VALIDATION OF A CRV MODEL USING TVWS MEASUREMENTS

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ABSTRACT

As autonomous vehicles advance, their commercial popularity will rise. This growth will increase the need for wireless transmission of data to these cars not only to drive more efficiently, but to also entertain the driver. As people are freed from the task of driving, the demand for in-car internet applications, such as Netflix or Skype, will grow. Currently, autonomous vehicles are allowed to transmit using the band specified by the IEEE protocol 802.11p. While vehicles can transmit data using the 5.9 GHz band (5.850-5.925 GHz), the band may not support wireless transmission of media to vehicles' infotainment systems. This requires an alternative. With the switch from analog to digital television, the government has vacated the analog TV bands. These bands provide a possible solution to the limitations of 802.11p transmissions. The vacated space is called TV white space. One proposed use of this white space is to provide Wi-Fi. This idea has been called White-Fi. According to our research, researchers have measured whether the specific frequencies are occupied but do not provide the unprocessed data. With this in mind, we measure the occupancy of the TV white space and we simulate how a network using this band would perform under the multiple scenarios of everyday driving.

1. INTRODUCTION

Although humans have developed many autonomous and semi-autonomous systems such as self-guided rockets, autopilot for airplanes, and cruise-control for cars, fully autonomous vehicles are still unproven. The idea of a self-driving car has been around almost as long as the automobile itself. In 1939, General Motors (GM) created its Futurama ride for the World's Fair. The ride allowed people to observe GM's vision of 1960, which included automated highways modeled after railroads. However, that vision was only science-fiction because computers were still in their infancy and did not have the necessary computational power to implement the vision. Nevertheless, today, faster computers and better sensors have brought self-driving cars closer to a reality with each prototype.

As companies such as Tesla and Google become successful in implementing autonomous vehicles, the demand for reliable wireless internet access within vehicles will rise for the following two reasons: first, vehicles will need to transmit and receive data from their surroundings for safety precautions; second, people riding in cars will presumably desire on-demand entertainment during their travels. While Wi-Fi has been considered, it is unlikely that this band will be an effective solution in high-bandwidth, high traffic situations.

Currently, 75 MHz of the 5.9 GHz band has been allocated by the FCC for the use of wireless access in vehicular environments (WAVE) that is controlled by IEEE 802.11p. 802.11p has been used for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. Although it performs well for these purposes, through literature review, it appears unlikely that the 802.11p protocol would be able to handle streaming video and audio [1] [2] [3] [4].

In 2009, the US Government vacated the bands between 470 MHz and 890 MHz that had previously been used to transmit analog television. These bands, referred to as Television White Space (TVWS), may be a solution to the limitations of 802.11p transmissions. One of the proposed uses of TVWS is the implementation of Wi-Fi across the bands, which has been dubbed White-Fi. While white space occupancy has been measured many times, the unprocessed data found by the authors is, if it exists, not easily available. Another issue with preceding research in vehicle transmission applications is that it does not address spectrum availability at highway speeds.

In order to gauge the viability of White-Fi for streaming purposes, we measure the TVWS from Tucson to Phoenix, Arizona. Afterwards, we create a White-Fi simulation, using background noise levels based on collected data.

2. BACKGROUND

2.1. Measurements

While researchers may choose slightly different approaches, the data-gathering process is mostly consistent. Researchers who desire to gather spectrum data chooses a channel or set of channels to measure, then use an antenna to gather aforementioned data. With the invention of software-defined radio (SDR), it is possible to accurately measure a large amount of channels during a short period. Since its implementation, many researchers have used SDR to determine spectrum occupancy in different areas of the spectrum. While several articles focus on spectrum occupancy from a driver's point of view, the majority gather data from a set location.

In the literature review, spectrum measuring processes were considered from a wide range of sources. Spectrum measurements in the United States were considered, and international data-collection was considered as well. Research conducted in Metro Cebu, Philippines, Melbourne [5], Australia [6], and Singapore [7] were just a few of the places in which TVWS data was collected.

One instance of spectrum measurement was done in Singapore by [7]. Over the course of 12 weekdays, the authors measured the spectrum from 80 MHz to 5.85 GHz in 60 MHz bands using a spectrum analyzer and a directional antenna. During the 12 days, a total of 1248 samples were taken for each channel. After the measurements were taken, the authors used a threshold power level to differentiate ambient noise from an actual signal. Using the threshold power level, the authors determined spectrum usage. As is the case with many spectrum measurements, the results cannot be used to verify the viability of TV White Space for two reasons: first, the measurements were taken in Singapore, where analog TV is still being broadcast from 494 MHz to 680 MHz. Second, because the measurements were taken from a still location, the measurements may differ from a vehicle that is driving at highway speeds. Therefore, another approach must be considered.

While spectrum measurements are taken worldwide, there are also many researchers who concentrate their measurements in the United States. Data has been gathered in Green Bank, West Virginia [8], Denver, Colorado, San Diego, California, and Los Angeles, California [9], but other than these instances, it is difficult to find recent TVWS measurements in the United States. This has led us to conclude that the measurements are sparse or undocumented. Another difficulty was discovering what other researchers used as their threshold values to determine occupancy. The inaccessibility of the unprocessed data does not allow other researchers to verify results.This is a potential problem because if the researcher picked a threshold value that was too high, it could have returned that that frequency was unoccupied when it actually was.

2.2. Simulation

The current segment of spectrum allocated to vehicles is 75MHz. While 75MHz sounds adequate for most purposes, this is offset by the fact that only 40MHz is useful for things other than safety or control messages. Also, service channels are together in pairs so only two can be bonded together for a 20MHz channel. The remaining segments of the channel are two safety channels, a control channel and a guard band at the beginning. Each channel with a bitrate of 27Mbps [3]. This means with channel bonding you can achieve maximum of 54Mbps throughput or a total of 108Mbps throughput if the road side unit(rsu) has multiple antennas.

According to Netflix help site, they recommend 3Mbps for standard definition and 10Mbps for high definition. This would mean that a single piece of infrastructure could only handle 10 cars in HD and 36 in SD. While 35 seems like sufficent amount of cars, during a traffic jam the density can be between 185-250 vehciles per lane per mile [10]. WAVE would not be able to handle 10% of the vehicle in HD. This also fails to factor in packet error or collisions on the medium.

With the vacating of the Analog TV bands, 420MHz of spectrum space has been made available. Previously Analog TV channels were 6MHz. This means in the range 470MHz-890MHz, there are 70 channels open. Not all of these channels are still open as the government has reallocated the space, but most of the band is still unlicensed. One of these channels has a capacity of 80Mbps at 40Mw of power [11]. While research has been done to show the reliability of WAVE [1], none, according to our research, has compared White-Fi in VANETs to WAVE through simulation to show, empirically, the extra capacity that the would actually be gained by using White-Fi for VANETs.

3. METHODOLOGY

3.1. Measurements

The measurements taken in this paper were made using a Universal Software Radio Peripheral (USRP) a USRP N200 with a LTE Dipole antenna attached. Since the antenna has a range of 698-2690 MHz, instead of measuring the full TVWS band, data was collected from 35 channels ranging from 680-890 MHz. The USRP's parameters were configured using a GNU Radio program that controlled the N200's sample frequency, sample rate, and the number of samples taken per channel. The information written to the file that is later analyzed includes the frequency being measured, the position at which the frequency is being sampled, and the signal power.

The GNU Radio program implemented one original block and several blocks from UHDGPS. The original blocked used, labeled Sweeper, periodically sends a message to the UHD: USRP Source block that tells it to change the frequency being sampled. While the UHD: USRP Source block was used, it was slightly modified from the original. The modification allowed the program to send a tag downstream every time the frequency changes. One of the other blocks used was the Trigger Sample-Timer Event block, which allowed the program to use 256 samples out of every 30 kilo-samples. The average power from the samples used was found using the CPDU Average Power block, and then the output from that was written to a JSON file along with the location, time, and frequency information.

Before gathering the actual experimental data, a few tests were conducted to check how the receiver measured the power and gain levels relative to the transmitted levels. First, two USRP N200s were connected by a coaxial cable: a receiver and a transmitter. Next, using GNU Radio, a signal was transmitted from one to the other, and the gains were compared using QT GUIs that are built into GNU Radio. After repeating the test several times with different signal strengths, it was concluded that the gain offset is approximately -10 dB.

The experiment was conducted in the following way: the USRP was powered through a power strip that drew power from the cigarette lighter and placed between the driver and passenger seats. A laptop, connected to the USRP via an Ethernet cable, was held by someone in the passenger seat of the car and used to monitor the USRP. The LTE Dipole antenna was threaded through the car's rear window and taped to the outside of the vehicle. During the experiment, all 35 channels were measured every 175 milliseconds, and the USRP's sampling rate was set at 6 MHz. The GNU Radio program was set to change frequencies every 5 milliseconds, or every 30 kilo-samples. Out of the 1000 samples taken per channel per scan, the first 300 samples were discarded, and the following 256 were used to determine the signal power at that time. The calculated signal power was then written to a JSON file. Once all of the hardware and software was configured, we drove from Tucson to Phoenix, Arizona.

3.2. Simulation

The simulation portion of this paper was done using OMNeT++ [12], a network simulation framework, that has the ability to simulate all levels of the OSI model. The framework uses module which can be built on an extended. The behavior of the modules are coded in C++ while the language that describes the modules and their connections is called NED(Network Description Language). Once the network is setup up, a configuration file is setup which can change the run time variables of the network. This configuration file can have multiple configurations and run numbers setup to allow for easy organization of multiple circumstances.

Along with OMNeT++, there are multiple frameworks that have been created through it to ease the future development of projects. The two framework that I build off of are called INET and Veins[13]. INET provides a very detailed breakdown of each layer of the OSI model from the physical layer to the application layer. It allows a user to customize background noise, bitrate, carrier frequency, packet size and more. It also has built applications such a UDP video stream client and server that we use in the simulation. This UDP video stream client and server are setup to stream a specific video size at a particular send interval with a packet size that is set at run time. The video size was set at 2GB with a packet length of 2000B which is below the default MTU which will allow for a the fastest transmission rate. The send interval is 25 microseconds for analog and 100 microseconds for WAVE since both speeds are faster than the fastest bit rate for each mode.

INET also has a module called a WirelessHost which has the basic setup for more wireless simulations. This module is configured for IEEE 802.11g, and while the carrier frequency and bit rate can be changed, the module has many submodules which demand the parameters be fit to 802.11 WiFi standard. To overcome this, the radio type had to be changed from IEEE 802.11 radio to APSK radio. The default mac type also had to be change since it required the radio of an 802.11 mode.

Once these modules were changed, the mac was configured with the default values for WAVE EDCA mac[14]. The power level was set to 1W so that area is covered regardless of the center frequency of the radio. Rayleigh fading was used for the path loss type and two separate radio configurations were made: one for Analog and the other for WAVE. The analog frequency is 528MHz and WAVE is at 5.9GHz. The bit rates for analog are 80Mbps, 160Mbps, 240Mbps, 320Mbps. The WAVE bit rates are 27Mbps, 54Mbps, 81Mbps and 108Mbps. Multiple bit rates are used to mimic a road side unit simultaneously using multiple channels to transmit and recieve.

Veins was the other framework was used. Most of veins wasn't used but the mobility model was used. Veins uses Sumo to simulate traffic. Sumo can be used to take maps from OpenStreetMap to generate traffic. A local server listens for the a sumo.cfg file, and when an OMNeT++ network is run that loads that file, it creates a connection to that server. The server handles the navigation and insertion of vehicle nodes in the simulation.

4. NUMERICAL RESULTS

4.1. Measurements

The drive from Tucson to Phoenix, Arizona, resulted in 85,167 power samples across the 35 measured channels - an average of 2,433 samples per channel. The data is processed in the following way: the data is separated into five-mile intervals. The percentage of occupied bands is then computed over each interval. The threshold value was ascertained by comparing the average power in each band in Tucson and Phoenix to known occupied bands. Based upon the comparison, it was visually concluded that -100db was approximately where the bands became unoccupied. The resulting percentages were then graphed as a line plot showing the occupancy throughout Tucson and Phoenix.

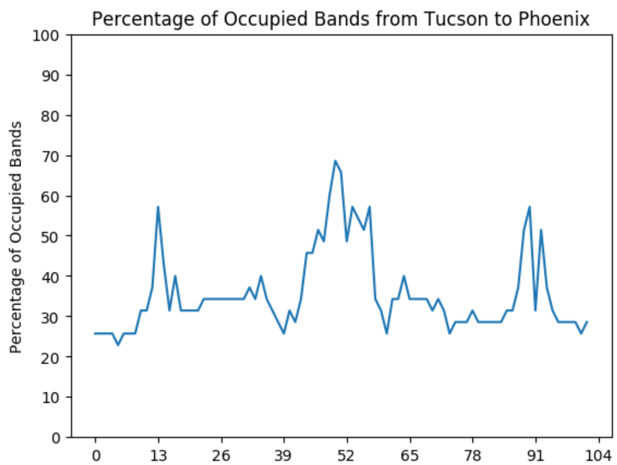

Figure 1

As figure 1 shows, there is some white space available. The highest occupancy level is around 70%, which leaves 30% of the 210 MHz free (about 63MHz).

4.2. Simulation

Table 1: The bitrate of a single RSU in each run to 200 vehicles in a 64,000m^2 area

Run Type - Amount of Channels	Throughput(MBps)
WAVE - 1	1.512
WAVE - 2	2.816
WAVE - 3	3.900
WAVE - 4	4.348
Analog - 1	5.711
Analog - 2	7.315
Analog - 3	9.624
Analog - 4	11.463

In the simulation, it record the bytes received and sent by each node. Using this we calculated the throughput of the RSU in each run type. As shown in Table 1 The 80Mbps analog run has a faster throughput than the 108Mbps WAVE run. The reason this most likely happens is the greater effect that the amount of radios transmitting in the small area have on the signals. This interference will hinder the ability of signals to reach their recipient properly.

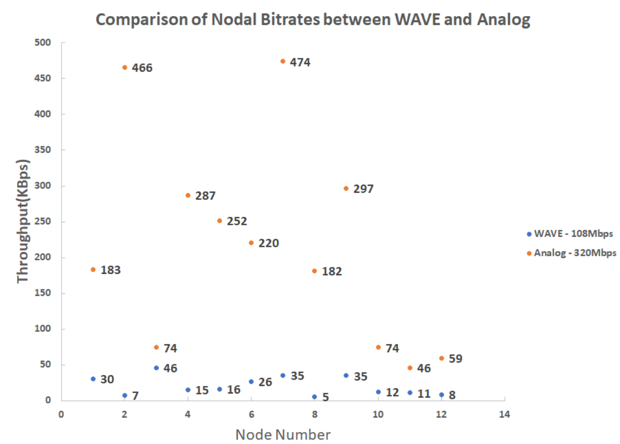

Figure 2

As figure 2 shows the comparison of the bitrates between the 4 channel Analog vs WAVE. You can see that most data points show similar trends as each other since each numbered node should enter and exit the simulation at the same time. This means they will send they ARP request at the same time, but since they are different bit rates and carrier frequencies, one transmission may take longer which why the trends are not exact. The timeouts for ack and arp requests are the same but the transmission time are different for each bit rate.

5. CONCLUSIONS

The need for the transmission of data and entertainment services to vehicles will require an abundance of bandwidth in order to service the amount of vehicles present in everyday traffic. Each passenger will want the ability to stream their favorite movies, work, or listen music while their car drives itself. The current 5.9GHz band does not have enough bandwidth to service one lane of a traffic, but the analog TV bands can provide better service. Based upon spectrum data gathered from Tucson to Phoenix, there is enough vacant space in the analog TV bands to create a sufficient amount of channels to provide smooth connection to vehicles from open to congested areas. That said, before this can become a reality real world tests need to be done to confirm how well the analog TV bands works in a vehicular network. The data does give an idea of how well the TV white space can be used to connect autonomous vehicles to the internet.

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