Abstract- In this paper, we look at the application of cognitive radio technology in vehicular networks. We explore some of the negative impacts of the vehicular environment on the operation of cognitive radios. These include a cognitive radio operating as a secondary (unlicensed) user not detecting a primary (licensed) user and thus causing interference to that user. We also look at how cognitive radios can choose a modulation technique based on the system signal to interference plus noise ratio (SINR). Lastly, we discuss how these findings can help us to apply cognitive radio technology to the vehicular environment.

Index terms: cognitive radios, vehicular networks

I. INTRODUCTION

In recent years, cars are becoming more connected both to road infrastructure and to each other [1]. The movement towards connecting cars has been motivated by the highly dynamic nature of the road situation as well as the need to save lives, time, money and the environment. Intelligent Transport Systems (ITS) are becoming more common, having their major application in toll collection systems. Their use can, however, be extended to public safety applications such as collision avoidance between vehicles, or between vehicles and other obstacles such as pedestrians. ITS applications require vehicle to vehicle (V2V) or vehicle and infrastructure (V2I) communication to happen in real time. In response to this, the Institute of Electrical and Electronics Engineers (IEEE) has created a new standard that adapts the IEEE 802.11a standard to vehicular environments. This standard, IEEE 802.11p, also known as WAVE (Wireless Access in Vehicular Environments), consists of seven 10 MHz channels operating in the 5.9 GHz frequency band [2]. Six of the channels are data channels while the seventh works as a control channel. The technology works well for Dedicated Short Range Communications (DSRC). With the guidelines given, vehicles are able to communicate in the minimum possible amount of time in order to avoid collisions or other accidents.

However, this technology is based on dedicated channels, which tend to use the available radio spectrum wastefully [3]. The world appears to be running out of spectrum, but in actual fact the spectrum is just not being used efficiently [4]. This wastage of spectrum can be attributed to the fixed allocation of radio frequencies by the regulatory authorities. This leaves frequency bands idle when the licensed user is not utilizing them. This creates the impression that there is a shortage of spectrum for users in the heavily used spectral regions. The sparsely used regions are underutilized. A solution would be to have a radio that can utilize the spectrum that is not heavily used so as to ease congestion in other areas.

The use of cognitive radio technology is being researched in order to solve the problem of spectrum shortage. Among other capabilities, a cognitive radio can use the information about its environment and user requirements to achieve specified objectives [5]. With this information, the radio can alter its transmission parameters in order to meet user needs. Cognitive radios can be used where high quality of service (QoS) guarantees are required. However, it is their ability to dynamically reconfigure themselves that makes cognitive radio networks complex adaptive systems. Responses to changes in parameters may be highly interdependent and small stimuli may result in massive responses [5]. Consequently, it is important to be able to accurately predict the behaviour that a cognitive radio will exhibit under various operating conditions.

This paper investigates the application of cognitive radios in vehicular environments, a new and relatively unexplored area of research. Due to the high mobility and changeability in the vehicular environment, communication between nodes is best achieved via the formation of ad hoc networks, or so-called Vehicular Ad hoc Networks (VANETs). The few existing studies in the literature have mainly focused on spectrum sensing techniques in cognitive radio vehicular networks. By contrast, this paper focuses on the impact of changes in the vehicular network on the radio propagation channel and in turn on the operation and performance of the cognitive radio vehicular network. We discuss the changes that occur in vehicular environments that could affect cognitive radio operation and performance.

Section II gives an overview of related work. Section III discusses the operational environment under consideration in this paper. Section IV examines the probability of missed detection over the Ricean channel and its effects on cognitive radio technology performance. Section V explains the choice of modulation techniques and Section VI presents the simulation experiments and results. Section VII concludes the paper.

II. RELATED WORK

Cognitive radios go through a continuous cycle of spectrum sensing, spectrum sharing, spectrum decision and spectrum mobility, collectively termed spectrum management [6]. These actions of the radios are influenced by the external environment. Most of the research on cognitive radios has been on spectrum sensing: [6] provides a good survey. Similarly, most of the existing work on cognitive radio VANETs is also on spectrum sensing e.g. [7]. Very little work has been done on the actual application of these radios in different environments. Gozalvez et al. [8] demonstrate the crucial importance of using realistic and accurate channel models to adequately understand, design and
optimize VANET communication protocols. In [9], the authors explain how propagation channel models impact on certain functions of cognitive radios, specifically, sensing and transmission strategy. Our paper goes on to investigate the reaction of cognitive radio in wireless vehicular environments and how it impacts the network. In [3] the author concludes that due to the long term issues that need to be considered [3], cognitive radio, WiMAX and IEEE 802.22 (Wireless Regional Area Networks) need to be researched for use in vehicular networks. Neel and Amanna in [10] explain the properties of cognitive radio technology that makes it suitable for use in vehicular environments.

III. OPERATIONAL ENVIRONMENT

The vehicular environment to be considered in this paper consists of vehicles travelling on a highway. There is one lane in each direction and the lanes are all demarcated by lines. Two secondary transmitter nodes using cognitive radios can communicate in one hop with their respective receivers. We assume that the cognitive radios are not licensed to use the WAVE channels. In the USA, this band is free but licensed [11]. This means that the operators in this band do not pay for its use, but have to follow certain rules for its usage. Although we are working with only two transmitter nodes for simplicity, we also assume the presence of other cognitive radio transmitters, the impact of which will be seen in our future work. We assume that these vehicles are equipped with on board units (OBUs) for communication purposes and periodically transmit messages over the WAVE channels in the 5.9 GHz band. An on-off traffic model is assumed. The pieces of information being periodically exchanged include position, free spectrum and channels that are suitable for data transmission. Using the same spectrum are some primary users. These primary users are vehicles using ordinary or ‘dump’ radios to exchange messages on the WAVE control channel and are licensed to use this channel. We assume an on-off model to model the primary user activities. We further assume that the nodes are equipped with a Global Positioning System (GPS) receiver so that they can estimate their positions and hence their distance from one another. The transmitters and receivers are within line-of-sight (LOS) of each other but the signal is occasionally blocked by other traffic on the highway. One transmitter/receiver pair is moving in a direction opposite the other. The vehicle speeds are such that one pair reduces the distance between them with time and the other pair increases the distance between them as shown in Figure 1. This is done so that the effects of distance between the vehicles on the choice of transmission power can be observed.

The channel in the vehicular environment is prone to fast fading. Because of the LOS component between the vehicles a Ricean fading channel model is used. This model with variance $\sigma$ has probability density function [8]

$$f(x,\sigma) = \frac{x}{\sigma^2} e^{-x^2/2\sigma^2}$$

(2)

if the transmitter and receiver have a dominant line of sight between them.

![Figure 1: Initial conditions of vehicular environment](image)

The Ricean K factor is set to 3 for medium density traffic. The various signals reach the receiver at different times because some of the signals are reflected or refracted along the way from the transmitter. These delayed signals thus move for longer distances to the receiver and so increase the path loss. In this model we assume that the receiver has an equalizer and so receives the multipath signals as well. Several models are suggested in literature to model path loss. In this paper we shall consider the two models that we found to be most appropriate to the given situation. Reference [8] suggest the use of the WINNER model [12]. This model distinguishes the difference between LOS and non-line of sight (NLOS) conditions. However in the WINNER model it is assumed that the minimum heights of the transmitter and receiver antennas are 5 m and 1 m. In this paper we assume that both transmitter and receiver antennas have a height of 1 m. In [8] a comparison of the WINNER model and the Two-Ray ground model shows that the received power is the same for up to a distance of about 165m between receiver and transmitter. The Two-Ray ground model is employed for LOS conditions and is widely used for vehicular environment simulations such as in [13]. Thus the distance attenuation between the nodes is modeled using the Two-Ray ground path loss model following results from [8]:

$$P_r = \begin{cases} 10\log_{10} \left( \frac{\lambda^2}{\pi d^2} \right) & \text{if } d < d_c \\ 10\log_{10} \left( \frac{h_a h_r}{\pi d^2} \right) & \text{if } d \geq d_c \end{cases}$$

(3)

and

$$d_c = \frac{4\pi h_a h_r}{\lambda}$$

(4)

Where $d$ is the distance between the transmitter and the receiver and $h_a$ and $h_r$ are the transmitter and receiver antenna heights respectively. Because of the high velocity of the vehicles the signal frequency is Doppler shifted and the shift is given by:

$$\Delta f = \frac{V_{sx} f_0}{c}$$

(5)

Where $V_{sx}$ is the transmitter (source) velocity minus the receiver velocity, $f_0$ is the frequency of the signal and $C$ is the speed of the waves.

The shadowing is modeled following a lognormal distribution with standard deviation $\sigma$ assumed to be equal to 5dB and zero mean.
While one transmitter is transmitting to its receiver, its signal is received as interference by other receivers in its interference zone. According to [6] WAVE standard has a transmission range of 1000m. All transmitters within that range of the receiver will therefore cause interference to it. We assume that the secondary receivers are equipped with sensors for energy detection that will allow them to detect any activity in their surroundings that includes the transmission of signals with energy above the energy threshold of the sensor.

Figure 2 above shows how SINR varies with distance between vehicles for the scenario described above. In this case, the pair of vehicles considered has an initial distance between them of 100m. Distance samples are taken over 10 seconds with velocities of the vehicles as depicted in figure 1. As the vehicles move closer to each other the system SINR increases because of the increased signal strength. However generally, the SINR is low and the system is prone to transmission errors.

IV. PROBABILITY OF MISSED DETECTION OVER THE RICEAN CHANNEL

In this section we look at one of the capabilities of cognitive radio that are affected by the vehicular environment. The idea of utilizing cognitive radios is to allow the spectrum to be used efficiently since they are capable of dynamic spectrum access. This means that they can access licensed spectrum as long as they do not surpass a certain amount of interference caused to the licensed users. If secondary transmitters do not detect other transmitters available in the spectrum they can easily surpass the allowed interference. We wish to apply the cognitive radio technology to the 5.9GHz band. The band is a dedicated channel and so can lie idle while the licensed users are not active. However, if cognitive radios can be used on this channel they can access the free spectrum opportunistically and hence increase the efficiency of use of the channel.

The nature of the environment prompts us to be concerned about whether our radios will be able to detect a primary user. Here we assume that the cognitive radio uses the energy detection technique to detect other users [7]. Due to multipath, shadowing and path loss the signal is degraded so much that a cognitive transmitter might not be able to detect the presence of a primary transmitter and hence end up causing an undesirable amount of interference. The type of fading considered in this paper is Ricean since a highway scenario is being emulated. Reference [14] gives the probability of a user being detected in a Ricean fading channel to be:

\[
P_d = Q_a \left( \frac{2\gamma}{\kappa+1+\gamma} \right) \left( \frac{2(k+1)}{\kappa+1+\gamma} \right)
\]

Where: \(Q_a\) is the generalized Marquum Q function
\(\gamma\) is the SINR
\(\lambda\) is the energy threshold used by the energy detector and
\(k\) is the Ricean k factor.

The Ricean k factor was chosen to be 3 for medium density traffic. Equation (6) is for the detection of unknown signals. However, in this work we assume that the noise power is known since the performance of the cognitive radios is susceptible to uncertainty in noise power. It should be noted that our energy detection technique cannot distinguish between the energy coming from primary users and that which is a result of noise. This increases the probability of missed detection since weak primary users can be mistaken for noise. To distinguish other cognitive radio signals from the primary user signals we assume that the cognitive radio users are synchronized with the same sensing and transmission schedules.

V. MODULATION TECHNIQUES AND THEIR IMPORTANCE

After detecting the presence of a primary user, cognitive radios may change their transmission parameters either to minimize the interference caused to other users or to improve its throughput given the available conditions. In this paper we have chosen to look at how cognitive radios can change their modulation techniques in the vehicular environment.

In order to choose an appropriate modulation scheme, we need to look at the advantages and disadvantages of using them. The WAVE standard uses the orthogonal frequency division multiplexing (OFDM) technique [2]. This technique works well with 1/2 quadrature phase shift keying (QPSK) modulation. This modulation scheme is not as bandwidth efficient as other available schemes. We require bandwidth efficiency because of the limit on the available radio spectrum. Reference [15] suggests the use of PSK in wireless communications because of its bandwidth efficiency. However, this technique is susceptible to noise and noise is very common in the vehicular environment. There is therefore need to find a compromise between bandwidth efficiency and susceptibility to noise. Cognitive radios can do this by changing their modulation scheme depending on the channel conditions.

The DSRC standard has been defined to work with binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (16-QAM) and 64-QAM and coding rates of 1/2, 2/3 and 3/4.

VI. SIMULATION EXPERIMENTS AND RESULTS

A. Probability of missed detection
In this simulation the aim was to determine what happens to the probability of a secondary transmitter not detecting another transmitter that is transmitting at the same time and within the same geographical area as the SINR increases. The simulation was done for two channel scenarios, namely, Ricean channel and additive white Gaussian noise channel (AWGN). The code was written in Matlab and equation (6) was applied.

Figure 3: Comparison of Probability of missed detection between a Ricean fading channel and an AWGN channel.

Figure 3 shows that the probability of missing is the same for both channels at SINR=0 but follows a linear pattern for an AWGN channel while it decays slowly for a Ricean channel. The probability of missed detection is generally higher for a Ricean fading channel for the full range of SINRs. This shows that the signal degradation in a Ricean fading channel causes more signals not to be detected. The same transmitter detects fewer transmitters in a Ricean fading channel than it would in an AWGN channel.

To produce Figure 4 SINR values were computed as was done for figure 1, but for different modulation schemes. Equation 6 was then applied.

Figure 4: Probability of missed detection over a Rician fading channel.

Figure 4 shows that QPSK gives the lowest probability of missing for lower SINR values. The QAM modulation schemes give a very high probability although it goes below that of QPSK for higher SINR values.

B. Modulation schemes

This simulation was carried out in order to determine the best modulation technique for the given SINR. This is important because as the traffic in a vehicular environment changes, so does the SINR. The cognitive radio can adapt to this new environment by choosing a modulation scheme that gives the lowest BER. In this simulation, a signal is passed through a Ricean fading channel and undergoes path loss and shadowing in the channel as explained in Section III. Depending on the channel conditions, different SINR values are obtained for the system. Different modulation schemes are used on the signal with SINR values ranging from 0dB to 20dB. There is not much change to values of BER for SINRs above 20dB. The modulation schemes are defined to be used in DSRC. The graphs below show the results obtained.

Figure 5: Comparison of modulation schemes at different SINRs. The schemes are BPSK, QPSK, 16-QAM, and 64-QAM

From the graphs shown in figure 5 16-QAM and 64-QAM give high levels of BER compared to the other two modulation schemes. For SINR up to 5dB QPSK is appropriate to use QPSK and BPSK can be used for SINRs higher than 5dB. However, we cannot rule out the use of QAM for modulation. 16-QAM and 64-QAM are bandwidth efficient and would work well in our case where using bandwidth efficiently is one of our aims. As an intelligent radio, a cognitive radio can learn the general SINR trend in its environment and thus choose the best modulation scheme to use from time to time.

Figure 6 is an extract of figure 5 above and specifically shows the BER- SINR relationship for the scenario in figure 1. For the particular scenario, low BER levels are achieved when either BPSK or QPSK are used.

Figure 6: Comparison of modulation schemes at different SINRs for the scenario depicted in figure 1.
VII. CONCLUSIONS

We have looked at how the performance of cognitive radios can be hampered by the environment in which they are operating. Propagation has effects on the sensing and transmission strategies. In this paper we assumed that a cognitive radio uses energy detection for sensing. Since the energy transmitted over the channel is degraded due to multipath, there are higher chances that a transmitter will not be detected by the cognitive radio. There are several transmission parameters that a cognitive radio can alter in order to adapt to its environment. In this paper we have looked at modulation techniques and how they can be altered depending on the environmental status. We looked at bandwidth efficient schemes and those prone to noise and concluded that these schemes can be interchanged depending on how the environment is changing. In addition, figures 4 and 6 show that although QPSK gives a lower BER at SINR above 4.94 dB, the probability of missing increases thereafter, making the QAM techniques a better choice of modulation for the purpose of avoiding interference.

The knowledge we have acquired from these experiments will help the cognitive radio designers to make decisions as to which techniques to use. Knowing the environment and its effects on propagation we can formulate a set of decisions and actions that can be attributed to the cognitive radio. This can be done by finding ways to mitigate these effects and matching them to the environment hence giving the cognitive radios a set of rules to follow in known situations.

Considering that there are several radios vying for the same spectrum we can use a game theoretic approach to make sure that there is fairness and efficiency in the usage of the spectrum. We can find the optimum conditions for the use of cognitive radio technology in vehicular networks.

In order for the cognitive radio to share the spectrum with other unlicensed users a game can be played so that all the radios can make the most efficient decisions given the circumstances. This is explored in our future work.

REFERENCES


Eugenia Nyanhete received her Bachelor of Engineering degree from the National University of Science and Technology, Zimbabwe in 2008. She is currently studying towards her Master of Technology degree at Tshwane University of Technology, specializing in telecommunications. Her research interests include Cognitive Radio technology and vehicular networks.