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MAC LAYER FOR DYNAMIC SPECTRUM ACCESS IN COGNITIVE RADIO NETWORKS

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ABSTRACT

Spectrum inefficient utilization and growing in demand of wireless services is one of the challenges facing the wireless communication systems as the spectrum is a finite resource. There is a need of better and smarter exploitation of the limited spectrum which will enables the usage and to allowing sharing of temporally unused spectrum allocated to the television broadcast service in non interfering basis, to bring broadband access to hard –to-reach low population density areas. Cognitive radio is employed as a technique in the managements and sharing of the white space (unused spectrum). This research provides study techniques for sensing the white space and managements for multiple accesses. This paper proposed a dynamic spectrum access scheme for cognitive radio networks. The approach will allow secondary user to operate in the presence of a primary user. The cognitive capabilities of the system includes electromagnetic interference (EMI) awareness, ranging and transmit power to control the spectrum access among primary and secondary users. (The scheme is based on electromagnetic interference (EMI) control. Ranging and transmitter power are parameters that need to be calculated/controlled in order to control the EMI). OPNET (Optimized Network Engineering Tool) have been used to model primary user with priority access and multiple secondary users. Performance analysis of results shows that, the proposed schemes protect the primary user from harmful EMI from the secondary user.

1. INTRODUCTION

Cellular systems are now well developed in many countries throughout the world. The essential feature of all cellular networks is that the final link between the subscriber and fixed networks is by radio. Radio spectrum is a finite resources, the amount of spectrum available for mobile communication is strictly limited. Today wireless networks are characterised by fixed channel allocations. However, some frequency band or bandwidths in the spectrum are unoccupied for some period of time, while some are partially occupied and the rest of the spectrum are heavily used. Due to increase in the demand of the spectrum, leads to the scarcity and inefficient utilisation of the spectrum. The channel allocation strategy, play a key role towards enhancements of the quality of service of the network. In fixed channel system some problems such as non-uniformity of traffic distribution, and the average blocking probability typically for mobile systems. In the case of TV broadcast system, the spectrum remains underutilized in some geographical locations. These are some of the challenges facing the wireless communication systems. Cognitive radio provides us with a novel way of solving spectrum in efficient utilization. It has emerged as a promising technology for maximising the utilization of the limited radio bandwidth while accommodating the increasing amount of service and applications in wireless networks [1].

General terms: MAC Layer for DSA**,** Study techniques for sensing the white space, techniques for multiple access and Use of OPNET to model primary user with priority access and multiple secondary users

2. BACKGROUND

A cognitive radio network is required to adapt its transmission parameters according to the changing in its environment and therefore it must be able to determine the status of the spectrum and as well as the activity of the primary user. The network should also be capable of dynamically accessing the white space. To achieve this goal, a spectrum sensing technique is required to determine the availability of the unused spectrum portion of the primary user. Due to the rapid in demand of the spectrum and aimed to meet the demand, there was request to the communication commission to create flexibility in the spectrum management policy in order to improve both technical and economic efficient spectrum utilization. Measurements on the spectrum usage have shown that the spectrum allocated to licensed users is not fully utilized at all times in all locations as shown in fig. 1 below. The dynamic spectrum approach has the potential to make use of the unoccupied spectrum allocated to licensed users.

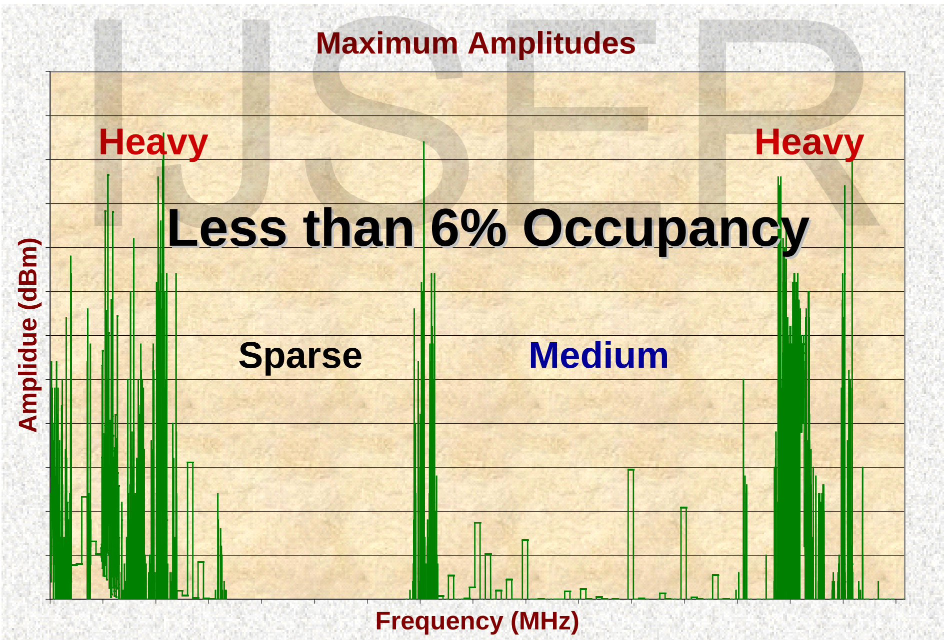

Figure: 1 spectrum usage [2]

The dynamic spectrum access vision has centred on the concepts of spectrum sharing between licensed and unlicensed users. In this case, the licences users are known as primary users. These licensed users have priority access to the spectrum and unlicensed users also known as secondary users can use the spectrum opportunistically. The secondary users cease transmission on the return of the primary user. For this to work, the secondary user needs to be able to detect the white space, configure itself to transmit in that white space and detect the return of the primary user. Dynamic spectrum access is important to future wireless service. The fundamental advantages of DSA are:

- It provides radios technology to let spectrum be shared more effectively
- It provides the networks the ability to manage environments, avoids and resolves interference, and adapt to usage.

Therefore, there is a need of an intelligent wireless transceivers to dynamically access the radio spectrum opportunities, such an intelligent wireless transceivers is referred as cognitive radio.

2.1 DYNAMIC SPECTRUM ACCESS MODELS AND ARCHITECTURE

Dynamic spectrum access (DSA) models for cognitive radio can be categorized as exclusive-use, shared-use and commons models [3]. The traditional command and control model licensed scheme, the spectrum is statically assigned to a particular spectrum licensee and this result to underutilization of the spectrum. This spectrum licensing scheme does not allow the flexibility usage of the spectrum according to the time varying demands of the users.

To overcome the above limitations, and to improve the spectrum utilization, unlicensed users should be allowed to access the spectrum opportunistically in a non interfering basis. The concept of open spectrum [4] was introduced. This concept provides a set of techniques and models that will allow dynamic spectrum access. This concept leads to a new spectrum access and licensing models that will improves the flexibility and efficient usages of the spectrum. Taxonomy of the different spectrum access models is shown in fig 2 below

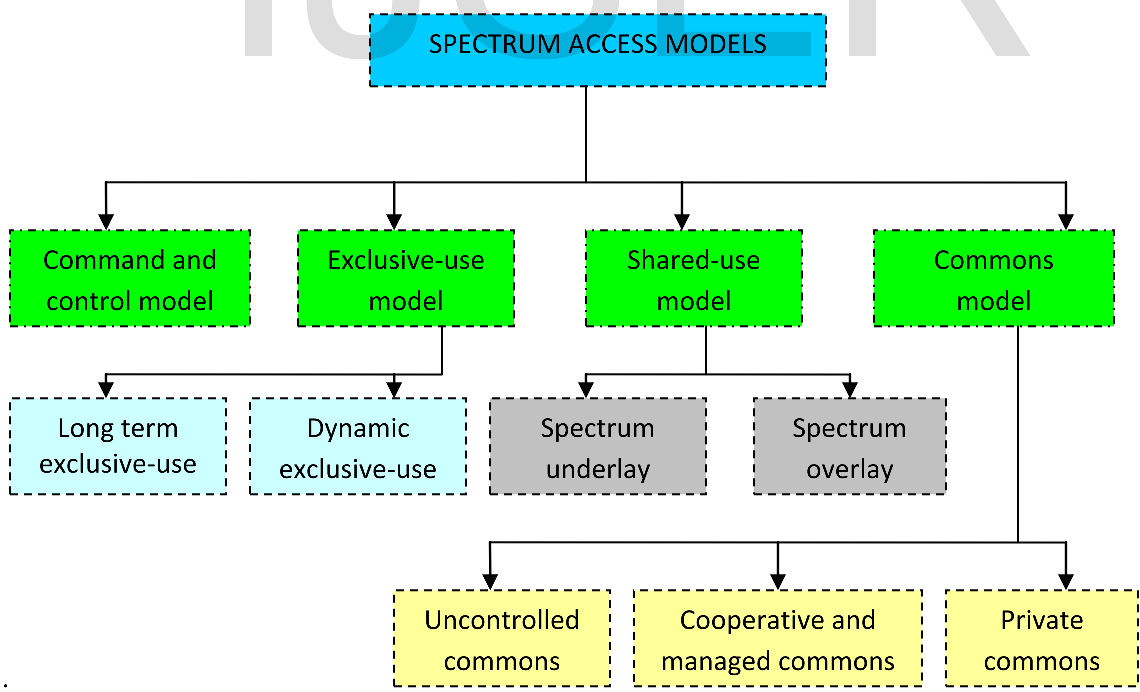

Figure 2: Spectrum access models

3. PROBLEM STATE

IEEE 802.22 standard is a standard that describe a physical and media access layer of a WRAN (Wireless regional Area Networks) that aimed to make use of an unused TV spectrum band also known as spectrum hole (white space) in a non interfering basis in order to bring broadband access to hard –to-reach low population density areas. IEEE 802.22 specifies that the networks should operate in a point-to- multipoint basis. A base station which is a professionally installed entity will manage its own cell in which the number of consumer premise equipments (CPE) operates. Hence, there will be another infrastructure put in place to help the unlicensed users also termed as secondary or cognitive users to make use of the TV unused portion of the spectrum band also known as the white space. All CPE in the IEEE 802.22 system must have the ability to perform spectrum sensing i.e. ability to detect signals: Digital TV signals with receiver sensitivity of -116dBm, for analogue TV the sensitivity is -94dBm and wireless microphone signals that are as low as -107dBm. The channel detection time for all signal type is 2s. The probability of detection is 0.9, while the probability of false alarm is 0.1s for all signals. To do all entities described above, the networks must have cognitive capabilities i.e. it is a cognitive radio networks. Cognitive radio techniques will be used to allow the sharing of geographically unused spectrum holes in a non interfering basis. This problem can be solved by considering the TV spectrum licensed user as the primary user and the customer premises equipments as the unlicensed or cognitive or secondary users. A channel access mechanism is designed for this cognitive system.

4. SYSTEM DESIGN AND SIMULATION

This section provides detail overview of the procedures used in the development of the proposed dynamic spectrum access (DSA) model. OPNET (Optimized Network Engineering Tool) version 14.5 is the environment of choice for implementing this model, is considered the most well reliable network simulation tool available today [5] and assists with testing and design of communication protocols and networks, it provides graphical user interface for definition of network models. OPNET consists of project editor where a network model can be created using the models from the standard library, run simulation, collect and analyse results. Node editor enables the behaviour of each network object such as the transmitter, source and sink to be defined. It also contains process editor where the process module which controls the functionality of the node model can be created and customises the operation in each state or for a transition. The purpose of this model is to use cognitive techniques to allow efficient access for secondary users of spectrum where the primary user has priority access and to evaluate delay experienced by the secondary user as a function of the amount of white space and the number of secondary users.

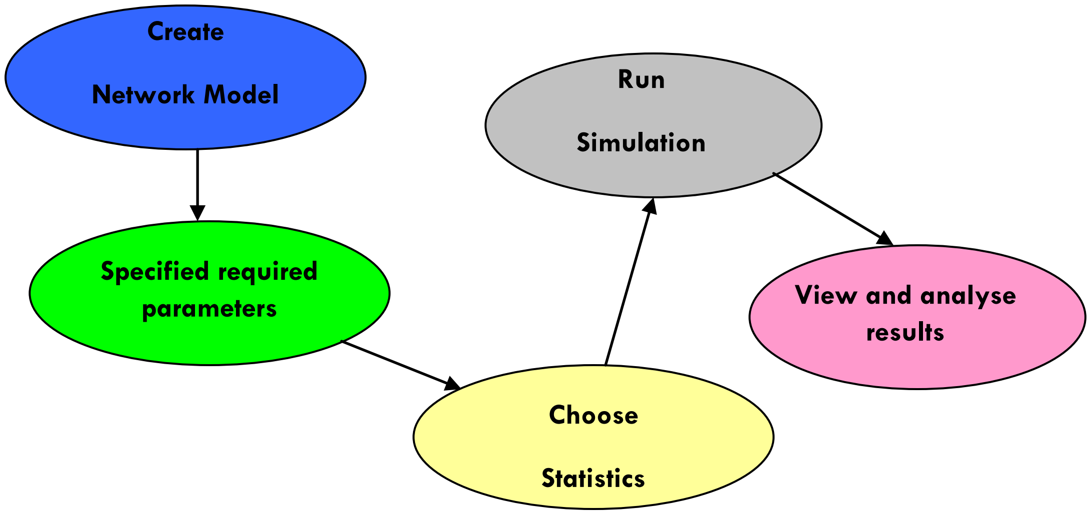

Figure 3: Model Work Flow for OPNET

Fig 3 above shows the system developments simulation flow. OPNET (Optimized Network Engineering Tools) version 14.5 was the simulation environments for the developments of proposed DSA.

4.1 SIMULATION SETUP

The simulation area is $4km^2$ with four (4) wireless local area network (WLAN) nodes, the primary transmitter, primary receiver, access point and the secondary user. All simulations are run for 5 min (300sec). Two access architectures have been considered. The first is a centralised access schemes where there is infrastructure put in place and the secondary users communicates with the central data base that collects all the information from a collaborative group of secondary users that learns about the primary user activity. The second is an infrastructure less or cognitive adhoc network where each secondary user makes a decision on dynamic spectrum access independently and autonomously without any central controller.

4.2 CLASSIFICATION OF SPECTRUM

A spectrum hole is defined as a frequency band that is assigned to a primary user exclusively, but is not allocated by this user at a specific time and place. In this research, a spectrum hole is defined as the period of time that the primary user is not transmitting. There are two (2) main classification of spectrum based on the occupancy [6, 7] namely:

1-The Black space: This is a spectrum that is fully occupied by a primary user

2-The white space: Unused space or not occupied by a primary users.

4.3 TRAFFIC GENERATION AND CHANNEL USAGE PATTERN

A traffic flow control mechanism based on an events based technique was deployed to model the primary user activity to generate an ON/OFF traffic over the period of 5min, the ON periods are the busy time and the OFF periods are the idle time as shown in Fig 4 below. This figure illustrates the 0/1 states, 0 denoting the channel is free and 1 denoting the channel is busy and occupied by the primary user, these 0/1 alternating stages is referred to as the channel usage pattern and the OFF periods represents the spectrum opportunists or spectrum hole commonly known as white space. The secondary user has the ability to detect the OFF times of the primary user and transmit packets over the white space if it's not within the *non-talk zone* of the primary receiver. The black spaces are not good candidates for dynamic spectrum access as the secondary user will cause severe interference to the primary user which would degrade the minimum *SIR* at the primary receiver. However, the white spaces can be use for dynamic spectrum access. In this research, we assume all the OFF periods from a primary user transmission are considered to as white spaces and can be identified instantaneously.

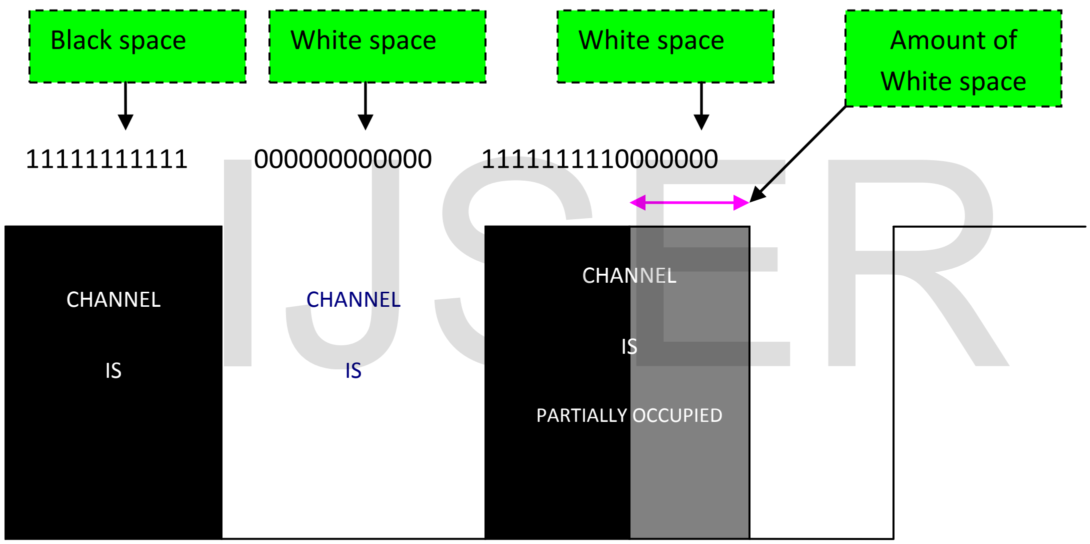

Figure 4: Traffic generation and channel usage pattern

Since a white space is the OFF periods i.e. the period of time that the primary user is not transmitting, the duration of the OFF periods accounts for the amounts of white space as shown in fig 5 below.

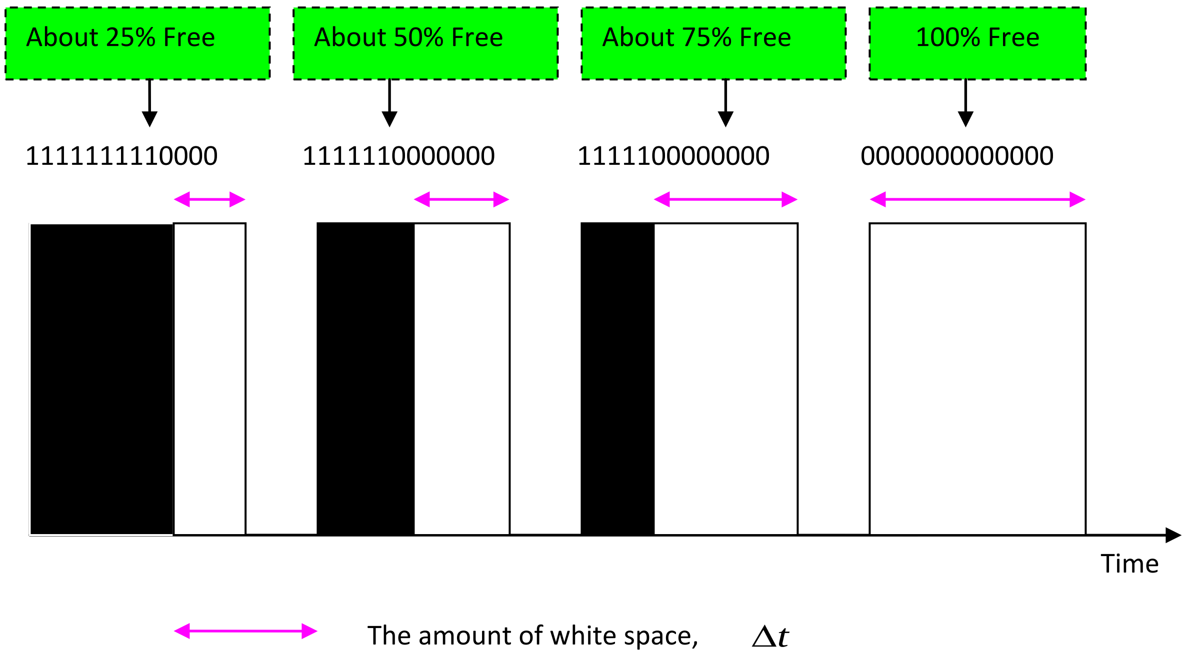

Figure 5: Variation of amount of white space

Figure 5 above shows the amounts of white spaces from primary user transmission. The white space is a function of time. A secondary user can transmit packets within the white space if the period of the white space Δt is greater than the sensing period.

The data rate at each user was 11Mbps and the packets inter arrival rate follow the exponential distribution with a mean value of 1000 packet/sec. The packet size is also exponential distribution with the mean value of 1024 Bytes. Since the packet size is below the 2034 bytes limit, fragmentation is not needed. Direct sequence spread spectrum (DSSS) was the modulation technique for both users as it provides highest throughputs for all users on the network [8]. It also helps to create a secure communication channel that is resistant to interference and sharing of single channel among multiple users. Therefore, at data rates of 11Mbps and a packets size of 1024 Bytes (8192 bits), the packet duration corresponds to 0.74milliseconds and 0.74 sec when transmitting 1000 packets therefore, at a transmission period of 300 sec there are about 403 time slots. The channel access mechanism was based on the CSMA/CA MAC protocol with modifications. IEEE 802.11b Standard channel sensing period (i.e. DIFS) of $50\mu s$ is used [9].

5. RESULTS AND CRITICAL ANALYSIS

This chapter provides simulation results and performance analysis of the proposed dynamic spectrum access (DSA) model. This presents an analysis of the cognitive CSMA/CA MAC protocol in terms of electromagnetic interference immunity, ranging and transmitter power control.

The simulation was carried out using wireless nodes with transmission frequency of 2.4GHz and speed of propagation $3x10^8 m/s$ for a distance of 0-3km between the secondary transmitter and the primary receiver. The results are shown in the figures below.

5.1 VARIATION OF PATH LOSS WITH DISTANCE FROM THE SECONDARY TRANSMITTER TO PRIMARY RECEIVER

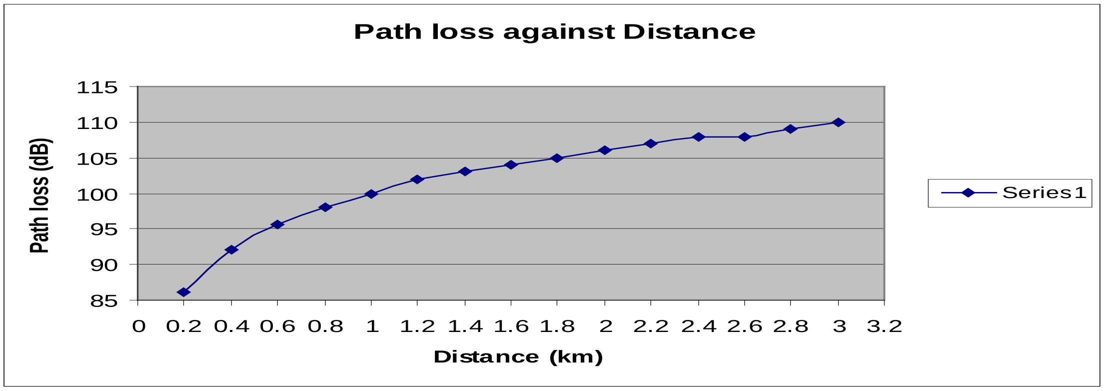

Figure 6: Variation of path loss with distance from the secondary transmitter to primary receiver

Fig.6 above shows the variation of path loss with distance. Path loss accounts for the signal attenuation due to physical distance. OPNET uses free space propagation model. The most important aspect of any characterization of radio propagation is how field strength varies as a function of distance and location. Fig .7 illustrates the effects of distance between the secondary transmitter and primary receiver. The same model is applied between primary transmitter and the primary receiver

5.2 VARIATION OF TRANSMIT POWER AND THE MAXIMUM RANGE FROM THE ACCESS POINT TO THE SECONDARY USER

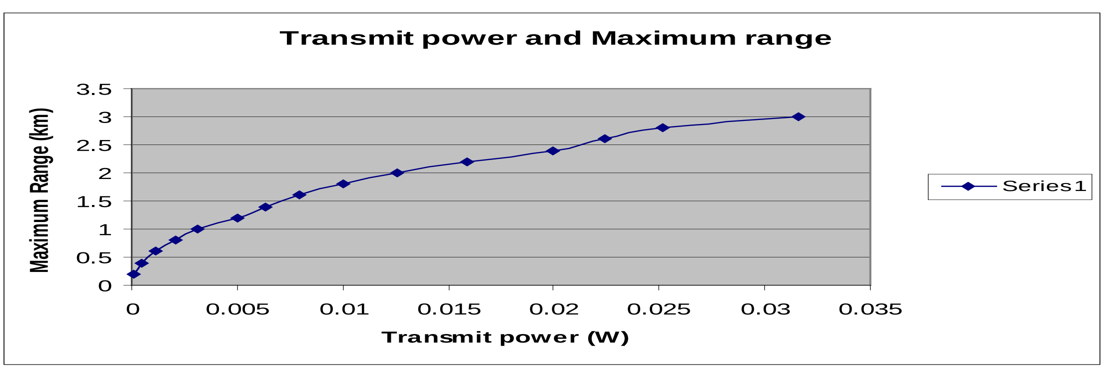

Figure 7: Variation of transmit power and the maximum range from the access point to the secondary user

Fig. 7 above shows the secondary transmitter communicating with other secondary users in a case of cognitive adhoc network without any centralized access point.. When the secondary user is transmitting at 5mW the maximum transmission distance to the access point is about 1.2km, this shows that as the secondary user moves away from the access point beyond 1.2km, it would require more power for the signal to be detected at the receiver of the access point. When the separation distance between the AP and the SU is 3km the secondary user requires a minimum of 32mW transmit power. This generally shows the variation of required power level with distance.

5.3 RECEIVED SIGNAL STRENGTH AT THE SECONDARY RECEIVER AS A FUNCTION OF TRANSMIT POWER OF PRIMARY TRANSMITTER AND DISTANCE

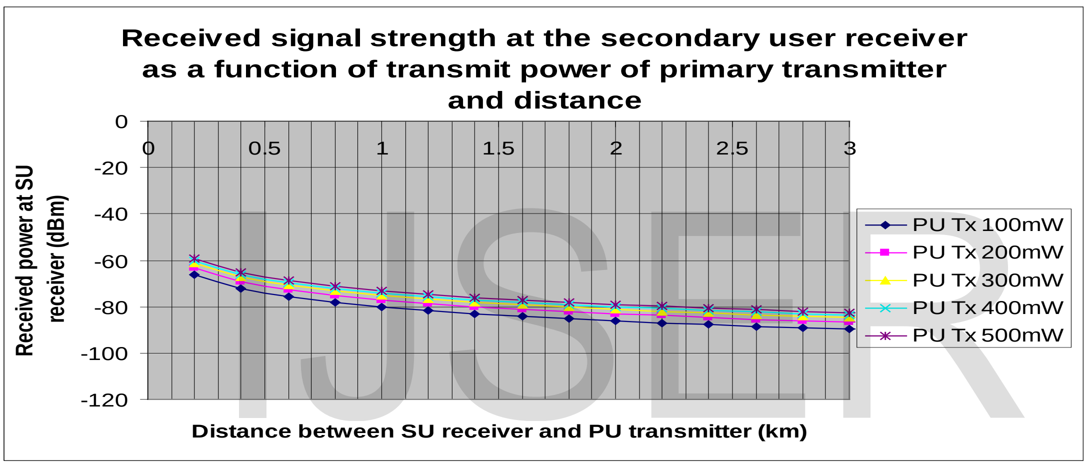

Figure 8 showing received signal strength at the secondary receiver as a function of transmits power of primary transmitter and distance.

In fig. 8 above, the signal strength at the secondary receiver decreases when the distance between the secondary receiver and the primary transmitter increase. This varies as a function of transmit power of the primary transmitter. About -80.1dBm was measured when they are 1km apart and the primary transmitter power of 100mW, this increases to -73.1dBm when the primary user increase its transmits power to 500mW at the same distance. The secondary user has to monitor the activity of the primary transmitter so that it would transmit on the channel once the primary transmitter is not transmitting on the channel. The decision about the presence of the primary transmitter depends on the signal strength received at the secondary receiver. Energy detection spectrum sensing technique is employed therefore; the level of the signal strength at the secondary receiver will play a key role in order to avoid uncertainty in the detection.

5.4 THE VARIATION OF INTERFERENCE POWER AT THE PRIMARY USER RECEIVER AS A FUNCTION OF DISTANCE TO THE SECONDARY TRANSMITTER AND TRANSMIT POWER OF THE SECONDARY USER

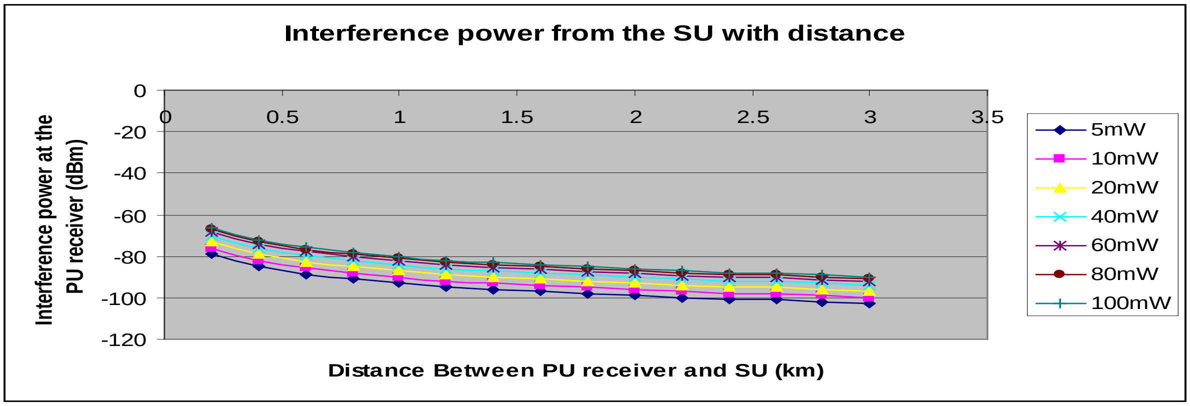

Figure 9: The variation of interference power at the primary user receiver as a function of distance to the secondary transmitter and transmit power of the secondary user

Fig.9 above shows the variation of interference power at the primary user (PRx) receiver with distance from the secondary transmitter (SUTx), as the SUTx increases its transmission power the interference power at the PRx increases this degrade the SIR at the primary receiver thereby increasing the interference power. In fig 11 above, the measured interference power at the primary receiver was -85.1dBm when the secondary transmitter is transmitting at 5mW and is 500m from the PRx. This decreases to -93dBm when distance between the SUTx and PRx is 1km and -103dBm when they are 3km apart. The interference power level decreases at the primary receiver when the distance from the secondary transmitter increases.

5.5 SIGNAL –TO –INTERFERENCE RATIO (SIR) AT THE PRIMARY USER RECEIVER AS A FUNCTION OF DISTANCE FROM THE PRIMARY TRANSMITTER AND THE SECONDARY USER

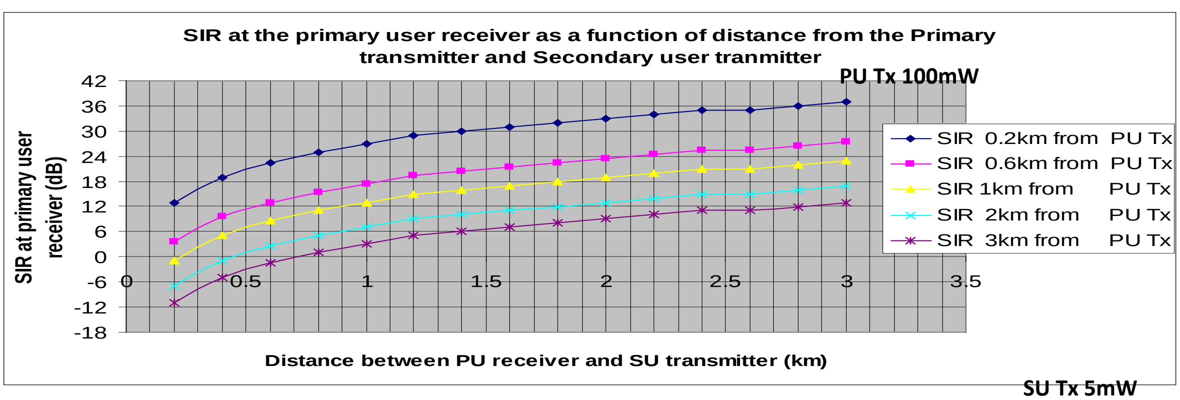

Figure 10: Signal –to –interference ratio (sir) at the primary user receiver as a function of distance from the primary transmitter and the secondary user

The primary receiver communicates with the primary transmitter whose signal varies with distance from its location. At the same time it received unwanted signals from the secondary transmitter which is located at some certain distance. The received signal quality at the primary receiver is typically measured by signal-to-interference ratio (SIR) which is the ratio of the power of the wanted signal and the aggregated power of the unwanted signals. Fig. 12 above shows the signal to interference ratio (SIR) at the primary receiver as a function of the distance between the primary user receiver and the secondary user transmitter. When the transmit power of the primary transmitter is 100mW and the secondary user is transmitting at 5mW. At 0.2km from the primary transmitter and 0.2km from the secondary transmitter, the SIR is 13dB and this increases when the primary receiver moves away from the secondary transmitter and this can be up to 36.9dB when they are 3km apart. When the primary receiver moves 1km from the primary transmitter and 200m from the secondary transmitter, the SIR degrades to about 0dB. This shows that location of primary transmitter, transmit power of primary transmitter, secondary transmitter location and transmit power of secondary transmitter are key parameters to be considered/controlled when modelling of interference. The main challenge is to determine the optimal transmit power and distance of the secondary user transmitter that will not degrade the SIR at the primary receiver below the threshold level. In order to correctly interpret the received signal at the primary receiver, the SIR must be above a given threshold. Different cellular systems require different SIR thresholds 18 dB, 14 dB, and 9 dB are required as the minimum acceptable SIR protection levels in Advanced Mobile Phone System (AMPS), Digital Time Division Multiple Access (TDMA) Such as IS-136, and Global System for Mobile Communication (GSM), respectively [10]. In this case 6dB was chosen as the minimum SIR at the primary receiver. Therefore, from the fig. 10 above, when the primary receiver is 2km from the primary transmitter (PUTx), the minimum distance secondary transmitter has to be from primary receiver is 800m in other to meet the target of 6dB SIR. This distance increases to 1.4km as the primary receiver moves 3km from the primary transmitter (PUTx).

6.0 CONCLUSION

Radio spectrum is a valuable and is needed for economic, societal and technological reasons. Inefficient utilization the spectrum and growing in the demand of wireless services is one of the challenges facing the wireless communication systems as the spectrum is a finite resource. Dynamic spectrum access will help to create flexibility in the spectrum management policy in order to improve both technical and economic efficient spectrum utilization. Cognitive radio is employed as a technique in the managements and sharing of the white space (unused spectrum allocated to TV broadcast services) in non interfering basis, to bring broadband access to hard –to-reach low population density areas. Spectrum sensing has been identified as a factor enabling the performance of cognitive radio networks in order to ensure that the secondary user will not interfere with the primary user, by monitoring and detecting the activity of the primary user. When the presence of the primary user is not detected the signal to interference at the primary receiver could be degraded. Therefore, transmit power control and ranging are the key features in the cognitive radio networks that will enable the control of interference in the system.

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