Cognitive Radio as Enabling Technology for Dynamic Spectrum Access

Wei Nai-qi
Dept. of UAV engineering
Mechanical Engineering College
Shijiazhuang, China
nickeywnq@163.com

Chen Zi-li
Dept. of UAV engineering
Mechanical Engineering College
Shijiazhuang, China
chzl123@126.com

Abstract—**Frequency spectrum scarcity is currently one of the mostly discussed topics in wireless communications. When there is no free spectrum available, no new broadband communication techniques can be put into operation. The double use of already assigned frequencies leads to interferences. A possible solution to the problem is Dynamic Spectrum Access (DSA), realized through Cognitive Radio (CR) technology. Cognitive Radios have the ability to detect unused spectrum segments and to adapt to it dynamically. This adaptation does not only concern a change of frequency, but may also include changes in waveform, bandwidth, or whatever leads to an optimal communication link. This paper gives an overview of the state-of-the-art Cognitive Radio approaches and points out opportunities offered by this technology to overcome the threat of spectrum scarcity.**

Keywords- Cognitive radio; Spectrum scarcity; Software Defined Radio; Secondary User

I. INTRODUCTION

The demand for frequency spectrum has been increasing over the past years. New wireless communication systems required higher amounts of bandwidth and they needed a designated spectrum band. Consequently, the frequency spectrum became scarce, but the utilization of the assigned spectrum only ranges between 15% and 85% [1]. However, conjoined with the technical need for more bandwidth, also the operational demands increased. One of the main reasons for this growing bandwidth demand is that "information dominance is critical for the future force" [2]. New services are necessary that require huge data rates. Consequently, a growing amount of free space is required in the electromagnetic spectrum, but as explained above, spectrum is already scant.

A possible solution for this is *Dynamic Spectrum Access* (DSA), which deals with the idea of sensing the spectrum for free space due to absence of an authorized user (primary user), dynamically allocating it and leaving it if the primary user starts to transmit again. In order to enable this dynamic access, an almost perfect knowledge of the spectral environment is necessary. For this purpose the spectrum must be observed, and unused bands, so called *spectrum holes*, must be identified. As there can be more than one unused channel, a decision has to be taken, which channel provides the best transmission conditions. According to this decision, the transmission must be started or continued on the selected channel. In order to implement those capabilities, a new class of radios was proposed, so called Cognitive Radios.

II. SPECTRUM SCARCITY PROBLEM

Because of frequency regulations, it was expected that newly developed wireless systems may interfere with existing users. Consequently, each system has been given an exclusive license, defining the area, in which transmissions are allowed, the time and the frequency band. By now, nearly all frequencies up to 300 GHz are assigned to dedicated services [3].

Nevertheless, new wireless technologies are developed, often not replacing but complementing the currently used systems. As all frequencies are already assigned, the addition of new technologies leads to a double use of frequencies and interferences might occur. One example is the usage of both terrestrial Digital Video Broadcasting (DVB-T) and Long Term Evolution (LTE) mobile services in the band between 790 and 862 MHz [4].

Moreover, these technologies often require larger bandwidth. If there is no free spectrum to allocate, the technology must be put into operation at frequencies used by other systems. Consequently, the design of new technologies without shutting down existing systems provokes a risk: Either there is a potential reduction of robustness due to interferences, or the new technology is not implemented at all, which leads to disadvantages in competition.

III. DYNAMIC SPECTRUM ACCESS

Users of wireless communication systems are often classified into primary and secondary users. Primary users are legally authorized to use a fixed frequency band at a fixed region during a certain time. If a user wants to use a band possessed by primary user, he can act as a secondary user. In order to regulate the concurrent access to it, several approaches have been proposed [5].

The first is called Dynamic Exclusive Use. According to this approach, there is always an exclusive use and no concurrency. The secondary user is allowed to use the primary user's band due to a sub-license. This sub-license is either based on fixed times, which must be negotiated between primary and secondary user, or on temporal and spatial traffic statistics.

A second approach, Hierarchical Access, enables a secondary user to use the primary user's band without his knowledge. This can either be achieved by only communicating when the primary user is absent or by transmitting despite his presence, but keeping interferences below prescribed limits. The first case requires a change to another free channel on the primary user's return, the second case requires underlay or overlay techniques like spread spectrum. In each case exact knowledge about the spectrum is necessary.

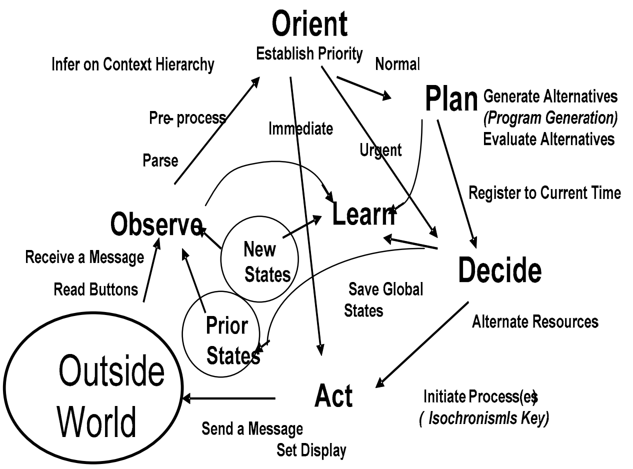
Open Sharing, the third approach, assumes that there are only peer users and license-free spectrum. For achieving communications free of interference, the actions of the radios must be coordinated. This can either be achieved in a centralized way or in a decentralized way.

IV. COGNITIVE RADIO

A CR is a radio that is able to perform DSA in a user-oriented way, which means that its primary aim is to fulfil the user's needs. In the ideal case, the user simply selects the service he wants to use, and the radio finds and uses the optimal transmission frequency, bandwidth, modulation type, etc. For this purpose the CR needs to have knowledge about the user's request and about the current spectrum utilization at both transmitter and receiver.

A. Cognition Cycle

Joseph Mitola III, who invented the name "Cognitive Radio", described a process how to consolidate user needs and spectrum utilization in his Cognition Cycle (see Figure 1). Each step of the process is depicted by a logical state in the diagram. Inputs like the electromagnetic spectrum are part of the Outside World. Those inputs must be observed by sensors or spectrum sensing capabilities. The gathered data is then evaluated and prioritized, so that the CR is able to orient itself. In case no urgent or immediate reaction is necessary, as a next step possible alternative actions are planned and evaluated. The evaluation results in a decision, which is then realized in an action. The results of this action are observed and evaluated, so that the CR is able to learn from its decisions.



Mitola's Cognition Cycle [6]

B. CR Architecture

Similar to legacy radios, CR uses the seven ISO/OSI layers to enable communication to other CRs. In order to be dynamically reconfigurable, transmission parameters must be changeable via software. Consequently, CR must be based on Software Defined Radio (SDR) technology.

For being able to observe its environment, the CR moreover must be equipped with different kinds of sensors. First of all, there is a need for a spectrum sensing capability. This exceeds the requirements for the PHY and MAC layer in an SDR, in addition to the communications part also the reception of other signals including their analysis must be implemented. An exemplary architecture for this is depicted in Figure 2[7].

Also the user's interactions must be observed and transformed into plans, harmonised with the options derived from the spectral occupation. This harmonization, which conjoins the user input with the spectrum sensing information under consideration of legal conditions, has to be executed in a central entity of the CR, the so-called Cognitive Manager. Here all incoming information is collected. Plans are created, and in a decision process one of those plans is selected and returned to the radio part in form of new transmission parameters. As these parameters may have influence on each of the ISO/OSI layers, they must be addressable separately. Consequently, there must be an interface between the Cognitive Manager and the radio part to enable direct access to each layer. Thus a cross-layer architecture is achieved.

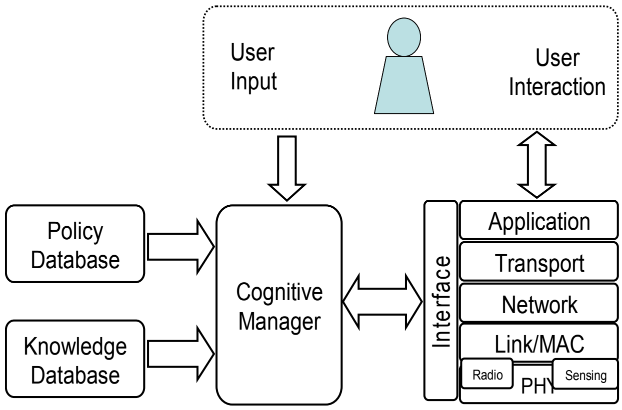


Figure 1. Cognitive Radio Architecture

In order to consider legal conditions, the CR must be aware of where it is allowed to transmit and which frequencies are forbidden [7]. Such regulations have to be known to the Cognitive Manager in form of policies, most probably stored in a policy database. As those policies may differ between different locations, the CR must have knowledge about its current location. For this purpose a CR must be equipped with a geo-location sensor, e.g. a GPS device. Gathered knowledge must be stored internally and recallable for any decision. On one hand this requires a storage possibility, like a knowledge database; on the other hand the knowledge must be stored in a computer-manageable form. Joseph Mitola III proposed in [6] a solution for this, the Radio Knowledge Representation Language (RKRL). Summarizing all those capabilities, the proposed architecture is able to fulfil the tasks assigned to Cognitive Radios.

C. Overcoming the Threat of Spectrum Scarcity

As described above, the implementation of new wireless technologies on already assigned spectrum bands always comes with the risk of interfering with existing systems. For avoiding those interferences, it is essential to be informed about transmissions of the other systems [7]. This either requires some kind of interoperability with those systems to exchange this information or a spectrum sensing capability to detect current transmissions. The latter solution is exactly what a CR does. A detected spectrum hole can be used by the CR.

If any of the primary users starts to transmit again, which determines the end of the spectrum hole, the CR does not stop to send. It dynamically finds another spectrum hole and continues transmission there. This way a nearly continuous communication without interferences is achieved. Akyildiz denominates this as “spectrum mobility” [1].

Due to the dynamics of a CR, it is not bound to existing channel assignments. If two neighbouring channels are unoccupied, a CR is able to dynamically adapt its transmission parameters in order to combine both channels and use them as one channel with a larger bandwidth. Thus also services with larger bandwidths can be used via CR technology.

Evaluating those capabilities, it is clear that CR can be used to implement new broadband services without requiring additional bandwidth. CR can solve the spectrum scarcity problem by achieving a better utilization of the existing spectrum assignment.

V. CONCLUSION

As the electromagnetic spectrum is completely assigned to communication technologies, which are still in use, newly developed wireless communication technologies consequently must be put into operation on already used spectrum bands. The addition of systems to those bands may lead to interferences and thus to less robust communications. CR is a technology that dynamically finds and uses spectrum holes. Thus the slender utilization of the assigned spectrum is exploited. By this, new spectrum resources, applicable even to broadband services, are exposed and can be used without causing interferences. All in all, CR technology offers a promising solution for the threats caused by the spectrum scarcity problem.

ACKNOWLEDGMENT

The authors wish to thank Professor Han Zhuang-zhi of the Radar Signal Processing Laboratory, Mechanical Engineering College, Shijiazhuang, China, for his support and sponsorship of this research.

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