International Journal of Innovative Technologies

WWW.IJITECH.ORG

ISSN 2321-8665
Volume.06, Issue.01,
January-June, 2018,
Pages:0351-0357

Power Strategy Optimization And Sensing of Advancing Green Communication to Enhance Energy Efficiency for CR Systems

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Abstract: Sensing and power strategy optimization is important research topics in cognitive radio systems that hold the promise of advancing green communication. This concept gives us a brief overview of the existing power allocation design in the literature and unifies them into a general power allocation framework. Based on the closed-form solution derived for this general problem, the impact of network topology on the system performance is highlighted, which motivates us to propose a novel location-aware strategy that intelligently utilizes frequency and space opportunities and minimizes the overall power consumption while maintaining the quality of service of the primary system. This work shows that in addition to exploring spectrum holes in time and frequency domains, spatial opportunities can be utilized to further enhance energy efficiency for CR systems.

Keywords: Cognitive Radios (CRs), LMSC, ICT.

I. INTRODUCTION

A cognitive radio (CR) is a radio that can be programmed and configured dynamically to use the best wireless channels in its vicinity to avoid user interference and congestion. Such a radio automatically detects available channels in wireless spectrum, then accordingly changes its transmission or reception parameters to allow more concurrent wireless communications in a given spectrum band at one location. This process is a form of dynamic spectrum management. In response to the operator's commands, the cognitive engine is capable of configuring radio-system parameters. These parameters include "waveform, protocol, operating frequency, and networking". This functions as an autonomous unit in the communications environment, exchanging information about the environment with the networks it accesses and other cognitive radios (CRs). A CR "monitors its own performance continuously", in addition to "reading the radio's outputs"; it then uses this information to "determine the RF environment, channel conditions, link performance, etc.", and adjusts the "radio's settings to deliver the required quality of service subject to an appropriate combination of user requirements, operational limitations, and regulatory constraints". The concept of cognitive radio was first proposed by Joseph Mitola III in a seminar at KTH (the Royal Institute of Technology in Stockholm) in 1998 and published in an article by Mitola and Gerald Q. Maguire, Jr. in 1999.

It was a novel approach in wireless communications, which Mitola later described as: The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs Cognitive radio is considered as a goal towards which a software-defined radio platform should evolve: a fully reconfigurable wireless transceiver which automatically adapts its communication parameters to network and user demands. Traditional regulatory structures have been built for an analog model and are not optimized for cognitive radio. Regulatory bodies in the world(including the FederalCommunications Commission in the United States and Ofcom in the United Kingdom) as well as different independent measurement campaigns found that most radio frequency spectrum was inefficiently utilized. Cellular network bands are overloaded in most parts of the world, but other frequency bands (such as military, amateur radio and paging frequencies) are insufficiently utilized. Independent studies performed in some countries confirmed that observation, and concluded that spectrum utilization depends on time and place.

Moreover, fixed spectrum allocation prevents rarely used frequencies (those assigned to specific services) from being used, even when any unlicensed users would not cause noticeable interference to the assigned service. Regulatory bodies in the world have been considering whether to allow unlicensed users in licensed bands if they would not cause any interference to licensed users. These initiatives have focused cognitive-radio research on dynamic spectrum access. The first cognitive radio wireless regional area network standard, IEEE 802.22, was developed by IEEE 802 LAN/MAN Standard Committee (LMSC) and published in 2011. This standard uses geolocation and spectrum sensing for spectral awareness. Geolocation combines with a database of licensed transmitters in the area to identify available channels for use by the cognitive radio network. Spectrum sensing observes the spectrum and identifies occupied channels. IEEE 802.22 was designed to utilize the unused frequencies or fragments of time in a location. This white space is unused television channels in the geolocated areas.

However, cognitive radio cannot occupy the same unused space all the time. As spectrum availability changes, the network adapts to prevent interference with licensed transmissions. Green Communication Challenge is an organization founded and led by Francesco De Leo that actively promotes the development of energy conservation technology and practices in the field of Information and Communications Technology (ICT). Green Comm Challenge achieved worldwide notoriety in 2007, when it enlisted as one of the challengers in the 33rd edition of the America's Cup, an effort meant to show how researchers, technologists and entrepreneurs from around the world can be brought together by an exciting vision: building the ultimate renewable energy machine, a competitive America's Cup boat. CT is helping society become more energy efficient: think of the positive impact on CO_2 emissions of telecommuting and ecommerce for example. Computers are helping us design more energy efficient products. But there is little doubt that, while other industries strive to become more energy efficient, computers and networks themselves risk becoming the "energy hogs" of the future, unless something is done.

Powering the over 1 billion personal computers, the millions of corporate data centers, the over 4 billion fixed and mobile telephones and telecommunications networks around the world requires approximately 1.4 Petawatt-hr a year (1.4×10^{15} W-hr) of electricity, approximately 8% of the global electrical energy produced in 2005. And consider that over 4 billion people around the world have never used a cell phone, almost three times as many as those who currently have access to one. Some estimates project that the above percentage will grow to 15% by 2020, but these projections may fail to take into account some of the disruptive trends we are witnessing today. Take Google for example: to power the over 75 billion searches performed in July 2009 the company needed an estimated one million servers, consuming an estimated 1.3 Terawatt-hr a year (1.3×10^{12} W-hr). The number of searches has grown over 60% between 2008 and 2009 alone.[5] It is no surprise that the company is planning to manage as many as 10 million servers in the future. The explosion of video on the net is another disruptive element. The Amesterdam Internet exchange (AMS-IX), which handles approximately 20% of Europe's traffic, saw its aggregate data traffic increase from 1.75 Petabyte per day in November 2007 to an expected 4 Petabyte per day in November 2009.

Much of this rapid increase in traffic is driven by widespread use of voice and, in particular, video over the Internet. Green Comm Challenge's founders believe that defining a corollary to Moore's Law is in order: increases in processor performance must be accompanied by a less-than proportional increase in energy consumption. This, of course, is no easy undertaking. It will require a new engineering approach to designing computers, cell phones and networks. It will also require a new management culture, capable of recognizing the attractive ROIs that green technology can generate, in addition to being more sensitive to the environmental impact of management's decisions. This is why Green Comm has fully embraced the ICT energy-efficiency challenge by establishing an interdisciplinary approach that involves some of the most innovative thinkers around the world. We are currently involved in the following four initiatives:

University of California, Los Angeles: we are coordinating the research efforts of 4 departments: Computer Science, Chemistry, Physics and Mathematics. Biology is expected to follow suit. For the first time in the history of UCLA, these teams have the opportunity to share research facilities and cooperate on Green ICT research projects. We are currently focusing on the study of new materials, superconductors, energy storage and cloud computing architectures. Last but not least, we are looking into the evolution of smart appliances, a project that promises to significantly reduce the energy consumption of user devices by eliminating hard disks and significantly "dumbing down" the processor, making it less energy hungry.

IESE, in Barcelona, is looking into the management implications of the widespread adoption of Green ICT practices. One of our goals is to educate CEOs on the following key issues: How sensitive is their business to the dynamics of the energy sector. What are the implications of energy price disruptions form a customer standpoint? Will customers be more likely to purchase their companies' products because they are more energy efficient, and respectful of the environment?

Investment Company: research by itself, while essential, will not carry the day. As members of the global business community we must be willing to invest in the future and assume risks. To this end we are planning on closing a $175M investment fund within the end of 2009. The fund will focus on the following areas:

- Cloud computing
- New-generation materials
- Machine to Machine communications, a.k.a. "the Internet of things", that is the notion that a multiplicity of device types can be allowed to communicate, making the network smarter and more capable of utilizing resources efficiently.

America's Cup: Green Comm Challenge sees the America's Cup as more than just a sailing race: it's a unique opportunity to rally some of the best minds in the world behind e very exciting goal: designing and manufacturing the ultimate renewable energy machine, a winning America's cup boat. While the future of the America's cup, at least as the multi-country competition the world had come to love, is being decided in a court of law, there is no official timeline for a competition involving the several challengers that have expressed interest in participating.[1] Green Comm Challenge remains committed to the event regardless of what venue and hull type will be chosen eventually.

II. THE PROPOSED POWER ADAPTATION SCHEME

The main functions of cognitive radios are:

Power Control: Power control is usually used for spectrum sharing CR systems to maximize the capacity of secondary users with interference power constraints to protect the primary users.

Spectrum sensing: Detecting unused spectrum and sharing it, without harmful interference to other users; an important requirement of the cognitive-radio network is to sense empty spectrum. Detecting primary users is the most efficient way to detect empty spectrum. Spectrum-sensing techniques may be grouped into three categories:

Transmitter detection: Cognitive radios must have the capability to determine if a signal from a primary transmitter is locally present in a certain spectrum. There are several proposed approaches to transmitter detection: Matched filter detection

Energy detection: Energy detection is a spectrum sensing method that detects the presence/absence of a signal just by measuring the received signal power. This signal detection approach is quite easy and convenient for practical implementation. To implement energy detector, however, noise variance information is required. It has been shown that an imperfect knowledge of the noise power (noise uncertainty) may lead to the phenomenon of the SNR wall, which is a SNR level below which the energy detector cannot reliably detect any transmitted signal even increasing the observation time. It has also been shown that the SNR wall is not caused by the presence of a noise uncertainty itself, but by an insufficient refinement of the noise power estimation while the observation time increases.

Cyclostationary-feature detection: These type of spectrum sensing algorithms are motivated because most man-made communication signals, such as BPSK, QPSK, AM, OFDM, etc. exhibit cyclostationary behavior. However, noise signals (typically white noise) do not exhibit cyclostationary behavior. These detectors are robust against noise variance uncertainty. The aim of such detectors is to exploit the cyclostationary nature of man-made communication signals buried in noise. Cyclostationary detectors can be either single cycle or multicycle cyclostatonary.

Wideband spectrum sensing: refers to spectrum sensing over large spectral bandwidth, typically hundreds of MHz or even several GHz. Since current ADC technology cannot afford the high sampling rate with high resolution, it requires revolutional techniques,e.g.,compressive sensing and sub-Nyquist sampling.

Cooperative detection: Refers to spectrum-sensing methods where information from multiple cognitive-radio users is incorporated for primary-user detection, Interference-based detection

Null-space based CR: With the aid of multiple antennas, CR detects the null-space of the primary-user and then transmits within the null-space, such that its subsequent transmission causes less interference to the primary-user

Spectrum management: Capturing the best available spectrum to meet user communication requirements, while not creating undue interference to other (primary) users. Cognitive radios should decide on the best spectrum band (of all bands available) to meet quality of service requirements; therefore, spectrum-management functions are required for cognitive radios. Spectrum-management functions are classified as:

- Spectrum analysis
- Spectrum decision

The practical implementation of spectrum-management functions is a complex and multifaceted issue, since it must address a variety of technical and legal requirements. An example of the former is choosing an appropriate sensing threshold to detect other users, while the latter is exemplified by the need to meet the rules and regulations set out for radio spectrum access in international (ITU radio regulations) and national (telecommunications law) legislation. An intelligent antenna (or smart antenna) is an antenna technology that uses spatial beam-formation and spatial coding to cancel interference; however, applications are emerging for extension to intelligent multiple or cooperative-antenna arrays for application to complex communication environments. Cognitive radio, by comparison, allows user terminals to sense whether a portion of the spectrum is being used in order to share spectrum with neighbor users. The following table compares the two:

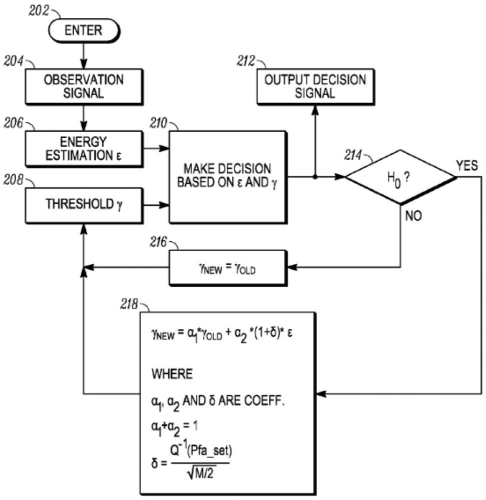
Point	Cognitive radio (CR)	Intelligent antenna (IA)
Principal goal	Open spectrum sharing	Ambient spatial reuse
Interference processing	Avoidance by spectrum sensing	Cancellation by spatial precoding/post-coding
Key cost	Spectrum sensing and multi-band RF	Multiple- or cooperative-antenna arrays
Challenging algorithm	Spectrum management tech	Intelligent spatial beamforming/coding tech
Applied technique	Cognitive software radio	Generalized dirty paper coding and Wyner-Ziv coding
Basement approach	Orthogonal modulation	Cellular based smaller cell
Competitive technology	Ultra-wideband for greater band utilization	Multi-sectoring (3, 6, 9, so on) for higher spatial reuse
Summary	Cognitive spectrum-sharing technology	Intelligent spectrum reuse technology

Note that both techniques can be combined as illustrated in many contemporary transmission scenarios. Cooperative MIMO (CO-MIMO) combines both techniques. CR can sense its environment and, without the intervention of the user, can adapt to the user's communications needs while conforming to FCC rules in the United States. In theory, the amount of spectrum is infinite; practically, for propagation and other reasons it is finite because of the desirability of certain spectrum portions. Assigned spectrum is far from being fully utilized, and efficient spectrum use is a growing concern; CR offers a solution to this problem. A CR can intelligently detect whether any portion of the spectrum is in use, and can temporarily use it without interfering with the transmissions of other users. According to Bruce Fette, "Some of the radio's other cognitive abilities include determining its location, sensing spectrum use by neighboring devices, changing frequency, adjusting output power or even altering transmission parameters and characteristics. All of these capabilities, and others yet to be realized, will provide wireless spectrum users with the ability to adapt to real-time spectrum conditions, offering regulators, licenses and the general public flexible, efficient and comprehensive use of the spectrum".Examples of applications include: The application of CR networks to emergency and public safety communications by utilizing white space. The potential of CR networks for executing dynamic spectrum access (DSA). Application of CR networks to military action such as chemical biological radiological and nuclear attack detection and investigation, command control, obtaining information of battle damage evaluations, battlefield surveillance, intelligence assistance, and targeting.

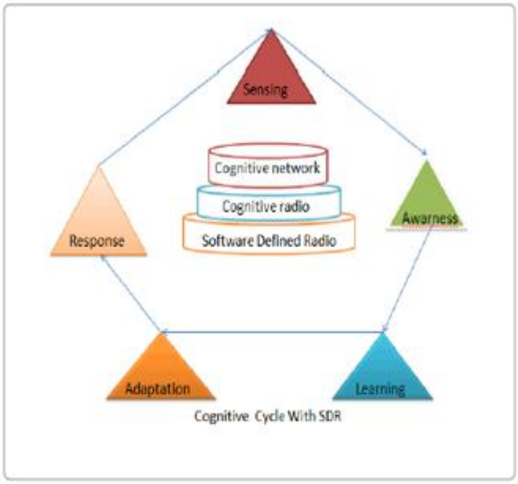
TV White Space database, also commonly referred to as **geolocation database**, is an entity that controls the TV spectrum utilization by unlicensed white spaces devices within a determined geographical area. Its sole objective is to enable unlicensed access to white space spectrum while protecting incumbent broadcasting services. TV White Space database was first brought as a way to overcome the technical hurdles faced by spectrum sensing techniques to precisely detect very weak primary signals. Spectrum is deemed available, or unavailable, to unlicensed usage depending on criteria that are regulator specific and thus the database operation can significantly vary between countries. Regulations on white space spectrum utilization are of extreme importance since they pose limits to the amount of white space spectrum that can be reclaimed by White Space technology for wireless broadband access. Having a certain degree of spectrum accessibility is crucial to the relevance and the successful adoption of TVWS as a technology. The FCC and the Ofcom were the first two spectrum regulators to draft rules enabling unlicensed access to unused TV spectrum in US and UK, respectively,. Similar actions were taken by regulators from other countries including Industry Canada and iDA of Singapore. Currently, many companies have obtained authorization to operate geolocation databases upon successfully complying to regulatory requirements.

III. THE PROPOSED SPECTRUM HANDOFF SCHEME

Cognitive radio (CR) is one of the new long term developments taking place and radio receiver and radio communications technology. After the Software Defined Radio (SDR) which is slowly becoming more of a reality, cognitive radio (CR) and cognitive radio technology will be the next major step forward enabling more effective radio communications systems to be developed. The idea for cognitive radio has come out of the need to utilise the radio spectrum more efficiently, and to be able to maintain the most efficient form of communication for the prevailing conditions. By using the levels of processing that are available today, it is possible to develop a radio that is able to look at the spectrum, detect which frequencies are clear, and then implement the best form of communication for the required conditions. In this way cognitive radio technology is able to select the frequency band, the type of modulation, and power levels most suited to the requirements, prevailing conditions and the geographic regulatory requirements.



In addition to the level of processing required for cognitive radio, the RF sections will need to be particularly flexible. Not only may they need to swap frequency bands, possibly moving between portions of the radio communications spectrum that are widely different in frequency, but they may also need to change between transmission modes that could occupy different bandwidths. To achieve the required level of performance will need a very flexible front end. Traditional front end technology cannot handle these requirements because they are generally band limited, both for the form of modulation used and the frequency band in which they operate. Even so called wide band receivers have limitations and generally operate by switching front ends as required. Accordingly, the required level of performance can only be achieved by converting to and from the signal as close to the antenna as possible. In this way no analogue signal processing will be needed, all the processing being handled by the digital signal processing. The conversion to and from the digital format is handled by digital to analogue converters (DACs) and analogue to digital converters (ADCs). To achieve the performance required for a cognitive radio, not only must the DACs and ADCs have an enormous dynamic range, and be able to operate over a very wide range, extending up to many GHz, but in the case of the transmitter they must be able to handle significant levels of power. Currently these requirements are beyond the limits of the technology available. Thus the full vision for cognitive radio cannot yet be met. Nevertheless in the future the required DAC and ADC technology will undoubtedly become available, thereby making cognitive radio a reality.



There are a number of ways in which cognitive radios are able to perform spectrum sensing. The ways in which cognitive radio spectrum sensing can be performed falls into one of two categories:

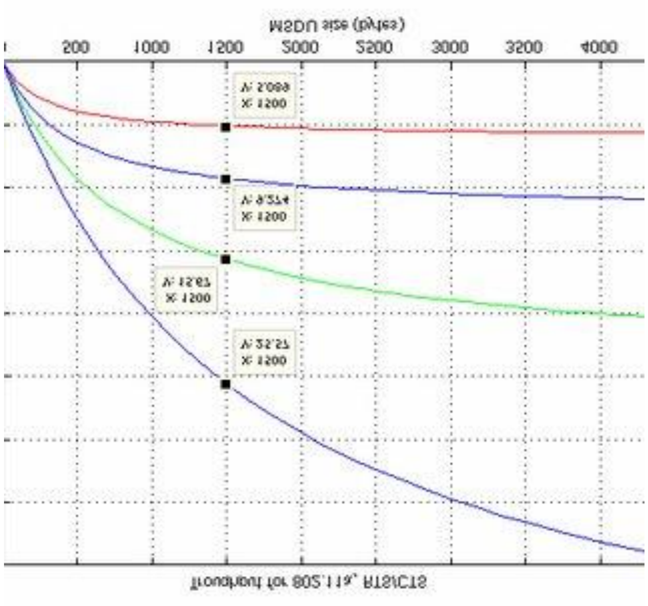
Non-cooperative spectrum sensing: This form of spectrum sensing, occurs when a cognitive radio acts on its own. The cognitive radio will configure itself according to the signals it can detect and the information with which it is pre-loaded.

Cooperative spectrum sensing: Within a cooperative cognitive radio spectrum sensing system, sensing will be undertaken by a number of different radios within a cognitive radio network. Typically a central station will receive reports of signals from a variety of radios in the network and adjust the overall cognitive radio network to suit. Cognitive radio cooperation reduces problems of interference where a single cognitive radio cannot hear a primary user because of issues such as shading from the primary user, but a second primary user acting as a receiver may be able to hear both the primary user and the signal from the cognitive radio system. Presents the proposed joint power adaptation and spectrum handoff scheme algorithm for the scenario where the SU receiver is mobile, where t is the total simulation time. The SU performs the power adaptation every δ_t. The proposed algorithm first computes the throughput S_1 and S_2 based on the current transmission scenario of SUs (i.e., saturated or unsaturated). Then, the probability of the potential PUs transmitting on the same channel with SUs can be computed using (11). The last step is to check whether it is time to the perform power adaptation and decides whether the spectrum handoff should be performed based on.

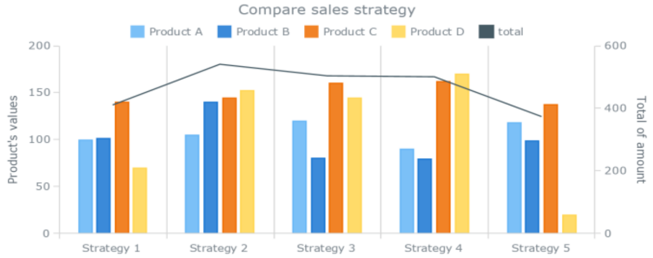
Then, the SUs have to stop the on-going transmission. There are two solutions to resume their transmissions. The first solution is that the SUs wait for the end of the PU transmission and continue to use channel 1 for transmission. In addition, another solution is that the SUs perform a spectrum handoff to use another channel [17]. In Fig., we show the example of a spectrum handoff. Since the first solution often results in a longer delay than the second solution, the second solution is used in this paper. Thus, when the PU in the additional transmission range the same channel (ch1) as the SU, the SU switches to ch2 to maintain the continuous communication. However, the locations of PUs and whether the PUs will collide with the current active SUs is unknown. In order to decide whether to perform a spectrum handoff, we first calculate the probability of having active PUs in the additional transmission range. To increase the transmission range of the SU transmitter. However, there may be active PUs which may be interfered by the SUs in the additional transmission range caused by the increase of the transmission power. Therefore, a spectrum handoff is necessary to avoid the collision between PUs and SUs. where $P_t(n)$ is the transmission power after the n-th power adaptation and P_t is the difference of the two consecutive rounds of power adaptation. Since the SU starts performing power adaptation when the distance is d_0, n starts with 0. Therefore, after increasing the transmission power, the transmission range of the SU transmitter becomes larger. However, as shown in Fig., the SU may interfere the commu-nication of PUs. Therefore, in order to avoid the interference to PUs, a spectrum handoff scheme is proposed.

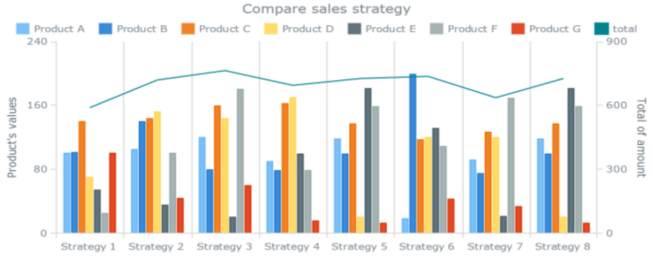
IV. PERFORMANCE EVALUATION

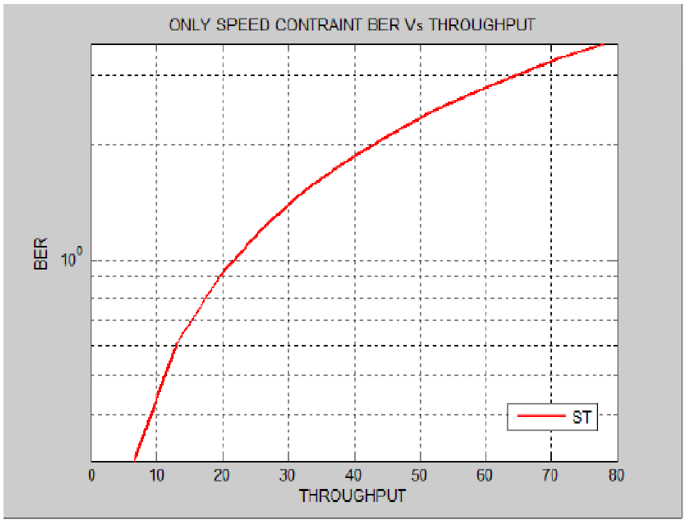
The parameters used in our simulations are listed in Table I. We assume that the SU received power is 1W in order to maintain the transmission. The initial distance between SU**.** In we use the P_{th} as the threshold to decide whether to perform a spectrum handoff. We can calculate the optimal threshold P_{th} using (17) which is equal to 0.4. SUs use this threshold to decide whether they should perform a spectrum handoff. Then, we compare the SU throughput under the optimal threshold with the SU throughput under the thresholds that are either greater than or less than the optimal threshold.



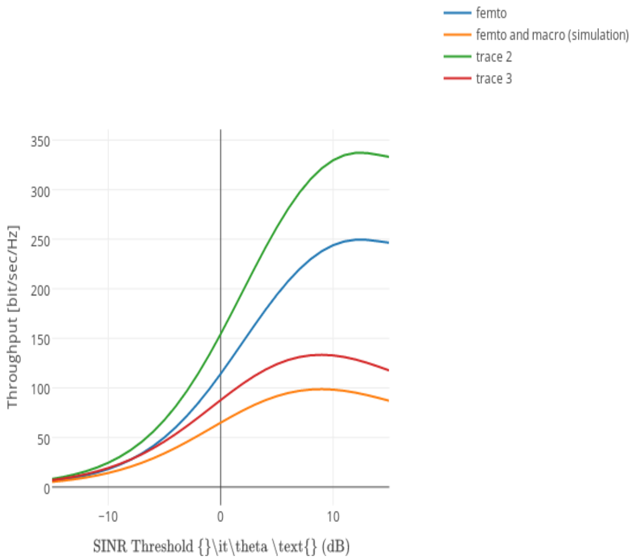
First of all, Fig. shows the simulation results of packet delivery ratio of the mobile CR network. We set λ_s as 2, 5, 10, 15, and 20 packet/s. Since the packet length is 50 time slot and every time slot is 0.002s, the service time X_s is 0.1s. From Fig., we can see when the arrive rate is 2 or 5packet/s, S_2 is equal to S_1. This is because that since the SU is unsaturated, the packet delivery rate is equal to λ_s. When λ_s is 10, 15 and 20 packets/s, we have $\lambda_s \times X_s > 1$. According to (14) and (15), the throughput S_2 is less than S_1, which is shown in Fig. From Fig., the throughput S_3 is much less than S_1 and S_2. This is because that if there is a collision with the PUs, the SUs have to wait for the end of the PUs transmission before retransmitting the collided packet. If the PUs always utilize the channel which is currently used by the SUs, the transmission of the SUs is significantly affected so that the throughput is much lower. Based on (13), we can calculate the optimal threshold P_{th}. That is, terms of the moving speed increases, the probability of the potential Pus.







In Fig., the SU throughput is shown when the threshold $P_{greater}$ is larger than P_{th}. We can see that the throughput is lower when the threshold is larger than P_{th}. Fig. illustrate the throughput in terms of the moving speed. It is shown that S_2 decreases as the speed increases. As the speed increases, the probability of the potential PUs rises due to the increase of A^*.



V. CONCLUSION

In this section, Sensing and power strategy optimization is important research topics in cognitive radio systems that hold the promise of advancing green communication a joint power adaptation and spectrum handoff scheme for mobile CR network is proposed. The proposed scheme incorporates the Based on the closed-form solution derived for this general problem, the impact of network topology on the system performance is highlighted, which motivates us to propose a novel location-aware strategy that intelligently utilizes frequency and space opportunities and minimizes the overall power consumption while maintaining the quality of service of the primary system,

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