

**2013**

**University of North Carolina Wilmington  
Master of Science in  
Computer Science and Information Systems  
Proceedings**

**<https://csbapp.uncw.edu/mscsis>**

DEVELOPMENT OF WHITE SPACES APPLICATIONS:  
RESULTS FROM A SERIES OF PROJECTS IN NEW HANOVER COUNTY

William W. Edwards

A Capstone Project Submitted to the  
University of North Carolina Wilmington in Partial Fulfillment  
of the Requirements for the Degree of  
Master of Science

Department of Computer Science  
Department of Information Systems and Operations Management

University of North Carolina Wilmington

2013

Approved by

Advisory Committee

---

Dr. Ron Vetter

---

Dr. Bryan Reinicke

---

Dr. Judith Gebauer, Chair

## **Abstract**

Development of White Spaces Applications: Results from a Series of Projects in New Hanover County. 2013. Capstone Paper. University of North Carolina Wilmington.

The aim of this project is to investigate network architecture for deploying white spaces networking technology, as it has been deployed in a specific metropolitan geographic area, namely New Hanover County, North Carolina. New Hanover County's white spaces deployment is among the first of its kind and intends to serve as a model for future deployments and technology development. It is generally seen as a first step in providing cost-effective broadband availability on a global scale. This report first positions the new white spaces technology by comparing it with similar technologies, namely Wi-Fi and WiMAX. It then reviews a number of innovative white-spaces-based projects that have been implemented in New Hanover County. One of these projects involves students and teachers at a middle school in an economically disadvantaged neighborhood in the County's largest city, Wilmington. Named the Youth Enrichment Zone (YEZ), this project is analyzed in more detail from its initial planning phase to deployment over the course of one year. Data collected from user traffic reports and surveys provide the basis for a success rating. Future recommendations were then generated using the knowledge, experience, and results gained over the course of this project. Based on the current results, New Hanover County plans to expand the centralized network further throughout the County and beyond. According to NHC, the new technology is proving an effective means at solving the ever-growing digital divide on a local level and has the potential to serve as a model for future expansion on a global level. Many promises were made before this technology was deployed by NHC. This project seeks to verify if these promises were met and to what degree.

**Table of Contents**

- ABSTRACT .....II**
- I: MOTIVATION..... 1**
- II: TECHNICAL BACKGROUND ..... 3**
  - A. Wi-Fi..... 3
  - B. WiMAX..... 10
  - C. WHITE SPACES ..... 15
  - D. COMPARISONS ..... 29
- III. NEW HANOVER COUNTY PROJECTS..... 31**
  - A. NHC’S ROLE IN THE WHITE SPACES PROJECT ..... 31
  - B. ACTIVITIES & EARLY INSTALLATIONS ..... 34
  - C. YOUTH ENRICHMENT ZONE ..... 49
- IV. ANALYSIS/RECOMMENDATIONS ..... 60**
  - A. SUCCESS RATING..... 67
  - B. SWOT ANALYSIS ..... 68
  - C. RECOMMENDATIONS ..... 69
- V. OUTLOOK/CONCLUSION ..... 72**
- VI. REFERENCES..... 74**
  - Appendix A. – Definitions..... 80*

## Table of Figures

FIGURE 1: COMPONENTS OF WI-FI (SOURCE: CVC WIZ, 2012).....	6
FIGURE 2: COMPONENTS OF WiMAX (SOURCE: HOWSTUFFWORKS, 2012).....	12
FIGURE 3: COMPONENTS OF WHITE SPACES (SOURCE: TENET, 2013).....	20
FIGURE 4: SPECTRUM BRIDGE WHITE SPACES NETWORK (SOURCE: SPECTRUM BRIDGE, 2012).....	22
FIGURE 5: SPECTRUM BRIDGE NETWORK TOPOLOGY (SOURCE: SPECTRUM BRIDGE, 2013).....	23
FIGURE 6: FIXED DEVICES (SOURCE: GOOGLE, 2013).....	28
FIGURE 7: MOBILE DEVICES (SOURCE: GOOGLE, 2013).....	28
FIGURE 8: ACCESS POINT (SOURCE: WILLIAM EDWARDS, 2012).....	37
FIGURE 9: 6HARMONICS ANTENNA (SOURCE: WILLIAM EDWARDS, 2012).....	37
FIGURE 10: KTS RADIO (SOURCE: 6HARMOINCS, 2012).....	38
FIGURE 11: HUGH MACRAE PARK MAP (SOURCE: GOOGLE, 2013).....	41
FIGURE 12: HUGH MACRAE PARK CHANNELS (SOURCE: BING, 2013).....	42
FIGURE 13: AIRLE GARDENS MAP (SOURCE: GOOGLE, 2013).....	43
FIGURE 14: AIRLE GARDENS CHANNELS (SOURCE: BING, 2013).....	44
FIGURE 15: VETERANS PARK MAP (SOURCE: GOOGLE, 2013).....	45
FIGURE 16: VETERANS PARK CHANNELS (SOURCE: BING, 2013).....	45
FIGURE 17: DOT TRAFFIC IP CAMERA.....	46
FIGURE 18: DOT TRAFFIC CAM, WATER STATION/SENSOR, & SCREEN GEMS BDG 8 (SOURCE: GOOGLE, 2013).....	47
FIGURE 19: OTHER LOCATION TOPOLOGY (SOURCE: TVBS, 2013).....	48
FIGURE 20: YOUTH ENRICHMENT ZONE MAP (SOURCE: NHC, 2012).....	51
FIGURE 21: BRC OFFICE AT D.C. VIRGO SCHOOL (SOURCE: BRC, 2013).....	53
FIGURE 22: YOUTH ENRICHMENT ZONE RADIO MAP (SOURCE: NHC, 2012).....	54
FIGURE 23: CAPE FEAR MUSEUM ROOF (SOURCE: WILLIAM EDWARDS, 2012).....	55
FIGURE 24: YOUTH ENRICHMENT ZONE TOPOLOGY (SOURCE: NHC, 2012).....	56
FIGURE 25: CAPE FEAR MUSEUM ROOF ANTENNA (SOURCE: WILLIAM EDWARDS, 2012).....	57
FIGURE 26: WILMINGTON PD (SOURCE: WILLIAM EDWARDS, 2012).....	57
FIGURE 27: HEMENWAY CENTER (SOURCE: WILLIAM EDWARDS, 2012).....	58
FIGURE 28: UNITED STATES SPECTRUM AVAILABILITY (SOURCE: GOOGLE, 2012).....	59
FIGURE 29: HEMENWAY AVERAGE & PEAK TRAFFIC RATES (SOURCE: NHC, 2013).....	61
FIGURE 30: HEMENWAY GRAPH (SOURCE: NHC, 2013).....	62
FIGURE 31: MLK AVERAGE & PEAK TRAFFIC RATES (SOURCE: NHC, 2013).....	63
FIGURE 32: MLK GRAPH (SOURCE: NHC, 2013).....	63
FIGURE 33: HEMENWAY TOTAL BYTES TRANSFERRED (SOURCE: NHC, 2013).....	64
FIGURE 34: HEMENWAY BYTE GRAPH (SOURCE: NHC, 2013).....	64
FIGURE 35: MLK TOTAL BYTES TRANSFERRED (SOURCE: NHC, 2013).....	65
FIGURE 36: MLK BYTE GRAPH (SOURCE: NHC, 2013).....	65
FIGURE 37: PEAK NUMBER OF CLIENTS (SOURCE: NHC, 2013).....	66

## Table of Tables

TABLE 1: COMPARISON OF WIRELESS TECHNOLOGIES (SOURCE: TVBS, NHC, 2013).....	<b>ERROR! BOOKMARK NOT DEFINED.</b>
Table 2: Site Locations (source: TVBS, 2013) .....	40

## I: Motivation

An October 2011 issue of *Time Magazine* stated that 73% of the world's population is without Internet access [32]. In the United States, 28% of rural areas have little to no access to broadband with speeds of 3 Mbps or faster, effectively limiting the electronic reach of the people living in these locations. This problem is even more pronounced in other areas of the world: In India, less than 0.75% of the 1.2 Billion people have access to high-speed Internet. In Brazil, less than 4% of the total population has Internet access [17]. Those without the means of connecting to the Internet are often missing important economic, social, and political opportunities acquired by their connected counterparts. The so-called digital divide<sup>\*</sup> between citizens with and without broadband Internet access doesn't only affect the poor [6]. Elderly and handicapped persons and the children of low-income families are also part of this growing portion of the population. According to a study conducted by The National Telecommunications and Information Administration (NTIA)<sup>\*</sup>, income, race, and level of education are factors in a rapidly widening digital divide [10].

One reason that is attributed to the uneven distribution of Internet access is the associated costs of laying fiber or cable in remote areas with a low population density. In rural areas, the costs for backhaul Internet access can be as high as 50% of all network costs [17]. Backhaul Internet refers to the portion of the network that comprises the intermediate links between the core network and the small subnetworks at the borders of the hierarchical network. As a result, wireless is often considered the only economically

---

<sup>\*</sup> Denotes Key Term, see Appendix

feasible solution. White spaces\* technology, the focus of this report, has recently emerged as an economically attractive alternative to costly cable-based wireless Internet access technologies. It's essentially based on the technology that has long enabled the transmission of TV signals. The idea is to use radio frequencies that have recently been freed up in connection with the shift from analog to digital TV broadcasting, called white spaces. As of 2013, developments are still ongoing to determine the technical and economic feasibility of white spaces-based systems to provide cost-effective broadband Internet access, but the hope is this emerging technology can provide a globally significant opportunity in helping close the digital divide.

This project investigates the network architecture for deploying white spaces networking technology to a specific metropolitan geographic area within New Hanover County, NC. This paper outlines the motivation behind researching white spaces and developing this project. It discusses the history, importance, and core value of that motivation. An analysis of the Youth Enrichment Zone (YEZ)\* project will detail New Hanover County's role in the white spaces project, their mission, goals, and associated installation activities. This case study plans to demonstrate how white spaces are used to address digital divide locally. The YEZ provides free wireless Internet connectivity to students attending D.C. Virgo Preparatory Academy\* as part of a program focused on creating unique education opportunities through the use of technology. The white spaces technology used for the YEZ will cover a geographic area near the school serving mostly students in low-income housing [2]. This paper concludes with a discussion of the collected data, determines whether this project was successful, and formulates recommendations based on that analysis.

Before we describe and analyze the projects in New Hanover County in more detail, the next section provides a technical background. In addition to highlighting key aspects of white spaces technology, we also position it with respect to similar approaches, namely Wi-Fi and WiMAX\*. This comparison of each technology will define and differentiate the basic components, parties involved, benefits, limitations, and abilities.

## II: Technical Background

In this section, three modern technologies are described that have the potential to provide wireless Internet on a large scale. This section concludes with a comparison of all three.

### A. Wi-Fi

The term Wi-Fi\* includes any type of network or WLAN product based on any of the IEEE 802.11 standards. Wireless Local Area Network (WLAN)\* links two or more devices using some wireless distribution method. The number 802.11 with no letter suffix was the original standard of the wireless networking family until it was ratified in 1997. All 802.11 designations apply to WLANs that operate at 1-2 Mbps; which are now obsolete [56]. Each extension to the original 802.11 appends a unique letter to the end, such as 802.11n and 802.11g. At the present time, white space uses IEEE 802.22 and IEEE 802.11af standards for Wireless Regional Area Networks (WRAN)\*.

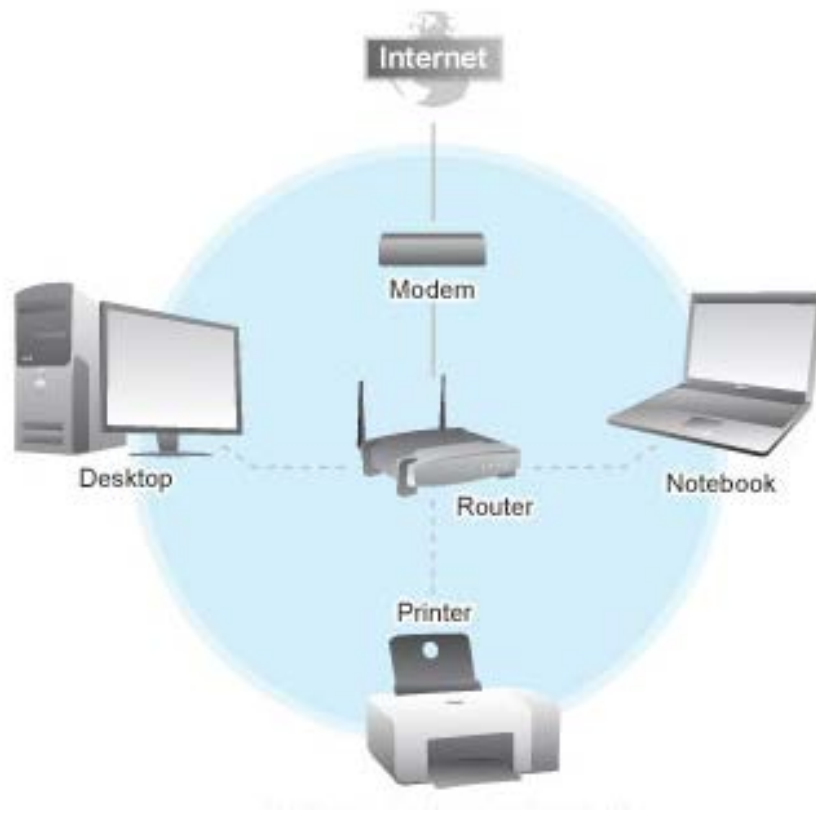
The Wi-Fi Alliance\* was formed in 1999 to establish and enforce standards for interoperability and backward compatibility; something the IEEE didn't practice. The

Wi-Fi Alliance enforces the use of the Wi-Fi brand to technologies from the IEEE\* standard. This includes WLAN, Wi-Fi, Wi-Fi Direct, PAN, LAN\*, and WAN\* connections [57]. The certification process requires full conformance to all associated authentication standards. The Wi-Fi Alliance has stated, “We are a broad-based group of innovators, providers, consumer groups, think tanks, and education organizations. We believe that more efficient use and expanded access to the nation’s spectrum resources are fundamental to the future of U.S. economic policy and global competitiveness.” Members of the WIA include: Dell, New America Foundation, Public Knowledge, Microsoft, Carlson, Aviacomm, Google, and Spectrum Bridge. As of 2010, the Wi-Fi Alliance consisted of more than 375 companies from around the world [58].

Wi-Fi is a technology that enables electronic devices to exchange data wirelessly using radio waves over a computer network. This means Wi-Fi works with no physical wired connection between sender and receiver, but instead uses radio frequency\* technology within the electromagnetic spectrum associated with radio wave propagation. Electromagnetic spectrum\* is the range of wavelengths or frequencies over which electromagnetic radiation extends. Any Wi-Fi enabled device can connect to a network resource using a wireless network access point. When a radio frequency current is supplied to an antenna, an electromagnetic field is created that is able to propagate\* through space. An access point then broadcasts a wireless signal for detection. These access points have a range of about 150 ft. inside buildings and about 300 ft. outdoors [56]. Coverage ranges from a small area the size of a single room to a large multiple square mile area using overlapping access points. A wireless access point is a device that

allows wired communication devices to connect to a wireless network using Wi-Fi, Bluetooth or any related standards.

The following Figure 1 is an overview of the basic components of Wi-Fi beginning with a wireless access point (WAP)\*. A wireless access point connects a group of wireless devices to an adjacent wired local area network (LAN). The access point relays data between devices to a single connected wired device, most often an Ethernet hub\* or switch\*. This allows wireless devices to communicate with other wired devices. Wireless adapters allow devices to connect to a wireless network using various external or internal interconnects. Wireless routers integrate a WAP, Ethernet switch, and internal router firmware application that provides IP routing, NAT, and DNS forwarding through an integrated WAN-interface [56]. A Wide Area Network (WAN)\* is a computer network that covers a broad area (i.e., any network whose communications links cross metropolitan, regional, or national boundaries). A router allows Ethernet Local Area Network (LAN) devices to connect to a single WAN device with configuration through one central utility. This utility may be an integrated web server accessible to LAN clients or an application running on a computer. Network bridges\* connect a wired network to a wireless network. Two wireless bridges are sometimes used to connect two wired networks over a wireless link. This may be helpful when a wired connection is unavailable [30].



**Figure 1: Components of Wi-Fi (source: CVC Wiz, 2012)**

To connect to a Wi-Fi LAN, a computer has to be equipped with a wireless network interface controller. This combination of interface controller and computer is called a station. These stations share a single radio frequency communication channel. All stations within range receive transmission on this channel. A carrier wave is used to transmit the data in packets. Each station is constantly tuned into the radio frequency channel accepting all available transmissions [30]. A Wi-Fi enabled device can connect to the Internet while within range of a wireless network. Wi-Fi can also allow communication directly from one computer to another without an access point intermediary by using an ad hoc transmission. An ad hoc network\* is a decentralized wireless network that doesn't rely on a preexisting infrastructure. The Wi-Fi Alliance

also encourages Wi-Fi Direct for file transfers and media sharing through a new discovery-and-security methodology. Wi-Fi Direct allows devices to connect to each other without the need for a wireless access point. This allows devices to directly transfer data between each other with an easier setup [57].

There are many advantages and disadvantages associated with current Wi-Fi technology. Let's first look at some key advantages. It allows for a cheap deployment of local area networks. It also allows for faster deployment, with setups times in the hour range. This quick deployment advantage supports both emergency and contingency plan situations. It can connect areas where cables cannot be run, such as older buildings and outdoor areas. It supports mobility and provides a signal to any clients within range. Another advantage is the ability to easily create a wireless mesh network. A wireless mesh network (WMN)\* is a communications network made up of radio nodes organized in a mesh topology. Wireless mesh networks usually consist of mesh clients, routers, and gateways. Manufacturers already build wireless network adapters into most current electronic devices. The price of Wi-Fi makes it an economical networking option with prices continuing to decline. Most products are "Wi-Fi Certified" which allows for backwards compatibility and most devices will work anywhere in the world. Newer Wi-Fi Protect Access (WPA)\* encryption is considered very secure, such as WPA2\* [20].

Now, let's look at some key limitations of Wi-Fi. The current fastest Wi-Fi standard, 802.11n, uses double the radio spectrum/bandwidth (40 MHz) compared to 802.11a or 802.11g (20 MHz). This means only one 802.11n network on the 2.4 GHz band at a given location is possible without interference from other WLAN traffic. The 802.11n assignment can also be used to setup bandwidth (20 MHz) only to prevent

interference in a dense community or when blocked by obstructions. Wi-Fi networks have a relatively limited range. A normal wireless access point may have an indoor range of 150 ft. and an outdoor range of 300 ft.; other wireless assignments can have more than double that range [20]. Also, the maximum amount of power a Wi-Fi device can transmit is limited by local regulations. Wi-Fi has a high level of power consumption compared to other standards. The high power consumption of Wi-Fi makes battery life a concern, especially in mobile devices. It is also difficult to estimate Wi-Fi signal strength for a given area because of the complex nature of radio propagation at typical Wi-Fi frequencies. The mobile use of Wi-Fi over wide range is extremely limited and other technologies are much more suitable for communicating with moving vehicles. In terms of security, the most common wireless encryption-standard, WEP\*, is easily breakable. This leads to concerns involving even properly configured networks [18]. Other problems with Wi-Fi include: Wi-Fi connections suffer from interference when other devices are in the same area, many access points default to the same channel contributing to congestion, and high-density areas have problems with overlapping channels when an excessive number of access points are involved.

Wi-Fi is the most common technology used to access Internet wirelessly by individuals and corporations [44]. This also makes it the technology with the most abuse cases and security breaches. Wi-Fi is sometimes considered less secure than other wired physical connections, such as Ethernet. Over time, Wi-Fi has adopted various encryption technologies to prevent unencrypted Internet detection by intruders. Tougher protocols like WPA and WPA2 were added after WEP proved too easy to break. Modern routers have a more extensive certification program to guard devices from intruders. The

problem with wireless network security is its simplified access to the network compared to traditional wired networks. One must gain entry to a building or break through an external firewall with wired networking. To access Wi-Fi, one merely needs to be within the wireless range of the Wi-Fi network.

Range-extendors and repeaters can extend the range of an existing wireless network. Range-extendors can increase a signal area size or allow a signal area to reach around obstacles. Wireless range-extendors work best in networks with low traffic throughput requirements, but are prone to degradation from interference from neighboring access points bordering parts of the extended network. Increasing the number of Wi-Fi access points provides network redundancy and implementations have moved toward “thin” access points with more network intelligence contained in a centralized network appliance. Outdoor applications may use mesh topologies. This is a type of networking where each node must not only capture and disseminate its own data, but also serve as a relay for other nodes. This means it must collaborate to propagate that data in the network [30].

Wi-Fi is the most widely adopted technology available. It’s highly economical and offers an expeditious deployment. This option, however, has limited reach and requires access points. Also, Wi-Fi’s weaker security attributes lead to more successful intrusion attempts. A basic Wi-Fi network typically consists of an ISP (Internet Service Provider), Modem (which establishes & maintains the connection with the ISP & converts the signals to and from the router), a router (which forwards traffic for the Internet to the modem, while keeping internal traffic inside the network) and a lastly

whatever devices are connected to the network. For example: Laptops, Printers, and Smartphones.

## B. WiMAX

The term WiMAX stands for “Worldwide Interoperability for Microwave Access” and is the fourth generation (4G) wireless Internet connection. It’s an IP-based wireless broadband access technology that’s essentially a combination of broadband and wireless Internet. This combination is used to deliver high-speed Internet access over a wireless connection. It was designed to provide 30 to 40 Mb/s rates with newer fixed base stations reaching up to 1 Gbit/s [14]. A base station\* is a unit functioning as a transmitter and receiver of broadcasting or other signals. WiMAX also enables the delivery of last mile wireless broadband access as an alternative to other technologies. The “last mile” is a term used to describe the final resort of telecommunication networks delivering communication connectivity to retail customers. It acts like a roadblock in a communication network and limits the amount of bandwidth data that can be sent to a customer. The actual distance may be considerably more than a mile. WiMAX can provide broadband wireless access up to 30 miles for fixed stations and 3-10 miles for mobile stations\* [14]. In comparison, the Wi-Fi WLAN standard is limited to about 150-300 ft.

There are a few parties involved in the creation and promotion of WiMAX technology. The name was created by the WiMAX Forum\*, which formed in 2001 to promote conformity and interoperability of the standard. The group seeks to promote the

adoption of all WiMAX compatible products and services. Products that pass the performance and interoperability testing receive the “Forum Certified” designation. The group also seeks to educate the world on WiMAX by providing training and offering a series of member events. The WiMAX Spectrum Owners Alliance is the first global organization comprised of owners of WiMAX spectrum [53]. Their mission was to deploy the WiMAX technology in those specified bands while focusing on regulation, commercialization, and deployment of WiMAX spectrum. The Telecommunications Industry Association (TIA)\* set three technical standards covering the air interface and core networking aspect of WiMAX High-Rate Packet Data systems using a Mobile Station with only one transmitter.

Figure 2 illustrates the basic components of WiMAX, which consist of a WiMAX tower and a WiMAX receiver. A tower or base station can provide coverage to over a 3,000 sq. mile area [33]. A receiver could be any WiMAX enabled device that receives a signal. This signal is received in the same way a Wi-Fi enabled device receives a signal from a router. WiMAX provides both mobile and fixed forms of wireless service. The mobile form uses the 802.16e standard and the fixed uses the 802.16d standard. Mobile WiMAX connects to a WiMAX tower using a small antenna inside of an enabled device. It uses a frequency similar to Wi-Fi to send transmissions to the receiver. The transmissions can bend around obstacles and can easily avoid interference [33].



Figure 2: Components of WiMAX (source: HowStuffWorks, 2012)

The fixed WiMAX standard uses a fixed antenna inside a building pointed toward a tower. It's a connection requiring a direct line-of-site to transmit more data with fewer errors [52]. A better line-of-site increases the stability and strength of the connection. It also uses higher frequencies to provide higher bandwidth with less interference. Line-of-sight frequency ranges reach a possible 66 GHz; while non-line-of-sight services use a lower frequency range around 2-11 GHz. This range of frequency is closer to Wi-Fi frequencies than line-of-sight. The last piece of the area network scale is the global area network \*(GAN). Currently, there's a proposal for GAN to use an IEEE 802.20 standard [52]. This standard is an IEEE Standard to enable worldwide deployment of multi-vendor interoperable mobile broadband wireless access networks. It works like cell phone

networks, allowing users to stay constantly connected to the network while traveling. It would provide mobile Internet access comparable to modern cable modem services. This means it could maintain a high level of bandwidth without a fixed location.

WiMAX can transmit over 70 Mbs/s, which is considerably faster than a current Wi-Fi connection. The fastest Wi-Fi connections can only transmit up to 54 Mbs/s under the most optimal conditions. The only difference being WiMAX is usually shared between businesses and homes. It still produces rapid transfer rates for each user even after users split it. The true value of WiMAX is distance, not speed. Wi-Fi's limited range doesn't compare to WiMAX's 30-mile radius from the base station [33].

The far-reaching coverage and high speed of WiMAX aren't the only advantages of this technology. WiMAX's multi-functionality allows it to perform multiple tasks simultaneously, such as high-volume data transfer, video streaming, telephone service, and high-speed Internet [53]. One base station can provide service to hundreds of users, with an almost immediate deployment. A wired network takes time to install and setup for each individual user. Plus, it's already standardized and the same frequency should all work together. With its many advantages, there are also limitations associated with WiMAX technology. Cost is one major factor currently hurting the WiMAX option. It's considered more expensive than both Wi-Fi and white spaces technologies [53]. Unlike Wi-Fi's multiple hotspots, however, a WiMAX buyer will only need to purchase one base station to cover a large geographic area. The availability of WiMAX is quickly spreading throughout the rest of the world, but is currently lagging in North America. As of 2011, the WiMAX Forum claimed nearly 600 WiMAX networks in over 148 countries, covering over 800 million subscribers [14]. A direct line-of-site is required for

more distant connections. Weather conditions can cause interference and disrupt a signal. Also, WiMAX's range potential is high, but these range statistics are only under ideal conditions. Other wireless equipment in the area can also slow the connection and cause interference. It uses multiple frequencies and consumes high levels of power. The shared bandwidth in a given radio sector can reduce dramatically with a high number of users. WiMAX requires a significant amount of electrical support with extremely high installation and operational costs.

The current status of WiMAX promises evolution and growth for the technology. The WiMAX Forum is currently working on the next generation of technology that would enable WiMAX's use for wireless carrier Ethernet services. In 2012, the WiMAX Forum announced they are interested in other radio access technologies [53]. They would like to accommodate harmonization and coexistence across multiple broadband wireless access technologies. In late 2012, the WiMAX Forum approved a release to focus on support for multiple radio access technologies. In 2013, the Forum began working on a release enabling features including load balancing and link aggregation. The Forum is also considering the use of WiMAX as a wireless backhaul solution for carrier networks. These continual updates and expanded deployments show a strong potential for WiMAX technology in the future. For now, WiMAX simply cannot compete for two main reasons, compatibility and cost. It's too expensive to compete with other existing technologies and lost the race against Long Term Evolution (LTE)\* [11]. The 4G technology operators had to choose between LTE and WiMAX, and ultimately chose LTE [37]. This happened because LTE was an upgrade to the pre-existing 3G technologies, which operators had sunk massive amounts of money into already. They were apprehensive about starting

over with the brand new WiMAX technology. White spaces are an alternative that holds a strong potential for success.

### C. WHITE SPACES

The term “white spaces” describes unused television spectrum\* that traditionally existed between TV channels as a buffer. Stations abandoned the spectrum after the transition from analog to digital television, which created large areas of frequency spectrum in the UHF range. Ultra High Frequency (UHF)\* designates a range of electromagnetic waves with frequencies between 300 MHz and 3 GHz (3,000 MHz). The television frequencies in the U.S. that were abandoned fall into the upper UHF 700 MHz band. This range covers TV channels 52 to 69 (698-806 MHz) [19]. All abandoned TV channels outside of the United States are in the Very High Frequency (VHF)\* range. The white spaces deployment projects in New Hanover County only deal with these TV white spaces. The Federal Communications Commission (FCC)\* established rules stating white spaces are used on a license-exempt basis. [16]. This free access to commercially available spectrum is one of the more attractive features of white spaces [9]. This spectrum could potentially support new services while increasing the reach and capacity of existing wireless systems. This derives from digital television’s ability to assign transmissions to adjacent channels without interference, which is something analog couldn’t achieve. The band is compressed into fewer channels, but still allows for more transmissions [1].

The evolution of white spaces began when a group of corporations in the computer technology industry approached the FCC about creating more license-exempt spectrums at frequencies less than 1 GHz. In 2004, an interest in the control of unlicensed use of TV white spaces started. By 2008, the proposed policies allowing unlicensed use of TV band spectrum were approved. In early 2009, the white space coalition began offering wireless broadband services to consumers after the digital switchover mandate in the United States. At the end of 2009, Microsoft began testing their prototype white spaces system [50]. After the Senate set the date to stop all analog broadcasts, eight large technology companies created The Wireless Innovation Alliance (WIA). The WIA is a broad-based group of innovators, providers, consumer groups, think tanks, and education organizations that believe that more efficient use and expanded access to the nation's spectrum resources are fundamental to the future of U.S. economic policy and global competitiveness. Members include: Dell, New America Foundation, Public Knowledge, Microsoft, Carlson, Aviacomm, Google, and Spectrum Bridge [54].

By the end of 2011, the FCC approved a database system created by Spectrum Bridge and allowed it to begin providing services to devices starting in early 2012 [51]. The FCC's Office of Engineering and Technology approved a fixed-location TV band transceiver that operates on a license-exempt basis for unused frequencies in the TV bands [25]. This was the first product allowed to perform this type of operation. The device works in conjunction with the Spectrum Bridge's database applied to the New Hanover County project [41].

The changing nature of the white spaces spectrum leads to a faster evolution process. New technologies must dynamically adapt to sustain life. This variance in how

spectrum is used creates the opportunity for growth of new services. New Hanover County has roughly 150 MHz of spectrum available using TV white spaces [27]. If you compare that to current Wi-Fi, it's almost twice the amount of bandwidth available as a result of TV white spaces. This abundance of bandwidth holds the potential for more wireless innovation. NHC has promised to use white spaces technology for several practical applications across the city. New Hanover County has listed possible real-world applications that utilize white spaces technology. Real-time remote access to video monitoring used to improve overall security for local law enforcement by supplying a virtual presence in parks and public areas. High-speed Internet access in the parks to enables County employees to be more productive and offer citizens the opportunity to stay connected via electronic devices. Remote monitoring and management of wetland areas to eliminate the associated costs traveling to monitoring stations to collect data required by the Environmental Protection Agency (EPA)\* [46].

All devices using wireless connectivity require spectrum. Current technology has trouble utilizing that spectrum in an efficient manner. White spaces seek to take advantage of that lost spectrum by using the TV Band Service. It also advertises 3 to 5 times more coverage than Wi-Fi and better non-line-of-site penetration [21]. The incorporation of white spaces technology could aid in creating healthcare and smart-grid applications\*. For example, a smart-grid application could work with controlling an electric power grid on varying scales. Also, white spaces could be used to increase efficiency of consumer electronics, while helping cope with bandwidth exhaustion.

Different frequencies are assigned for specific uses and the rights to broadcast over these frequencies are licensed out by national bodies. Some examples of these

specific uses include: FM radio (88-108 MHz), cell phones (824-849 MHz), air traffic control radar (960-1,215 MHz), and global positioning systems (1,227-1,575 MHz) [19]. This allocation process creates something called a band plan\*. A band plan is a plan for assigning white spaces between used radio bands or channels to avoid interference. These white spaces also occur naturally between channels. Gaps exist because assigning transmissions to adjacent channels causes problematic interference. Other white spaces are present when a radio spectrum is never used or becomes free after technical changes.

Television white spaces can be either licensed or licensed-exempt. In Canada, they have what's called light licensing, which facilitates proliferation in rural and under-served areas due to lower spectrum costs. In the United States, license-exempt spectrum has lower start-up costs, which results in rapid development in markets without technology bias [23]. License-exempt spectrum holds the potential to trigger innovation among smaller companies. They can develop new products and services without the challenge of entering a bidding war between current industry giants like Google and Microsoft. It also creates the opportunity for smaller projects that are intended to serve a community rather than make a profit, such as the Youth Enrichment Zone. Licensed spectrum typically has higher start-up and infrastructure costs, however, the cost of this spectrum is transferred to the users. These high infrastructure costs prevents rural areas with lower population densities from experiencing true broadband wireless access [31].

The economic value of white spaces and license-exempt spectrum is strong. The total global gain from Wi-Fi and other license-exempt technologies is estimated between \$50-100 billion annually [36]. The license-exempt model encourages innovation and shows perpetually generated revenues. License-exempt spectrum doesn't mean money is

out of the equation. For example, visiting an airport or coffee shop, customers may still pay for the Wi-Fi services. The United States President's Council of Advisors on Science and Technology states that more efficient use of spectrum will be obtained through spectrum sharing.

Spectrum sharing improves the spectrum utilization through the use of white spaces. Less than 14% of the spectrum is effectively utilized and 86% of the spectrum is never used [15]. The United States Presidential Memorandum in 2010 requires 500 MHz of spectrum made available for commercial use within 10 years [34]. Smartphones generate 24x the data of basic cell phones and tablets create 5x more traffic than smartphones. Data volumes have more than doubled 4 years in a row. These enhanced mobile devices are leading to a United States bandwidth deficit [22].

Spectrum sensing is based on detection and avoidance. Spectrum sensing and signal classification techniques can efficiently detect various types of friendly and unfriendly signals. Spectrum databases are used in the Television Band White Spaces. Database driven approaches work in ways similar to cloud computing. This means multiple devices can connect and operate using a real-time communication network. Beacons can provide substantial gain in low signal-to-noise conditions. It has the ability to detect and decode without malicious node issues. Unlike spectrum databases, beacons are able to operate in real time.

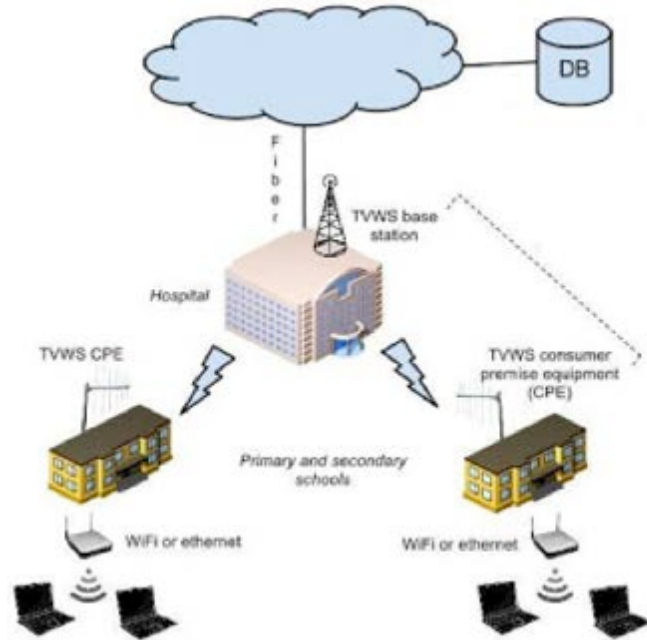


Figure 3: Components of White Spaces (source: TENET, 2013)

Figure 3 illustrates the basic components of a white spaces network, which are modeled after Wireless Regional Area Network (WRAN)\* topology. A typical white space network consists of spokes and hubs, which is any architecture that uses a central connecting point. It is the same as a star topology in a network. A network hub is hardware that functions as a central hub to all nodes. The network operates in a point-to-multipoint basis inside a predetermined zone. These systems are made up of a Base Station Unit (BSU) that can communicate with multiple Subscriber Units (SU's). The BSU's provide a sector antenna beam pattern and multiple units can be used to create a 360 degree sector. BSU installation locations will form a network boundary. This ensures it will properly reach all intended white spaces users and devices. Most importantly, a base station simply consists of a low-powered transmitter and router. Additionally, it may serve as the gateway between a wireless network and a wired

network. The base station is connected to equipment using a wireless link. This equipment may include routers, switches, telephones, or handheld devices. The base station controls the medium access for all connected equipment. Hubs are used for cognitive sensing and receive reports from the equipment containing data about the spectrum sensed. The base station uses this information to switch to a different channel or remain on the current one.

This project uses a KTS Agility White Spaces Radio to capture the unused spectrum and deliver the signal to access points. The Agility White Spaces Radio is designed for use in harsh environments and incorporates non-line-of-sight (NLOS) white spaces features. The radio is designed for Ethernet-IP-enabled industrial telemetry applications and supports data rates up to 3 Mbps and ranges up to 5 miles or greater at lower data rates. It operates in the unlicensed spectrum from 470-698 MHz to create point-to-point or point-to-multipoint networks for fast, cost-effective connections that don't require extensive planning [60].

In general, the IEEE 802.22 standard maintains access to any preexisting database is the recommended technology for access security. The standard seeks to define the messaging format, techniques, and timers to access the database. A white spaces device will not transmit until a database administrator verifies clearance. The database will maintain continually updated information on all TV white spaces locations. Constraints will be set that restrict power from exceeding the levels required, which will help reduce interference with current spectrum users [1].

In this project, the base station connects to the Internet and communicates with Spectrum Bridge's white spaces database, shown in Figure 4. This is a custom-made

database developed by Spectrum Bridge, Inc. It then connects to a device or client after negotiating for an available channel, shown in Figure 5. The FCC requires that unlicensed TV band devices contact an authorized database system to obtain a list of channels that are authorized for operation. Channel use authorizations are determined for a specific location. Radios operating as white space devices are required to provide their geographic location for authorization, using an Internet connection, to a TV band system authorized by the Commission. The database returns a list of authorized channels available for operation by the TVBD for the reported location. If authorized, the connection is allowed to pass.

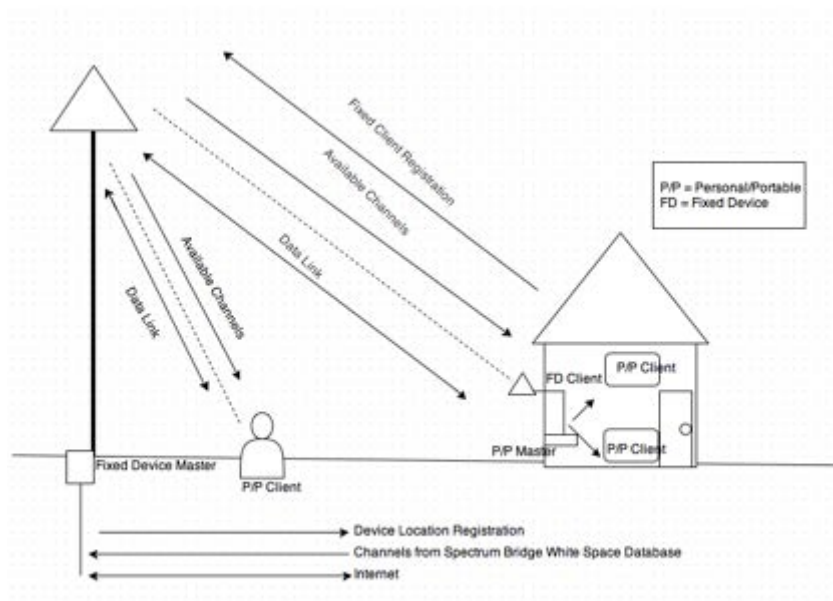


Figure 4: Spectrum Bridge White Spaces Network (source: Spectrum Bridge, 2012)

The current white spaces technology uses an IEEE 802.22 standard. It can transmit up to 22 Mbps a distance of over 60 miles, which makes it especially useful when trying to serve densely populated rural areas [19]. This distance is achieved by taking advantage of the powerful transmission qualities of the UHF and VHF TV bands.

The 802.22 standard has a typical cell radius of 30-100 kilometers, a (6,7,8) MHz channel bandwidth, and a channel capacity of 18 Mbps. Additionally, it has a user capacity of 1.5 Mbps for downlinks and 384 kbps for uplinks [23].

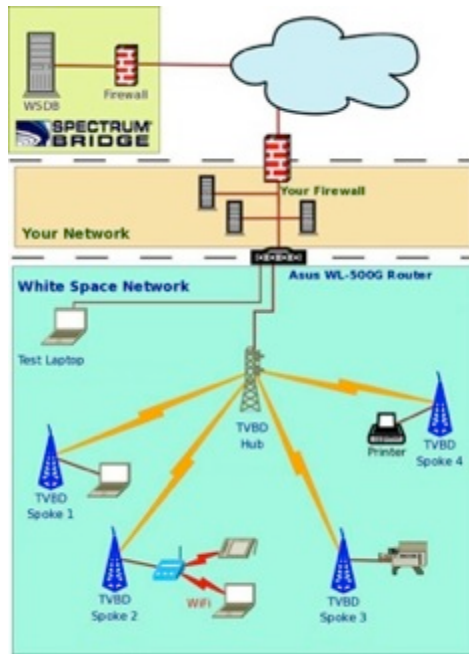


Figure 5: Spectrum Bridge Network Topology (source: Spectrum Bridge, 2013)

As of 2013, a new IEEE standard proposal is being developed. The IEEE 802.11af standard uses the TV white spaces with cognitive radio\* technology. A cognitive radio is aware of its environment and its internal state. It holds knowledge of these environmental elements and makes decisions based on this knowledge. Cognitive radios can also store defined objectives and make decisions based on that behavior. In Cognitive Radio Technology by Bruce Fette, he states “Some of the radio's cognitive abilities include determining its location, sensing spectrum use by neighboring devices, changing frequency, adjusting output power or even altering transmission parameters and characteristics.” This standard operates at frequencies below 1 GHz, which allows a

signal to reach longer distances. Currently, the lowest band is 2.4 GHz in Wi-Fi systems. [40]. The 802.11af standard would also provide more bandwidth by accessing additional unused frequencies. This new standard would deploy geographic sensing using a geographic database\*. This knowledge of available channels would enable the system to bypass used channels. The 802.11af standard has a 470-719 MHz operating frequency range, a channel bandwidth of 6 MHz, and transmission power of 20dBm [40].

Television white spaces have different unused channels or frequencies in different markets. For example, TV channel 2 (54 MHz-60 MHz) may be unused white spaces and available for unlicensed communications in the Wilmington, NC market. TV Channel 2 could also be licensed to ABC and unavailable for unlicensed use in the Myrtle Beach, SC market. The national geo-location database administrator would be accessed by the person/entity wanting to communicate over TV white spaces. In Wilmington, the database would approve use on Channel 2, but in Myrtle Beach, it would reject it. Spectrum Bridge Inc. was the first national geo-location database administrator approved by the FCC. For now, these geo-location administrators are providing national information for unlicensed usage only on TV white spaces or spectrum between 54 MHz and 698 MHz (TV channels 2-51) [43]. The goal is to use the geo-location database administration system for other spectrum bands in the future. Geo-location database administrators currently FCC authorized includes: Spectrum Bridge, Microsoft, and Google. The purpose of the TVWS database administrator is to prevent interference between unlicensed and licensed spectrum [50].

White spaces technology offers several distinct benefits to its users. According to Microsoft, it can potentially deliver a signal over 4x the distance and cover 16x the area

of a conventional Wi-Fi network at the same power levels [32]. This would significantly help to reduce associated network costs. The estimated 400-meter reach offers increased flexibility when compared to Wi-Fi's 150-meter indoor reach. Along with providing greater distances, white spaces can penetrate common obstructions. Wi-Fi technology is limited because many obstacles block it. Concrete walls, foliage, buildings, and topographical challenges are less problematic for TV white spaces because of its shorter wavelength. Just like a typical TV signal passes through walls, the wireless Internet signal mirrors this capability. It can serve sparse populations in remote parts of developing countries. This holds the potential to ignite a global economy boom similar to the emergence of Wi-Fi's impact on the Internet [61].

Among the many advantages of white spaces, there are some disadvantages as well. One issue is the white spaces interference with existing broadcast services; which is a very complex process. Also, there's a challenge to find unused frequencies, which may require additional built-in GPS radio functionality. Another concern with white spaces is electricity availability. Although providing affordable broadband to a desolate country sounds promising, it's nearly impossible without some type of reliable power supply. Microsoft is currently working to solve this issue by developing solar-powered base stations. Microsoft says one of the biggest challenges for white spaces is policy makers and regulators regarding the allocation of spectrum as a revenue-generating opportunity. Spectrum auctions draw large-scale bidding wars that slow deployment and raise costs for users [12].

The greatest disadvantage affect TV White spaces (TVWS) technology is the FCC 600 MHz TV spectrum auction anticipated in 2014 [49]. It is possible the whole

unlicensed TVWS access protocols could change to be much more like unlicensed Wi-Fi is today. This uncertainty leads to reduced market participation and slower product development. The FCC could designate a contiguous lineup of TVWS frequencies nationwide. Currently, Wi-Fi frequencies are nationwide at 2.4 GHz, 3.6 GHz & 4.9/5.0 GHz. If the FCC creates rules or designations for the 600 MHz auction that call for a contiguous nationwide lineup of frequencies then a significant technological barrier will be reduced [12]. Currently, TVWS is different in every market and in order to access these frequencies an FCC approved geo-location database (Google, Spectrum Bridge, etc.) must authorize use of the particular TV frequencies in a particular geographic location. The geo-location database\* requirement would be eliminated for designated nationwide frequencies and chips would be more efficiently created if the FCC designated, for example, frequencies 608 MHz-614 MHz nationwide as unlicensed TVWS [26].

The potential bidders for this spectrum are currently unknown. TMF Associates\* analyst Tim Farrar said the number of licenses up for auction is solely dependent on how much broadcasters are paid to give up their spectrum. If Verizon and AT&T fully participate in the auction, you can expect the bidding prices to rise. If both parties are involved, the auction could easily raise more than \$20 billion [12]. If the rules prevent both parties from participating, the auction could fail. The FCC's goal is up to 120 MHz of spectrum (20 TV channels in upper UHF band), with the auction rules currently being written. Under the FCC's proposed rules, broadcasters will submit bids to relinquish their 6 MHz pieces of spectrum in a reverse auction. During this voluntary process, the FCC will pay them after they give up their spectrum. The FCC anticipates there being 6 MHz

guard bands to separate spectrum blocks used by carriers. The white spaces between the blocks will be open for unlicensed use. This is all part of the FCC's goal of freeing up 300 MHz of spectrum for mobile broadband by 2015 [25].

The two main powerhouses behind TV white spaces are Google and Microsoft [60]. It benefits Google by allowing for cheaper advertising through cheaper broadband. Telecommunications carriers are against it because they don't want people to have access to cheaper broadband and TV stations are against it because they fear interference. The FCC appointed Microsoft as the white spaces database manager and Google as a white spaces administrator in late 2011. Google has been pro-white spaces since 2008 and has been lobbying Congress for years [5]. Key Bridge Global was against Google's appointment deeming it an unfair advantage [34]. Key Bridge is a supplier of online information systems and services. They claim Google will greatly benefit from the information it collects as an administrator by allowing them develop devices that utilize the white spaces spectrum. The FCC states it doesn't consider Google a threat because all administrators would be prohibited from using database information to engage in anti-competitive practices [34].

For now, Google is working industry and regulators to make additional spectrum available by enabling spectrum sharing through a database [3]. This TV white spaces database is part of Google.org's efforts to make spectrum available for broadband access. This could help alleviate the digital divide since Google's mission is to improve global connectivity. The spectrum database has been certified by the FCC and is available to wireless devices that are approved by the FCC for TV white spaces bands. The database will allow registered devices to check the database automatically. Figure 6 and Figure 7

show spectrum availability in the U.S. as of January 29, 2013. The different white space channels are represented by color. In the following figures, green shows specific channels that are available and non-green shows unavailable channels.



Figure 6: Fixed Devices (source: Google, 2013)



Figure 7: Mobile Devices (source: Google, 2013)

TV Band white spaces play a vital role in providing broadband Internet to locations previously inaccessible. The VHF and UHF bands traditionally reserved to broadcasters have highly favorable propagation characteristics. They have an extensive reach that penetrates through foliage and obstacles. White spaces offers amplified coverage and capacity Wi-Fi can't compete with. They meet the requirements necessary to alleviate the digital divide, including: lower costs, longer reach, and more thoughtful

regulation. These regulations must support a license-exempt approach if rural broadband is to become a reality [32].

#### D. COMPARISONS

This section will compare the varying aspects of White spaces, Wi-Fi, and WiMAX technologies. Wi-Fi is the cheapest, most ubiquitous, and most backwards compatible technology available. It's highly economical and offers the fastest deployment speed. This option, however, has the most limited reach and highest power consumption. It has the easiest mesh network construction of the three technologies. Wi-Fi only uses unlicensed spectrum, which is currently the most popular in end-user devices. Wi-Fi has the weakest security attributes, which leads to more successful intrusion attempts.

The current status of WiMAX encourages evolution and growth for the technology. It has the second longest reach, but it's also the most expensive. WiMAX covers large areas, many sq. miles, while Wi-Fi provides access to local area networks only. They both can use unlicensed spectrum to deliver an Internet connection in a network, but WiMAX can use both licensed and unlicensed spectrum. The quick deployment of WiMAX can reach many users, but optimal conditions are always necessary. It's potentially the fastest technology, but also has the most interference issues. WiMAX has the second longest reach, but has the least availability in North America.

White spaces have the most extensive reach and the best coverage of the three technologies. It has the best obstacle penetration and lowest power consumption. It's currently the fastest growing, but has the most uncertain future. It meets many of the requirements necessary to alleviate the digital divide, including: lower costs, longer reach, and more thoughtful regulation. At a technical level, white spaces have a slower bit rate speed and the lowest efficiency, but excel at providing range and scalability.

There's not a clear winner at this point. White spaces and WiMAX are relatively new technologies. They continue to change and evolve on an almost weekly basis. WiMAX is releasing WiMAX 2 in late 2013, which could propel it to the front or back of the line [19]. Some actually consider white spaces to be an extension of WiMAX, while others consider it a combination of Wi-Fi and WiMAX. They don't have to beat each other and they can actually work together. The New Hanover County project uses a combination of white spaces and Wi-Fi. All three technologies can offer a potential solution to providing wireless Internet access to rural areas and helping to close the digital divide. Table 1 compares varying technical aspects of White Spaces, Wi-Fi, and WiMAX technologies.

**Table 1: Comparison of Wireless Technologies (source: TVBS/NHC, 2013)**

Comparison	White Space	Wi-Fi	WiMAX
Access Protocol	Request/Grant	CSMA/CA	Request/Grant
Bandwidth Efficiency	2.4 bps/Hz	2.7 bps/Hz	5 bps/Hz
Bit Rate	Works @ 2.4 bps/Hz	Works @ 2.7 bps/Hz	Works @ 5 bps/Hz
Bit Rate Maximum	Peaks @ 19 Mbps	Peaks @ 54 Mbps	Peaks @ 100 Mbps
Encryption	Mandatory AES-GCM	Optional-RC4	MAND-3DES, OPT-RC4
IEEE Standard	802.22	802.11	802.16
Mobility	None	In Development	Mobile WiMAX 802.16e
Primary Application	Wireless LAN	Wireless LAN	Broadband Wireless
Quality of Service	Yes	No	Yes
Range	22 Mbps ~ 60 Miles	54 Mbps ~ 300 feet	70 Mbps ~ 40 Miles
Scalability	1 to 100s	1 to 10s	1 to 100s
Channel Sizes	Fixed-689 to 806 MHz	Fixed-20 MHz	Flexible-1.5 to 20 MHz
Mesh	Yes	Vendor Proprietary	Yes

### III. New Hanover County Projects

#### A. NHC'S ROLE IN THE WHITE SPACES PROJECT

New Hanover County (NHC) plays a critical role in this project's white spaces deployment. This role included developing goals in which the County takes responsibility for accomplishing. The foremost goal consists of accessing available TV White Spaces spectrum and managing the deployed network by dynamically assigning non-interfering frequencies to devices throughout the serviced areas. This action corresponds to another goal of effectively providing bandwidth to deficient locations at any given time. The NHC government has an ongoing mission of connecting its citizens in all areas of the County [35]. This initiative includes areas that were previously considered impossible to cost-effectively reach using existing technology. NHC perpetually explores new ways of leveraging innovative technologies, while attempting to enhance existing services provided to its community [59].

New Hanover County was asked to participate in early pilot projects due to its involvement in the switch from analog to digital television. Wilmington and NHC had developed relationships with FCC members during that project, which carried over into the white space pilots and proof of concepts [60]. NHC was asked to develop technical components, define standards, and test prototype equipment necessary to make white spaces work. The County served as a "playground" for both the government and commercial sectors.

The economical factor was not the primary concern during the life of this project. NHC was paying upwards of \$400/month in AT&T services for each location. Antennas were installed that cost approximately \$2,500 each, which means they would pay for themselves in about 6 months [27]. New Hanover County's goal was not to reduce costs, but to enhance services. This has been their mission from the beginning, although economic factors can play a smaller role. They started these projects with a grant-funded budget of \$10,000 [28].

Spectrum Bridge Inc. plays an important part in New Hanover County's white spaces platform deployment. They provided the equipment used and developed the technology necessary to make this project possible. Spectrum Bridge began with the concept of wireless market dynamics changing the way spectrum is allocated and managed. As a result, they created a platform that seeks to improve spectrum utilization and availability. Their mission statement reads, "Our mission is to virtualize spectrum with cloud-based software solutions that dynamically allocate and manage spectrum for next generation wireless networks. As a recognized thought leader in spectrum management globally, we have employed a continuous innovation process of developing technology that has produced seminal intellectual property for managing spectrum." Spectrum Bridge Inc. works to reduce spectrum allocation costs and manage it efficiently. They enable high-speed and low-cost bandwidth across wireless networks and applications [65]. They achieve this using their unique patented spectrum management technology. Spectrum Bridge's white spaces platform was certified to serve as the first TV white spaces database. This is the first time the United States has initiated a database solution to allocate and manage wireless frequencies [6].

Two other key players in this project are TV Band Service LLC (TVBS) and 6Harmonics. TVBS provides wireless communication services to government and enterprise operations. The company works with next-generation technology, including TV white spaces, to reduce costs and improve performance for a range of applications. These applications may include: wireless broadband Internet, energy, environmental monitoring, traffic management, security, and law enforcement [22]. TVBS is a privately held company with its headquarters located in Wilmington, NC. TVBS is a subsidiary of EUE/Screen Gems. Screen Gems\* has been in the TV business for over 70 years and has a 50 acres production complex in Wilmington, NC. TVBS was started in order to leverage its physical and intellectual assets in pursuit of new technologies and business opportunities the digital television transition would unveil, including TV white spaces. 6Harmonics designed and produced some of the prototype radios used during the initial white spaces deployments. As of 2013, some of those prototypes are still being used and others have been replaced by newer commercial radios.

Keith Bolick from TVBS and Peter Sun from 6Harmonics were both onsite during the site installations. Peter Sun is the Founder and Vice President of 6Harmonics Inc., which operates out of Ottawa, Ontario. Craig Marshburn, the network administrator at NHC, provided data traffic reports. Two key players from New Hanover County were Leslie Chaney and Shannon Eakins. Leslie Chaney is the IT Director of New Hanover County and an instrumental liaison between all parties involved. Shannon Eakins is a New Hanover County IT support specialist. He worked on-site and facilitated the installation processes.

New Hanover County's white spaces deployment doesn't have constrained time parameters. Early testing started in 2010 with the primary objective of getting a transceiver radio that could communicate in the TV white spaces spectrum with a geo-location database administrator [59]. As of 2013, it's considered an ongoing project with no set end date [38]. NHC plans on expanding the technology throughout the County and eventually the entire state of North Carolina. Their schedule has been very dependent on the availability of the 6Harmonic's prototype radios, which are produced in custom lots, rather than mass-produced. These radios use white spaces to deliver the Internet signal to a connected access point. There have been delays and periods of time where no activity occurred. These instances can be attributed to a wide range of possible issues. For example, in late 2012, the radios were held at customs for over a month due to security checks. New Hanover County has been working on various projects for over 2 years.

## B. ACTIVITIES & EARLY INSTALLATIONS

Spectrum Bridge selected four locations across the country for their white spaces platform deployments. Named "The Big Four", these sites included Plumas, California; Claudville, Virginia; Logan, Ohio; and Wilmington, North Carolina [41]. Wilmington was selected as the first deployment because it was the first city in the United States to switch from analog to digital television. Its relatively flat terrain only solidified it as the prime location. In a press release, Wilmington openly welcomed this new technology with the hopes of facilitating fundamental industry sections, including: health care, energy, education, and rural development. The video surveillance capabilities associated

with white spaces also provided promising improvements for traffic monitoring and park security [47].

Early testing started in 2010 for TV Band Service (TVBS). Their main partners consisted of Koos Technical Services (KTS) and Spectrum Bridge Inc. (SBI). KTS worked on the transceiver radios and SBI managed the geo-location database. The primary technical objective for testing was to get a transceiver radio that could communicate in the TV white spaces spectrum (54 MHz to 698 MHz). [39] The primary regulatory component was to have a radio that could communicate with a geo-location database administrator. There were three main testing objectives: To determine if national geo-location database management could be used as a way to utilize geographically-specific uncultivated spectrum for unlicensed use without interfering with licensed spectrum communications; To determine if transceiver radios could perform with agility and communicate in different frequencies efficiently; To determine the performance characteristics of wireless signal communications in the TV band to establish the real world business case.

Two important benefits of the Spectrum Bridge Solution are cost effectiveness and bandwidth efficiency [41]. The networks were deployed using fewer towers than were previously required for unlicensed frequencies. In addition to reducing costs, accessing all available spectrums when optimizing network performance provides bandwidth efficiency. Hanover County plans on utilizing Spectrum Bridge's new TV White Spaces database-driven technology for future applications such as monitoring storm water flow, connecting additional security cameras, expanding Wi-Fi access to area public schools, and enabling remote monitoring and reporting of medical devices for at-

risk populations. This network is monitored remotely by Spectrum Bridge's intelligent TV white spaces Network Management Application and integrated database, which dynamically assigns non-interfering frequencies to White Space devices. These White Space devices are assigned channels in real-time to assure TV broadcasts, along with other protected TV band users in the area, are prevented from facing problematic interference.

Before this project, the only existing infrastructure in New Hanover County consisted of a few hard-wired networks at various locations [4]. The introduction of the new technology of white space radios allowed for an extension of the wired network into outdoor areas relatively easily. Capitalizing on the existing fiber optic infrastructure, Spectrum Bridge Inc. installed its proprietary white spaces software applications into existing communications equipment at the wireless transmitter hubs in three locations to offer high-speed premium Internet connectivity. Additional transmitters with SBI's software were then connected to a wide range of remote white space devices so that TV white space frequencies could be used to communicate back to the hubs.

A typical white space network consists of transmitters and hubs. Most of the deployments in NHC/Wilmington are using KTS AWR radios along with Telex ALP-450 antennas\* [48]. There's a balance of the deployments by using prototype radios and custom antennas designed by 6Harmonics. All networks have to be created by integrating prototype white spaces radios. The antennas on the roof receive the white spaces signal, which is hard-wired to an access point inside the building. The access points are standard Cisco routers typically mounted to the ceiling inside of a building, shown in Figure 8.

That access point then propagates that Wi-Fi signal to other access points located in the surrounding area.



**Figure 8: Access Point (source: William Edwards, 2012)**

The antennas are securely mounted to the roof outside of the building. The 6Harmonics antenna is a Channel Master Masterpiece HDTV Antenna Series with a UHF 30 mile range, shown in Figure 9. It has a heavy-duty construction with a tough powder coated finish, UV stabilized plastics, bifurcated rivets for extra strength, and 0.5-inch aluminum elements. All ends are crimped and machined to reduce the risk of cuts and scratches. It has a high performance F-Type PCB Balun that ensures quality connection and faces down to minimize water ingress.



**Figure 9: 6Harmonics Antenna (source: William Edwards, 2012)**

The KTS radio is a black 3.5 x 5.0 x 1.4-inch box weighing almost three quarters of a

pound, shown in Figure 10. It can take on channel sizes up to 5 MHz and service data rates up to 4 Mbps. It's a waterproof machine designed for outdoor use. The radio can run in the UHF and VHF bands or 900 MHz zone with data rates averaging 0.5 to 3.1 Mbps [43].



Figure 10: KTS Radio (source: 6Harmonics, 2012)

6Harmonics supplied the antennas and some of the custom-built radios. Only standard networking equipment on all switches and wireless access points were used. IP video cameras were positioned in parks and public places.

KTS Agility White Spaces Radios (AWR) radios eliminate the constraints most wireless deployments are currently challenged by, such as problematic terrain, propagation limitations, and congestion of other unlicensed frequencies (900 MHz, 2.4 GHz, and 4.9 GHz) [43]. These qualities allow wireless operators to experience a more cost-effective solution as the inherent bandwidth and non-line-of-site coverage. AWR utilizing TV white spaces frequencies allow for fewer devices to be deployed and a better quality of service for users and applications. It has a variable broadband data rate up to 3.25 Mbps. New Hanover County and TVBS are implementing a wide selection of

possible radios and configurations at first. They are looking for the optimal combination and have plans to make replacements if needed.

The Federal Communications Committee (FCC) required the regulatory component for testing. They wanted to introduce geo-location spectrum management and administration functionality into unlicensed spectrum bands. There is unused spectrum in certain geographical markets, but this spectrum is in different frequencies at each location. Unlicensed Wi-Fi is geographically contiguous at 2.4 GHz and 5 GHz throughout the country [13]. There's no need for spectrum management locally because all transceiver radio chips are made to communicate at these frequencies.

The white spaces network was designed, supplied, and installed by the TV Band Service. They were responsible for the white spaces network, related radios, and connectivity. New Hanover County (NHC) was responsible for the network IP cameras, mounting kits, AC power supply, Power Over Ethernet (POE) supply, internal Secure Digital High Capacity (SDHC) media, backhaul\*, Internet POP\*, Wi-Fi routers for citizen internet access, pole attachments, lift, and other equipment needed for hardware maintenance [36].

The County decided in the beginning to split the project up into two phases. These phases are identified in Table 2, as either deployment phase 1 or 2 [36]. The following table shows the description, type, exact location, distance, status, and deployment phase. The status column represents what activity occurs at each location. For example, Location 4 on the table below would indicate an upgraded Cisco access point was installed at the Hemenway Center. Initial locations included: Hugh MacRae Park (Internet) located at 314 Pine Grove Drive, Airlie Gardens (surveillance) located at 300

Airlie Road, Veterans Park (Internet, surveillance) located at 835 Halyburton Memorial Parkway, and Martin Luther King Highway (Internet) located at 615 Bess Street. All locations are located inside of the Wilmington, NC city limits [39].

**Table 2: Site Locations (source: TVBS, 2013)**

	Location Description	Type	Latitude	Longitude	Distance	Bearing from Hub	Status	Deployment Phase
1	Hemenway Hub 1	Hub	34.207554	-77.879999			Upgrade Channel A	1
2	Hemenway Hub 2	Hub	34.207554	-77.879999			New Channel B	1
3	HM Park Pavilion Cam	Spoke	34.207844	-77.883061	0.18	276	Upgrade w/new Camera	1
4	HM Cisco AP	Spoke	34.206881	-77.883357	0.20	257	Upgrade	1
5	HM Playground AP	Spoke	34.208190	-77.882506	0.15	287	New w/new AP	1
6	Airlie Garden Hub 1	Hub	34.215090	-77.829664			New Channel A	2
7	Airlie Garden Hub 2	Hub	34.215090	-77.829664			New Channel B	2
8	Tree Viewer Cam 1	Spoke	34.213679	-77.829323	0.10	169	New w/Camera	2
9	Tree Viewer Alternate	Spoke	34.214331	-77.829272	0.06	157	New w/Camera	2
10	Bottle Garden Camera	Spoke	34.214059	-77.828524	0.10	138	New w/Camera	2
11	Parking Lot Camera	Spoke	34.215677	-77.828810	0.06	50	New w/Camera	2
12	Airlie Gardens Gate Cam	Spoke	34.217995	-77.829389	0.20	4	New w/Camera	2
13	PD HQ Hub	Hub	34.253044	-77.941446			New Channel A	1 or 2
14	New PD Camera	Spoke	34.260920	-77.928600	0.91	54	Upgrade	1 or 2
15	Veterans Park Hub 1	Hub	34.098293	-77.904095			New Channel A	2
16	Veterans Parks Cam 1	Spoke	34.100198	-77.906211	0.18	318	New w/Camera	2
17	Veterans Parks Cam 2	Spoke	34.100147	-77.905627	0.16	326	New w/Camera	2
18	Veterans Parks Cam 3	Spoke	34.101399	-77.906141	0.24	331	New w/Camera	2
19	Veterans Parks Cam 4	Spoke	34.099784	-77.914530	0.61	280	New w/Camera	2
20	Veterans Parks Cam 5	Spoke	34.101479	-77.914512	0.63	290	New w/Camera	2

## Hugh MacRae Park

The Hugh MacRae Park site has one hub, which is located on the Maintenance Building and currently serves two spokes. The first spoke is mounted on a park pavilion and is connected to a Cisco fixed IP camera with zoom. These cameras with zoom will be used by the Wilmington Police Department. New Hanover County (NHC) intends to replace that camera at a later time. The second spoke is located on the Booster Club Building for the sports fields. This spoke has a Cisco outdoor access point, which provides community Wi-Fi to that section of the park. NHC added a third spoke and public Wi-Fi access point at a pavilion located near the children's playground. This case was used for testing cameras and public Internet in parks. Figure 11 is a satellite view of Hugh MacRae Park with each camera and hub pinpointed using Google Maps [3].



Figure 11: Hugh MacRae Park Map (source: Google, 2013)

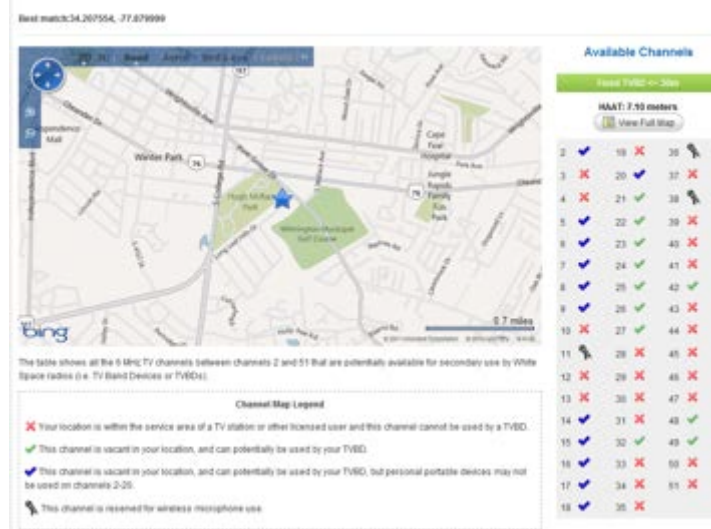


Figure 12: Hugh MacRae Park Channels (source: Bing, 2013)

Using Bing, Figure 12 displays the available channels at this particular location. Anyone can use this spectrum browser to see TV white spaces spectrum that is available in that specific location. The database will allow registered devices to check the database automatically, identifying what spectrum is available locally and using those available bands. Also, these channels tell the user which TV channels between 2 and 51 are potentially available for secondary use by white spaces radios. A blue check means the channel is vacant, and can potentially be used by TV band devices. Portable devices may not be used in channels 2-20. A green check means the channel is vacant and can potentially be used by your TV band devices. A red “X” means your location is within the service area of a TV station or another licensed user. A TV band device cannot use a channel with a red “X”. Channels 2 through 6 are in the low VHF spectrum, channels 7 through 13 are in the high VHF spectrum, and channels 14 through 51 are the UHF bands [36].

## Airlie Gardens

Airlie Gardens is a valuable cultural and ecological component of NHC and North Carolina's history. The County Government wants to ensure this location is protected through the installation of video cameras with recording capability. The cameras provide views of the Airlie Oak, The Minnie Evans Bottle Chapel, the remote park area, and the two-gate front entrance. To provide additional bandwidth, a two-channel/two hub installation was implemented. This case tested the effectiveness of the cameras at providing adequate security at a given location. Figure 13 is a satellite view of Airlie Gardens with each camera and hub pinpointed using Google Maps.



Figure 13: Airlie Gardens Map (source: Google, 2013)

Using Bing, Figure 14 displays the available channels at this particular location.

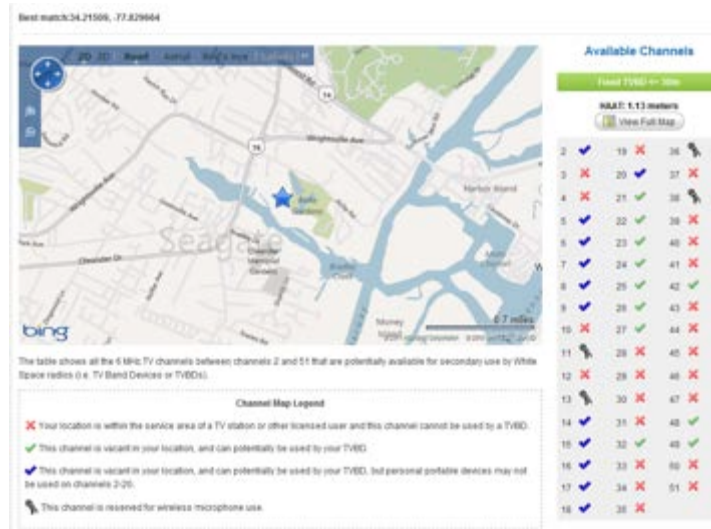


Figure 14: Airle Gardens Channels (source: Bing, 2013)

## Veterans Park

Veteran’s Park is one of the county’s best multi-use facilities with many sports fields, snack bars, and clubrooms. All of these sites have been affected by vandalism and the park wanted to install cameras with recorders to reduce this problem. One hub is installed at the maintenance facility to provide links to multiple cameras located near the ball fields. Figure 15 is a satellite view of Veterans Park with each camera and hub pinpointed using Google Maps.



Figure 15: Veterans Park Map (source: Google, 2013)

Using Bing, Figure 16 displays the available channels at this location.

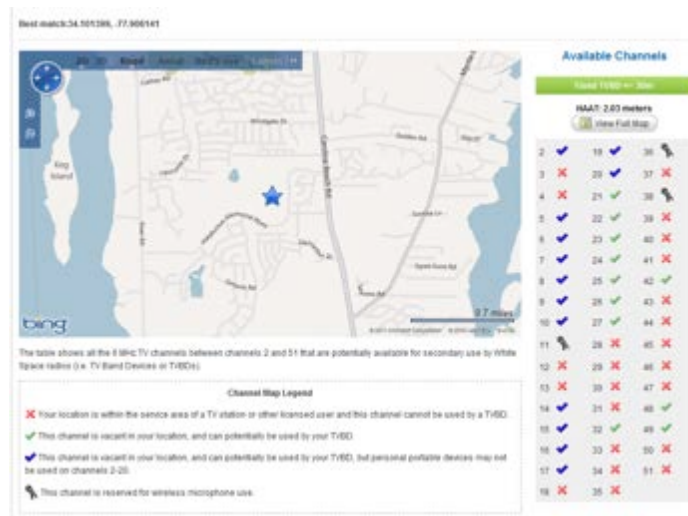


Figure 16: Veterans Park Channels (source: Bing, 2013)

### **Other Locations – DOT Traffic IP Camera**

Located away the Youth Enrichment Zone, this installation is currently linked to the hub located at EUE/Screen Gems. An IP Camera is a type of digital video camera commonly used for surveillance, and which unlike analog CCT cameras can send/receive data using a computer network and the Internet. The County wanted to relocate the hub to provide a direct connection to the City of Wilmington’s Police Headquarters Building improving connectivity to users. The current hub location and proposed hub location are show in Figure 17.



**Figure 17: DOT Traffic IP Camera**

### **Other Locations – Screen Gems**

Before the Youth Enrichment Zone, the following networks were also deployed to test various conditions. Water quality monitoring at Page’s Creek was deployed to monitor the amount of water pollution in real time without having to send a boat to sensor. Water level monitoring at the Screen Gems collection pond was deployed to monitor the water level in real-time. Traffic monitoring at the MLK hurricane evacuation route was deployed to see if video could be used efficiently in hard to reach areas. Figure 18 shows the network around Screen Gems Studios.



Figure 18: DOT Traffic Camera, Water Station/Sensor, & Screen Gems Building 8 (source: Google, 2013)

Public Internet transmits to the Senior Center Hub and concessions stand public Wi-Fi access. There's a firewall between the public Internet and router/gateway that is received by an operations laptop. There's also a firewall between public Internet and the NHC Government Network. This network transmits a signal to the Maintenance Facility Hub and the park pavilion camera. The MLK site deployment was done with prototype non-FCC certified radios before the FCC voted to allow white spaces communications. As of 2013, all site locations listed are currently working [4]. There are plans to update these sites with a new generation of radios in late 2013. Figure 19 shows how the Building 8 Hub at Screen Gems feeds the other three locations including: DOT Traffic Camera, Water level Sensor, and Wastewater Pump Station. The Screen Gems hub sends a signal to access point spokes.

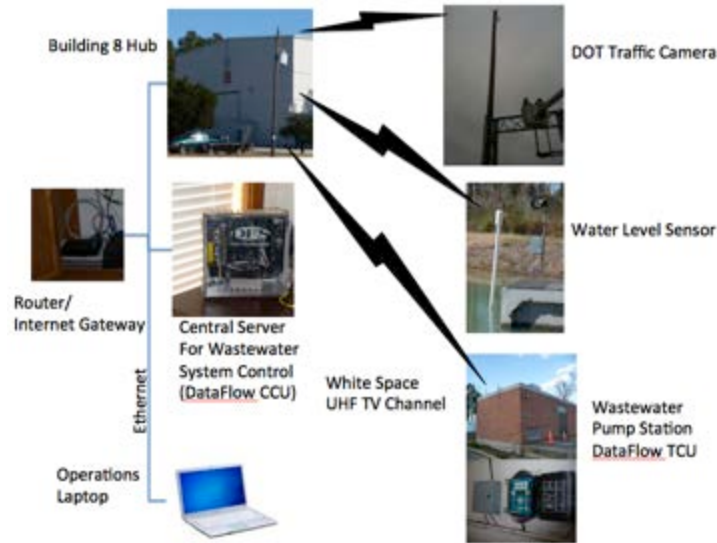


Figure 19: Other Location Topology (source: TVBS, 2013)

TVBS had tested various white spaces radios including Adaptrum, KTS, and many others. Initially, TVBS determined it didn't want to be in the equipment testing business, but in the network delivery business [45]. Therefore, they used only radios from KTS and 6Harmonics for now. They only use Spectrum Bridge's database with a focus on investigating real-world networks that have a value proposition for communities. Since there's no white space "chips" at this time, all networks have to be created by integrating prototype white spaces radios with existing connectivity protocols, which means using either Wi-Fi or direct Ethernet connections. Many video cameras are used and include either a direct connection to a white spaces radio or a connection to a Wi-Fi router. The wireless access point is directly connected to a white spaces radio. A white spaces router can connect to virtually any Wi-Fi router and TVBS has used many. NHC uses standard Cisco and other network switches to connect to a white spaces radio via hardware Ethernet connection.

In consumer broadband applications, all devices have Wi-Fi chips. By

connecting a white spaces radio to a Wi-Fi router, the consumer is able to access the Internet from a previously unreachable location [62]. This wouldn't be physically or economically feasible without the use of white spaces. For example, when attaching a white spaces radio to a NHC Internet point of presence (POP)\*, the POP is usually directly connected to the Internet backhaul. From there, one can attach a white spaces radio to a Wi-Fi router a mile away. A user can access the Internet through this Wi-Fi router [31]. Previously, you would need to lay a cable down or have a microwave system in order to provide connectivity.

### C. YOUTH ENRICHMENT ZONE

The Youth Enrichment Zone (YEZ) is a project modeled after the Harlem Children's Zone. The Harlem Children's Zone (HCZ) is a non-profit organization for poverty-stricken children and families living in Harlem, providing free support for the children and families in the form of parenting workshops, a pre-school program, three public charter schools, and child-oriented health programs for thousands of children and families [2]. The goal in NHC is to create a low-cost wireless infrastructure providing connectivity to 95 economically challenged 6<sup>th</sup> grade students who attend DC Virgo Middle School and live in an area entitled The Youth Enrichment Zone [4]. This initiative is enabled through the following government entities and private companies: TV Band Service, New Hanover County, New Hanover County Schools, City of Wilmington, and the Blue Ribbon Commission on the Prevention of Youth Violence. The new technology intends to provide a cost-effective means to solve the ever-growing

digital divide on a local level and has the potential to serve as a model for future expansion on a global level.

In May 2011, The New Hanover County Board of Education voted to shut down DC Virgo Middle School due to low school attendance and perpetual budget cuts. During the 2010-2011 school year, Virgo's attendance dropped to 180 students in a facility that could hold 400 students [4]. During this time, a group of community leaders began work on the Blue Ribbon Commission\* on the Prevention of Youth Violence. This group conceptualized a cohesive set of multi-disciplinary initiatives to target the most at-risk youth in New Hanover County [2]. The commission established a geographic area near DC Virgo School as the Youth Enrichment Zone. All programs would be developed specifically for the youth in this area. Figure 20 illustrates the boundaries of the YEZ, which include: Market Street, 4<sup>th</sup> Street, Nixon Street, McRae Street, and 14<sup>th</sup> Street [63].



## Youth Enrichment Zone

The boundaries of the Youth Enrichment Zone include: Market Street, 4th Street, Nixon Street, McRae Street, Rankin Street and 14th Street.

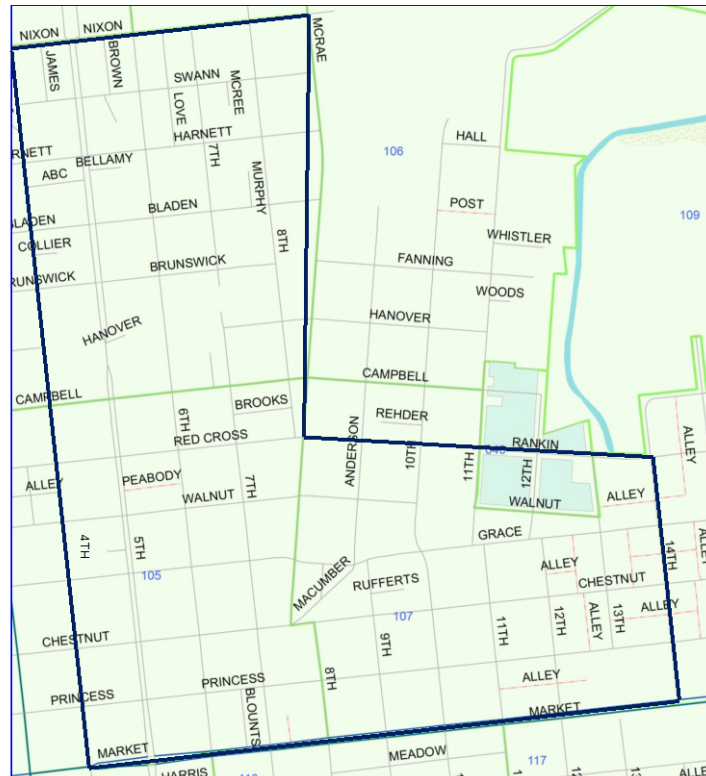


Figure 20: Youth Enrichment Zone Map (source: NHC, 2012)

While the New Hanover County School Board contemplated plans on how to reopen DC Virgo School, a partnership emerged between the Board and the Commission. Both parties determined DC Virgo would reopen in fall of 2012 with a focus on providing unique educational opportunities through the use of technology and programs. These programs were designed to engage parents with their students. They planned to open Virgo to approximately 95 sixth graders in the first year and additional students in subsequent years. Each student would be given a tablet computer and technology will be

integrated into every area of the curriculum. The students work in a connected environment with ready wireless access while at school. The problem is most of these students have no Internet connectivity at home. To address this problem, they decided to create a wireless ecosystem utilizing white spaces to serve those students [2].

The partners involved with this project wanted to create a wireless ecosystem in the Youth Enrichment Zone to support students and families targeted by the Commission's mission. Also, content delivery using TV Band Datacasting (TVBD)\* was tested in Summer 2012 for a possible implementation in to the YEZ initiative. The wireless ecosystem was planned to be a heterogeneous network consisting of Wi-Fi for direct student device connections supported by white spaces technology for backhaul. TV Band Datacasting\* would supplement the network for large data file deliveries and assured content reception for off-line use [36]. The County provides the Internet bandwidth necessary for the project and the City of Wilmington provides the physical locations for the devices. TVBS supplies the television bandwidth for TVBD. Wilmington, NHC, and the Commission partner to insure the technology is supported and maintained.

In Fall 2012, the DC Virgo Preparatory Academy reopened with only 6<sup>th</sup> grade students [4]. The students were given iPads to use both at school and home. They can connect to the County's public wireless at any of the locations served by the white spaces network. Before receiving their iPads, the students and their parents must sign a Student/Parent User Agreement. This form outlines the policies, procedures, and informational guide associated with the iPad Program. Students turn in their iPad and all accessories on a daily basis to their homeroom teacher for charging and syncing. Loaner iPads are issued to students when they leave them for repair in the Media Center. The

New Hanover County School District makes no guarantee that the network will be up and running 100% of the time. In the rare case that the network is down, the District is not responsible for lost or missing data. All school issued iPads are only synced with designated school laptops located on campus. The iPads for this program carry a one-year basic AppleCare protection on them. Damage to an iPad is assessed on an individual basis [2].

The Blue Ribbon Commission has been working to get wireless throughout the inside of the school building. They will continue to install additional hotspots around the Youth Enrichment Zone [2]. After reopening in 2012, the Blue Ribbon Commission relocated its office to DC Virgo Preparatory Academy, shown in Figure 21. This office serves all children and families within the boundaries of the Youth Enrichment Zone. All Blue Ribbon Commission Leadership, Technical Advisory Board and Action Team meetings are held at this office. Youth Enrichment Zone and DC Virgo families use this office as a bridge to resources. Individuals are referred to a number of organizations, programs, and services to assist them. The following are photos of the BRC front office space at DC Virgo and the adjoining meeting room.



Figure 21: BRC Office at D.C. Virgo School (source: BRC, 2013)

Figure 22 illustrates student addresses inside of the Youth Enrichment Zone. Each colored circle on the map represents the number of students per address. The three black triangles (WS Radios) on the map represent the Wilmington Police Department, Hemenway Center, and the Cape Fear Museum, shown in Figure 23. The MLK Center is outside the boundaries of this map [64].

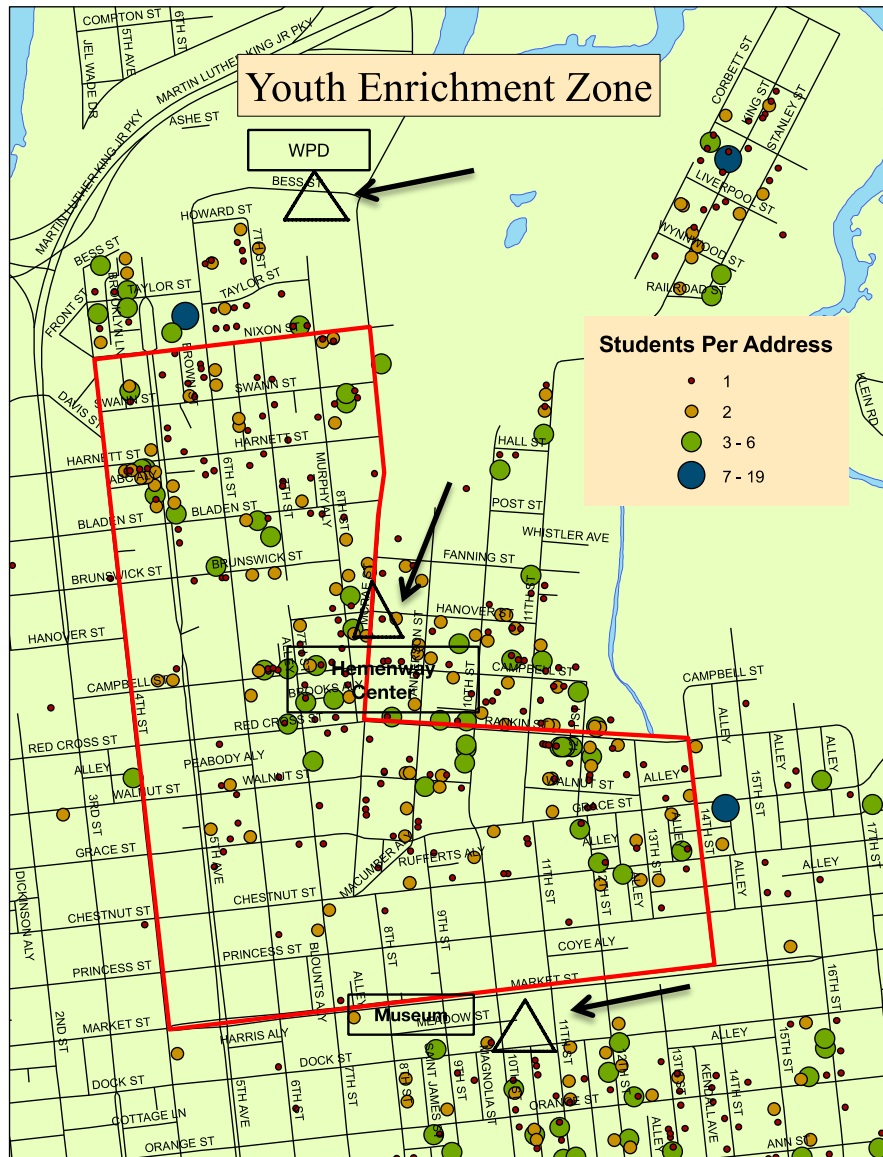


Figure 22: Youth Enrichment Zone Radio Map (source: NHC, 2012)



**Figure 23: Cape Fear Museum Roof (source: William Edwards, 2012)**

Additional deployments are planned for purposes beyond this project. Access points were attached to private businesses that volunteered to have their buildings used as hubs. Most of these locations participated, which only helps the city share these resources. Some of these locations include: 320 Chestnut Street, FBC, Chestnut St. Presbyterian, Grace United, St. Stephens, Central BC, Community Health Center, Ronnie’s Crab Shack, Mt. Zion, Mt, Calvary, Miracle Rest, Community B&G Club, Dorothy Johnson, Temple Rock, The Cross Ministry, NHHS, Dreams, and Worner Temple. More access points will be added as Wilmington expands the project. Increasing the number of access points

makes the network stronger [34].

Figure 24 illustrates the basic layout of the Youth Enrichment Zone. It displays how each site is connected to another. Both TVBS and Leslie Chaney, IT director of New Hanover County, helped formulate this figure [4].

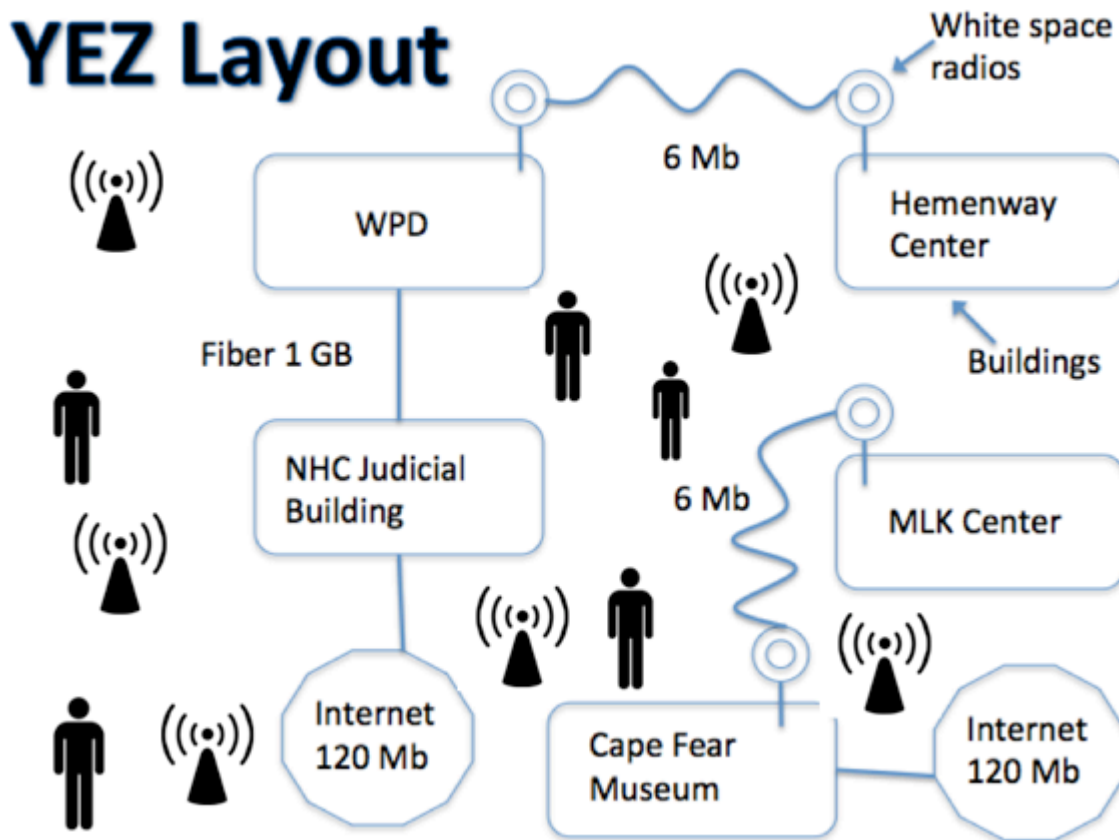


Figure 24: Youth Enrichment Zone Topology (source: NHC, 2012)

The Cape Fear Museum receives 120 Mbps of Internet from AT&T paid for by NHC. It transmits the signal to the MLK Center using white spaces antennas [4], shown in Figure 25.



Figure 25: Cape Fear Museum Roof Antenna (source: William Edwards, 2012)

A WAP access point was installed in the MLK Center to provide 802.11 N wireless to the building and surrounding area. The NHC Judicial Building receives 120 Mbps of Internet from AT&T [4]. A hardline fiber connects the NHC Judicial Building with the Wilmington Police Department, which transmits 1 GB between each building. An antenna installed on the WPD roof, shown in Figure 26, sends a signal to the Hemenway Center antenna.



Figure 26: Wilmington PD (source: William Edwards, 2012)

Each white spaces radio and antenna transmits 6 Mbps to receiving buildings. Another WAP access point is installed inside of the building that supplies 802.11 N wireless to that area [4], shown in Figure 27.



**Figure 27: Hemenway Center (source: William Edwards, 2012)**

Future plans include Lake Grove and Portia Hine Park, each receiving signals from the WPD antenna. Currently, the Wilmington Fire Department receives 12 Mbps Internet from AT&T with 802.11 Wi-Fi [4]. The plan is to add another antenna on the Fire Department roof that also broadcasts to a nearby park. The benefits include: no line of site required, it's cheaper, and it propagates better [59]. The equipment was developed by 6 Harmonics, the installations are conducted by TVBS, SBI runs the database and controls the system, and New Hanover County orchestrated the plan. The access points are all Cisco routers attached to the ceilings inside of the building. There are roughly 50 access points in different buildings across New Hanover County. Two access points are installed in the Hemenway Center and MLK Center as part of the Youth Enrichment Zone project. United States spectrum availability is displayed in Figure 28.



Figure 28: United States Spectrum Availability (source: Google, 2012)

## IV. Analysis/Recommendations

As of June 2013, all sites affiliated with the Youth Enrichment Zone are live, and TVBS reported that the network is running smoothly [38]. Recent firmware upgrades that were installed in some of the KTS radios have vastly improved the reliability to a link that was experiencing intermittent connection issues. There are plans to replace the 6Harmonics prototype radios with production versions later this summer. New Hanover County and the City of Wilmington have announced that they are pleased with the white space deployments [4]. The projects have allowed them to provide Wi-Fi and/or video surveillance to previously unreachable areas at a reasonable cost. The County pays several thousand dollars per month for its 120 Mbps Internet connection [4]. This Internet expense is not a new cost, but was underutilized before the introduction of white spaces. For New Hanover County, the only new cost will be for the prototype radios from 6Harmonics at about \$2,500 each. The county has not paid for these radios yet, since they are still considered experimental and have not been FCC certified [4].

According to TVBS, New Hanover County is ready to start planning an expansion with additional sites. As radios and funding becomes available, additional sites will be added to the network. There are plans to incorporate two more parks inside the zone in late 2013. As of July 2013, all networks are running. Some of the KTS radios had firmware upgrades and others were updated. The 6Harmonics prototype radios will probably be replaced with commercial radios later in 2013. TVBS is considering replacing all existing radios with new Redline radios. In an interview, TVBS stated they

believe the new Redline Radio is the best technically performing radio available, but the price is prohibitive [42]. If the price were reduced by 90%, the value proposition would emerge for many other applications because the performance is so good [39]. The only real issues during the project were some prolonged delays and some minor equipment malfunctions. Some of the early prototypes developed by 6Harmonics had to be completely uninstalled and replaced with newer radios. New Hanover County citizens are currently using the white spaces network. People can openly access the white spaces network without entering a password. This was a policy decision made by New Hanover County that could change at any time. The cameras have do have security features that prevent tampering with security surveillance.

Beginning in July 2012, live Internet access at the Hemenway Center and the MLK Center has been recorded. Currently, the equipment at these two access points is maintained by TVBS. The following data has been tracked for one year between June 2012-June 2013. Figure 29 the average transmit, peak transmit, average receive, and peak receive for the Hemenway Center [7].

Average and Peak Traffic Rates- Hemenway				
Date	Average Transmit (bps)	Peak Transmit (bps)	Average Receive (bps)	Peak Receive (bps)
July 2012	0.000	0.000	0.000	0.000
August 2012	0.000	0.000	0.000	0.000
September 2012	0.000	0.000	0.000	0.000
October 2012	42.360	2608.000	23.420	1733.000
November 2012	0.000	0.000	0.000	0.000
December 2012	0.000	0.000	0.000	0.000
January 2013	149.130	16684.000	67.590	8579.000
February 2013	7.590	2454.000	1.690	227.950
March 2013	115.780	32403.000	23.130	3566.000
April 2013	660.300	15162.000	131.550	2336.000
May 2013	0.000	0.000	0.000	0.000
June 2013	9.320	973.380	29.690	11945.000

Figure 29: Hemenway Average & Peak Traffic Rates (source: NHC, 2013)

The Hemenway Center was one of the later installations deployed. It didn't go live until late December, which is reflected in the numbers above. It hit its highest peak in early April 2013, but dropped back down in May 2013. This could be attributed to the school closing in late May for summer break. NHC states that the site was available in May, but they think nobody was using it. Trends for the Hemenway Center are illustrated in Figure 30.

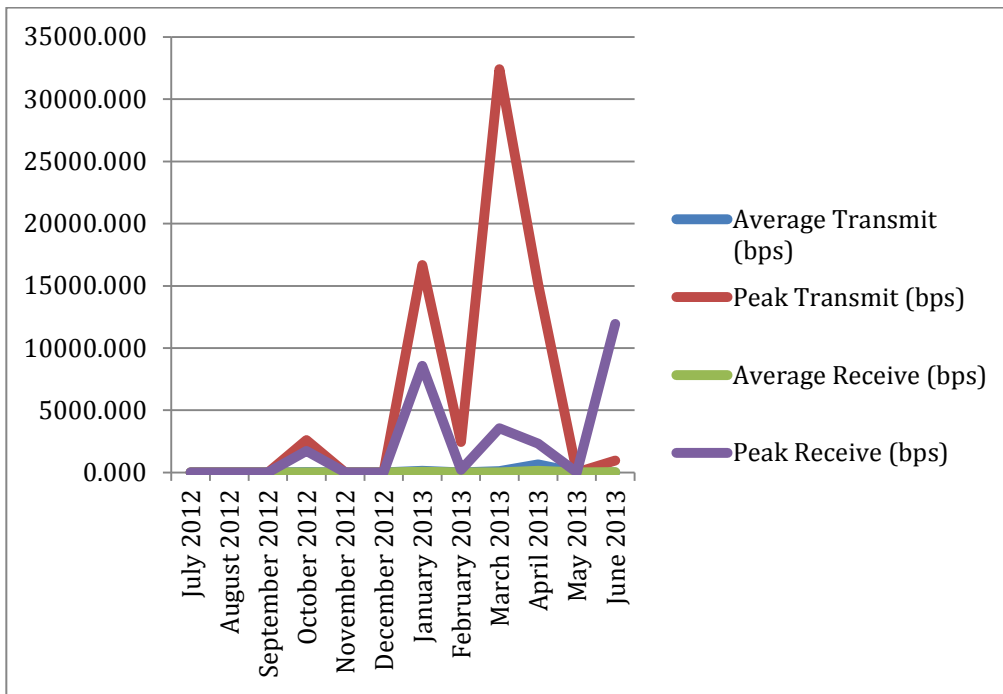


Figure 30: Hemenway Graph (source: NHC, 2013)

Average and Peak Traffic Rates-MLK				
Date	Average Transmit (bps)	Peak Transmit (bps)	Average Receive (bps)	Peak Receive (bps)
July 2012	59.950	1257.000	20.610	318.780
August 2012	465.320	31511.000	57.830	6452.000
September 2012	1.033	140668.000	104.460	8525.000
October 2012	244.480	17882.000	72.050	3933.000
November 2012	487.420	17433.000	81.500	1507.000
December 2012	663.430	48181.000	109.350	14219.000
January 2013	1572.000	96529.000	214.230	8804.000
February 2013	3682.000	361919.000	554.110	106022.000
March 2013	5001.000	199162.000	1108.000	322015.000
April 2013	3390.000	181182.000	1324.000	148135.000
May 2013	4561.000	392536.000	223.850	26073.000
June 2013	6496.000	317343.000	329.420	23425.000

Figure 31: MLK Average & Peak Traffic Rates (source: NHC, 2013)

In Figure 31, traffic rates from the MLK Center show definite signs of increased usage. The rise looks like people are beginning to find the signals in early 2013, shown in Figure 32. This report predicts that user trends will continue to increase as more people discover these connections. The MLK Center is not affected by the school schedule. It's located further away from the YEZ than any other site. The Hemenway Center has less foot-traffic than the other sites. It's more out-of-the-way, which probably led to a more gradual traffic increase.

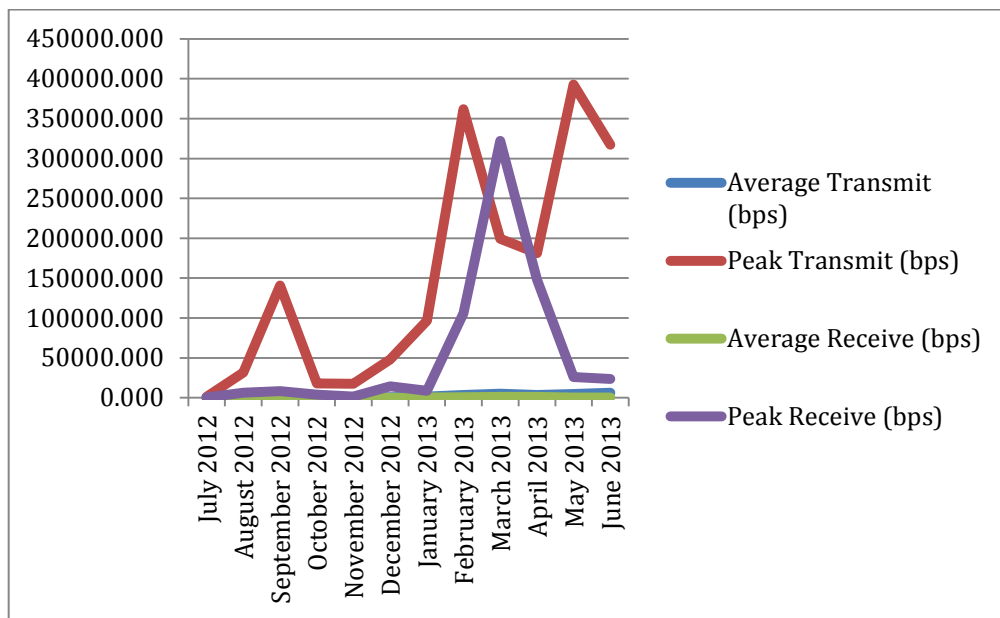


Figure 32: MLK Graph (source: NHC, 2013)

Total Bytes Transferred-Hemenway			
Date	Total Bytes Transmitted (MB)	Total Bytes Received (MB)	Total Rx + Tx (MB)
July 2012	0	0	0
August 2012	0	0	0
September 2012	0	0	0
October 2012	20.8	66.5	31.3
November 2012	0	0	0
December 2012	0	0	0
January 2013	97.1	36.4	133.5
February 2013	17.5	3.9	21.4
March 2013	295.8	59.1	354.9
April 2013	840.2	165.8	1006
May 2013	0	0	0
June 2013	2.6	8.2	10.8

Figure 33: Hemenway Total Bytes Transferred (source: NHC, 2013)

The total bytes transferred report from the Hemenway Center location appears random, shown in Figure 33. This report doesn't detect any accurately illustrated or useful trends. This report predicts Hemenway Center is the least used site on this project, shown in Figure 34. New Hanover County only provided the traffic reports for two locations, Hemenway Center and MLK Center.

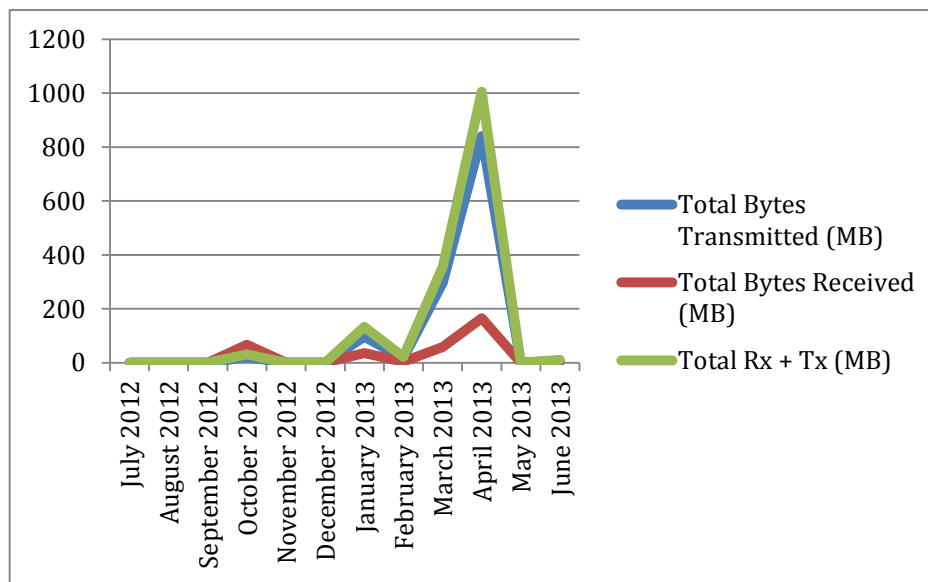


Figure 34: Hemenway Byte Graph (source: NHC, 2013)

Total Bytes Transferred-MLK			
Date	Total Bytes Transmitted (MB)	Total Bytes Received (MB)	Total Rx + Tx (MB)
July 2012	7.1	2.6	9.7
August 2012	363.4	47.4	410.8
September 2012	1433.6	142.1	1536
October 2012	196.7	66.5	263.3
November 2012	143.8	17.6	161.3
December 2012	1433.6	228.5	1638.4
January 2013	3481.6	477.5	3993.6
February 2013	8192	1228.8	9420.8
March 2013	12595.2	2764.8	15360
April 2013	8192	3072	11264
May 2013	3788.8	213.6	3993.6
June 2013	3891.2	196	4096

Figure 35: MLK Total Bytes Transferred (source: NHC, 2013)

Based on Figure 35, this report assumes the MLK Center more closely represents all other sites in this project. Both the MLK & Hemenway Centers are located furthest away from downtown Wilmington. This report predicts the Cape Fear Museum, Wilmington PD, and surrounding parks display an increased user trend, shown in Figure 36. These sites have a higher likelihood of people walking by with their wireless device in hand. The network administrator of Information Technology in New Hanover County, Craig Marshburn, confirms these predictions [7].

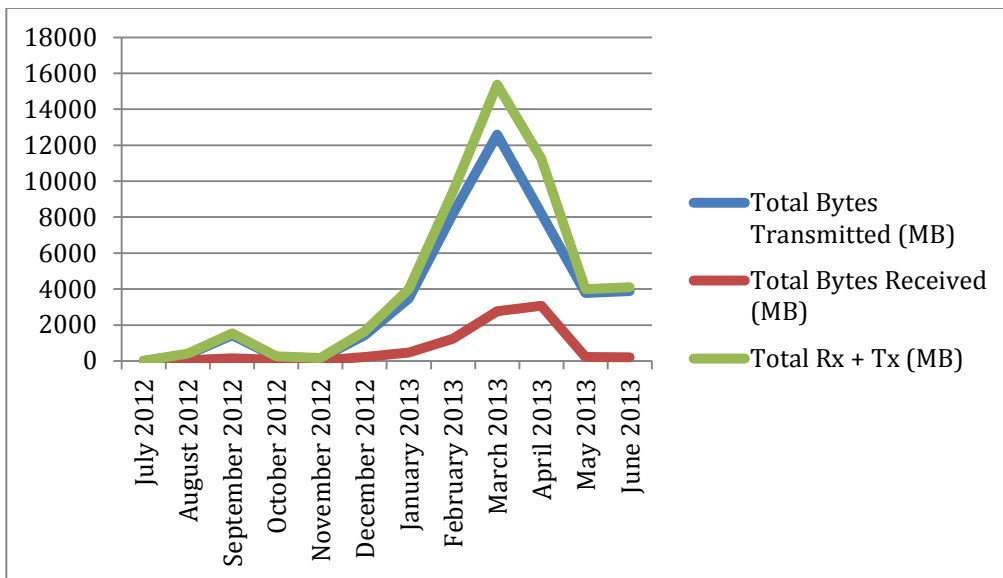
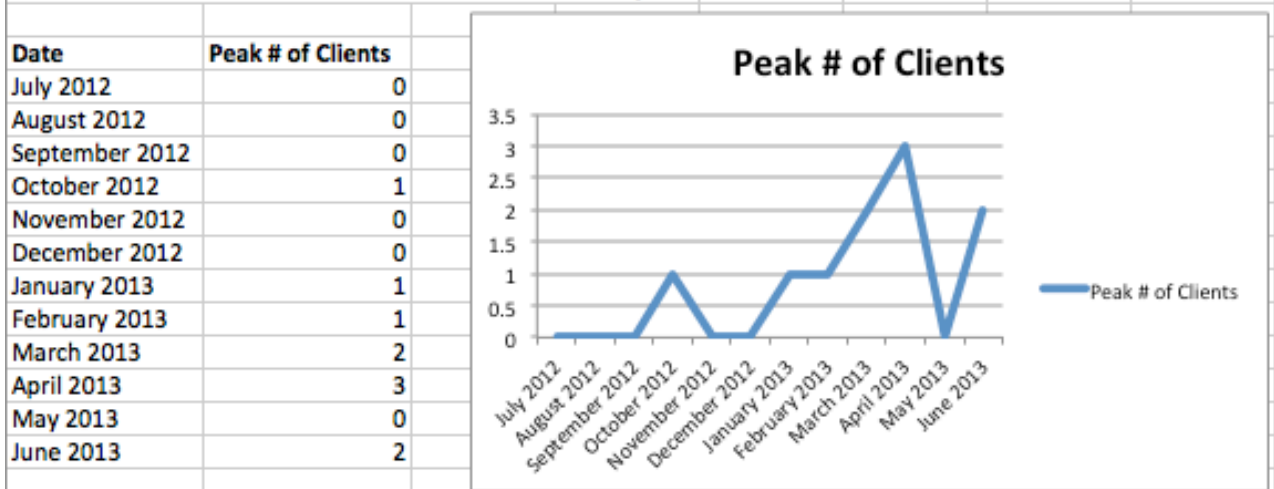


Figure 36: MLK Byte Graph (source: NHC, 2013)

### Peak Number of Clients-Hemenway



### Peak Number of Clients-MLK

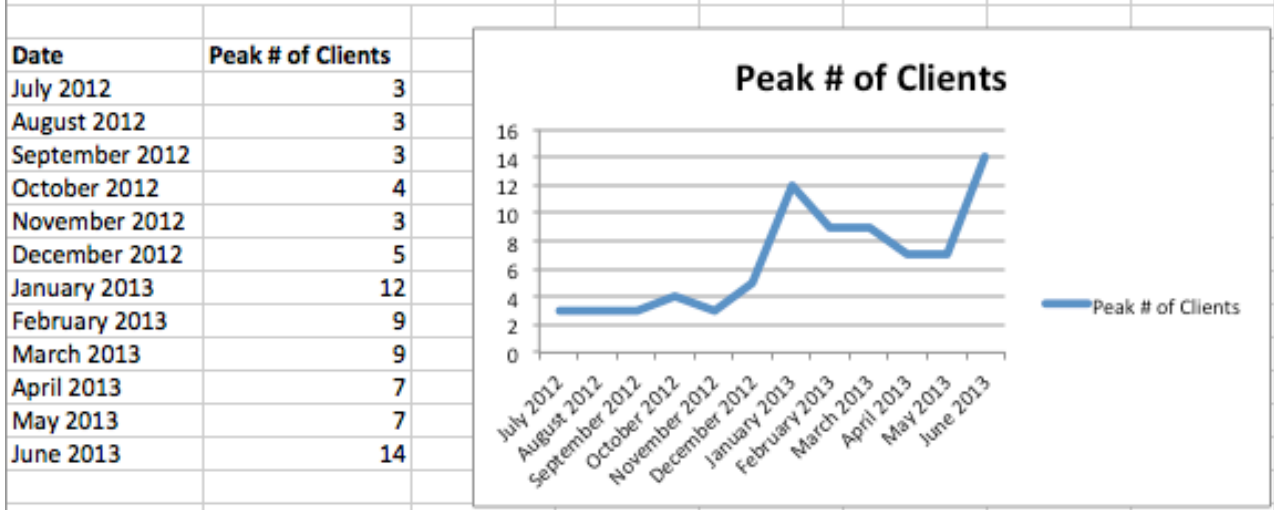


Figure 37: Peak Number of Clients (source: NHC, 2013)

Although these numbers appear small, the percentages are extremely positive. Most recently, the peak number of clients at the MLK Center doubled in only a month from May to June 2013. If the number clients continue at this current rate, the volume of users will be considerable in a short amount of time. One can clearly observe an upward trend from Figure 37.

## A. SUCCESS RATING

According to New Hanover County, the project was successful and they will continue to expand this model beyond downtown, Wilmington. D.C. Virgo School has another opinion on the white spaces Internet capabilities. In an interview, the principal and Executive Director of BRC stated that D.C. Virgo students couldn't connect to the Internet from home. No communication from New Hanover County has indicated a loss in Internet availability [4]. Although, data traffic reports provided by a NHC systems administrator do present a surprising low client volume from those locations. One of those locations being the Hemenway Center located near D.C. Virgo School. It's known that New Hanover County continues to work and will continue to work on these networks for many years. They have a long-term plan for properly utilizing white spaces in the NHC community. It's important to remember Wilmington, NC is the first city to work with white spaces in this way. It's not running perfectly as of mid-2013, but this report give it an adequate success rating for the 1-year timeframe covered in this project. It will most likely take a couple more years for the network to operate at its fullest potential.

## B. SWOT ANALYSIS

The following is an overview of TV White Spaces SWOT analysis from a consumer point-of-view:

A major strength of white spaces is the ability to work in conjunction with other technologies like Wi-Fi. In the New Hanover County project, this practice was used to create a wireless mesh network that propagates signals from base stations to neighboring access points. Long-range TV white spaces signal propagation requires fewer base stations, which yield less expensive networks. White spaces have high coverage, strong obstacle penetration, low power consumption, and continues to rapidly grow as a technology. It can also be used for certain applications more cheaply than licensed spectrum [23].

A major weakness of white spaces is its slow technical development due to regulatory uncertainty. As of 2013, the future of white spaces is very unclear. Events within the next couple years, especially the 2014 Spectrum Auction, could radically change how white spaces are used and managed. In the New Hanover County project, network signal strength currently seems both inconsistent and unreliable according to multiple sources. This network needs more time to operate at its full potential and additional testing is needed [12].

White spaces could play a significant role in closing the digital divide gap. This opportunity provides the potential for a global market boom similar to Wi-Fi's emergence. If it remains unlicensed, white spaces could build an interconnected network of all enabled objects. This could reduce the cost of connectivity and make available

many new network applications, such as: farming, surveillance, and environmental monitoring [10].

The single largest threat to white spaces is unpredictable regulations. There is uncertainty on how much TV white spaces will be available in the future due to the upcoming 600 MHz auction by the FCC in 2014. All of the large telecoms want the TV spectrum to be licensed under their control. In addition, many states have passed laws that prevent governments from getting into the broadband business. Large corporations are apprehensive about putting much money into white spaces until the 600 MHz auction is over and the amount of TV white spaces is known. The lesser amount of TV white spaces available, the fewer investments will be made by these large corporations [12].

### C. RECOMMENDATIONS

The following are recommendations for potential white spaces consumers formulated using knowledge and experience gained from the New Hanover County projects:

Be particular about commitments to TV white spaces at this time; current regulatory uncertainty impedes technological investment and progression. It is recommended to wait until after the FCC 600 MHz TV spectrum auction in 2014. The outcome of this event is too unpredictable to risk at this time. The FCC could also auction the entire available spectrum and leave nothing for TV white spaces. If the FCC designates a contiguous lineup of unlicensed TV white spaces frequencies or not, then it's

possible TV white spaces frequencies will be available on a market basis. There should still be areas with a lot of unused TV spectrum, especially rural areas.

Efficient consumer rural broadband is still a ways off, it is recommended waiting for technological developments in this market. Considering the \$2,000 approximate cost of an FCC approved broadband performance radio, TV white spaces radio doesn't deliver a value proposition for individual consumers. This would also include the costs of a Wi-Fi router, cabling, backhaul, and business overhead expenses. Until investment is made to drive down costs through scale, it is recommended consumers stay away from this market. Even then, the limited capacity of 8 Mbps over a 6 MHz TV channel doesn't make a robust connection [19]. Capacity will always be an issue, but technology can improve it. The New Hanover County project's main focus is technology efficiency and feasibility with less concern on financial practicality. Also, it covers an urban community with a cluster of users, rather than a more spread-out group in a rural area.

A more efficient and immediate use of federal spectrum could be achieved through spectrum sharing. As of 2013, the technologies used for spectrum sharing are relatively new and still developing. Testing of this concept is currently happening in various applications. For example, the military might have radio spectrum it uses for communicating at a bombing test range. When that test range is not in use, a smartphone would be able to pluck a signal from that spectrum. Sharing between federal users and commercial users could increase capacity by thousands.

Possible future white spaces applications may include the introduction of '5G' next generation data services [36]. There's a growing demand for more data and faster data services throughout the world. Some companies anticipate the technology could

arrive by 2014. Until then, the interoperation of white spaces devices needs to be fully tested. It is recommended they examine how the databases and processes mitigate against creating harmful interference to current spectrum users. Interference is one primary concern involving white spaces with multiple base stations and access points, like the Youth Enrichment Zone mesh wireless network used in this project.

## V. Outlook/Conclusion

This report has discussed the motivation and importance of white spaces. The aim of this project was to investigate network architecture for deploying white spaces networking technology, as it has been deployed in a specific metropolitan geographic area, namely New Hanover County, North Carolina. This project tested the value of white spaces at a local level. The new technology was determined a potential efficient means to solve the ever-growing digital divide. This report analyzed and compared three different technologies with similar functions. As of 2013, determining a clear winner would not be prudent. These technologies can be utilized together in combinations to facilitate new functions and opportunities. For example, the New Hanover County project used both white spaces and Wi-Fi to create a wireless mesh network.

This project followed the early activities and installations of NHC's white spaces deployment. This report studied the YEZ to discover if this small-scale model could be applied globally. It proved an adequate success for the time followed, but needs additional testing and improvements before future expansion. An interview conducted with the Director of the Blue Ribbon Commission provided a contrary stance on the current status of white spaces not previously indicated by New Hanover County. This interview stated the white spaces near D.C. Virgo School were not consistently functioning or reliable. This report formulated a SWOT analysis highlighting the strongest and weakest aspects of white spaces. Recommendations were generated using the knowledge, feedback, and experience gained throughout the course of this project.

If this project continued for another couple of years, the pace would definitely not slow down. Although this was an emerging technology when this project started back in early 2012, the avalanche of new information that comes in daily remains unyielding. Future work would involve covering the 2014 spectrum auctions and observing how that scenario plays out. Other future work would involve investigating why D.C. Virgo students are having difficulty connecting to the Internet from home. It could be a temporary problem with the system, but this information didn't arise until after the project was completed. Lastly, this project would attempt to solve how to practically and economically deploy a white spaces network in a location like extremely rural location like Africa. Talks with TVBS have suggested Africa is the next chapter in the book of white spaces. This information is highly compelling and holds the potential to change the world.

Many lessons were learned over the past year working on this project. Working with a team of highly skilled professionals in this particular study was a unique opportunity. This project involved hands-on experience working in the field and observing a citywide project from its inception was a satisfying journey. Of course, there were ups and downs along the way. There were moments when the finish line seemed miles away. This project and report were only completed thanks to the unending support of those involved. It was shocking how many people were willing to offer assistance, for little in return. White spaces hold a strong possibility of serving as the catalyst for a worldwide technological revolution. It's been a privilege witnessing the dawn of this technology at its premiere location.

## VI. References

- [1] Anderson, N. 2008. *White spaces, angry faces: Inside the battle over 'interference'*. [online] Available at: <http://arstechnica.com/features/2008/09/white-spaces-battle/> [Accessed: May 2012].
- [2] Brcyez.org. 2013. *United Way - Blue Ribbon Commission | Prevention of Youth Violence*. [online] Available at: <http://www.brcyez.org/> [Accessed: January 2013].
- [3] Brodtkin, J. 2013. *Google offers searchable map of all white space spectrum in the US*. [online] Available at: <http://arstechnica.com/information-technology/2013/03/google-offers-searchable-map-of-all-white-space-spectrum-in-the-us/> [Accessed: April 2013].
- [4] Chaney, L. (2012, May 14). Email interview.
- [5] CNET. 2013. *Google tests 'white space' database for FCC certification*. [online] Available at: [http://news.cnet.com/8301-1035\\_3-57572394-94/google-tests-white-space-database-for-fcc-certification/](http://news.cnet.com/8301-1035_3-57572394-94/google-tests-white-space-database-for-fcc-certification/) [Accessed: March 2013].
- [6] Connectedworldmag.com. n.d.. *Connected World Mag*. [online] Available at: [http://connectedworldmag.com/10\\_2\\_magazinearticle.aspx?id=MAZ0120327101251680](http://connectedworldmag.com/10_2_magazinearticle.aspx?id=MAZ0120327101251680) [Accessed: May 2013].
- [7] Craig Marshburn (personal communication, March 8, 2013)
- [8] Dailywireless.org. 2013. *dailywireless.org » California Gold Country Gets White Space*. [online] Available at: <http://www.dailywireless.org/2013/04/23/california-gold-country-gets-white-space> [Accessed: May 2013].
- [9] Dailywireless.org. 2013. *dailywireless.org » FCC Supports National White Space Networking*. [online] Available at: <http://www.dailywireless.org/2013/02/04/fcc-supports-national-white-space-networking/> [Accessed: February 2013].
- [10] Digital Divide. 2012. *Stanford.edu*. [online] Available at: <http://www-cs-faculty.stanford.edu/~eroberts/cs201/projects/digital-divide/start.html> [Accessed: March 2013]
- [11] K. Fazel and S. Kaiser, *Multi-Carrier and Spread Spectrum Systems: From OFDM and MC-CDMA to LTE and WiMAX*, 2nd Edition, John Wiley & Sons, 2008, ISBN 978-0-470-99821-2 [Accessed: August 2012]
- [12] FierceWireless. 2013. *600 MHz broadcast TV spectrum - Spectrum auction guide*. [online] Available at: <http://www.fiercewireless.com/special->

reports/600-mhz-broadcast-tv-spectrum-spectrum-auction-guide [Accessed: April 2013].

- [13] Fitchard, K. 2013. *Neul releases the first white space chip for the internet of things*. [online] Available at: [HTTP://GIGAOM.COM/2013/02/12/NEUL-RELEASES-THE-FIRST-WHITE-SPACE-CHIP-FOR-THE-INTERNET-OF-THINGS/](http://GIGAOM.COM/2013/02/12/NEUL-RELEASES-THE-FIRST-WHITE-SPACE-CHIP-FOR-THE-INTERNET-OF-THINGS/) [Accessed: March 2013].
- [14] FreeWiMAXInfo.com. 2012. “*What is WiMAX Technology (IEEE 802.16)?*” [online] Available at: <http://freewimaxinfo.com/> [Accessed: October 2012]
- [15] Google.org. 2013. *Spectrum Database – Google*. [online] Available at: <http://www.google.org/spectrum/whitespace/channel/> [Accessed: 21 Jul 2013].
- [16] Grotticelli, M. 2013. *White space data for operating unlicensed devices now available Towers/Antenna content from Broadcast Engineering*. [online] Available at: <http://broadcastengineering.com/towersantenna/white-space-data-operating-unlicensed-devices-now-available> [Accessed: March 2013].
- [17] Gustin, S. 2013. *Free Federal Wireless Broadband For All Americans? Fuggedaboutit! TIME.com*. [online] Available at: <http://business.time.com/2013/02/06/free-federal-wireless-broadband-for-all-americans-fuggedaboutit/> [Accessed: February 2013].
- [18] Brain, Marshall. M. 2013. *How WiFi Works*. HowStuffWorks.com. [online] Available at: <http://www.howstuffworks.com/wireless-network.htm> [Accessed: March 2013]
- [19] Ieee802.org. *IEEE 802.22 WRAN WG Website*. [online] Available at: <http://www.ieee802.org/22> [Accessed: June 2012].
- [20] Deyo, Anthony. iPoint. *Wireless Networking (Wi-Fi) – Advantages and Disadvantages to Wireless Networking*. iPoint-tech.com. [online] Available at: <http://ipoint-tech.com/wireless-networking-wi-fi-advantages-and-disadvantages-to-wireless-networking/> [Accessed: May 2013]
- [21] Information-age.com. 2013. *Putting white space to work | Information Age*. [online] Available at: <http://www.information-age.com/technology/mobile-and-networking/123456877/putting-white-space-to-work> [Accessed: February 2013].
- [22] Interdubs.com. *TV Band Service LLC*. [online] Available at: <http://www.interdubs.com/r/euescreengems/?al=WyxEEf> [Accessed: January 2013].

- [23] Kim, R. 2010. *All You Need to Know About White Spaces Broadband*. [online] Available at: <http://gigaom.com/2010/09/22/all-you-need-to-know-about-white-spaces-broadband/> [Accessed: July 2012].
- [24] Kjonline.com. 2013. *High-tech buoy to blast Great Pond data worldwide | The Kennebec Journal, Augusta, ME*. [online] Available at: <http://www.kjonline.com/news/High-tech-bouy-to-blast-Great-Pond-data-worldwide.html> [Accessed: March 2013].
- [25] Kurz, P. 2013. *FCC gives nod to nationwide TV white-space database operation | Regulation content from Broadcast Engineering*. [online] Available at: <http://broadcastengineering.com/regulation/fcc-gives-nod-nationwide-tv-white-space-database-operation> [Accessed: March 2013].
- [26] Lasar, M. 2011. *FCC green lights first white space broadband device*. [online] Available at: <http://arstechnica.com/tech-policy/2011/12/fcc-green-lights-first-white-space-device/> [Accessed: May 2012].
- [27] Leslie Chaney (personal communication, June 6, 2012)
- [28] Leslie Chaney (personal communication, December 3, 2012)
- [29] Luna, L. 2012. *FCC names nine white-space database providers*. [online] Available at: <http://www.fiercebroadbandwireless.com/story/fcc-names-nine-white-space-database-providers/2011-01-27> [Accessed: June 2012].
- [30] Mitchell, Bradley. Computing Wireless/Networking. *Wireless Product Equipment*. [online] Available at [http://compnetworking.about.com/od/wireless/ss/wirelessgear\\_7.htm](http://compnetworking.about.com/od/wireless/ss/wirelessgear_7.htm) [Accessed: June 2012]
- [31] Mlinarysky, Fanny. "The Role of White Spaces in the Realm of Wireless Broadband." Powerpoint presentation. F, Mlinarysky, President OctoScope, Inc. [7 June 2011].
- [32] Mobile Technology | Wireless Broadband | Wireless Carriers | RCR U.S. Wireless News. 2013. *Putting white space to work in rural areas* Mobile Technology | Wireless Broadband | Wireless Carriers | RCR U.S. Wireless News. [online] Available at: <http://www.rcrwireless.com/article/20130301/infrastructure-2/white-space-rural/> [Accessed: April 2013].
- [33] Montloin, Cecilia. 2013. Future Electronics. *The Essential Elements of WiMAX technology and the Component Choices Available to the WiMAX Device Designer*. [online] Available at: <http://www.my-ftm.com/0804/080437.asp> [Accessed: March 2013]

- [34] Parker, T. 2012. *TV white spaces roundup: Another database administrator, new IEEE standard and more.* [online] Available at: <http://www.fiercebroadbandwireless.com/story/tv-white-spaces-roundup-another-database-administrator-new-ieee-standard-an/2013-03-06> [Accessed: July 2012].
- [35] PBS.org. 2013. *Watch now: Monday, April 8, 2013 | NC Now | UNC-TV Video.* [online] Available at: <http://video.uncctv.org/video/2364992308> [Accessed: April 2013].
- [36] Seiz, W. (2013, June 6). Telephone interview.
- [37] Segan, Sascha. 2012. PCMag.com *WiMAX vs. LTE: Should You Switch?* [online] Available at: <http://www.pcmag.com/article2/0,2817,2403490,00.asp> [Accessed: June 2012]
- [38] Shannon Eakins (personal communication, June 6, 2013)
- [39] Shannon Eakins (personal communication, October 8, 2012)
- [40] Mody, Apurva. "IEEE 802.22 – Cognitive Radio Regional Area and Smart Utility Networks." Powerpoint presentation. A, Mody, Chairman WhiteSpace Alliance. [Accessed: May 2013]
- [41] Spectrumbridge.com. 2010. *Spectrum Bridge Inc. | Success Story | Wilmington, NC | First TV White Spaces "Smart City".* [online] Available at: <http://www.spectrumbridge.com/ProductsServices/WhiteSpacesSolutions/success-stories/wilmington.aspx> [Accessed: June 2012].
- [42] Stockhouse.com. 2013. *Redline Launches World's Fastest Wireless Broadband Solution Operating in "White Space" Frequencies-T.RDL-Stockhouse news.* [online] Available at: <http://www.stockhouse.com/news/canadianreleasesdetail.aspx?n=8859561> [Accessed: April 2013].
- [43] Sun, Peter. "TVBS field deployment sites." Powerpoint presentation. Suite 9 & 10, 21 Concourse Gate. Ottawa, Ontario K2E 7S4 Canada. June 2013. Television White Spaces. November 2008. R.E.D. Borthand B. Oberlie. Considerations for Successful Cognitive Radio Systems in US TV White Space. In DySpan, 2008.
- [44] The Columbus Dispatch. 2012. *FCC might favor spectrum for Wi-Fi over wireless firms.* [online] Available at:

<http://www.dispatch.com/content/stories/business/2013/01/28/fcc-might-favor-spectrum-for-wi-fi-over-wireless-firms.html> [Accessed: May 2012].

- [45] Thejournal.com. 1994. *Google Uses TV White Spaces To Provide Wireless Broadband to 10 Schools -- THE Journal*. [online] Available at: <http://thejournal.com/articles/2013/03/26/google-uses-tv-white-spaces-to-provide-wireless-broadband-to-10-schools.aspx> [Accessed: November 2012].
- [46] Thompson, Jason. Chairman, New Hanover County Board of Commissioners. "Putting White Spaces to Work." Smart County Applications. 15 June 2010. TV-Band White Space Devices. November 2008.
- [47] TVBS. "TV Band White Spaces Smart City Trial." Powerpoint presentation. TVBS. Next Generation Wireless Communications. Wilmington, NC. 24 February 2010.
- [48] TVBS. "TV White Spaces Trials." Powerpoint presentation. TV Band Service LLC. February 2010.
- [49] Tvnewscheck.com. [online] Available at: <http://www.tvnewscheck.com/article/67030/12-auction-facts-that-you-need-to-know> [Accessed: January 2013].
- [50] Tvtechnology.com. 2009. *TVTechnology: FCC Designates Microsoft White-Spaces Database Manager*. [online] Available at: <http://www.tvtechnology.com/feature-box/0124/fcc-designates-microsoft-white-spaces-database-manager/209803> [Accessed: May 2012].
- [51] Tvtechnology.com. 2013. *TVTechnology: FCC Opens Google White-Space Database for Public Trial*. [online] Available at: <http://www.tvtechnology.com/article/fcc-opens-google-white-space-database-for-public-trial/218001> [Accessed: February 2013].
- [52] Weinshenk, Car. 2010. "Speeding Up WiMax". *IT Business Edge*. "Today the initial WiMax system is designed to provide 30 to 40 megabit-per-second data rates." [online] Available at: <http://www.itbusinessedge.com/cm/community/features/interviews/blog/speeding-up-wimax/?cs=40726> [Accessed: August 2012]
- [53] WiMAX Industry. 2013. "WiMAX FAQs". *WiMAX Industry Broadband Wireless News & Marketplace*. [online] Available at: <http://www.wimax-industry.com/wp/tu/wimaxfaqs.htm> [Accessed: Jan. 2013]
- [54] Whitespacealliance.org. 2011. *WhiteSpace Alliance*. [online] Available at: <http://www.WhiteSpaceAlliance.org> [Accessed: June 2012].

- [55] Whytock, P. 2013. *White Space: The First Frontier For The "Internet Of Things"* | *Europe News content from Electronic Design*. [online] Available at: <http://electronicdesign.com/europe-news/white-space-first-frontier-internet-things> [Accessed: April 2013].
- [56] Wi-Fi. 2010. *Wi-Fi Networking Technology*. Encyclopedia Britannica. [online] Available at: <http://www.britannica.com/EBchecked/topic/1473553/Wi-Fi> [Accessed: August 2012]
- [57] Wi-Fi.org. *The Wi-Fi Alliance: An In-Depth Look*. Wi-Fi Alliance. [online] Available at: <http://www.wi-fi.org> [Accessed: January 2013]
- [58] WirelessInnovationAlliance.org. *About WIA*. Wireless Innovation Alliance. [online] Available at: <http://www.wirelessinnovationalliance.org/> [Accessed: September 2012]
- [59] Wilmingtonbiz.com. 2013. *New Hanover County to offer free Internet access*. [online] Available at: [http://www.wilmingtonbiz.com/industry\\_news\\_details.php?id=3069](http://www.wilmingtonbiz.com/industry_news_details.php?id=3069) [Accessed: April 2013].
- [60] William Seiz (personal communication, May-July, 2013)
- [61] Woyke, E. 2012. *World's First Commercial White Spaces Network Launching Today In North Carolina*. [online] Available at: <http://www.forbes.com/sites/elizabethwoyke/2012/01/26/worlds-first-commercial-white-spaces-network-launching-today-in-north-carolina/> [Accessed: October 2012].
- [62] Wwaytv3.com. 2010. *What are "White Spaces" and how will they affect you? | WWAY NewsChannel 3 | Wilmington NC News*. [online] Available at: [http://www.wwaytv3.com/what\\_are\\_quotwhite\\_spacesquot\\_and\\_how\\_will\\_they\\_affect\\_you/02/2010](http://www.wwaytv3.com/what_are_quotwhite_spacesquot_and_how_will_they_affect_you/02/2010) [Accessed: August 2012].
- [63] "YEZ Boundaries Map." Map. Youth Enrichment Zone. Wilmington, NC. May 2012. Print.
- [64] "YEZ Student Density Colored Map." Map. Youth Enrichment Zone. Wilmington, NC. May 2012. Print.
- [65] Za.news.yahoo.com. [online] Available at: <http://za.news.yahoo.com/white-spaces-slash-internet-access-costs-073112494.html> [Accessed: April 2013].

## Appendix A. – Definitions

This section will establish common industry terms used for this study. It will also give a brief overview of the organizations involved with this topic. Other key terms are explained in context throughout the paper. Terms are highlighted in bold.

### Terms:

**Ad Hoc Network:** a decentralized wireless network that does not rely on a preexisting infrastructure

**Antenna:** the part of a radio receiver by means of which radio signals are received

**Authorized Shared Access (ASA):** Spectrum Bridge's unique and patented spectrum management solution, which enables methods of dynamic spectrum allocation. ASA also provides the means to provision and allocate licensed spectrum

**Backhaul:** comprises the intermediate links between the core network and the small subnetworks at the edge of the entire hierarchical network

**Band:** a small section of the spectrum of radio communication frequencies in which channels are usually used or set aside for the same purpose

**Base Station:** a unit functioning as a transmitter and receiver of broadcasting or other signals

**Blue Ribbon Commission (BRC):** formed in 2008 to address growing concerns about youth violence in the Wilmington area. It's a collaborative of various elected, faith-based and other community leaders, as well as individuals with extensive knowledge of the ongoing problems associated with youth violence. They seek to provide leadership, foster collaboration, and develop resources for addressing youth violence in New Hanover County

**Bridge:** a forwarding technique used in packet-switched computer networks. Unlike routing, bridging makes no assumptions about where in a network a particular address is located

**Cognitive Radio:** a paradigm for wireless communication in which either a network or a wireless node changes its transmission or reception parameters to communicate efficiently avoiding interference with licensed or unlicensed users

**Customer Premise Equipment (CPE):** any terminal and associated equipment at a subscriber's premises and connected with a carrier's telecommunication channel at the demarcation point

**Digital Audio Broadcasting (DAB):** a digital radio technology for broadcasting radio stations, used in several countries, particularly in Europe

**Datacasting:** the broadcasting of data over a wide area via radio waves

**D.C. Virgo Preparatory Academy:** New Hanover County School's eighth middle school that will open in August 2012 in downtown Wilmington, NC.

**Digital Divide:** the gap between people with effective access to digital and information technology, and those with very limited or no access at all

**Environmental Protection Agency (EPA):** an independent federal agency established to coordinate programs aimed at reducing pollution and protecting the environment

**Federal Communications Commission (FCC):** an independent government agency that regulates interstate and international communications by radio and television and wire and cable and satellite

**Geographic Database:** a collection of spatial data and related descriptive data organized for efficient storage and retrieval by many users

**Global Area Network (GAN):** A network that (a) is composed of different interconnected computer networks and (b) covers an unlimited geographical area

**Hub:** A device that is essentially a multiport repeater. When an electronic digital signal is received on a port, the signal is amplified and forwarded out on all segments except the segment from which the signal was received

**IEEE Standard:** an organization within IEEE that develops global standards in a broad range of industries

**Local Area Network (LAN):** A computer network that links devices within a building or group of adjacent buildings

**Long Term Evolution (LTE):** a highly optimized mobile broadband OFDMA solution designed from the ground up to deliver high-speed broadband data, voice (VoIP), and Multimedia services

**The National Telecommunications and Information Administration (NTIA):** an agency of the United States Department of Commerce that serves as the President's principal adviser on telecommunications policies pertaining to the United States' economic and technological advancement

**Mobile Station (MS):** a station in the mobile service used while in motion or during halts at unspecified points

**Point of Presence (POP):** an artificial demarcation point or interface point between communications entities

**Propagate:** the process of spreading to a larger area or greater number

**Radio Frequency:** any of the electromagnetic wave frequencies that lie in the range extending from below 3 kilohertz to about 300 gigahertz and that include the frequencies used for communications signals

**Screen Gems Studios:** owns and operates film and television production facilities in Wilmington, NC. TVBS is a subsidiary of EUE/Screen Gems.

**Smart-Grid:** combines traditional power hardware with sensing and monitoring technology, information technology, and communications to enhance electrical grid performance and support additional services to consumers

**Spectrum:** refers to the part of the electromagnetic spectrum corresponding to radio frequencies – that is, frequencies lower than around 300 GHz (or, equivalently, wavelengths longer than about 1 mm)

**Switch:** a network switch or switching hub is a computer-networking device that connects network segments

**Telecommunications Industry Association (TIA):** a global trade association headquartered in the United States that represents about 600 telecommunications companies. TIA helps create universal networking and education standards for the telephony, data networking, and convergence industry

**Telecom, Media and Finance Associates (TMF):** a consulting and research firm based in Menlo Park, CA focused on business planning, technical analysis, and spectrum valuations

**UHF:** ultra high frequency designates a range of electromagnetic waves with frequencies between 300 MHz and 3 GHz (3,000 MHz)

**VHF:** very high frequency, denoting radio waves of a frequency of about 30–300 MHz and a wavelength of about 1–10 meters

**White Spaces:** underutilized portions of the radio frequency spectrum. Frequencies allocated for analog television and those used as buffers to prevent interference between channels

**Wide Area Network (WAN):** a computer network that covers a broad area (i.e., any network whose communications links cross metropolitan, regional, or national boundaries)

**Wired Equivalent Privacy (WEP):** a security protocol that encrypts data sent to and from wireless devices within a network, not as strong as WPA encryption

**Wi-Fi:** a trademark of the Wi-Fi Alliance that manufacturers may use to brand certified products that belong to a class of wireless local area network (WLAN) devices based on the IEEE 802.11 standards. 802.11 the most widely used WLAN technology

**WiMAX (Worldwide Interoperability for Microwave Access):** is a wireless communications standard designed to provide 30 to 40 megabit-per-second data rates, with the 2011 update providing up to 1 Gbit/s for fixed stations

**WiMAX Forum:** formed in June 2001 to promote conformity and interoperability of the standard

**Wireless Access Point (WAP):** a device that allows wired communication devices to connect to a wireless network using Wi-Fi, Bluetooth or related standards

**IEEE 802.22 Wireless Regional Area Networks (WRAN):** aimed at using cognitive radio (CR) techniques to allow sharing of geographically unused spectrum allocated to the television broadcast service, on a non-interfering basis, to bring broadband access to hard-to-reach, low population density areas, typical of rural environments, and is therefore timely and has the potential for a wide applicability worldwide

**Wireless Local Area Network (WLAN):** links two or more devices using some wireless distribution method (typically spread-spectrum or OFDM radio), and usually providing a connection through an access point to the wider Internet

**Wireless Mesh Network (WMN):** A wireless network with multiple access points allowing free mobility with connectivity within the meshed area. Wireless meshes can be used to share LAN and Internet connectivity over a wide area, such as a business park, warehouse, or industrial yard.

**Wi-Fi Protected Access (WPA) & Wi-Fi Protected Access II (WPA2):** two security protocols and security certification programs developed by the Wi-Fi Alliance to secure wireless computer networks

**Wireless Innovation Alliance (WIA):** a broad-based group of innovators, providers, consumer groups, think tanks, and education organizations that believe that more efficient use and expanded access to the nation's spectrum resources are fundamental to the future of U.S. economic policy and global competitiveness

**Youth Enrichment Zone (YEZ):** a wireless ecosystem deployed in downtown Wilmington, North Carolina that provides free wireless Internet connectivity to students attending D.C. Virgo Preparatory Academy as part of a program focused on creating unique education opportunities through the use of technology

## Acknowledgements

The success of this project was made possible by the combined efforts of all individuals involved. Patience and encouragement were driving forces in keeping this project on track. When times were tough and the chips were down, they lifted my spirits and pushed me forward. I would especially like to thank Dr. Gebauer for always pointing me in the right direction. She supported me throughout this prolonged journey. Whenever I had a problem, she had a solution. I would also like to thank my committee members, Dr. Bryan Reinicke and Dr. Ron Vetter, for offering valuable input during my proposal. I would like to greatly thank Leslie Chaney, IT Director of New Hanover County. Without Leslie Chaney, this project would not exist. I'm sure when she agreed to help me back in early 2012, she had no idea the magnitude of work involved. Leslie continually told me what I should do, who I should talk to, and when I should do it. She guided me through this yearlong process and never once said "no" to any request. I also want to thank Mr. William Seiz. He came onto the project late, but provided a critical role. A lot of information about this technology is difficult or impossible to find. It's an emerging technology with minimal documentation available for public viewing. Mr. Seiz was my all-knowing white spaces wizard who didn't hesitate to answer a phone call at 9:00 PM on a Thursday night. Other parties that were instrumental to this project include: Keith Bolick, Shannon Eakins, Craig Marshburn, Peter Sun, New Hanover County, the City of Wilmington, TVBS, and Spectrum Bridge Inc.