Editorial

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Biographical notes: Xavier Fernando is a Professor at Ryerson University, Canada. He received his PhD from the University of Calgary, Alberta. He is a co-author of more than 70 research articles, a book and a patent. He is leading Ryerson Communications Research Lab. His research interests include signal processing for wireless communications. He is in the IEEE COMSOC Education Board Working Group on Wireless Communications. He has delivered invited talks worldwide. His work has won prizes including IEEE MTT Bronze Prize in 2010, second prize in Sarnoff Symposium in 2009, IEEE Toronto Section Exemplary Service Award in 2007 and Opto-Canada Best Poster Prize 2003.

Patrick Mitran is an Assistant Professor in the Department of Electrical and Computer Engineering at the University of Waterloo. He received his BEng and MEng in Electrical Engineering from McGill University as well as SM and PhD in Engineering Science from Harvard University. His interests are generally in communications, information theory and signal processing. Currently, he is mostly interested in the study of cooperation and cognition in wireless networks both from an information theoretical viewpoint as well as coding theory and signal processing perspectives. This includes such aspects as capacity analysis, distributed source/channel coding, network coding and bi-directional coded cooperation.

Lian Zhao is an Associate Professor at Ryerson University, Canada. She received her PhD in Electrical Engineering from the University of Waterloo in 2002. Her research interests are focused on the wireless communications, radio resource management, power control, rate allocation, cognitive wireless networks, wireless sensor networks, intelligent sensors and control systems.

Wireless communication is booming; the global mobile phone subscribers topped five billion in July 2010, which is expected to grow at a compound annual growth rate (CAGR) of 36.5% through 2014 [International Data Corporation (IDC), September 2010]. Therefore, we see that the demand for user-based wireless applications such as cell phones, PADs, web-friendly mobile terminals as well as autonomous wireless sensor networks keeps increasing rapidly. With the transition from principally wired communication infrastructure towards versatile, tether less anywhere communication, the perceived scarcity of quality spectrum is becoming a challenging problem that will only get worse. Next generation wireless networks will support many types of communication simultaneously, provide a mix of services and demand far greater data rates, thus increasing the demand for available quality spectrum by orders of magnitude.

Compounding this problem is the large number of legacy licensed users who were given exclusive access to their spectrum at a time when the current demands of digital wireless communication were not envisioned. This is aggravated by the fact that these legacy incumbent users under-utilise their spectral resources. Indeed, the TV broadcast band is a prime example of this, which is among the best quality in terms of propagation characteristics for serving metropolitan and urban areas due to its typical wavelength and building penetrating characteristics, yet is locked away and largely unused.

While the TV broadcast band also finds additional use in, for example, police dispatch services, recent studies have shown that in large cities, the average usage can be as low as 10%. Indeed, one FCC study in the USA has shown that in New York City, between 30 MHz and 3.0 GHz, only 13.1% of the spectrum is actually employed on average. There is no reason to believe that these statistics are unique and certainly spectrum occupancy is even less in less densely populated environments.

These facts and the growing demand for wireless data services heavily suggest that the future of wireless communications will depend on more sophisticated spectrum sharing techniques than the current dominant exclusive access approach. Indeed, some of the most utilised spectrum is the unlicensed 2.4 GHz band where the application to wireless local area networks has been an indisputable success story. Not limiting the devices that may employ the unlicensed spectrum beyond some basic sharing requirements has allowed for significant innovations in terms of technology and services provided.

Cognitive radio, or prioritised spectrum sharing, is one method to address these issues and the topic of this special issue. Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment, and adapts its internal parameters to achieve reliable communication efficiently utilising the spectrum. In a cognitive radio network, the users typically belong to two classes, primary and secondary. Primary users are the incumbents who have licensed the spectrum for exclusive access, while secondary users may only access the spectrum provided they do not interfere with the primary users.

The vital tasks for a cognitive radio in a cognitive radio network are therefore,

a identify vacant spectrum, either through sophisticated sensing techniques, coexistence features that allow the primary and secondary network to share a minimal amount of information, or geolocation techniques, and vacate spectrum when primary activity is detected

b based on identified vacant spectrum and other information, coordinate and implement efficient network formation with other secondary users.

Therefore, cognitive radio concept will change the way the radio spectrum is shared and will require enabling technologies such as dynamic spectrum access (DSA), spectrum sharing, flexible spectrum policy, and improved spectrum sensing techniques.

While the literature on spectrum sensing is vast, depending on the knowledge of the primary users, some of the techniques proposed range from energy detection, matched filter detection, cyclostationary detection, wavelet detection and can be combined with cooperative spectrum sensing and data fusion. Further techniques include coexistence features that allow the primary users to explicitly make their presence known via a beacon (e.g., IEEE 802.22.1) or in the case of TV broadcast bands, geolocation can be used to determine vacant channels.

In this special issue we investigate significant new researches that address CR technical challenges and provide insight into the most recent efforts carried out by researchers not only to overcome these difficulties but to pave the way to bring this promising technology to the market where it is expected to have the broadest impact on our life ever seen.

Current primary user detection requires secondary users to stop their communications while sensing the available spectrum before it can be used. Moreover, secondary users need to monitor the spectrum periodically to avoid interference to the primary network. The sensing and monitoring time is considered as an idle time as there is no data exchange between users. In 'Efficient detection of primary users in cognitive radio networks' by Xuetao Chen et al., an approach to detect the primary user during the communication phase of the secondary users is presented. The approach implements the concept of interference detection in the presence of a desired signal. A support vector machine (SVM) based classifier is proposed as interference detection technique to detect the primary user over a medium bit error rate and low interference to signal power ratio (ISR) which is considered as a most difficult detection case. The approach aims to minimise the idle time as well as to reduce the channel vacation time. The work shows how the idle time can be used to train the SVM during the connection initialisation phase. Their results show that 76% classification accuracy is achievable with ISR larger than –10 db and a heterogeneous sensing channel conditions.

Appropriate modelling of the spectrum occupancy by both licensed and unlicensed users is necessary to do clear system analysis in a cognitive framework. In our article, 'A continuous-time Markov chain model and analysis for cognitive radio networks', by Amir Sepasi Zahmati, Xavier Fernando and Ali Grami, a continuous-time Markov chain model is developed to better describe the radio spectrum usage. The state space vector and the transition rate matrix that completely describe the system are obtained; a steady-state analysis is performed and the stationary state probability (SSP) vector is derived. The authors investigate the inaccuracy of the existing spectrum sensing model (missed opportunities), and derive an improved expression for the maximum throughput of secondary users as a function of the primary user traffic parameters and the achieved opportunity ratio (AOR). The optimum sensing period that maximises AOR is also analytically obtained. This model is very general and applicable to systems with *N* secondary users in the vicinity of the primary user.

The article in this special issue, ‘Cross-layer design in opportunistic spectrum access-based cognitive radio networks’ by Foukalas et al. presents a cross-layer design approach for reliable data transmission over a cognitive radio network by combining adaptive modulation at the physical layer and hybrid automatic repeat request at the data link layer. The authors investigate a framework for achieving high spectral efficiency over fading channels and discuss the potential gain in applying the cross layer approach for opportunistic spectrum access (OSA). The study shows that significant improvements in spectral efficiency are achievable through a cross-layer design optimisation that follows OSA principles and utilises an optimal power adaptation policy for channel allocation. Specifically, this work introduces a robust approach that is suitable for deployment in wireless communication networks that encompass cognitive capabilities. We may consider this approach as the core technology in satisfying future user demands for guaranteed quality of service (QoS) requirements posed by the variety of applications running on the mobile devices.

The next generation wireless networks will provide end-to-end service through heterogeneous communication networks using heterogeneous access technology and channel environment. The information available from such networks is known to be incomplete and heterogeneous. Neuro-fuzzy logic-based algorithms can make intelligent decisions based on such incomplete and heterogeneous information. These algorithms are usually fast in their computations due to their intrinsic parallel processing. Our next article shows how the self-learning, self-organising, and self-tuning capabilities can be combined in a single scheme to enhance future spectrum access technologies and hand-off (HO) controllers. The article, ‘Neuro-fuzzy-based hand-off and opportunistic spectrum access for cognitive cooperative network’, by Kaiser and Ahmed provide an overlook into future wireless network design challenges and investigates neuro-fuzzy-based opportunistic spectrum access and spectrum hand-off for cognitive cooperative networks (CCN). The study aims to increase the average throughput and to reduce the outage probability of cognitive radio networks. NF-based algorithms enable each secondary user to determine the most appropriate channel for its data transmission. The Mamdani-adaptive neuro-fuzzy interference system (M-ANFIS) is implemented to construct spectrum access and HO controller models. The study shows how to maximise the channel capacity for the secondary network operation while keeping the secondary users transmission power below the interference temperature via implementing an intelligent power control scheme.

The problems of reporting channel bandwidth limitations in cognitive radio networks are investigated in our article ‘On the throughput performance of cluster-based cognitive radio networks’ by Sattar Hussain and Xavier Fernando. The authors investigate a distributed spectrum sensing scheme that eliminates the need for a base station and replaces it with a local master fusion centre. A cluster-based cooperative spectrum sensing approach that reduces the usage of the reporting channels is introduced in this work. The minimal dominating set (MDS) approach is used as a clustering scheme. The study shows how the sensing efficiency, sensing accuracy, and per-node throughput are affected by the various parameters of the clustering approach. A systematic way to find an optimal number of cooperative clusters that gives a minimum probability of false alarm is presented. In addition, an optimal sensing time is obtained for maximum per-node throughput capacity. The work reveals that under bad channel conditions, it is not necessary to include the entire cooperative user for the best performance. Instead, an optimal number of clusters that gives a minimum probability of false alarm and consequently a maximum per-node throughput is obtained. When this optimal number matches the minimal dominating set, the reporting channel bandwidth requirements are also achieved. A maximum per-node throughput is also obtained corresponding to an optimal sensing time for different values of error probabilities.

Efficient cognitive modulation techniques that can take advantage of the dynamic and heterogeneous vacant spectrum are also important. In 'OFDM/OQAM modulation for efficient dynamic spectrum access' by A. Skrzypczak, J. Palicot and P. Siohan, we show that OFDM/OQAM may be a serious candidate for the spectrum insertion problem in cognitive radio network. The work discusses the flexibility in frequency offered by a multicarrier modulation (MCM) that can be exploited by OFDM/OQAM modulation techniques. The fact that well localised frequency pulse shape can be employed makes this modulation attractive for an optimised dynamic spectrum insertion. As the detected bands of frequencies can have different width, the retained modulation should be able to transmit on any bandwidth. From this, MCM seems to propose a more flexible and more dynamic solution compared to the single carrier modulation techniques as the signal bandwidth is directly linked to the number of carriers. Specifically, the modulation scheme should fit with the transmission over frequency selective channels. The study also reveals that the generated power spectra introduce quite limited interference to the primary user.

The next article, 'Differentiated service provisioning in the MAC layer of cognitive radio mesh networks' by Kiam Cheng How, Maode Ma and Yang Qin, proposes a MAC-layer QoS provisioning protocol (MQPP) for IEEE 802.11-based cognitive radio networks to support differentiated service in wireless mesh networks. The study shows how to achieve significant improvements in terms of lower delay and higher throughput by combining adaptive modulation and coding (AMC) algorithms with dynamic spectrum access techniques. Moreover, MQPP provides clear service differentiations for different traffic classes under all traffic loads. The proposed model contributions can be summarised in two points:

1 using a hierarchical adaptive MQPP by cognitive nodes to provide a differentiated service for different types of traffic via varying the transmission power to increase the signal to interference noise ratio

2 distributing the traffic to a vacant frequency spectrum when a desired data rate is unattainable via power control.

The proposed scheme has several advantages over the existing solutions. First, costly switching delay is avoided by utilising AMC as a prime option. Second, vacant channels are identified to support the data transmission rate required by high priority traffic when AMC is insufficient. Moreover, by identifying the vacant channels through the use of cognitive radio techniques, the noise effectiveness can be mitigated by distributing network traffic across multiple vacant channels to reduce the node density per transmission channel.

In summary, we present a collection of articles that investigate critical approaches introduced for cognitive radio-based wireless communications. Most of the technical challenges discussed in these articles will be the core subject of much future research.