Use of Cognitive Femtocell in GSM White Space Spectrum

Kalyani R. Joshi[1]

Department of E&TC, PES's Modern College of Engineering, Pune

[1]krjpune@gmail.com

Abstract –

Radio spectrum is the basic resource to carry information for wireless networks and cyber-physical system (CPS) relies on wireless networks for devices control and information backhaul. But, the increasingly CPS wireless applications badly affects spectrum scarce situations. For the existing spectrum allocation schemes, an efficient way against spectrum scarcity is considered to be dynamic spectrum access (DSA). Cognitive femtocells, with spectrum environment observation and parameters adaption abilities, can access and share more valuable spectrum dynamically to support massive wireless service deployment.

***Keywords** – cognitive radio, femtocells, duty cycle*

I. Introduction

Due to massive network scale of CPS, the wireless networks suffer heavy traffic load. The basic resource to carry information for wireless networks is radio spectrum. Because of the exponential data growth, the efficient use of radio spectrum in CPS communication becomes necessary. The efficient spectrum utilization provides efficient spectrum opportunities for emergent technologies or services and utilizes already crowded frequency bands with better spectrum efficiency. The problem of spectrum scarcity caused by static spectrum allocation schemes is solved by dynamic spectrum access (DSA) technology.

DSA facilitates the devices to analyze the spectrum bands and access them if unoccupied until the arrival of an incumbent transmitter. Primary users (PUs) are assigned with licensed frequency bands. When PUs are absent, secondary users (SUs) can opportunistically use the spectrum in DSA scenario [4]. In order to detect the spectrum opportunities or the PUs, SUs sense the spectrum with sensors. Depending upon the sensor readings and spectrum decision algorithm, the SU decides the state of frequency band as idle or busy. Reliable PU detection is important and challenging in DSA technology. In addition to this, there are other difficulties like deployment of new infrastructure for access control, hardware support, security/privacy issues and network management. Reusing the existing infrastructures to tackle with these issues provides cost efficiency and ease of deployment. In that regard, femtocells are posed to be good candidate. Deployed at the homes or small area public places, femtocells are low power plug-and play base stations providing connectivity to the cellular operator's network via a broadband connection such as digital subscriber line (DSL) or cable [3].

Cognitive femtocells [2], with spectrum environment observation and parameter adaption abilities, can access and share more valuable spectrum dynamically to support massive wireless services deployment. Femtocells, also acting as extensible gateways for CPS, integrate CPS devices into cellular operator's networks. Hence femtocell air interface and network infrastructure enables mass deployment of CPS services. The cognitive femtocells share GSM macrocell's spectrum holes in an intra-operator manner. The spectrum holes enable the femtocells to serve the CPS devices with high capabilities.

In this paper, GSM white space spectrum measurement and its reuse with the help of cognitive femtocells deployment is studied. Also to this, effective duty cycle model (EDC) is applied which decreases PUs miss detection and interference probabilities over duty cycle (DC) model [1]. The paper is organized as follows: section II explains about cognitive femtocell, section III reviews GSM spectrum measurement architecture. The effective duty cycle (EDC) algorithm is stated in section IV and section V concludes the paper.

II. Cognitive Femtocell

The surest way to increase the system capacity of a wireless link is by getting the transmitter and receiver closer to each other, which creates more spatial reuse. Femtocells, recent less expensive concept over microcells, hot spots and distributed antennas are data access points installed by home users to get better indoor voice and data coverage. Femtocells, also called home base stations (BSs), which 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. The key advantage of femtocells is that there is very little upfront cost to the service provider. The win-win essence of femtocell approach is the subscriber is happy with high data rates and reliability and the operator reduces the amount of traffic on their expensive macrocell network, and can focus its resources on truly mobile users.

A. Technical Aspects of Femtocells:

The capacity benefits of femtocells with respect to its technical aspects are as follows:

1. Reduced distance between the femtocell and the user, which leads to higher received signal strength.
2. Lowered transmit power, and mitigation of interference from neighboring macrocell and femtocell users due to outdoor propagation and penetration losses.
3. As femtocells serve only around one to four users, they can devote a larger portion of their resources (transmit power and bandwidth) to each subscriber. A macrocell, on the other hand, has a larger coverage area (500 m–1 km radius) and a larger number of users; providing quality of service (QoS) for data users is more difficult.

The first two points illustrate the dual improvements in capacity through increased signal strength and reduced interference. The third point shows that deploying femtocells will enable more efficient usage of precious power and frequency resources [3].

B. Cognitive Femtocells:

The concept of cognitive femtocell (CF) is the combination of conventional femtocell with in accordance with cognitive radio (CR) technology. For the user, femtocells provide higher bandwidth with lower power consumption at the cost of new device instalment and broadband backhaul connectivity. Similarly, application of DSA in CRs increases the spectral efficiency and eases the penetration of new operators with novel wireless services. For the user, CR facilitates more autonomous operation with more cost-effective and personalized services. For both parties, it induces diverse challenges of hardware and software complexity in addition to the management of more complicated systems. The integrated network architecture aims to cover the best practices of femtocells and CRNs at the cost of challenges for these two concepts. This *cognitive femtocell* idea also leads to simpler and easier proliferation of CR into practical systems. The CF accesses the operator's network via wired broadband IP connection. In order to control interference on the femtocells in the vicinity and underlaying macrocell, a CF constructs the radio environment map (REM) of the femtocell by sensing its operating environment as shown in fig 1. Since the femtocell coverage region is on the order of tens of meters, the interference per frequency band can be assumed to be uniform in its coverage region due to spatial correlation [2].

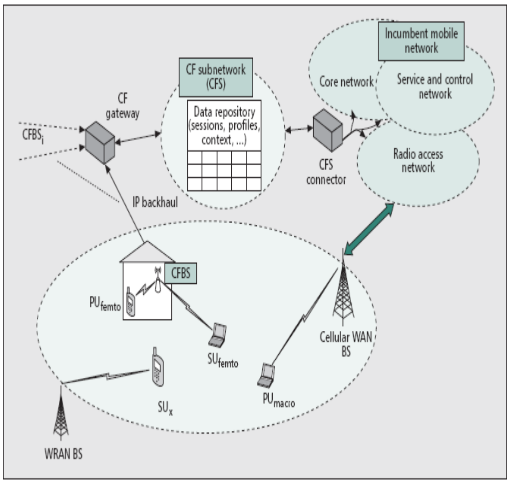

Figure 1.: Cognitive femtocell network architecture with network subsystems, SUs and PUs

III. Gsm Spectrum Measurement Architecture

It is important to get quantitative information about PUs' activities based on actual measurements in order to devise proper DSA strategies. GSM 900 spectrum band is the most ubiquitous and harmonized worldwide wireless spectrum band available today. Almost all cellular operators possess the 2G spectrum resources, particularly the GSM 900 spectrum. In markets where the 2G is reaching the end of its life cycle gradually, refarming GSM spectrum will provide new opportunities for future broadband wireless applications.

A.Uplink Signals for measurement of white space:

Measurement is the most intuitive and effective way to reflect spectrum dynamic. It is concluded that uplink signals (GSM 900UL, GSM 1800UL, UMTS UL) were hard to detect even using high-end spectrum analyzers. And for the same reason it was found difficult to accurately estimate white space capacity only with uplink spectrum measurement power due to the sensor noise. Due to low uplink transmission power and intermittent channel occupancy, the uplink cellular spectrum would be a better choice for cognitive femtocells deployment.

B. Spectrum measurement architecture:

As shown in Fig.2, a spectrum measurement framework generally contains three parts: an antenna, a receiver, and software (for instrument control and data post-processing).

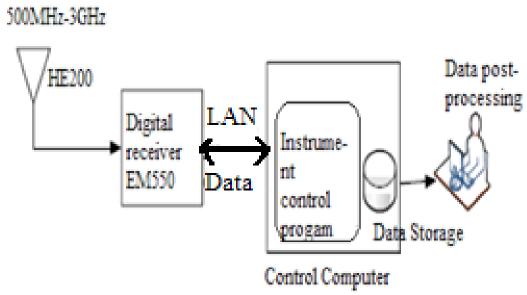

Figure 2: Spectrum measurement framework

While changing the setting of receiver's frequency span and frequency bin, it is important that the receiver can rapidly tune its internal local oscillators (LO) and intermediate frequency (IF) filters, otherwise the probability of intercepting a short duration intermittent signal may be decreased. Hence, the miss-detection probability will increase. So there is a trade off during a spectrum measurement inside a receiver (i.e., a spectrum analyzer), as equation (1):

$$T_{sweep} = k * \frac{\Delta f}{B^2_{IF}} T_{sweep} = k * \frac{\Delta f}{B^2_{IF}} \quad (1)$$

Where T_{sweep} is a minimum sweep time (seconds) required for a given frequency span Δf (Hz) and a given resolution bandwidth B_{IF} (Hz), and k is a constant proportionality factor. So through decreasing T_{sweep} of a spectrum analyzer, we can increase PU detection probabilities. And the smaller T_{sweep} is, the larger the collected data volume. So data post-processing load is heavy at a high time-granularity measurement periodicity scenario

Typically, spectrum measurement in the presence of errors performs a binary hypotheses test over a given channel (i.e., H_0 if the channel is idle and H_1 if the channel is occupied). Accordingly, the miss-detection probability δ and false-alarm probability β, can be defined as:

$$\delta = P_r [H_0/H_1] \quad (2)$$

$$\beta = P_r [H_1/H_0] \quad (3)$$

In a perfect spectrum measurement, SUs are fully aware of PUs' spectrum occupancies and consequently forbid any risky SU's access. But in real-scene GSM spectrum measurement, due to bursty and frequency- hopping protocols, high miss detection probability δ will occur. Hence, DSA in GSM white space scenario by SUs must consider true PUs' traffic patterns rather than those of the measured. In order to perform a GSM uplink spectrum measurement considering the two features, we need a spectrum measurement framework that can sense fast (e.g., simple energy detection) and detect weak signals (e.g., high receiver gain).

C.Reuse Factor:

In a GSM network planning, the frequency reuse pattern is designed to increase the capacity of channel along with the reduction in co-channel interference. In traditional GSM network spectrum planning, frequency reuse factor (*1/K*) is the rate at which the same frequency can be used in the network, where *K* (often 7) is the number of macrocells which cannot use the same frequencies for transmission. With the case of *N* channels and a reuse factor *1/K*, *N/K* channels are used in each macrocell. Hence, the potentially GSM white space capacity is *N*(K-1)/K* channels in a cognitive femtocell.

IV. Effective Duty Cycle Model

The duty cycle (DC) model describes the spectral occupancy in time dimension, expressed in terms of duty cycle. The DC can be defined from both probabilistic and empirical viewpoints. From a probabilistic perspective, the DC can be defined as the probability that the channel is busy. From an empirical perspective, the DC can be estimated as the fraction of time the channel is declared as busy [5].

A. Need of EDC Model:

To compute the DC, the presence of a PU signal needs to be determined for each voltage level compared with a threshold level [6]. However, the choice of DC model would be limited for the reuse of huge GSM white spectrum. The huge spectrum has dummy white spaces and hence more probabilities of interference between PUs and SUs. It should make sure that interference to PUs is below a limited threshold [1]. Hence, an Efficient Duty Cycle (EDC) model is proposed to validate GSM white space capacity and meanwhile guide adaptive spectrum access algorithms design. To overcome high miss-detection probability δ in capture busty GSM communication channel occupancies, we exploit spectrum clusters in GSM session processes.

B. Concept of EDC:

In the model, a constant ΔP is defined as minimum time interval between two spectrum clusters. When the distance between adjacent spectrum occupancy time samples is below the predefined value ΔP, DSA between the two samples' white space is denied. Since the two time samples belong to the same GSM session process. Such model makes SUs repetitively ask the measured data "What is the time interval between mine and last spectrum occupancy?" Time intervals less than ΔP are regarded as PU occupancy. The ΔP value can be changed adaptively according to specified PU communication protocols.

EDC model works better than DC model in high time-granularity measurement periodicity scenarios. As the measurement periodicity becomes large, the interference probability will increase. Because SUs lost most of PUs' occupancy information, the interference probability will increase correspondingly. SUs cannot recover PUs' occupancies information even with EDC model. Hence, the interference probability caused by cognitive access can only be satisfied when SUs' time-granularity measurement periodicity no coarser than variation of PU traffics. In the GSM white space case, the SU must measure the white space with a time granularity periodicity smaller than a GSM time slot.

V. Conclusion

The key insights of reframing cellular operator's own licensed GSM spectrum for cognitive femtocell deployment are documented. The availabilities of extra capacity in GSM network are investigated empirically to the design of GSM uplink spectrum measurement mechanisms. Ideally perfect spectrum measurement results can hardly be obtained due to inherent measurement tradeoffs. It is observed that there is a large scale white space due to artificial GSM network planning. Due to shortage of traditional DC model in capturing short-duration and frequency hopping signals, an Efficient Duty Cycle (EDC) model to accurately characterize the white space in GSM network traffic considering miss-detection probability in actual spectrum measurements was designed. After discussing the concept of the EDC model it is clear that it can also decrease interference probabilities at high time granularity measurement periodicity scenarios. Hence this conceptual study may provide insights and motivation to spectrum management regulators and wireless network planners.

References

1. Herranz, C.; Osa, V.; Monserrat, J.F.; Calabuig, D.; Cardona, N.; Gelabert, X., "Cognitive Radio enabling opportunistic spectrum access in LTE-Advanced femtocells," *Communications (ICC), 2012 IEEE International Conference on* , vol., no., pp.5593,5597, 10-15 June 2012
2. G. Gur, S. Bayhan, and F. Alagoz, "Cognitive femtocell networks: an overlay architecture for localized dynamic spectrum access," *IEEE Wireless Communications*, vol. 17, no. 4, pp. 62 -70,August 2010.
3. Chandrasekhar, V., Andrews, J., "Femtocells Networks: A Survey", *IEEE Communication Magazine*, June, 2008.
4. I. F. Akyildiz, W. Y. Lee, M.C. Vuran and S. Mohanty, "NeXt Generation Dynamic Spectrum Access/ Cognitive Radio Wireless Networks: A Survey," *Computer Networks Journal (Elsevier)*, vol. 50, September, 2006:2127-2159.
5. Miguel López-Benítez and Fernando Casadevall, "Spectrum Occupancy in Realistic Scenarios and Duty Cycle Model for Cognitive Radio", *Advances in Electronics and Telecommunications*, Vol. 1, No. 1, April 2010
6. Miguel López-Benítez and Fernando Casadevall, "Discrete-Time Spectrum Occupancy Model based on Markov Chain and Duty Cycle Models", *IEEE International Symposium Spectrum Acces Networks (DySPAN),* 2011
7. Vijay K. Garg, "Principles & Applications of GSM", PHI Publications.