The Spectrum Crisis Solution: Using Cognitive Radios to Free Up Latent Bandwidth in Existing Spectrum

The explosive growth of wireless data over the past few years has made the subject of available spectrum a hot topic. In fact, many in the industry have called our current situation a “looming spectrum crisis.” Responses to this “crisis” have included lobbying efforts to get the FCC to find new sources of licensed spectrum, proposals to reallocate existing licensed spectrum and carriers using the argument of needing more spectrum as justification for the acquisition of competitors (as seen by AT&T’s $39 billion proposed purchase of T-Mobile.) From this it would be easy to conclude that there is not enough spectrum available to satisfy the current and future growth of wireless data.

In truth, this crisis isn’t the result of insufficient amounts of available spectrum, but rather the result of inefficient use of the currently available spectrum. Rather than demanding more spectrum, a smarter response to the call for increased bandwidth would be to focus on getting more use out of spectrum that has already been allocated. More effective utilization of the available spectrum can be accomplished in a number of different ways. Advancements in radio technology, such as the movement to the LTE standard from the previous 3G networks, for example, have allowed for better spectrum utilization. A recent FCC filing from AT&T noted that LTE is 30%-40% more efficient in spectrum usage than its own latest 3G technology. Why is this? It is attributed to the incorporation of new advanced technologies such as MIMO antennas, improved bits/hertz modulation techniques and advancement in receiver design that are all part of the LTE standard.

Key Takeaways

- There isn’t a spectrum crisis, but rather a crisis with the current under-use of available spectrum.
- Incremental advancements in 3G and 4G radio technology have led to incrementally better spectrum utilization. New thinking and innovation must be embraced if we are to get ahead of the mobile data tsunami.
- An emerging class of radio systems called cognitive networks can use existing and future spectrum allocations in an entirely new and efficient manner to keep the wireless industry ahead of the demand curve.
- xG Technology is one vendor that is designing networks that move from making the radio cognitive to making the entire network cognitive.
- Typical use cases of an advanced cognitive radio network include Military, Rural Broadband, Public
- With its long history of dedicating spectrum to a single network operator and/or application, the FCC is starting to embrace the concept of shared and opportunistic use spectrum.
- The continued advancement of wireless technology by a few industry visionaries, combined with the need for better utilization of spectrum, are why cognitive radios have emerged as a leading solution for increasing wireless bandwidth capacity from our scare spectrum resources.
There are other innovations that will also help network operators make better use of the available spectrum, such as Femtocells. This is a solution where a very small cell base station allows service providers to extend service coverage indoors, especially where access would otherwise be limited or unavailable. Another example is cell splitting, where more coverage and capacity is created in a wireless system by having more than one cell site cover a particular amount of geography. Each cell site would cover a smaller area, and thus offer the ability to reuse frequencies more times in a larger geographic coverage area. However, as we will uncover in this document, there are other, even more powerful advancements that can be brought to bear on this issue. In fact, it is our belief that industry needs to look beyond these incremental advancements and consider approaching spectrum use in an entirely new way if we are to truly address the mobile data juggernaut.

To this end, there is an emerging class of radio systems being deployed, called cognitive networks, that can use existing and future spectrum allocations in an entirely new and more efficient manner. Using cognitive radio techniques, the cognitive network can intelligently share spectrum and extract more bandwidth via “opportunistic use” of shared spectrum resources. At the heart of this is a radio that has the ability to dynamically change frequencies when needed, while also employing advanced signal processing techniques to mitigate radio frequency (RF) interference from other users on the same system or competing network. Today’s cognitive radio systems are taking advantage of new antenna technology (such as MIMO) and digital signal processors (DSPs) with advanced, innovative software algorithms. This evolution has also yielded a class of DSPs that are incredibly powerful, yet still energy-efficient. These and other technologies are enabling a new generation of smart (i.e., cognitive) radios. As we will explain in this paper, these new cognitive radios will be the essential ingredient needed to make significantly better use of available spectrum, thereby addressing the real issue we face: a “mobile bandwidth crisis.”

**Introducing the Cognitive Radio**

The industry definition of a cognitive radio is a device that, unlike a traditional radio, can dynamically find and use available frequency to improve throughput and connectivity. This can be done via real-time sensing that allows the radio to scan for unused frequencies and then instantly tune to them. Cognitive radios can also rely on a database that can tell it what channels are available (usually based on the radio’s location and known spectrum restrictions in that area). Either or both of these techniques can be used to help the cognitive radio avoid interference and optimize its throughput and connection reliability on a dynamic basis. With detailed information about its local RF environment, smart radios are able to change power output, frequency and receive or transmit parameters, in order to extract latent (unused) bandwidth and capacity from crowded unlicensed, as well as underutilized licensed wireless spectrum.

**The FCC’s Role in Spectrum**

In the past, all radios were designed with the assumption that they were operating in a spectrum band that was free of interference. There was no requirement to design these radios with the ability to dynamically change channels or change spectrum bands in response to interference. Not surprisingly, these radios required pristine, dedicated (i.e., licensed) spectrum to operate. This led to the FCC licensing spectrum to a particular network operator (cellular paging, wireless cable TV, etc.) so that interference would be carefully controlled. Because of this past legacy, significant blocks of spectrum were underutilized. Even in “highly utilized” spectrum bands, valuable spectrum can sit idle in sparsely populated areas or at certain hours of the day (like 2a.m., for example) when network use dramatically drops.

There are also applications, paging for example, that have fallen out of favor and contribute to this underutilization. Despite the dramatic drop in the use of pagers, a large amount of spectrum is still dedicated to this application. An analogy of this dedicated use approach is much like the railroad systems of the past versus the superhighways of today. With railroads, once the train is put into use it stays on its track and uses the track exclusively in its area. It doesn’t need to steer around obstacles or repeatedly jump back and forth between several different tracks. The only actions that the train can
take are to brake or accelerate. In fact, switching tracks is done by a central control that changes the tracks for the train. The train is just along for the ride; it has very few tasks and simply goes where the tracks take it.

The train is much like traditional radios (static and unintelligent) where the railway track system is much like the dedicated spectrum allocations (static and defined for a single use and/or owner) with manual reconfiguration happening on a sporadic basis.

This regulatory policy has led to inefficient use of spectrum and hence the declaration of a spectrum crisis. The FCC, in some cases, is still assuming that radios remain unintelligent and incapable of sharing spectrum. As a result, they have continued allocating spectrum based upon this assumption. However, the FCC is starting to embrace the concept of shared spectrum and opportunistic use spectrum enabled by cognitive radio networks.

Shared and opportunistic use bands are much more like multi-lane superhighways, and cognitive radios are like high performance cars with skilled drivers that have dynamic decision making capabilities. These intelligent drivers are making dynamic choices to change lanes, speed up, slow down, or exit and enter other highways or streets if the road they are on is getting congested. In this analogy, the cars, much like the cognitive radios, have more intelligence and flexibility than their rail counterpart and hence have the flexibility to optimize their routes (fastest, shortest, most scenic, etc.) in ways that the trains on dedicated tracks do not. When radios are also embodied with cognitive decision-making capabilities and have access to shared spectrum bands, these radios can extract far more bandwidth than is possible with dedicated radios and spectrum.

As stated above, the FCC is starting to relax the rules of how spectrum is allocated and accessed. A good example of this is the shared use of TV broadcast spectrum via the creation of TV White Spaces (TVWS) for wireless broadband. The FCC (and other spectrum regulatory agencies like the UK’s Ofcom) is allowing cognitive radios to use freed-up spectrum resulting from the transition from analog to digital TV broadcasts. While the FCC and other regulatory bodies are starting to see the light with the reallocation of spectrum towards shared use, this is a recent phenomenon and has not yet been widely implemented.

Operators and consumers are able to use available unlicensed spectrum bands for the delivery of new applications and inexpensive broadband capacity. An example of this is the data offload efforts of some carriers that use 802.11 Wi-Fi (in the 2.4 and 5.8 GHz unlicensed bands) in densely populated areas where their 3G network is congested. This allows carriers to continue supporting mobile voice and data services over their licensed spectrum, while data that can be consumed at a fixed location (airport, coffee shop, office, etc.) is forced over an unlicensed Wi-Fi link.

However, the popularity of Wi-Fi and other devices that use these frequencies has resulted in crowded and noisy spectrum that not only has to support the carriers’ smartphone data, but all other applications from other devices in that band as well. The interference in these bands affects the capacity and efficiency of this spectrum for conventional radios. However, where conventional radios see “walls of interference”, cognitive radios can uncover “windows of opportunity” and recover up to 85% of the total unused bandwidth in these frequencies.

**Moving beyond the traditional definition of a cognitive radio**

Several vendors have researched and experimented with cognitive radios. This research predominately falls under the industry defined use of a cognitive radio where cognitive capabilities are restricted to dynamic spectrum access (DSA) within the radio device. There is one vendor, xG Technology, based in Sarasota, FL, that is looking to expand the application of cognitive techniques beyond DSA in the individual radios. They are leveraging cognitive technology in other aspects of the radio’s operation and across the entire xG wireless network. Their xMax cognitive radio networks are incorporating MIMO antennas and advanced signal processing algorithms to improve interference mitigation and withstand much higher levels of noise, jamming and general interference than conventional radios and competing cognitive radio solutions.
The recent advancements in cognitive radio systems can be traced to the availability of cheaper, faster digital processors, MIMO antenna technology and newly developed waveforms. These and other innovations provide better signal resolution quality, higher resistance to interference, more robust connectivity, longer range, increased capacity, higher bandwidth and a much better utilization of wireless spectrum.

**Cognitive networks vs. cognitive radios**

Another development worth citing is the move from making only the radio cognitive to making the entire network cognitive. Some vendors remain focused on making the radio more efficient, other vendors believe that it is more important to leverage cognitive properties across the entire network. Making the end user devices and network infrastructure cognitive enables both to dynamically react to a wide range of conditions. For example, in *xG Technology’s xMax* system, the end user radio is used to inform the network of changes in the RF environment, core infrastructure and other relevant conditions. This allows the network itself, and not just the radios, to adapt dynamically.

When only the radio itself is cognitive, each radio will individually optimize its parameters and throughput based on local conditions, without regard to overall system performance. What may be optimal for the radios on an individual basis may not lead to overall network optimization in terms of coverage, throughput or other measures. By propagating and collecting data from individual radios across the network, a cognitive system approach can make the entire network smarter, and optimize total network throughput. This enables new and useful features such as self-RF planning that can simplify the deployment and operation of the network. The network’s performance may suffer for several seconds in the initialization process, but after the RF data is collected, better utilization and performance can be achieved automatically and continuously. This makes the network vastly more adaptable, self-sustaining and self-optimizing in many ways. The ability for the network to provide a level of self-RF planning is only one example of what a cognitive network can offer.

These networks are typically capable of dynamically sensing, analyzing and operating across multiple frequency bands, which would be difficult at best to manually configure and optimize. Because a cognitive radio network can self-optimize and self-configure, little-to-no frequency coordination between cognitive radio nodes or other radio networks operating in the same frequencies is needed. This leads to an often overlooked benefit of having a self-planning, self-optimizing network: it reduces or eliminates the need for skilled radio technicians. These cognitive radio networks use software, powerful on-board computing power and real-time RF sensing to supplant expensive and overburdened radio technicians.

A cognitive network approach will also allow the network to adapt to different applications and users by optimizing a variety of real-time parameters (latency, throughput, range, priority, etc.) on an application or per user basis. A situation where this could have been beneficial was in New York City on September 11th, 2001. The public safety wireless communication network antennas and repeaters were destroyed when the WTC towers collapsed. Critical wireless communications were lost since first responder radios in the area relied on those repeaters. With a cognitive radio network as described above, the network would have recognized that a portion of the infrastructure was missing (the repeaters) and would have reestablished communication via switching to a “mesh” mode. It would have then leveraged other available spectrum to increase capacity and/or reprioritize communication to support high-priority personnel and messages.

Clearly, a cognitive network approach offers some significant advantages over conventional radio networks, as well as radio-only cognitive approaches.
Typical Use Cases of an Advanced Cognitive Radio Network

Military Applications

When it comes to wireless technology, the military has some of the most exacting requirements due to harsh conditions and mission critical needs. Long ranges, intentional and unintentional jamming, and the fact that the enemy is constantly attempting (and sometimes succeeding) to destroy communications infrastructure has put a high value on robust and resilient communications networks. Adaptive cognitive radio networks are an ideal solution for military applications. Cognitive radios can provide interference mitigation and frequency adaptability that can greatly increase mission critical survivability. It is for these and other reasons that the military was the first to adopt cognitive radios and continues to test and deploy networks based on this technology. Cognitive networks can provide even more resilience and self-sufficiency to the challenges facing military deployments. A case in point is xG Technology’s xMax System which is currently (as of this writing) being deployed and tested at the White Sands Missile Range training area in New Mexico. xMax is also being trialed to provide cellular services to soldiers in the garrison area of the Fort Bliss, Texas Army base.

Rural Broadband

There is a great need to provide cost-effective wireless broadband access to rural communities. In fact, the FCC is launching a national broadband plan that is primarily focused on bringing broadband services to rural and underserved urban areas. Cognitive radio networks are well positioned to provide efficient wireless broadband connectivity over unlicensed or TV white spaces frequencies using zero-cost spectrum. By utilizing advanced features such as interference mitigation and radio frequency adaptability, cognitive radio networks will be able to leverage the vast amount of unlicensed and TV white spaces frequencies in rural areas. It is fortunate that the areas having the highest concentration of limited or no broadband access now have vast amounts of free spectrum available. The Connected Analysis Group expects to see cognitive radio networks deployed extensively by rural broadband providers as cost-effective DSL loop extensions to outlying customers and as an easy way to poach customers from surrounding competitors’ markets.

Public Safety

A cognitive radio network can provide primary or secondary mobile voice and broadband connectivity for emergency workers. The network can utilize unlicensed and licensed public safety frequencies (if desired) to provide mission critical voice and data applications for police, fire and other emergency workers — even in harsh RF environments or hostile terrain. Cognitive networks are ideal for disaster response as well. Real-time sensing allows a smart network to dynamically adapt to outages, while also enabling automatic RF channel planning during deployment. As mentioned earlier, this frees up human time and attention — both of which may be in short supply during a crisis. A tactical cognitive radio network can augment an already-existing public safety network during a disaster, and can function as a backup (in the event of network failure due to natural or manmade causes) to keep the mission critical communication open.

Smart Grids

Smart grid networks can use wireless networks for various applications, including smart meter reading, collection of sensor data, performance measurements and control of distribution infrastructure. In addition to licensed narrowband voice channels, utilities commonly use an unlicensed band (900MHz) for wide area data and telemetry. A smart grid network wireless network can be deployed across entire service areas to transport the meter readings back to a central location. This requires wireless coverage for very large areas that must be able to avoid interference from other devices (particularly if using an unlicensed band) that are operating in that area.
The other clear application for cognitive networks is monitoring and control at power substations. The environment at these installations is usually not very RF-friendly. This is due in large part to interference from other wireless devices and noisy electrical power equipment that can impede or block wireless signals from traditional radios. In addition, some stations are categorized as essential infrastructure by the U.S. Department of Homeland Security. This can add the requirement of video surveillance, which can require additional bandwidth capacity from the wireless system. Cognitive radio networks that incorporate advanced interference mitigation and MIMO antenna technology (for added capacity and range) are ideal for these harsh RF environments.

As utilities add smart grid deployments and support them with wireless networks, they will have to find ways to grow capacity, increase reliability and improve use of the available spectrum. Cognitive radio networks can play an important role in that advancement.

**Outlook for the Cognitive Radio Market**

As with any emerging technology, there will be some challenges before this technology is fully embraced by the mainstream market. Early adopters of cognitive radio solutions will gain valuable experience and benefits from this promising technology. However, there are two key challenges that The Connected Analysis Group sees that must be addressed to make these systems reach their full market potential:

The first is the requirement for vendors to create affordable commercial cognitive network solutions. *xG Technology* has led this effort by deploying early networks in several commercial and military environments. These deployments include an *xMax* trial deployed at the United States Army’s Fort Bliss and in the adjacent White Sands Missile Range. The company has also deployed its *xMax* cognitive network in rural telecom markets including Lewisville, Arkansas and MacCleneny, Florida. These networks will be used to deliver advanced mobile VoIP, messaging and eventually broadband services to residential customers in these underserved rural communities.

The second challenge for cognitive radio networks is that the initial adoption rate of any new and disruptive technology has traditionally been slow. This certainly was true for the adoption of Wi-Fi when it was first introduced in smartphones. Several years ago, smartphone manufacturers would disable Wi-Fi in some phones because they felt that the cellular network should be the preferred (and billed for) connection. It wasn’t until their networks were being dragged down by bandwidth-intensive applications on smartphones that carriers rediscovered the benefits of offloading traffic to the Wi-Fi network. Now carriers encourage smartphone users to leverage Wi-Fi hotspots or other Wi-Fi networks whenever possible. Carriers are even deploying their own Wi-Fi networks in densely populated areas so they can reduce the amount of data traffic on the cellular network.

The Connected Analysis Group anticipates that the same thing will happen with cognitive radio networks. That is, carriers will be initially resistant to supplementing their mobile networks with cognitive overlays, due to lack of experience (and in many cases, a lack of understanding) with the many benefits today’s commercial cognitive solutions can bring. These include capacity offload and much longer ranges than Wi-Fi networks offer. Deploying a cognitive system that can dynamically access available spectrum would enable carriers to extend their ability to offload traffic much further out into the network than is possible with Wi-Fi, while still leveraging cost-free unlicensed spectrum.

We can envision a wide range of technologies being pioneered in cognitive networks today, including self-RF planning, dynamic spectrum access (DSA) and advanced interference mitigation finding their way into mainstream mobile networks and other wireless devices in the not too distant future. In short, the advantages of cognitive radio networks and technologies are too great to ignore, and it will not be long before their benefits are realized across a wide range of commercial, military, public safety and other applications.
It is important to acknowledge that this evolution cannot happen in a vacuum. Regulatory bodies like the FCC must do their part by embracing and encouraging higher spectrum utilization via cognitive and opportunistic use techniques. The good news is that the FCC and other regulatory bodies appear to be embracing these ideas, albeit tentatively.

To ensure better use of spectrum and to address the looming spectrum crisis, some of the following will need to happen:

The FCC should follow through on its promise to make more “opportunistic use” bands available. They must create realistic and workable rules for dynamic spectrum access that make cognitive radios viable, while reasonably protecting primary spectrum users. In addition, they should work to create type approval rules now so that manufacturers will know how to begin to design affordable products for the market. Lastly, allocating additional spectrum for unlicensed use would further spur innovation and help relieve congestion on commercial cellular networks.

However there is more that the FCC can do to ensure the better use of spectrum. One approach is to move away from the old school command and control mentality that licenses (i.e., limits) valuable spectrum to just one network operator or application. Instead, the Commission can create rules that enable cognitive systems to efficiently (and fairly) share the spectrum amongst different networks, applications and users.

Some of these ideas are being trialed in the TV white spaces rules, where the band is being shared between unlicensed wireless devices and TV broadcasters. In this case, the TV broadcasters are the protected incumbent users of the band; yet new white spaces devices will potentially have access to hundreds of megahertz of bandwidth – particularly in underserved rural areas. Similar initiatives should be applied to other underutilized bands as well. The creation of these shared use rules will in turn drive the wireless industry to build radios networks that can adapt to a shared spectrum scenario. If the FCC creates clear and reasonable type approval rules, vendors can build and deploy these radios with confidence. This innovative approach will not only drive the availability and adoption of cognitive technology, but will also address the issue of underutilized and inefficient spectrum use that is unfortunately the norm in today’s wireless networks.

Summary

The continued advancement of wireless technology by a few industry visionaries, combined with the need for better utilization of spectrum, is the reason why cognitive radios have emerged as a leading solution for increasing wireless bandwidth capacity from our scare spectrum resources. As this technology continues to mature and prove itself in a wide variety of applications, regulatory bodies such as the FCC, will need to continue to adapt their spectrum use policies and way of thinking to leverage these exciting new capabilities. With the explosion of wireless voice and data traffic that is expected over the next 10 years, we must be willing to embrace this highly innovative approach to optimizing spectrum access and utilization. By taking advantage of advancements in cognitive radio systems and fostering appropriate and progressive regulatory rules, tomorrow’s wireless capacity challenges stand a good chance of being met.

Bill Rubino, Principal Analyst
The Connected Analysis Group, LLC
brubino@connected-analysis.com
www.connected-analysis.com
+ 978-314-9480