrum databases are conservative and underestimate the amount of spectrum available for DSA networks. However, as spectrum sensing is expensive and power hungry, a low-power, low-cost spectrum sensing system could accelerate the adoption of DSA networks.

Second, spectrum sharing in new spectrum bands has many new challenges. Until today most of the effort has focused on sharing the spectrum with TV towers in the TV Spectrum, and the Navy in the CBRS spectrum. New techniques will have to be developed to enable spectrum sharing with other primary users, such as satellites, cell towers, and other transmitters.

3 POLICY

The WhiteFi research had significant impact on spectrum policy decisions worldwide.

Several groups had opposed the use of TVWS spectrum, claiming that it would interfere with the reception of TV signals. The WhiteFi research showed that such concerns were unfounded and that white spaces networks can indeed be built without causing any harmful interference to TV receivers and other primary users. This has attracted spectrum regulators from around the world to see a demonstration of our WhiteFi technology on Microsoft campus [10]. The system consisted of antennas on rooftops that provided Wi-Fi like connectivity in Microsoft shuttles. Several policy makers from around the world, including from India, Brazil, Singapore, China, and others visited the Microsoft campus to see the demonstration that we had put together.

Subsequent to the FCC Chairman's visit to Microsoft campus in August, 2010, the FCC finalized rules for operating in the TV White Spaces spectrum in October that year. This was a remarkable ruling, since for the first time the spectrum was allowed to be shared under the auspices of a spectrum database. Subsequently, the TVWS rules have also been finalized in other countries, including Canada, Singapore, Columbia, Malawi, South Africa, UK, and others.

Following the TVWS ruling, the FCC also adopted similar spectrum sharing rules in other parts of the spectrum. Most recently, the CBRS spectrum in 3.5 GHz has been opened up for secondary use, where the Navy gets primary access, secondary access is given to users who have paid for the spectrum, and the unused spectrum can be used by tertiary users. Some of these spectrum sharing techniques, and how to build networks in them, were initially proposed in the WhiteFi paper.

4 INDUSTRY & STANDARDS

The IEEE 802.11 standards body has finalized a standard, IEEE 802.11af, for operating Wi-Fi in the TV White Spaces [4]. This standard is called the *White-Fi standard*, based on our original SIGCOMM paper. It leverages techniques that were first proposed in the WhiteFi paper, such as using multiple channel widths [9], and coordination protocols, to ensure a seamless operation of the network in this spectrum.

There are a few companies building TVWS radios, such as Adaptrum, Radwin, Redline, and 6Harmonics. Researchers can try to build TVWS radios using the architecture presented in [13]. Few radio manufacturers are starting to building IEEE 802.11af compliant hardware. The initial versions are expected to be available in 2020.

The industry has also set up a Global Alliance, which includes Microsoft, Google, Facebook, and others, called the Dynamic Spectrum Alliance [2]. This alliance meets annually, and drives policy and industry discussions on spectrum sharing, and on bridging the digital divide.

More recently, several companies have been implementing spectrum sharing in the CBRS band (3.5 GHz), e.g. with Private LTE.

5 SOCIETAL IMPACT

Because signals in the TV spectrum propagate very well, and a lot of this spectrum is available in rural areas, WhiteFi can be used to provide Internet access at a fraction of the cost. Microsoft has worked with partners to connect remote areas in Africa using this technology since 2012, connecting high schools, hospitals, libraries, and homes to the Internet in Kenya, Tanzania, and other sub-Saharan countries [15].

Microsoft also launched an initiative, called *Airband*, through which it is partnering with rural ISPs to use TV White Spaces along with other technologies to connect the rural population that does not have any Internet access. This includes a pledge to connect 3 million rural Americans to broadband by 2022.

6 SUMMARY

The WhiteFi paper from SIGCOMM 2009 opened up a new research area on how to network devices when the wireless spectrum is shared with transmitters that have higher priority. The paper has not only led to significant follow-on research in this space, but also to new government regulation, an IEEE standard, and products such as Microsoft FarmBeats. Most importantly, it has led to bringing Internet connectivity to remote regions around the world.

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