Construction of Cognitive Radio Based Emergency Communication System and Application Scenario Analysis

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Abstract

Cognitive Radio (CR) can optimize system objects by dynamically assigning network resource and adjusting network operations in terms of network environments and conditions. So CR technology is very suitable for building emergency communication system to improve resource utilization ratio and enhancing dependability and availability of communication services apparently. In this paper, background requirements of constructing cognitive radio based emergency communication systems are expatiated and technical traits of CR are introduced. Then, network architecture and model of cognitive emergency communication system are proposed. In addition, CPE and SAN are explained too. In the end, several application scenarios and future works of cognitive emergency communication network are discussed and prospected.

Keywords: *Cognitive Radio; Cognitive Network; Emergency Communication System; Architecture; Cognitive Process Engine*

1. Introduction

Emergency communication is a temporary and fast response special communication mechanism for coping with natural disasters or urgent cases by suing various communication techniques and resources [1]. The current deployment of emergency communication network, either the satellite shortwave or trunking communication system, mostly depends on the preset network infrastructure, with low reliability and lack of cognitive ability and adaptability, so it cannot make full use of scarce cyber source to optimize network performance. One of the two reasons is that internal network lacks timely and effective monitoring and response mechanism, so network units (including the host, network equipment and network protocol) cannot utilize time-varying cyber source dynamically and make reasonable, correct adjustments, and the other reason is the lack of enough coordination and communication between network elements, and they respond to network events just according to their own understanding of the information and capability. Obviously, such action is isolated and passive, not active coordination. In order to maximize the use of cyber source in the complex heterogeneous emergency network scene and ensure that emergency command communication can be carried out promptly and reliably, there is pressing need for us to upgrade the adaptability of current emergency communication network and allow network units to monitor network status actively, interact with each other and take appropriate action according to predetermined targets.

Cognitive Radio (CR) [2] is recognized as a new intelligent wireless communication technology, which improves the utilization rate of wireless spectrum through dynamic spectrum access and opportunistic spectrum access, in a wireless network environment with spectrum resource getting increasingly scarce. CR has the abilities of spectrum sensing, active learning and intelligent processing. It changes the real-time radio operating parameters and adjusts the internal state of the system through interaction with the working network environment and perception, understanding and active learning of the external environment so that the wireless device can automatically adapt to external wireless environment and the changing needs of themselves [3]. If we compare the traditional emergency communication system's defects with the advantages of cognitive radio technology, it's easy to discover that it will be very necessary to adopt the CR to establish a emergency communication system with cognitive ability in a scene with complex and changeful network environment and resource shortage. In that way, we could improve resource utilization efficiency of emergency communication network and enhance the intelligence, reliability and applicability of the emergency communication system in all kinds of network environment. In emergency scene, for instance, cognitive radio station could not only alter communication settings to reduce the channel interference and improve the service quality according to network conditions, but also make correct decisions via the network environment real time monitoring and analysis and adjust the network behavior to optimize the network overall performance.

2. Basic Concepts and Principles of CR

The term Cognitive Radio (CR) was coined by Dr. Joseph Mitola of Swedish Royal Institute of Technology in 1999 based on software radio technology [2]. He described a cognitive radio system that adopts radio-domain model to reason about controlled radio regulations including RF bands, air interfaces, protocols and spatial and temporal patterns and uses radio knowledge representation language (RKRL) to represent knowledge of radio regulation, software modules, user needs and application scenarios in a way that supports individual service flexibility and satisfies customer needs better. In a narrow sense, CR is a radio device which can modify the parameters of transmitter through interaction with working environment. In a broad sense, CR is a smart radio communication system, which can sense and learn form the external environment via the use of artificial intelligence technology, and through the real-time adjustment to some operation parameters (such as transmission power, carrier frequency and modulation and coding) to be adaptive to the change of received radio signal statistics characteristics, thus realizing the high reliable communication in anytime and anywhere as well as the effective utilization of spectrum resource [3].

In conclusion, CR extends software radio with spectrum sensing and intelligent processing capabilities, and modifies the wireless operation parameters and adjusts the system interior state in a real-time manner, and enables radio devices to be automatically adaptive to external changing environment and the need through the environmental awareness, understanding and self-initiative study. CR technology is aimed to innovate the traditional fixed spectrum resource allocation scheme, and based on the concept of spectrum reuse, allow CR equipments to dynamically share the spare spectrum resource in some opportunistic manner through radio environment sensing (called Spectral Hole, namely the band is allocated to one specific licensed user but not used by the user at special time and space), so as to enhance the utilization of the available spectrum resources [4]. The core concept of CR is to make wireless communication equipments cognitive of the spectral hole and make the intelligent and rational use of its capacity.

In order to better understand the basic concept of CR, it is necessary to distinguish CR and Software Defined Radio (SDR). What SDR concern is the realization of radio signal processing whereas CR is mainly focusing on sensing the change of operation environment and thereby adjusting the system parameters. CR features with moderate sensing capabilities: waveform sensing, spectrum sensing, network sensing, location sensing, user needs sensing, language sensing, status sensing and security strategy sensing, in which the spectrum sensing is the most concerned. The most distinctive feature of CR is intelligence, which makes it distinguished from other normal SDR. CR technology implements real-time detection on the radio environment in working areas, obtains the spectrum utilization update and forecast the channel capacity; CR offers spectrum management capability and is able to analyze and evaluate the spectrum resources and determine the available spectrum resource over time and space, and perform spectrum resources sharing and allocation following a certain rules. CR can dynamically adjust its working band and transmission power as well as other parameters so as to offer efficient and reliable communications. CR can also learn from previous mistakes, and the recurrence of observation, consideration and action is different from today's mobile phone which is only able to switch data and execute network commands on pre-assigned frequency. In this sense, CR is more sophisticated concept which covers not only signal processing, but also perform reasoning and planning according to different tasks, policies, rules and targets [3].

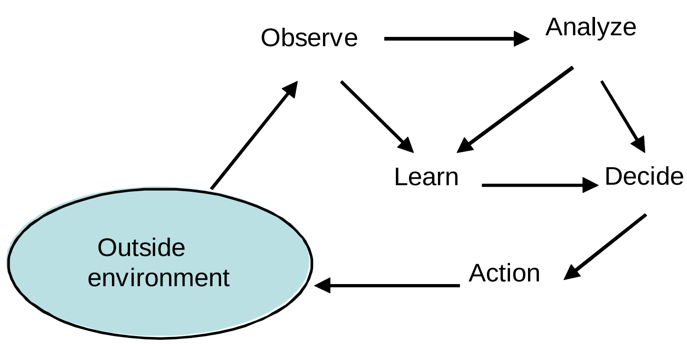

Figure 2. The cognitive cycle of CR

CR identities the frequency band which meets the Interference Temperature (IT) requirement by analyzing electromagnetic environment, and once the channel status of the specific band meets the communication requirement, it sends request to network for radio resource allocation, and after it obtain resource the communication process starts. In CR terminology, the band licensed user is called Primary User (PU) and the unlicensed radio user is called Secondary User (SU). In the course of communication process, SU should perform effective communication transmission without interfering PU at working band. SU is only allowed to use the unused band of PU and once it senses PU is about to use the band, SU has to switch over to other unused band within defined time, thus the collision between PU and SU could be avoided and the communication process of CR will not be interrupted. Nevertheless, CR should also avoid too frequent band switch-over, as it will lead to dramatic decline of SU's QoS and also reduce the spectrum utilization [5]. The cognitive cycle of CR system (Observe-Analyze-Learn-Decide-Action) is shown in Figure 1, in which the outside environment provides stimulus and CR processes and analyzes the stimulus and thereby extract the information which benefits to enhance system performance. For example, through analyzing the location information offered by GPS, it may decide if the communication environment is indoors or outdoor. The processing takes place in the observation stage, and acquires the capacity information through received and transmitted information, including the capacity allocated to users or demanded by users. Based on above information, CR orients the resource planning and decision-making, and activates access control process, and adjusts the communication system to achieve optimal performance, and then start the next round of observation based on the obtained information and rules.

3. Construction of Cognitive Emergency Communication System

3.1. Network Architecture

In view of the characteristics of emergency communication, a four-layer Cognitive Network supporting Emergency Communication (ECCN) is presented, as shown in Figure 2. From the top to the bottom are heterogeneous network infrastructure layer, (software) adjustable/adaptive network layer and cognitive processing layer and application layer in the system structure of ECCN, described as follows:

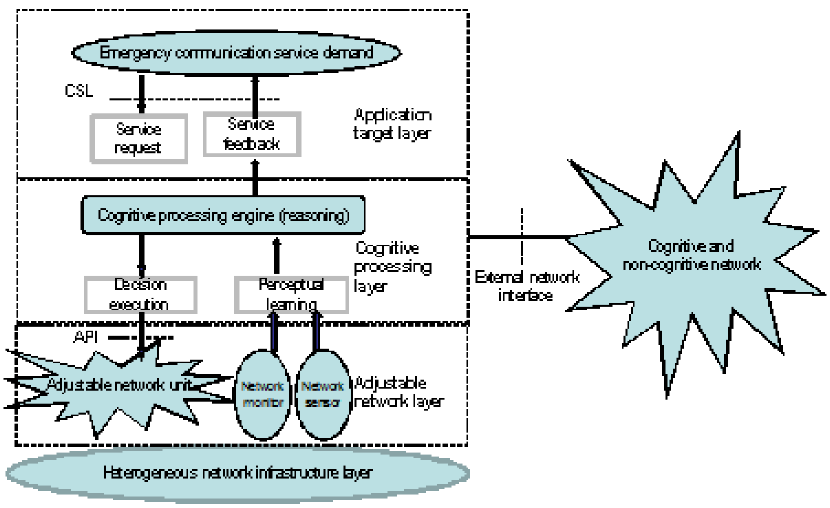

Figure 2. Cognitive emergency communication network's architecture

Network infrastructure layer contains the various network systems and communication equipments at the scene of event, and it's the platform network operates on.

Adjustable network layer superimposes on the underlying network infrastructure, including Software Adjustable Network (SAN) unit [4], network state monitor and sensor. Adjustable network unit (*e.g.*, cognitive radio station) is the execution unit of cognitive decisions, and it adopts practical operations on network systems and equipments based on the cognitive decision commands. Reconfigurable network is composed of network infrastructure layer and adjustable network layer (reconfiguration generally means that it can adapt to the network requirements by adjusting the operation parameters without any change of hardware).

Cognitive processing layer is the core decision-making layer of ECCN. It receives emergency service requests in real time and gets access to the underlying network state information by network monitor and sensor. And then it analyzes the information of upper and lower layers to make decisions via Cognitive Processing Engine (CPE), and guides the operation of various lower adjustable network units. What's more, cognitive processing layer will also feedback information like network service level to the upper applications and users besides the control of decisions.

The upper layer is the application target layer, and the targets of system task are proposed by the users or application needs which drive the behavior of emergency communication system through identification, adjustment and optimization. Without the guidance of target, network equipments may operate on different goals, which may cause undesired consequences. Finally, the cognitive network also includes providing an external network interface to interconnect with external cognitive/non-cognitive network.

It is not difficult to see that the ECCN architecture comprises two control loops: one is the feedback control loop between the application target layer and the cognitive processing layer (the users make a request to the network for service -> cognitive processing engine does analysis and inference -> the network feed its service ability back to the users -> users adjust their application requirements); the other is the cognitive control loop between the cognitive processing layer and the adjustable network layer (monitors and sensors transmit the information of network state and adjustable network unit to the cognitive processing layer -> the cognitive processing engine does analysis and makes decisions -> the cognitive processing layer sends the instructions of decision to the adjustable network unit to guide network's specific operation). The change of network state can be active or passive. And passive changes are unpredictable, such as the node's shift, addition and deletion and the changes of wireless channel environment; active changes turn the network to a desired state through adjustment and configuration of the network devices in a planned way. The network state information includes local information (such as BER, available link bandwidth and node residual energy, *etc.*) and global information (such as the end-to-end delay and network connectivity). In the architecture of ECCN network, all cognitive network nodes constituting a cognitive emergency network synergistically, take appropriate action to meet the requirements of application and achieve the system targets according to cognitive decisions [5].

3.2. Cognitive Processing Engine

By unique Cognitive Specification Language (CSL), cognitive processing engine maps the system target to a form the lower cognitive process could understand, in order to guide the specific operant behavior of the adjustable network units, and something like extensible markup language (XML) can be employed [6]. Cognitive processing engine utilizes a variety of artificial intelligence, machine learning, decision support, adaptive algorithms for learning and inference, and makes the best decision according to the current network status information with the successful experience and knowledge combined, and then has the information of these successful decision-making stored in a database for later direct use for a similar situation. In network design stage we can determine learning and inference rule in advance according to the experience, but cognitive processing engine could modify the predetermined rules in the running stage on the basis of the current network status. Whatever choice of learning method, cognitive processes need to be able to quickly learn or converge to a solution, and when the state is changed the learning is still able to achieve a fast convergence. For the network whose environment often change, for example, the mobile wireless network, fast convergence is very important.

As cognitive emergency communication network must coordinate network node action on the basis of application demand to optimize the system overall target, cognitive processing engine carries out integrated intelligent management and global optimization of cyber source on the cognitive network nodes. And the information interaction and collaborative operation between the CPE of several nodes enable multiple independent cognitive nodes to integrate as a unified cognitive network eventually. The functional structure of CPE is as shown in Figure 3. CPE is a multi-functional software entity which uses the network state information and the information of each layer of the protocol stack to make analysis based on the strategy information provided by the library. Then it schedules resource use through calling the appropriate optimization mechanism and algorithm, and adjusts the parameters of each layer in the cross-layer protocol stack to obtain the best system settings matching the application demand. Subsequently, CPE observes behaviors of nodes and the result of network optimization, then sums up the experience through reasoning and learning, update strategy and stored in a strategy library. In addition, the CPE can also make decision to employ suitable channel resource and communication technology at the right time, which guarantees the quality of service for different users [5].

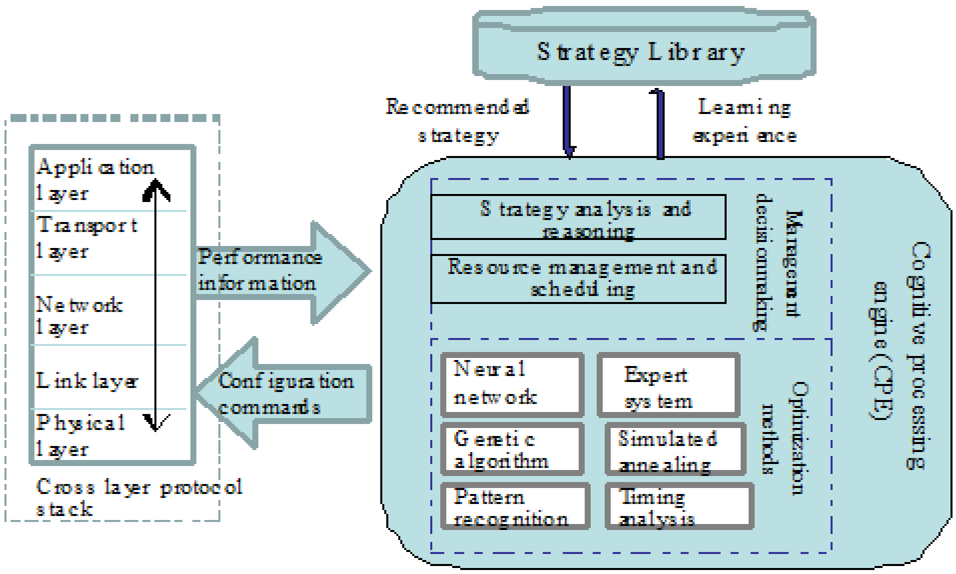

Figure 3. The functional structure of cognitive processing engine

CPE is modular and extensible, which may add the appropriate optimization and adjustment tools when needed, including neural networks, pattern recognition, genetic algorithm, expert system, timing analysis and Calman filter, *etc*. For example, genetic algorithm or simulated annealing method could be considered for use in the case that CPE will perform multi-dimensional optimization for large amounts of data. In order to deal with a large amount of historical data more effectively, it is necessary to carry out the information classification and clustering, using methods including neural network, time series analysis, etc. At the same time, in order to ensure that the operation of CPE is reliable, we must guarantee the quality of data for use in the decision-making process, and the Calman filter, Bayesian inference and statistical learning theory could be employed to deal with the uncertainty of reasoning and ensure the reliability of data.

3.3. Cognitive Processing Engine

Software adjustable network (SAN) is actually an independent research field, like the SDR design independent of cognitive radio. However, SAN needs to provide network interfaces which cognitive processing layer can understand and use. The interfaces should be flexible and extensible, which are similar to the application program interface (API) or an interface description language (IDL). SAN also includes the network elements that could be modified, and they can be used as policy control points (PCP) of the cognitive network. These network elements may include any internet object or element, and cognitive processing layer can operate each adjustable network element through the API. A simple example of software adjustable network (SAN) is a wireless network that supports directional antenna (antenna can search for receiving or transmit at different rotation angle). The wireless network which includes a network unit for regulating has the basic features of SAN. But it needs to be pointed out that it can be called cognitive network, only when adjusting the antenna direction is to serve the target of the system's cognitive behavior. Otherwise, it can only be called a wireless network using smart antenna, if you modify the antenna only in order to realize the link layer's partial target.

4. Analysis of Application Scenarios

The emergency communication system with cognitive ability designed in this paper can deal with resource shortage in an emergency through real time resource perception and adaptive management, which is applicable to a variety of emergency scenarios [7-8]. First of all, the wireless spectrum resource scarcity makes special allocation of emergency communication frequency band very difficult, and the limited spectrum cannot meet the needs of the rapidly growing emergency communication service demand. The emergency communication system with cognitive ability doesn't need to distribute the spectrum beforehand or negotiate communication frequency; it can improve emergency communication capacity by using idle spectrum dynamically. Secondly, cognitive emergency communication network can guarantee the quality of key service through the priority and the preemption right of spectrum usage in a condition with no network infrastructure. Thirdly, after an emergency incident, it will be time-consuming and labor-consuming to reconstruct the network according to the damage to infrastructure at the site, whereas cognitive emergency communication system can sense network dynamic changes of the environment in real time and realize adaptive resource management, to meet the fast and flexible support for emergency communication needs. Finally, it can set cognitive decision center node in the temporary emergency network organized by various departments on the scene in a case that public communications network paralyzes, and the emergency decision center of each sector can also be attached to the rear command and control center, with unified allocation and scheduling of emergency communication resources realize and the joint collaboration of network across different functional departments [12]. Take dealing with unexpected events in a city as an example, we'll describe the application of cognitive emergency communication network.

Emergency treatment is an important research topic of modern city management, and it is a premise that the emergency department personnel (police, fire fighting, medical staff) understands the situation rapidly, accurately after arriving at the scene for handling an emergency successfully. On the emergency scene, each of the rescue agencies usually tends to deploy their own emergency radio communication network, and will compete for the use of these scarce wireless resources, thus causing severe communication interference, thereby hampering rescue action. Therefore, we could upgrade the emergency wireless communication networks of various agencies to equip them with cognitive ability, in order to coordinate the emergency communication networks' operation of multiple agencies and deliver a variety of emergency information accurately and timely. For example, the cognitive radios carried by emergency personnel of various agencies are able to detect and collect active radio locations and transmitting frequency information through adaptive spectral perception, and optimize the use of scarce frequency resources through the dynamic spectrum access (DSA), thus to improve the spectrum utilization rate and avoid the communication interference between the rescue organizations to some extent. In addition, cognitive emergency communication system can realize adaptive adjustment according to the network environment change to ensure that the different users and applications use cyber source in accordance with its importance and to guarantee the quality of important service.

5. Conclusions

Cognitive radio and cognitive network is a hot technique that has aroused wide concern and been subjected to intensive research in the industry in recent years, and it can improve the spectrum utilization rate significantly and optimize the network performance. The thought of cognitive radio is applied to emergency communication field in this paper, and we provide the ideas of constructing a emergency communication system with cognitive ability; describe the network system structure, cognitive processing engine, adjustable network and other key components, and analyses several common application scenes. At present, the research on the emergency communication network with cognitive ability has just started; there are still many problems about technique and management to be solved. We must excavate the potential of emerging preponderant techniques including cognitive radio, cognitive network, ad hoc network, cooperative communication based on the realistic requirement, and establish an adaptive stereo emergency communication system with dynamic resource perception access, the combination of the space and the ground, the combination of the wired and the wireless, and the combination of the static and the dynamic to maximize the social service efficiency of emergency communications.

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References

[1] X. Zhang, R. Wang and X. Dong, “Emergency communication new technology and system applications”, Machinery Industry Press: Beijing, **(2010)**.
[2] S. Haykin, “Cognitive radio: Brain-empowered wireless communications”, IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, **(2005)**, pp. 201-220.
[3] P. Sutton, L. E. Doyle and K. E. Nolan, “A Reconfigurable Platform for Cognitive Networks”, Proc. CROWNCOM 2006, Mykonos Island, Greece, **(2006)** June, pp. 231-238.
[4] R. W. Thomas, D. H. Friend and L. A. DaSilv, “Cognitive Networks Adaptation and Learning to Achieve End-to-End performace objective”, IEEE Communications Magazine”, **(2006)** December, pp. 51-57.
[5] J. Zhang and H. Tang, “Emergency mobile communication system based on dynamic spectrum access”, Telecommunications Science, vol. 12, **(2008)**, pp. 16-20.
[6] C. Liu and H. Wang, “A new trend of the network development -- cognitive network”, Data communication, vol. 2, **(2009)**, pp. 1-5.
[7] P. Pawełczak, R. V. Prasad and L. Xia, “Niemegeers, Cognitive radio emergency networks – requirements and design”, IEEE DySPAN 2005, **(2005)** November 8–11, pp. 601–606.
[8] A. Gorcin and H. Arslan, “Public Safety and Emergency Case Communications: Opportunities from the Aspect of Cognitive Radio”, DySPAN 2008, 3rd IEEE Symposium on，Chicago，USA, **(2008)** October 14-17, pp. 1-10.
[9] P. C. Newton and L. Arockiam, “An Intelligent Technique to Improve Quality of Service (QoS) in Multihomed Mobile Networks”, IJAST, vol. 7, no. 6, **(2009)**, pp. 11-20.
[10] J. Wang, X. Yang, Y. Zheng, J. Zhang and J. -U. Kim, “An Energy-Efficient Multi-hop Hierarchical Routing Protocol for Wireless Sensor Networks”, IJFGCN, vol. 5, no. 4, **(2012)**, pp. 89-98.
[11] T. Oh, Y. B. Choi, M. Guthrie, K. Harold, D. Copeland and T. -h. Kim, “Reeling in Cognitive Radio: The Issues of Regulations and Policies Affecting Spectrum Management”, IJFGCN, vol. 3, no. 3, **(2010)**, pp. 71-79.