Improving Detection Performance of Cognitive Femtocell Networks

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Abstract :
Femtocell is envisioned as a highly promising solution for indoor wireless communications. The spectrum allocated to femtocells is traditionally from the same licensed spectrum bands of macrocells. The capacity of femtocell networks is highly limited due to finite number of licensed spectrum bands and the interference with macrocells and other femtocells. A radically new communication paradigm is proposed by incorporating cognitive radio in femtocell networks. The cognitive radio enabled femtocells are able to access spectrum bands not only from macrocells but also from other licensed systems (e.g. TV), provided the interference from femtocells to the existing systems is not harmful. It results in more channel opportunities. Thus, the co-channel interference can be greatly reduced and the network capacity can be significantly improved. Further, detection performance can be improved by decreasing the collision probability with the help of double threshold energy detection.

Keywords: Co-channel interference, Cognitive radio, Collision probability, Double threshold energy detection, Femtocell network, IEEE 802.22, Licensed user.

I INTRODUCTION

In mobile wireless networks, the demand for higher data rates and lower power consumptions is continuously increasing, while the capacity provided by the existing macro cell networks is limited.

The Studies on wireless usage show that more than 50 percent of all voice calls and more than 70 percent of data traffic originate from indoors. Voice networks are engineered to tolerate low signal quality, since the required data rate for voice signals is very low, on the order of 10 kb/s or less. Data networks, on the other hand, require much higher signal quality in order to provide the multimegabit per second data rates. For indoor devices, particularly at the higher carrier frequencies, high data rates are very difficult to achieve. This motivates for the femtocell approach [1].

Femtocells, also called home base stations (BSs), are short-range low-cost low-power BSs installed by the consumer for better indoor voice and data reception. The user-installed device communicates with the cellular network over a broadband connection such as digital subscriber line (DSL), cable modem, or a separate radio frequency (RF) backhaul channel. While conventional approaches require dual-mode handsets to deliver both in-home and mobile services, an in-home femtocell deployment promises fixed mobile convergence with *existing* handsets. Compared to other techniques for increasing system capacity, such as distributed antenna systems and microcells, the key advantage of femtocells is that there is very little upfront cost to the service provider [1].

In macro cell networks, traditional spectrum allocation methods are mostly based on coloring methods where no neighboring cells can use the same spectrum at the same time. Since the number of femtocells could be much higher than the number of macro cells in a certain area, this kind of spectrum allocation requires more spectrum bands. This will lead to inefficient and unfair spectrum utilization. This motivates the study to improve the spectrum utilization and cell capacity.

In the meantime, it has been shown that spectrum is not efficiently used by licensed (primary) users/systems according to the exclusive spectrum allocation regulation. In recent years, cognitive radio (CR) technology has been developed to allow unlicensed users to exploit spectrum opportunities from primary systems to enhance the spectrum utilization greatly [1]. It then inspires to incorporate the CR technology into femtocell networks, where the CR-enabled femtocell users (FUs) and FBSs can identify and utilize the spectrum opportunities from the licensed systems such as macro cell networks and TV broadcast systems.

II. Related work

According to Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%. Although the fixed spectrum assignment policy generally served well in the past, there is a dramatic increase in the access to the limited spectrum for mobile services in the recent years. This increase is straining the effectiveness of the traditional spectrum policies.

The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically. *Dynamic spectrum access* (DSA) is proposed wherein unlicensed (secondary) systems are allowed to opportunistically utilize the unused licensed (primary) bands, commonly referred to as “spectrum holes”, without interfering with the existing users [2].

2.1 Cognitive Radio Technology

A "Cognitive Radio" is a radio that can change its transmitter parameters based on interaction with the environment in which it operates [2]. The ultimate objective of the cognitive radio is to obtain the best available spectrum through cognitive capability and reconfigurability. The Fig.1 shows cognitive cycle. The steps in cognitive cycle are as follows :–

1. *Spectrum Sensing*: A cognitive radio monitors the available spectrum bands, captures their information and then detects the spectrum holes.
2. *Spectrum Analysis*: The characteristics of the spectrum holes that are detected through spectrum sensing are estimated.
3. *Spectrum Decision*: A cognitive radio determines the data rate, the transmission mode and the bandwidth of the transmission. Then, the appropriate spectrum band is chosen according to the spectrum characteristics and user requirements.

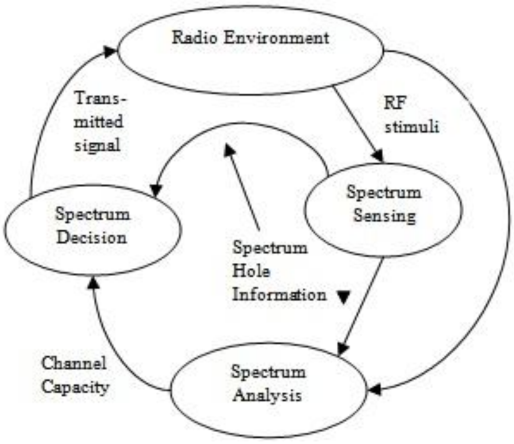

Figure 1: Cognitive Cycle [2]

The two main characteristics of cognitive radio are:–

- *Cognitive Capability*: Cognitive capability refers to the ability of the radio technology to capture or sense the information from its radio environment. Through this capability, the portions of the spectrum that are unused at a specific time or location can be identified. Consequently, the best spectrum and appropriate operating parameters can be selected.
- *Reconfigurability*: The cognitive capability provides spectrum awareness whereas reconfigurability enables the radio to be dynamically programmed according to the radio environment. More specifically, the cognitive radio can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design.

In 2004, Federal Communications Commission (FCC) indicated that unutilized TV channels in both Very High Frequency (VHF) and Ultra High Frequency (UHF) bands could be used for fixed broadband access. From then on there has been overwhelming interest from research community to develop a standard for Wireless Regional Area Networks (WRAN) systems operating on TV white space using CR technology. IEEE 802.22 WRAN is the first standard developed using CR technology that operates on TV white spaces and focuses on constructing fixed point-to-multipoint WRAN that will utilize VHF/UHF TV bands between 54 MHz and 862 MHz. IEEE 802.22 WRAN systems share the geographically unused TV spectrum on non-interfering basis in rural environment where it is difficult to provide broadband access [3]. IEEE 802.22 is developed to utilize unused TV bands without providing harmful interference to incumbent users.

2.2 Cognitive Femtocell Networks

The surest way to increase the system capacity of a wireless link is by getting the transmitter and receiver closer to each other. It creates the dual benefits of higher-quality links and more spatial reuse. A less expensive alternative is the recent concept of femtocells. The cognitive radio femtocell network works as follows:–

- System initialization: In the beginning, whenever a Femtocell Base Station (FBS) turns on, it first senses the spectrum environment to initialize an available spectrum list. The FBS is responsible to allocate spectrum to its users, and inform them the suitable uplink transmission power. Synchronization between neighboring FBSs is not obligatory in Cog-Fem, but it is an option if any FBS wants to synchronize with its neighbors. The synchronization can be implemented by listening to neighboring femtocells information to obtain the frame length and structure.
- Number of transceivers: Each FBS is equipped with two transceivers. One is called a *sensing radio*, used for spectrum sensing, while the other one is called a *cognitive radio*, used for data communication of both intra-femtocell and inter-femtocell on the selected channels, so that, FBS can do spectrum sensing and data transmission simultaneously.

- Spectrum sensing and primary system protection: Each FBS is able to sense the available spectrum. Whenever an FBS detects the return of a Primary User (PU), it will then stop transmission, and inform its FUs and the neighboring FBSs about the existence of the PU. It then update the available channel list, and run the spectrum sharing algorithms to select new channels and allocate new time-sub-channel blocks for its FUs.
- Control channel: There are two kinds of control channels. One is called *inter-femtocell* control channel, whereby each FBS can communicate with each other. The other one is called *intra-femtocell* control channel, whereby each user in a femtocell can communicate with its FBS to obtain the channel information and allowed transmission power. This control channel could be a dedicated control channel or a rendezvous channel which can be selected according to some metrics such as channel availability. Since every FBS has a broadband connection to the Internet, in spite of using the inter-femtocell control channel, neighboring FBSs can communicate with each other through the broadband connection. Similarly, an additional FBS controller in the Internet can be helpful for the management of FBSs.
- Handover between Macro cell and Femtocell: Whenever an FU moves into a femtocell from a macro cell, it can detect the existence of an FBS by listening to the control channel information, and decide to switch into the femtocell network. By contrast, whenever an FU moves out of a femtocell, it can detect that the strength from FBS is weaker than the strength from macro cell BS (MBS), then it decides to switch into the macro cell network [6].

2.3 Improving Detection Performance of Cognitive Femtocell Networks

The single threshold energy detection may cause serious interference to the primary user. In order to increase the efficiency of the network, double threshold energy detection is proposed. Another detection threshold is added within the conventional single-threshold energy detection algorithm, and it becomes a double-threshold energy detection algorithm with two detection thresholds ($Vth0$ and $Vth1$). The primary user will be detected if and only if $V > Vth1$, and will not be presented if and only if $V < Vth0$, corresponding to $H1$ and $H0$, respectively. When the detected energy V is in ($Vth0$, $Vth1$], this result is invalid because of easy to mistaken. It needs re-detection.

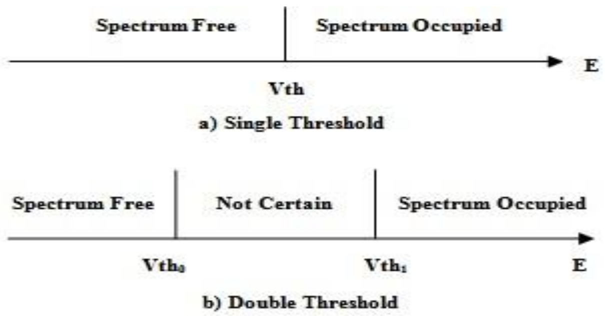

Figure 2: Energy Detection Decision [5]

The probability of collision between the cognitive user and the primary user is $p_c = p\{V ‘< V_{th0} \mid H_1\}$. It is the probability of the primary user which is not detected, but in fact it is existed, and this unoccupied spectrum will be allocated to the cognitive user. It indicates the interference of the cognitive user to the primary user because of the uncertainty of the spectrum detection. The larger the probability of collision between the primary user and the cognitive user, more serious will be the interference of the cognitive user to the primary user. On the contrary, there is less interference [5]. Double threshold energy detection algorithm can decrease the collision probability between primary user and femtocell user effectively. It avoids the femtocell user interfering the primary user.

III. DOUBLE THRESHOLD ENERGY DETECTION ALGORITHM – THE PROPOSED TECHNIQUE

In the proposed technique, the double threshold energy detection algorithm is used to reduce the collision probability between primary user and femtocell user. The received RF power is given to the FPGA platform through the power sensing unit and converter. The block diagram for transmitter and receiver is shown in Fig.3 and 4:–

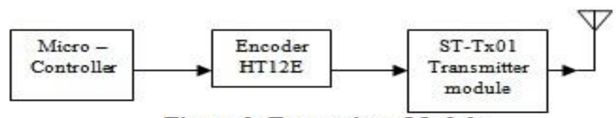

Figure 3: Transmitter Module

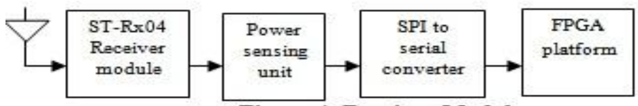

Figure 4: Receiver Module

3.1 Transmitter Module

The input data is generated using microcontroller and given to the encoder.

The encoder is capable of encoding information which consists of N address bits and 12-N data bits. Each address/data input can be set to one of the two logic states. The programmed addresses/data are transmitted together with the header bits via an RF transmission medium upon receipt of a trigger signal.

The HT12E encoder begins a 4-word transmission cycle upon receipt of a transmission enable (active low). This cycle will repeat itself as long as the transmission enable is held low. Once the transmission enable returns high, the encoder output completes its final cycle and then stops.

The encoded data is transmitted through the RF transmitter i.e. ST-Tx01 receiver module.

3.2 Receiver Module

The transmitted data is received through the ST-Rx04 receiver module and then it is given to the power sensing unit for detection RF signal.

The received RF power is converted in voltage output using IC AD8318.

The AD8318 is a demodulating logarithmic amplifier, capable of accurately converting an RF input signal to a corresponding decibel-scaled output voltage. It employs the progressive compression technique over a cascaded amplifier chain, each stage of which is equipped with a detector cell. The AD8318 maintains accurate log conformance for signals of 1 MHz to 6 GHz and provides useful operation to 8 GHz. The input range is typically 60 dB (re: 50 Ω) with error less than ±1 dB. The AD8318 is specified for operation up to 8 GHz. As a result, low impedance supply pins with adequate isolation between functions are essential. In the AD8318, VPSI and VPSO, the two positive supply pins, must be connected to the same positive potential. The VPSI pin biases the input circuitry, while the VPSO pin biases the low noise output driver for VOUT. Separate commons are also included in the device. CMOP is used as the common for the output drivers. Pin CMIP and Pin CMOP should be connected to a low impedance ground plane.

This voltage output is given for analog to digital conversion to the IC 7887 which is a 12-bit ADC.
This digital data is given to the SPI to serial converter. Then, the data is serially transmitted to the FPGA platform.

The double threshold energy detection algorithm is developed on the FPGA platform to reduce the collision probability between the primary user and femtocell user.

The simulation result will be analyzed to see the improvement in the collision probability.

4. CONCLUSION

The review of cognitive femtocell network can be concluded as follows:-

- Cognitive radio is a solution for spectral crowding problem. It introduces the opportunistic usage of frequency bands that are not heavily occupied by licensed users.
- Cognitive radio can be incorporated in femtocell networks to solve the indoor coverage problem and to improve the system performance.
- The cognitive femtocells can achieve almost twice average capacity than the coloring method.
- Co-channel interference can be reduced significantly by using cognitive radio in femtocell networks.
- It will be interesting to see how the double threshold energy detection algorithm is useful in significantly reducing the collision probability.

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