

Cognitive radios: The future of SDR technology

By Dr. Bruce Fette, Ph.D.

The future of two-way radio communication lies in the ability to use a single device to network with other types of devices while intuitively maximizing limited bandwidth and harnessing the power of flexible and adaptive software-based protocols. That future – the Cognitive Radio (CR) – is drawing closer, thanks to Software-Defined Radio (SDR) technology.

Cognitive radios will learn and autonomously perform “cognitive” functions as a form of intelligence that comes from their ability to be defined and upgraded using software. SDR is the foundation upon which cognitive radio will be built. To understand cognitive radio, we first must take a look at SDR.

The term *SDR* was originally coined by DARPA’s chief scientist, Dr. Joe Mitola, who saw a graduation of technologies that began with the hardware-defined radio and evolved into the digital radio and the software-defined radio in which all applications can be configured by software. The Software Defined Radio Forum (SDRF) has been working with this technology for several years and similarly defines SDR as a *radio in which the software manages and controls the radio’s waveform properties and applications*. Furthermore, an SDR is reprogrammable and may be upgraded in the field with new capabilities.

One of the SDRF’s functions is to define the standards by which those upgrades can be performed so that new technology can be harmoniously integrated into the radio after it has been fielded without completely replacing all the previous hardware functionality. These standards will allow equipment developers and, eventually, users to enhance the capabilities of their equipment. Because SDRs can be upgraded, bugs can be fixed and additional functions can be delivered to customers, creating incremental value.

SDR technology standardizes the architecture and supports a wide variety of modulation strategies, access strategies, and protocols as well as higher-level systems protocols such as trunked radio (a system used by local government and industry to operate private systems when a large number of mobile radios need to share frequencies), satellite communications systems, and even wireless access.

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The US military has embraced the properties and characteristics of SDR technology by way of the Joint Tactical Radio System (JTRS) initiative, which will bring communications interoperability to each of the armed services across all of their platforms. JTRS software-defined radios can fulfill multiple military communications functions and will ultimately be small enough to integrate into miniature robotic devices or body electronics worn by soldiers. Today, some 20,000 SDRs are being used by the US military and government agencies including the US Navy’s Digital Modular Radio (DMR), combat search and rescue radios, and specialized radios for government agencies in law enforcement and Homeland Security applications. SDR technology will improve interoperability among military services, coalition partners and public safety officers while solving bandwidth problems by reducing the number and types of radios required to accomplish operational objectives.

From SDR to CR

CR builds on SDR technology. It represents an SDR with not only the ability to adapt to spectrum availability, protocols, and waveforms but the capability to *learn*

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CR technology enables the radio itself to learn, allowing it to perform “cognitive” functions such as identifying and using empty spectrum to communicate more efficiently. CRs will sense and adapt their behavior according to the environment in which they operate. Once there is an embedded machine in which the software implements the protocols programmed for it, the radio is able to be smart and alert and it can “negotiate” with its environment. For example, a CR would learn about various services of interest to its user by being aware of its user’s activities. The radio knows how to find those services and knows the likelihood that some services will be of interest to the user in the immediate area. For instance, a CR could be aware of a Bluetooth network and what is available and of interest to its user within the Bluetooth service zone. It could also be aware of what’s available in a wireless LAN range, cell phone range and so on.

How does a CR get that smart? The defense community refers to a process called the OODA Loop – Observe, Orient, Decide, and Act. This is similar to the process humans perform as they go about deciding what to do in a situation. Those concepts can be extended to include planning and learning in the cognition cycle. The CR may do many of these kinds of things. It may observe and orient itself to the spectrum environment and decide and act on certain needs and wants of its user.

Academic research, industrial research, and research in the Department of Defense will synthesize new protocols, *etiquettes*, and technologies in the form of software that’s integrated into the CR. SDRs and cognitive radios must use etiquettes to know when it’s appropriate to interact and how to interact with their environment.

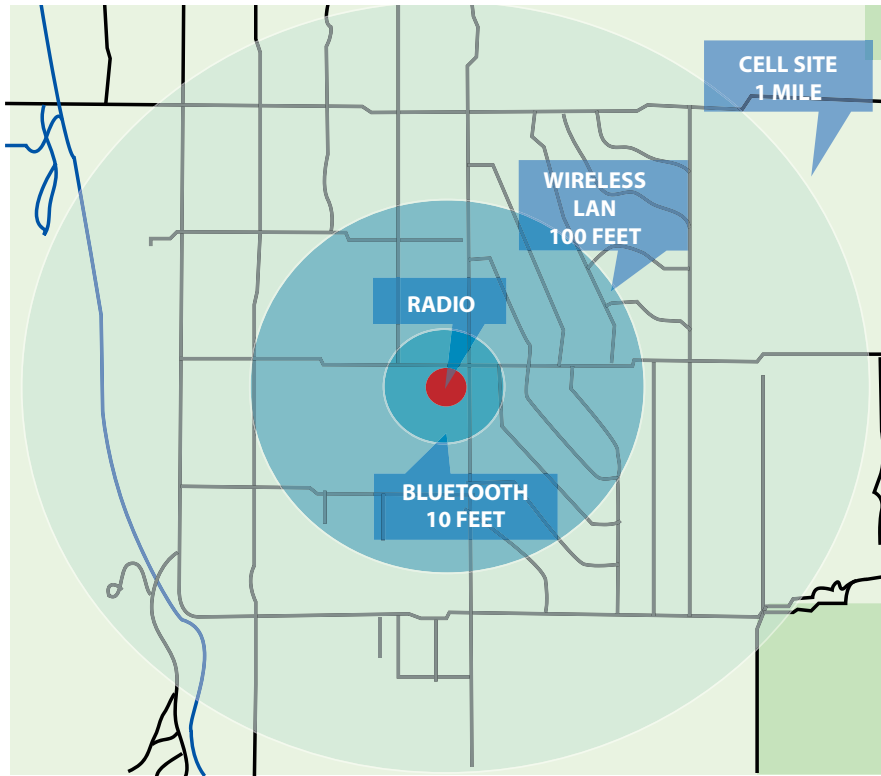


Figure 1

Figure 1 shows a representation of what a cognitive radio knows:

- Where it is
- Which services are available – can identify and then use empty spectrum to communicate more efficiently
- Which services interest the user – and how to find them
- The current degree of needs and future likelihood of its user’s needs
- How to learn and recognize usage patterns
- How to apply *Model Based Reasoning* about user needs, local content, and environmental context

Technology drivers and infrastructure

Key embedded technologies essential to evolving the SDR into a CR will include DSPs that, among other functions, manage modulation, cryptography, protocols, and source coding for voice, data, and imagery. High-density FPGAs are enabling shared, in-system reconfiguration and are the workhorses that change waveforms and adjust performance characteristics, frequency, power regulation, and other attributes. General Purpose Processors (GPPs) must manage more complex modem and operating environ-

ment controls that include the Software Communications Architecture (SCA), CORBA, and Real-Time Operating System (RTOS). GPPs will need to have significantly increased processing functionality while keeping size and power consumption to a minimum.

As the embedded enabling technologies advance core radio functionality, the next step in CR will be the application of two basic communication “etiquettes”: infrastructure and spectrum awareness. These two etiquettes will determine *when* it’s appropriate to interact and *how* to interact with the communication environment – the “smart” part of the cognitive radio.

Infrastructure supports the radio’s ability to manage policy, which is the regulatory governance (like the FCC) that defines user requirements pertaining to which frequencies are available for which purposes, which power levels may be used, and modulation and access permissions. Historically, infrastructure has proven to be a powerful tool in improving communication

system performance, particularly for trunked radios, cellular spectrum borrowing, and demand-defined multiple access. For the defense community, the most common infrastructure is Demand Assigned Multiple Access (DAMA). More than 30 years old and fully mature, the DAMA system processes and grants military communication user requests for a certain amount of time and bandwidth, thereby enabling a voice, data, image, or other communications events.

Spectrum awareness is based on waveform *orthogonality*, meaning that waveforms are intentionally designed to minimize interference between multiple users. Waveform differentiation can be found in time, frequency, code, modulation, and antenna beam-forming techniques. Orthogonality is particularly important for military applications, such as the Navy’s DMR.

In Figure 2, the DMR can identify a number of existing signals in the frequency, spectrum, space. It identifies the frequency and modulation type of the signal and it tracks the signal. At the top of the screen in the figure, there is a green and red bar. The activity levels of the signals from the last 10 seconds are measured, providing a way to identify an occupied or unoccupied channel. When the user releases the channel, it is immediately free for another user on the same frequency. It also indicates that new waveforms may occupy the open frequency in this spectrum space. Orthogonality is particularly important considering the number of waveforms associated with military and coalition communications.

What CR will do

To recap, CR infrastructure awareness indicates the radio’s ability to operate



Figure 2

according to policy. Spectrum efficiency optimizes radio performance by a number of factors based on orthogonality in the dimensions of time, frequency, code, or modulation.

The cognitive radio will also be capable of sensing, responding, and determining optimal responses to network and geographic operating conditions. Take, for example, an ad hoc network, which is a popular and pervasive network architecture (Figure 3). For an ad hoc network, when node “A” wishes to communicate with node “Z,” it doesn’t need to generate a *transmit* signal strong enough to cover the entire distance between the two nodes. Rather, node “A” sends a signal strong enough to communicate to an available node that is along the path to “Z”; this reduces power and saves energy. By moving along the path from open node to open node, the information bypasses potential delays caused by the transmission “waiting” for “busy” nodes to become available.

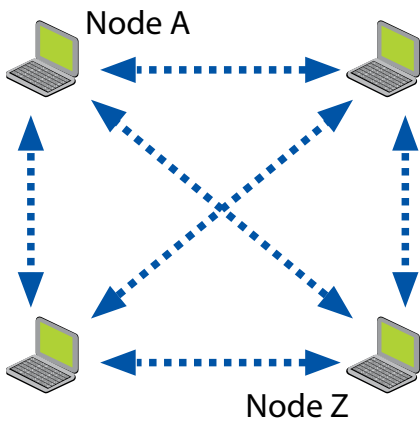


Figure 3

In addition, cognitive radios will be aware of subtle nuances within the network’s structure such as the physical environment that includes data links, transport, and management layers. Figure 4 provides an example of a protocol stack and illustrates the interoperation and bridging of existing defense communication networks.

Geographic awareness is significant, particularly for international and coalition communications. This awareness generates the radio’s ability to “discern” local infrastructure or policy, transmitters and receivers, terrain, propagation channels, and the location of network members.

FTP, TFTP		TELNET		SMTP			TNS	
BGP		SNMP		MIB Extensions		BOOTP		
TCP							UDP	
IPSO, ICMP, IGMP, SDB, Tailored SNDCEF								
Mil-STD-188-220		X.25/x.75 inc ADDSI			Mil STD 110A	Mil STD 141A	IP-SDR	
Mil-STD-188-220		HDLC-LAPB/LAPD			Mil STD 110A	Mil STD 141A	HDLC LAPB/LAPD	
RENAD Layer	HQ-II-NAD Layer	EPLRS NAD Layer	Non-DAMA Access Layer	Non-DAMA Access Layer	Mil STD 110A	Mil STD 141A	WNW MAC	
Singars SIP	Havequick II	EPLRS VHSIC	WB TACSAT	SATCOM DAMA	HF Modem	HF ALE	WNW Like	

Figure 4

As an example, a US Air Force jet is flying across European airspace. Each country has different communication standards, frequencies, and protocols. With a cognitive radio, the flight plan is programmed into the radio, and just as GPS tells the pilot where they are, the radio would adopt the communication architectures of the airspace throughout the flight – without pilot interface.

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Another link in the chain of awareness for CR is its ability to understand a user’s operating requirements. Through software, the cognitive radio could reference the user’s rank, role, and access requirements along with the databases and networks needed to complete normal operating tasks, thus keeping information consistent with the user’s mission.

Additional cognitive abilities would authenticate and certify system access. Defined and managed by the user or the user’s superiors, it can be accomplished over the air. Next, speech and language identification can be added. This is a component of functional awareness where the radio understands the syntactic and semantic context of dialog and can switch back and forth between text and speech, even performing biometrics on the user.

What’s next?

Supporting and maintaining the communications security policy is also critical for the protection of personnel and data; it is an integral part of the radio’s cognitive functions. Understanding and implementing national security policy, network operator, hardware/software, server authentication policies, stability and performance assessments round out the majority of a CR’s functions.

The work of the SDRF, with its associated workgroups and committees, will bring the technologies and associated policies necessary for CR to standardization and reality. †

Bruce Fette, Ph.D., is chief scientist for the communication networks business area of General Dynamics C4 Systems in Scottsdale, AZ, and has worked for 34 years in advanced signal processing for telephony and RF communications. Fette currently serves as the SDRF’s technical chair and is a panelist for the IEEE Conference on Acoustics Speech and Signal Processing Industrial Technology Track. He holds 35 patents and has been awarded the Distinguished Innovator Award. He received his BS in electrical engineering from the University of Cincinnati in 1969, his MS in electrical engineering from Arizona State University in 1974, and his Ph.D. from Arizona State University in 1981.



For more information, visit the General Dynamics C4 Systems website at www.gdc4s.com.