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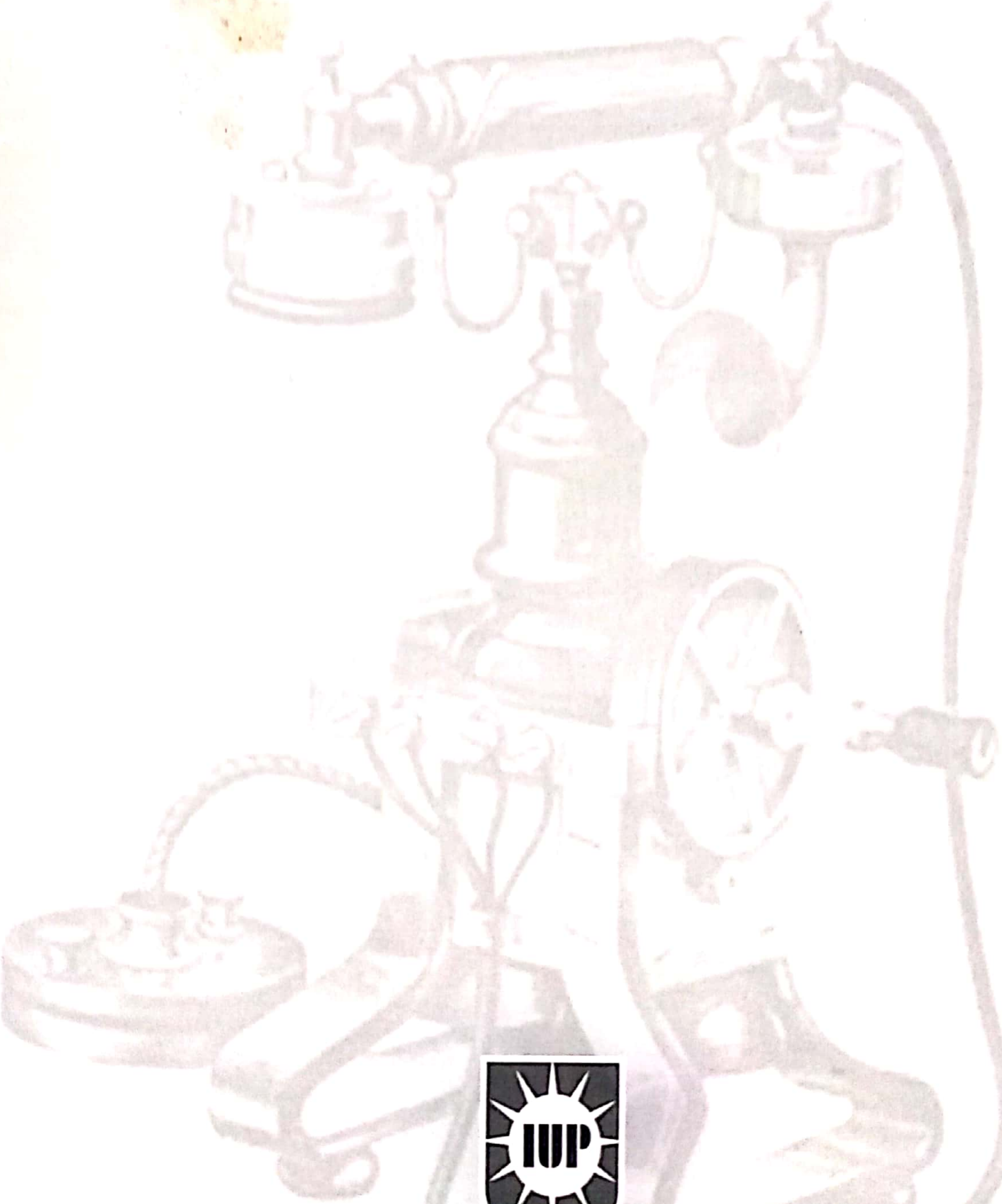

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Focus

New demands of 3G and 4G wireless standards require processing of various air interfaces and signal processing functions onto a single programmable radio module comprising suitable hardware and software components. Further, the proliferation of various wireless standards on a single usable mobile equipment needs a hardware circuitry to support multiband and multi standard network accessibility at a minimum usable power. Obviously to meet such requirements, conception of Software Defined Radio (SDR) is growing as a core technology in wireless communication. This technology enables the users to download software of a radio to switch over to a band of spectrum of a new standard to access the desired network. These mobile instruments use programmable chips, including general purpose DSP and FPGAs with tunable RF filters and other components to generate and process the signal in any desired radio band. Some recent trends in modern wireless technology are also getting attention towards enhancement of the spectral utilization through new wireless standards based on adaptive spectrum sensing, cognitive radio, etc.

The papers in the current issue address some of the research problems related to radio coverage, digital radio generation, spectrum utilization through cognitive radio networks and capacity enhancement in ad hoc mobile networks followed by a problem of transient reduction in signal generation for image compression.

The first paper, "Spatial Coverage of FM Radio Transmitter in Niger State, Nigeria", by M O Ajewole, O D Oyedum, A T Adediji, J O Eichie and A S Moses, reports the measurement of electric field strength of Frequency Modulated (FM) radio signals from Crystal FM, Minna, on 91.2 MHz and Power FM, Bida, on 100.5 MHz in Niger State, Nigeria. The authors have used Digital Signal Level Meter, GE-5499 to measure the signal strength in the signal range of 30-120 dBμV to determine the coverage areas of the Niger State and concluded that the configuration of the FM radio transmitters in the Niger State does not give optimum coverage in the State.

In the second paper, "Digitally Controlled Oscillator with Novel Variable Capacitance NAND Gate", the authors, Manoj Kumar, Sandeep K Arya and Sujata Pandey, have presented a design of a Digitally Controlled Oscillator (DCO) based on delay cells involving three-transistor NAND gate. They have used two design approaches based on three, five and seven-stage DCO and a four-bit controlled DCO. The first approach showed better results in terms of power dissipation, whereas the second showed wider range of output frequency. The findings of the study claim superiority of DCO over Voltage Controlled Oscillator (VCO) in All Digital Phase Locked Loop (ADPLL) design.

The concept of Cognitive Radio (CR) emerges due to the functionality of SDR by sensing and adopting new unused band of spectrum if that spectrum is not used by the primary users. However, such idle spectrum cannot be used if the primary user begins to communicate. The authors, Johnson Adegbenga Ajiboye and Yinusa Ademola Adediran in their paper, "Cognitive Radio Networks, a Key Technology of Future Wireless Communication: Challenges and Opportunities", have presented an overview of CR Networks. They have emphasized that the current approach of fixed spectrum allocation makes the spectrum resource to be underutilized, thereby creating spectrum holes which can be harnessed using CR.

The fourth paper, "Analysis and Optimization of Dynamic Source Routing Protocol for Wireless Mobile Ad Hoc Networks", by C C Uzoh, J Onubogu and K Akpado, reports a triangular mesh theory to create a model for the analysis of conventional Dynamic Source Routing (DSR) protocol in wireless ad hoc networks. The DSR protocol has been analyzed using animations and ad hoc DSR-enabled network designed with the MATLAB interactive tool and QualNet Simulator respectively. The analyses, optimization and simulations of DSR protocol for mobile ad hoc networks have provided more clarity in the wake of presenting the protocol as a global standard.

The final paper, "Reducing Color Transients in Monoscope Signal Generator by Analyzing and Correcting Signal Waveforms", by Sarika Malhotra, R K Singh and Sayed A Imam, reports a monoscope-based solution for the geometric aspects in the display panels, including the vertical and horizontal alignment and resolution issues. The authors have presented a technique to detect the presence of color transient interference in the signal by analyzing the signal waveforms on oscilloscope. They have also suggested a suitable measure to suppress and reduce the transient effect on the quality of the signal.

V K Chaubey
Consulting Editor

Cognitive Radio Networks, a Key Technology of Future Wireless Communication: Challenges and Opportunities

Johnson Adegbenga Ajiboye and Yinusa Ademola Adediran***

It is a well-known and established fact that the current approach of fixed spectrum allocation, the command-and-control model, makes the spectrum or the finite resource to be grossly underutilized or inefficient. There are so many bands of the spectrum already licensed to users but which in reality are unoccupied at some instance in time thereby creating spectrum holes. These are 'opportunities' that could be harnessed. Cognitive Radio (CR) is a promising technology being envisioned to solve the problem of spectrum underutilization and allows for real-time spectrum management. The CR, in a noninterference basis, opportunistically explores the unused channel, thereby ensuring efficient usage of this 'scarce' resource. The CR is a sure technology for the next generation wireless systems. In a CR, a licensed user, also called a Primary User (PU), has a priority over the Secondary User (SU) which has no spectrum license. Therefore, at the arrival of a PU, an opportunistic SU vacates the occupied channel and seeks another empty channel to be allocated. In this way, spectral efficiency is greatly enhanced. In this work, we examine the challenges that this new technology is bound to face.

Keywords: Cognitive Radio (CR), Primary user, Secondary user

Introduction

In 1999, Cognitive Radio (CR) idea was first introduced by Joseph Mitola III, a well-known industry figure, and was well-accepted and promoted by the Federal Communications Commission (FCC) later. It was defined 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: (a) detect user communication needs as a function of use context; and (b) to provide radio resources and wireless services most appropriate to those needs" (Wang *et al.*, 2010). CRs therefore are radio systems that continuously perform spectrum sensing, dynamically identify unused ('white') spectrum, and then operate

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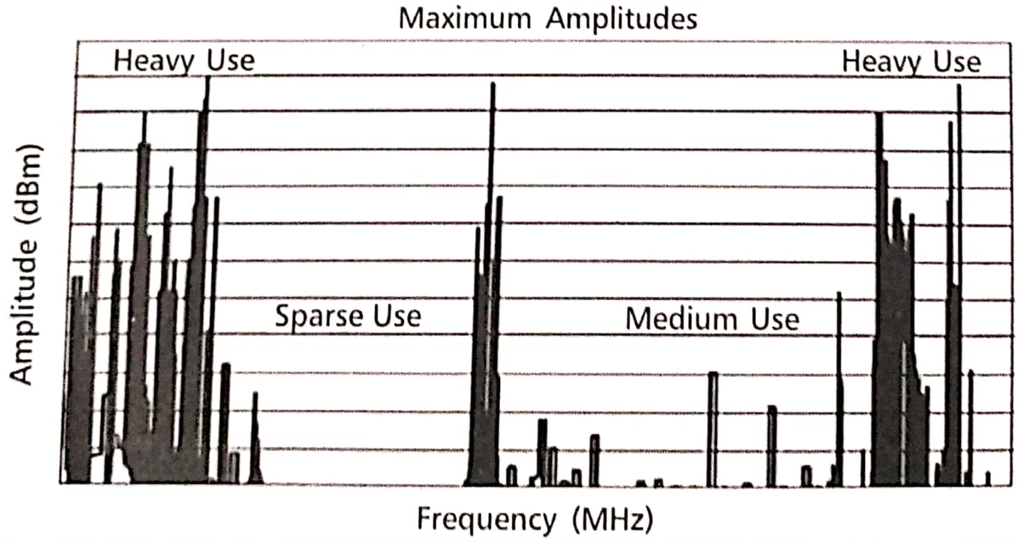
in this spectrum at times when it is not used by incumbent radio systems. A CR is a wireless communication system that is aware of its environment. There has been a geometrical growth in the number of devices based on multiple wireless standards and technologies (Liu and Wang, 2011). Though this growth is being appreciated, there are, however, newer problems or rather new challenges to be faced. One of the major challenges is that there is a scarce radio spectrum. Another challenge is that dissimilar radio systems are difficult to coexist in a shared spectrum (Berlemann and Mangold, 2009).

The CR aims to bridge up the gap between the scarcity of wireless spectrum resources and underutilization of the licensed spectrum. In CR, a Secondary User (SU) is simply an opportunist, taking control of the Primary User's (PU) spectrum or channel when it is idle. However, the SU is aware of this and monitors the PU in such a way as to avoid any interference when the SU becomes active. In this way, a highly efficient economical use of the frequency spectrum is being achieved.

Therefore, a CR can automatically select and use the best in terms of Quality of Service (QoS) for a radio transmission and also the cheapest service in terms of cost. The CR, in addition to this, has the ability and capability to delay or bring forward certain transmissions depending on the currently or soon to be available resources. The learning and reasoning capabilities of CR are expected to fulfill this exciting goal which would be implemented in software. CR is an intelligent wireless communication concept expected to solve the problem of spectrum scarcity (Amini *et al.*, 2008). This concept however, incorporates many ideas from several already existing research fields. In fact, one of the driving forces behind the rise of the CR concept has been the increased resource demand of new types of wireless networks, including mobile ad hoc networks and wireless meshes.

Figure 1 shows the gross underutilization of the radio frequency spectrum being caused by the current static allocation policy on spectrum usage (Tumuluru *et al.*,

Figure 1: Radio Frequency Spectrum Usage



2009). The rapid proliferation of wireless technologies is expected to increase the demand for radio spectrum. Recently, FCC opened up sub-900 MHz TV band to unlicensed services because of high underutilization of these bands (Sengupta *et al.*, 2007). However, for unlicensed SU devices to gain access to these bands, it is required that these devices detect licensed users or PU and avoid interference. Radio communication employs a transmitter to encode information and generate radio waves, and a receiver is used to detect and decode the signal. The electromagnetic waves occur at low frequencies in the range of 3 Hz to 30 GHz, and are being propagated through the air.

Aim of Research

CR technology is a promising technology being envisioned to address the current problem of spectrum usage. It is expected to be a technology that will be acceptable to all, as it will not cause any 'harm' to the licensed users of the spectrum, hence priority is given to the licensed PUs. The aim of this research is to review some of the early works on CR technology and consider a number of the research technology challenges that need to be solved, in order to deploy this new technology in realization of the practical implementation.

Review of Related Work

A new spectrum handoff approach for multiple channels CR networks to support delay sensitive applications, such as VoIP, has been proposed (Lertsinsrubtavee *et al.*, 2008). In their work, several spectrum handoff approaches for multiple channels CR networks in order to support delay sensitive applications were proposed. CR users calculate the delay probability density function and decide whether to perform a handoff operation. Furthermore, they introduce a novel backup channel technique to reduce the impact of error prediction on the handoff operation. Liu *et al.* (2011) also developed a novel approach for authenticating PUs' signals in CR networks, which conforms to FCC's requirement. Their approach integrates cryptographic signatures and wireless link signatures (derived from physical radio channel characteristics) to enable PU detection in the presence of attackers. To gain unfair share of radio channels, an attacker (e.g., a selfish SU) may mimic a PU's signal to evict other SUs. Therefore, a secure PU detection method that can distinguish a PU's signal from an attacker's signal is required.

Cooperative radio resource management for multiple CR networks in interference environments was investigated (Xie *et al.*, 2007). The objective of the research was to manage shared radio resources fairly among multiple noncooperative CR networks. An emphasis was on the underlying predictability of network conditions and management solutions tailored to different interference environments. A multi-agent-system-based approach is proposed to achieve information sharing and decision distribution among multiple CR networks in a distributed manner.

An opportunistic scheduling policy for CR networks that maximize the throughput utility of the SUs (unlicensed) subject to maximum collision constraints with the PUs (licensed) was developed (Urgaonkar and Neely, 2010). A cognitive network with static PUs and potentially mobile SUs was considered. Lyapunov Optimization technique was utilized to design an online flow control, scheduling and resource allocation algorithm that meets the desired objectives and provides explicit performance guarantees. Huang *et al.* (2011) considered a scenario where SUs can opportunistically access unused spectrum vacated by idle primaries. They introduced two metrics to protect primary performance, namely, collision probability and overlapping time, and also presented three spectrum access schemes using different sensing, back-off, and transmission mechanisms. They showed that indistinguishable secondary performance under given primary constraints was achieved. They also provided closed form analysis on SU performance, presented a tight capacity upper bound, and revealed the impact of various design options, such as sensing, packet length distribution, back-off time, packet overhead and grouping. Their work sheds light on the fundamental properties and design criteria on opportunistic spectrum access.

A study of the fundamental trade-off between sensing capability and achievable throughput of the SUs was done (Liang *et al.*, 2009). A study of the design of sensing slot duration to maximize the achievable throughput for the SUs under the constraint that the PUs are sufficiently protected was done. Using energy detection scheme, they proved that there indeed exists an optimal sensing time which provides the best trade-off. Cooperative sensing is also studied based on the methodology of the proposed sensing throughput trade-off. A computer simulation was presented to evaluate the proposed trade-off methodology. Salameh and Krunz (2009) worked on improving spectrum efficiency through opportunistic spectrum access. CRs have been proposed as a key enabling technology for such an opportunistic policy. One of the key challenges to enabling multihop CR communications is how to perform opportunistic medium access control while limiting the interference imposed on licensed users. In their work, they highlighted the unique characteristics of multihop CR networks, discussed key MAC design challenges specific to such networks, and presented some of the work that has been done on MAC design for CRN's (Salameh and Krunz, 2009). The significant underutilization of the spectrum has inspired many research works to pay efforts to the CR technology (Mishra *et al.*, 2005; and Zhang *et al.*, 2010). According to Arslan (2007), "technologies that enable continued growth include adaptivity, smart antenna technology, and more efficient use of existing spectrum". The CR technology aims to achieve these.

Cognitive Radio: Challenges

For this new technology to be implemented, some challenges must be overcome. The challenges require development of CR technologies like spectrum sensing. The greatest challenge of spectrum sensing is being able to develop sensing techniques that is capable of detecting very weak PU signals. A new wireless PHY and MAC layer design is also envisaged. A CR network is expected to require a very large amount of network (and channel) state information to enable efficient discovery, self-organization and cooperation techniques. Certainly, this will pose a serious challenge for the future generation technology.

In addition to the required advances in CR technology, network architectures, hardware requirements and information aids that support, these are the challenges that will surely confront this new technology. There is a need to design radios that are reliable and capable of sensing the spectral environment over a wide bandwidth and also able to detect the presence/absence of legacy PU and access the spectrum only if the communication does not cause interference with PU. There is need for a reliable and intelligent coordination mechanism that will permit coexistence and cooperation within the network.

Spectrum servers will be a basic requirement in ensuring sharing of the scarce resource. The function of these servers will be to advice and mediate on how the sharing will be done. Obviously, this is an important and a core task in the CR network. These servers with software capabilities must be intelligent enough to make the actual decisions on how the spectrum is shared. Through the use of logical systems, it should be able to make logical inferences and conclusions, and through sensing and measurements, it should be able to utilize its experience for the planning of future actions and also adapt to improve the overall communication quality and satisfy the user's needs.

Cognitive control channel is necessary in the spectrum coordination mechanisms. A cooperative coexisting multi-radio system with terminal devices equipped with SDR capability is essential in CR networks. This is also a challenge to the CR technology.

Routing in CR networks is another basic challenge. Links vary much more rapidly. Duration of available link is only a fraction of inter arrival time for control packets and traffic. CR nodes may only transmit in one time duration. Network security is a problem in CR networks, since CR node may not have enough time to get a secure certificate within the short opportunistic time frame it has.

CR networks consist of CRs and nodes from various coexisting networks. These may operate using different communication parameters, in different frequency bands, and in different geographical locations. Hence, CR shares spectrum with different types of systems. The CR must be able to deal with different RF spectrum and baseband varieties concurrently. This, therefore, requires a more efficient, robust and reconfigurable hardware architecture. Expectedly, this will pose many challenges across all the layers of a CR system design, e.g., spectrum sensing, resource allocation, interference management, RF design and implementation issues.

Future mobile terminals are expected to be able to communicate with various heterogeneous systems which are different by means of the algorithms used to implement baseband processing and channel coding. New protocols and algorithms for spectrum sharing are therefore required. The flexibility in the spectrum access comes with an increased complexity in the design of communication protocols at different layers. This impacts greatly on both the hardware and software requirements for a CR network. The challenge therefore lies in being able to design and implement flexible and energy-efficient architectures.

Investigation is continuing on different techniques that can be deployed in CR to be able to reuse locally unused spectrum to ensure increase in the total system capacity. The ultimate aim is to develop efficient algorithm. The algorithm should be able to maximize the QoS for the opportunistic SU (unlicensed user), while minimizing the interference to the PU (licensed user).

There is also a need for policy and regulatory changes in order to deploy CR technology and overcome the existing barrier.

Conclusion

CR has a great advantage with regard to spectrum utilization and, therefore, it is expected that this advantage will be harnessed in the future wireless networks. CR ensures that spectrum licensing and assignment becomes more dynamic. The result is that there will be greater flexibility in responding to emerging demands or needs of the information society as well as to market demands. The CR will utilize an approach that tries to bridge the gap between the two extremes of unlicensed open spectrum and the command-and-control licensing schemes. With a change in the current regulation and with a more flexible regulatory framework, CRs will improve capacity, efficiency, coverage and QoS of future radio networks. This work has given in-depth challenges and the 'hurdles' that must be addressed to make CR technology a reality.

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