Using the White Space for Digital Inclusion

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***Abstract*-People who do not have Internet access in the world are about 66 percent. These individuals are lagging behind, in the digital sense, due to their remote location, lack of economies of scale, quasi-nomadic nature, and/or low-income. WiFi-based municipal, commercial, and/or Community Wireless Networks have emerged as solutions to provide shared and affordable wireless Internet access to such digitally isolated communities. However, the spectrum used by WiFi (e.g., 2.4 Ghz) is becoming crowded. In addition, the spectrum used by WiMax is regulated in most countries. Therefore, the white space spectrum has emerged as another solution for affordable and shared connectivity solutions. White space refers to spectrum allocated for broadcasting services but not used. This paper provides a brief overview of the white space spectrum, compares it with the WiFi spectrum, outlines key existing projects, suggests a research agenda, and concludes with some policy implications and future work. We hope that this paper brings the attention of the IT community, policymakers, and community activists to the capabilities of white space.**

Keywords- white space; digital inclusion; IEEE 802.11af; broadband policy.

I. INTRODUCTION

Pervasive computing and ubiquitous communications are increasingly becoming essential to conduct our daily life affairs. The Internet, in particular, has grown to be a superhighway for accessing tremendous social economic, social, entertaining and personal services and opportunities. The International Telecommunication Union (ITU) estimates that 3.8 billion people do not have affordable mobile broadband and 2.6 billion cannot afford it [5]. According to the Internet World Stats [33], the percentage of people who do not have affordable high speed Internet is 85 in Africa; 73 in Asia, 37 in Europe; 22 in North America. In addition, 66 % of the world populations do not have access to affordable and reliable Internet services. These people are lagging behind, in the digital sense, because they are not part of the information society. Such communities usually lack viable commercial incentives to attract telecommunication companies. This could be due to their remote location, harsh terrain, high costs of deploying and maintaining infrastructures, low income and willingness to pay, and insufficient population density and/or limited capacity [29][17]. As a result, the market mechanisms have failed to achieve digital inclusion of the society at large. A study by the World Bank estimates that an increase of 10 percent in broadband penetration can boost the economic growth in developing countries by 1.38 percent [8].

Wireless communications can provide the much needed high-speed Internet access to any community in any location either through terrestrial telecommunication infrastructures (e.g., WiFi, and WiMax) or satellite backbones. Wireless communications are particularly beneficial to a wide range of populations [16]. For example, those who by their nature are quasi-nomadic (e.g., the healthcare practitioners, real estate brokers, municipal employees, nomadic herders, the mobile business persons, etc.) would find these emerging infrastructures to be of great benefit. Another group that would benefit from these emerging technologies is those who live in rural and underserved areas. Such areas usually do not have sufficient economies of scale due to lack of the population density, harsh geographical location, and/or low income of their residents. In other words, these areas do not have the necessary commercial incentives to attract telecommunication companies. Such social settings, we believe, require innovative and customized solutions for the digital inequality problem.

Wireless standards (e.g., Wi-Fi and WiMax) have gained the capabilities to provide a wide range of customized connectivity solutions that suit different social settings. They enable individuals to use laptops, Wi-Fi phones, Personal Digital Assistants (PDAs) security cameras and other portable communications devices. In addition to providing mobile and flexible real-time communications, these emerging communication technologies achieve significant time, money and effort savings to their users. As a result, wireless communications have the potential to provide ubiquitous and affordable Internet access and assist all communities to become and remain full participants in the emerging Internet-based "Information Age.” Therefore, numerous societies have built autonomous Community Wireless Networks (CWNs) with their own resources, taking advantage of the free 2.4 GHz spectrum and available open source [4][32].

However, the 2.4 Ghz band has become too crowded because many communication technologies use it. These include Bluetooth devices, WiFi enabled devices, cordless phones, etc. Frequency regulation bodies in some countries have unregulated chunks of white space frequencies. For example, the switching to digital television has deregulated spectrum frequencies between 50 MHz and 700 MHz. In addition, WiMax spectrum is regulated in most countries.

White space has emerged as an alternative, or complement, for the licensed spectrum or the unlicensed one which is becoming more crowded. The term "White space" refers to the unused or sparsely occupied spectrum frequencies allocated to broadcasting services or guard channels of cellular networks in particular areas of a country [6][7][14][15]. In every town, there is a number of TV channels remained unused or have been abandoned after transferring to digital TV.

Innovators, researchers, and technology vendors, regulation authorities are working on devices, software, database, and policies that focus on reusing these frequency bands. They believe that reusing this spectrum can enhance the wireless landscape by offering the potential for substantial bandwidth and long transmission ranges [14]. It would also benefit rural and underserved communities which cannot afford high Internet fees of traditional Internet Service Providers (ISPs) as it improve market competition.

Therefore, there are two types of white space [7][15]:

i. Spectrum allocated for TV channels but not used locally;

ii. Spectrum allocated between radio bands to prevent channel interference. For instance, UK has allocated chunks of spectrum and left it open as buffering gaps between the high-powered transmissions carrying broadcast TV in order to avoid interference.

The remainder of this paper is structured as follows. We first discusses in Section II the importance of white space. Section III discusses the research issues related to white space. Then, in Section IV, we compare the white space spectrum with WiFi. In Section V and VI, we discuss the regulations and highlight the existing white space key projects. Finally, in Section VII, our designed project is described.

II. THE IMPORTANCE OF WHITE SPACE

It is believed that opening up this white space to lower-powered devices can provide more wireless spectrum for data transmission to support a large range of devices and services. This spectrum is important because:

i. Having high-speed Internet access has become crucial for people, organizations, and governments to conduct their business. White space-based communications would play a key role in supporting the exponential growth of mobile data communications. This is because the current spectrum allocated for wireless networks (e.g., cellular and Wi-Fi, WiMax) would not be enough. In particular, it is estimated that the number of Internet-connected devices would exceed 50bn worldwide by 2020, according to data from Cisco [7]. According to Hengeveld [5], the Internet of Things (IoT) will connect more a large number of devices which makes reusing this spectrum a necessity.

ii. It can cover the shortage of available spectrum and thus enabling communication to devices that are not well served with the previously allocated spectrums. For example, white space could be used to provide wireless broadband Internet access, similar to Wi-Fi, but over much longer distances. It can also support mobile devices like tablets and smart phones. In addition, it could be used as an extension of fixed-line broadband to reach places that are not connected via traditional cables. Moreover, white space has the capabilities to penetrate walls and underserved areas because it does not require line-of-sight technology, unlike satellite communications and microwave broadband. Reusing spectrum or using unused one increases the amount of available spectrum.

III. RESEARCH ISSUES

Hengeveld [5] suggests a research agenda for the white space-based communications. According to Hengeveld [5], research on white space could include proving broadband to rural communities, building campus networks, conducting basic research, and initiating lab trials. In addition, regulatory authorities may conduct pilot trials, studies for technical and do economic feasibility, develop prototype devices, support field test, and design measurements. With respect to the commercial sector, Hengeveld suggests opportunities including developing volume devices, adopt projects for rural broadband networks, implement campus networks, build smaller form factors, and develop standards-based devices. In addition, they could also work on building databases for available white space, provide certifications, implement use case experimentation, and adopt vertical integration.

White space devices allow secondary users to use this portion of spectrum which is not used by the primary user. Therefore, there is a major concern regarding interference between the primary signal and secondary signal. Researchers should find solutions that protect the secondary signal from interfering with the primary one. Another research area is finding new methods of access and suitable business models for this new connectivity solution. Table 1 shows key database providers, hardware providers, and other important technology vendors.

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TABLE I. THE WHITE SPACE ECOSYSTEM [5]

Database Providers (United States)	**Hardware Providers (today)**	**Other Potential Players (growing interest)**
Frequency Finder, Inc.	Adaptrum	Atheros (Qualcomm)
Google	Airspan	ARM
Comsearch	6Harmonics	Alcatel-Lucent
Key Bridge	Carlson	Broadcom
LS Telcom AG	KTS	CSR
Microsoft	Lyrtech	Dell
Neustar	MLED	Hewlett Packard
Spectrum Bridge (Approved)	Neul	Intel
Telcordia Technologies (Ericsson)	Shared Spectrum	LG Electronics Marvell Semiconductor Nokia, Inc. Research in Motion Samsung

British Telecom plans to use white space for the purpose of providing affordable Internet access to about 500,000 households who currently lack Internet access [5]. According to its experimental tests, white space devices can provide speed up to 4 to 8 Mbps. In addition, the signal range could research 6 KM transmitter.

The key findings of the Cambridge project is that white space devices is their ability to successfully co-exist with broadcasters and other regulated data communications [5]. In addition, scientists suggest that white space could be used for a wide spectrum of applications. This trial project also evidences a growing industrial interest and readiness. The results and recommendations of such trial projects will assist regulatory authority to make the right decisions concerning white space in their countries. Similarly, we are working on a campus based network to be used for basic research, bring about awareness, and provide connectivity to our university and neighboring communities. Table 2 provides a brief description of selected projects.

IV. COMPARISON WITH OTHER SPECTRUMS

In this section, we need to compare white space with Wi-Fi standards in terms of signal range, data rate, and regulation issues. White space can be a novel choice for Wireless Internet Service Providers (WISPs) or public wireless access with greater broadband capabilities as compared to WiMAX or Wi-Fi. White space spectrum can outperform other wireless technologies (e.g., Wifi and WiMax) in terms of:

1. Providing superior communication range and it is able to penetrate solid obstacles such as trees and buildings. Unlike Wi-Fi, which has a relatively limited range, and can be blocked by obstacles, a network utilizing white-space technology can cover greater ranges than Wi-Fi while requiring less equipment. For instance, Super-WiFi [13] which is a project based on white space spectrum could provide a maximum transmission range of 250m.
2. No Line-of-Sight (LOS) is required between the points being connected because it operates in low-frequency and thus it can penetrate obstacles without the need for towers and additional infrastructure needed to prevent interference.

The long range characteristics of white space could support cellular offloading, rural broadband backhaul, Wide-coverage hotspots, bridges among small networks, sensor network, and wireless surveillance system [5].

V. WHITE SPACE REGULATIONS

The fixed spectrum allocation scheme used nowadays leads to immense underutilization of the scarce spectrum space. For instance, Shared Spectrum Company conducted a research aiming to quantize the white space spectrum in Washington DC. The results of that research detected 62% of white space even in the most crowded areas of the city [20].

Thus, a critical change is happening in the spectrum regulations. This is introducing and enabling spectrum sharing between primary or licensed users and license-exempt or secondary users. The sharing is toll free for the secondary users with a condition that they must not cause any disturbance to the primary users of the spectrum. The first instance of sharing the spectrum was sharing the unused UTF digital TV spectrum bands. Regulatory bodies, such as FCC from the USA and Ofcom from UK, stated that other spectrum should follow the digital TV white spectrum to share the unused spectrums [18]. The FCC has enabled the digital TV white space sharing in 2008 [19]. Cognitive radio is an example of a technology that relies on TV white space for communication and this technology is now running in the real-word environment.

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TABLE II. REGULATORY LANDSCAPE OF TV WHITE SPACES.

Country/ Region	Law	Regulat ion	Polic y	Trials/Pilots
United States	Done	Done	Done	Trials complete/Pil ots ongoing
UK	Pending	Pending	Done	Trials complete/Pil ots planned
Finland	Done	Done		Trials complete/Pil ots planned
Canada	Pending	Pending		Trials ongoing
Singapore		Pending		Trials complete/Pil ots planned
South Korea				Trials planned
European Commissi on		Pending	Done	Trials ongoing
China				Trials ongoing
Japan				Trials planned
Brazil				Trials planned

VI. WHITE SPACE-BASED PROJECTS

A number of white-space based wireless networks have emerged all over the world. For instance, the local government in Wilmington, North Carolina, has built the "smart city" network to extend monitoring and managing capabilities to areas that have been unreachable except by physical visits [11][22]. This experimental network is used for traffic monitoring (using wireless cameras), providing free Wi-Fi in city parks and unserved areas, and monitoring quality of water in remote wetlands. A future plan involves providing e-healthcare and offering broadband service to local schools using this white space-based solution.

Another whitespace project was held in Cambridge, England on June 29, 2011 and it was a commercial trail on whitespace Wi-Fi. It was conducted by Microsoft. In the demonstration, whitespace system successfully provided a broadband IP connectivity allowing an Xbox to stream live HD videos from the Internet.

The Blue Ridge Mountain terrain in Claudville has made Internet access hard to come by. Its citizens earn $15,574 per capita, and hence, the big ISPs haven't rushed to Claudville. However, the white space provided cheaper high-speed internet connectivity to some rural areas of Claudville [2].

The Smart Grid network uses white space for smart grid technologies in California, USA [1]. In particular, the purpose of the network is to provide more efficient, and greener and lower cost utilities wireless network. It is built by a consortium of Plumas-Sierra Rural Electric Cooperative & Telecommunications, Plumas County, and Spectrum Bridge Inc. and Google. The experimental trails have proven the white space is an effective option to deal with difficult terrain and offer another medium for affordable wireless connectivity. It has proven to have good propagation characteristics, the ability to penetrate foliage and no need for line of sight. In other words, whit space has the capability to overcome major technical challenges in difficult train areas.

West Virginia University in July 2013, became the first university in the USA to use available broadcast TV channels in order to provide wireless broadband on campus and nearby [21]. It has partnered with the Advanced Internet Regions consortium to build a wireless network for its campus and surrounding area using the TV white space [21]. These frequencies were left empty after TV stations moved to digital broadcasting. Another purpose is to study the viability of delivering connectivity to rural areas and small towns for the purpose of sustaining economic development, improving quality of life, and improving their competitive advantages in the knowledge economy. Another focus of our project is to measure the impact of our prospective network on building human capital and social capital for its remote community. Table 3 provides a brief description of selected projects.

VII. RESEARCH DESIGN

We are planning to establish a pilot TVWS based network in our university campus. The network would utilize TV white space and solar-powered base station. This new network will coexist with the current WiFi network we have. It will be used to provide broadband access in case the college's wired or wireless networks went down and to enable cheap Internet access to the surrounding society. We used a tool called "show my white space" version 2.6, which is developed by Spectrum Bridge. The tool is used to search and locate available TV white space channels in a certain area. The tool could not detect any available white space channels neither in our town nor in the capital. However, it detected several available channels in Cambridge area, as shown in Figures 1 and 2.

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TABLE III. DESCRIPTION OF KEY WHITE SPACE-BASED PROJECTS.

Project	**Region**	**Project Specifications**
Smart City	Wilmington, North Carolina, USA	Using white space spectrum to connect the city's infrastructure and public services. It also provides public Wi-Fi to some previously underserved communities [11, 12]
Cambridge Project	Cambridge, UK	White space implementation trial
West Virginia University Project	Virginia, USA	Provide wireless broadband on campus and the surroundin**gs**.
Claudville	Claudville, Virginia, USA	High-speed internet connectivity to rural areas of Claudville [2]
Smart Grid	Plumas, California, USA	Real-time broadband connectivity to remote substations and switchgear

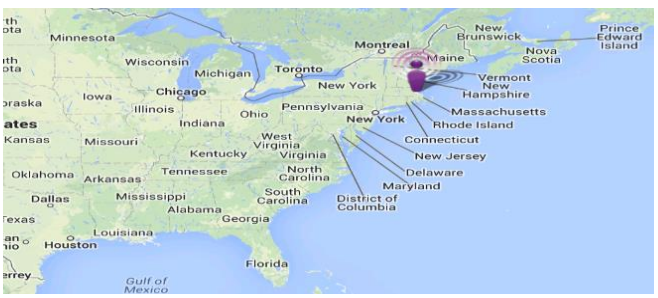

Figure 1. Cambridge area.

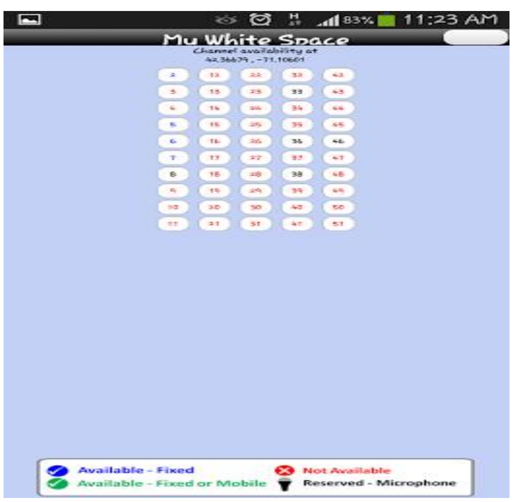

Figure 2.Available white space in the Cambridge area.

The reason could be that all the channels are already occupied by primary users or the white space concept is still not applied in practice. This means that the spectrum space in the area is underutilized and wasted. So, we recommend that the unused spectrum should be released, or deregulated, as it can provide free Internet access to the public in rural areas. It would also enhance related basic research.

VIII. CONCLUSION

TV band white spaces are unused spectrum left between broadcast channels. They exist in different places on different channels. More specifically, it is a spectrum band that is licensed to primary users, the part of spectrum that is unused by the primary user at specific locations and sometimes at specific time. Indeed, the use of white space will provide a new source of bandwidth and thus invaluable connectivity, while not having to rely upon traditional mobile phone networks. It can provide connectivity to both mobile and fixed devices and the internet where Wi-Fi cannot reach. Currently, we are building a pilot network in our campus to bring about the awareness, suggest relevant broadband policy, conduct basic research, and measure its social and economic effects on rural areas.

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