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Cognitive networks with trainable adaptive radio systems

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Abstract

This paper explains cognitive networks and applications of them with trainable adaptive radio systems to enable the intelligent connections amongst various nodes. Cognitive networks are used for wireless communication with the help of a node changing its transmission or sensing parameters to communicate efficiently by avoiding interference with authorized or unauthorized users. The change of parameters is based on the active monitoring of various factors in both external and internal radio environment, including radio frequency spectrum. Cognitive networks work as two-layer architecture, the second layer transmit the signals on the frequency band assigned to the first layer by sensing the radio frequency band in order to avoid the interference toward the first layer. Cognitive networks enable users to focus on the content and context rather than configuration and management of the networks. In this study, a new method is proposed for establishing and managing cognitive wireless networks with the help of trainable and adaptive radio systems.

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Keywords: Cognitive Networks, Adaptive Radio, Trainable Network Systems

1. Introduction

There have been tremendous advances in wireless communications in recent years, including in wireless radios, networks, and mobile devices. The existing network infrastructure of planned cellular networks is being complemented by heterogeneous self-organizing systems with hybrid infrastructure and peer-to-peer communication modes. Moreover, multi-band/multi-radio devices have been rapidly emerging recently. Regulatory bodies in various countries found that most of the radio frequency spectrum was inefficiently utilized. This was the reason for allowing unlicensed users to utilize licensed bands whenever it would not cause any interference (by avoiding them whenever legitimate user presence is sensed). This paradigm for wireless communication is known as cognitive radio. Cognitive radio is a technique for wireless communication in which either a network or a wireless node changes its transmission or reception parameters to communicate efficiently avoiding interference with licensed or unlicensed users. The change of parameters is based on the active monitoring of several factors in the external and internal radio environment, such as radio frequency spectrum, user behavior and network state. Cognitive networks are the latest progression of cognitive functionality into the networking stack, an effort which began with a layer one and two focus on cognitive radios, and has lately been extended to layer three and beyond.

The cognitive radio has attracted researchers' attention in these days for realizing frequency sharing system at the frequency bands assigned to primary systems. In the cognitive radio, the secondary cognitive terminals transmit the signals on the frequency band assigned to the primary system by sensing the radio frequency band in order to avoid the interference toward the primary systems. In cognitive networks, the interference situation is fluctuated in terms

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of time, frequency and location. Therefore, the basic routing technique is not effective for applying to the ad-hoc cognitive networks. Ad-hoc cognitive radio concept, in which the cognitive terminals transmit the signals with small power not to give the interference toward the primary systems. Moreover, the multi-hop communication is used for expanding the area of the secondary cognitive system.

The idea of cognitive radio was first introduced and described by Mitola [1] 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 detect user communications needs as a function of use context, and to provide radio resources and wireless services most appropriate to those needs.

2. Literature

Krenik and Batra [2] points that cognitive radio is a new technology that allows spectrum to be dynamically shared between users. It offers the potential to dramatically change the way spectrum is used in systems and to substantially increase the amount of spectrum available for wireless communications. Devroye et al. [3] consider cognitive network as a structure consisting of n random pairs of cognitive transmitters and receivers communicating simultaneously in the presence of multiple primary users. In their study, two scenarios are considered for the network scaling law: First, when each cognitive transmitter uses constant power to communicate with a cognitive receiver at a bounded distance away, and second, when each cognitive transmitter scales its power according to the distance to a considered primary user, allowing the cognitive transmitter-receiver distances to grow.

Lee et al. [4] present a framework of cognitive network management by means of an autonomic reconfiguration scheme. They propose a network architecture that enables intelligent services to meet QoS requirements, by adding autonomous intelligence, based on reinforcement learning, to the network management agents. The management system was shown to be better able to reconfigure its policy strategy around areas of interest and adapt to changes. They presented preliminary simulation results showing their autonomous reconfiguration approach successfully improves the performance of the original AODV protocol in a heterogeneous network environment. Similarly, Raychaudhuri et al. [5] describes a framework for research on architectural tradeoffs and protocol designs for cognitive radio networks at both the local network and the global internetwork levels. Several key architectural issues for cognitive radio networks were discussed, including control and management protocols, support for collaborative PHY, dynamic spectrum coordination, flexible MAC layer protocols, ad hoc group formation and cross-layer adaptation. The overall goal of their work was the design and validation of the control/management and data interfaces between cognitive radio nodes in a local network, and also between cognitive radio networks and the global Internet. Protocol design and implementation based on this framework will result in the CogNet architecture, a prototype open-source cognitive radio protocol stack.

Moreover, Hamdi and Letaief [6] discuss the techniques used to deal with the issues related to spectrum sensing and interference avoidance for cognitive radio systems. An extensive analysis on cooperative communications in both centralized and decentralized networks was discussed. They also proposed new methodologies to protect the operation of incumbent, licensed radio services. Their analysis suggested that collaboration may improve the usage and the spectrum sharing while causing no interference to the primary system. Furthermore, Sutton et al. [7] presents a reconfigurable platform based on an architecture specifically designed for nodes within a cognitive network. In their study, they presented a node architecture specifically designed for cognitive networks to address these deficiencies and facilitate the requirements of network-wide observation and adaptation.

However, Dietterich and Langley [8] states that current computer networks require human managers to oversee their behavior and ensure that they deliver the services desired. They point out that, to this end, the network managers must detect unusual or undesirable behaviors, isolate their sources, diagnose the fault, and repair the problem. These tasks are made more challenging because large-scale networks are managed in a distributed manner, with individuals having access to information about, and control over, only portions of the system. On the other hand, Pitchaimani et al. [9] evaluate an approach to network layer independence in wireless cognitive networks, utilizing and extending HIP to provide host identity across a myriad of network layers that evolve to meet application and environmental constraints and requirements. They detailed a use case for this type of flexibility, specifically, a disaster relief scenario with complex usage and security requirements, and present evaluations that validate this approach. This work was a part of CogNet, an architectural framework for research into architectural tradeoffs and protocol design approaches for cognitive radio networks at both local network and the global internetwork levels. Similarly, Biswas et al. [10] introduce a technique to tackle both wideband and cooperative spectrum sensing tasks. They divided the wideband spectrum into several subbands. Then a group of cognitive radios was assigned for sensing of a particular narrow subband. A cognitive base station was used for collecting the results and making the final decision over the full spectrum. Their proposed algorithm minimized time and amount of energy spent for wideband spectrum scanning by a cognitive radio, and effectively detected the primary users in the wideband spectrum thanks to cooperative shared spectrum sensing. However, Jeon et al. [11] showed that using single-hop transmission, suitable for cognitive devices of opportunistic nature, in both scenarios, with path loss larger than 2, the cognitive network throughput scales linearly with the number of cognitive users. They explored the radius of a primary exclusive region void of cognitive transmitters. They obtained bounds on this radius for a given primary outage constraint.

Fujii and Suzuki [12] proposed a novel multi-band routing method for cognitive radio using ad-hoc networks. They consider the stable routing method suitable for multi-hop cognitive networks with small power by using multi-band for improving the performance of the secondary cognitive networks. Similarly, Koulouriotis et al. [13] define Dynamic Cognitive Networks (DCNs) as a novel approach to functionalize cognitive mapping and complex systems analysis, which were recently supported by Fuzzy Cognitive Maps (FCMs). The modeling and inference limitations met in FCMs, especially in situations with strong nonlinearity and temporal phenomena, pushed towards DCNs; their theoretical framework was scheduled to confront the preceding weaknesses and offer wider possibilities in causal structures management. Trying to contribute to the enhancement of DCNs, at first, systemic and environmental metaphors were introduced with practical mathematical formalisms and generalized nomenclature. Nonlinear and asymmetric cause–effect relationships, decaying mechanisms, inertial forces, diminishing effects and biases formulate a powerful set of adaptive characteristics that strengthen the operational behavior of DCNs. Second, the strategic reorientation of DCNs was attempted as generalized approximation tools. On the other hand, Sutton et al. [7] states that cognition cycle in a network can be divided into two entities: Cognitive Engine concerning itself broadly with reasoning, cognition and deduction and Reconfigurable Node focussing solely on the processes of observation and action. The reconfigurable node formed a platform for cognitive networks by providing an architecture designed specifically for reconfiguration and observation, not only at the radio layers of the individual node, but also throughout the node network stack and on a network-wide scale. Similarly, Jeon et. al. [11] study two distinct, but overlapping networks which operate at the same time, space and frequency. The first network consisted of n randomly distributed primary users which form either an ad hoc network, or an infrastructuresupported ad hoc network in which one additional base stations support the primary users. The second network consisted of m randomly distributed cognitive users for both cases. The primary users had priority access to the spectrum and do not change their communication protocol in the presence of secondary users. The secondary network, however, needs to adjust its protocol based on knowledge about the locations of the primary nodes so as not to harm the primary network's scaling law. With the help of percolation theory, they showed that when the secondary network was denser than the primary network, both networks could simultaneously achieve the same throughput-scaling law as a stand-alone ad hoc network.

Similarly, Thomas [13] developed a general, three-layer cognitive network framework, based loosely on the framework used for cognitive radio. In their framework, they considered the possibility of a cognitive process consisting of one or more cognitive elements, software agents that operate somewhere between autonomy and cooperation. They identified three critical design decisions that affect the performance of the cognitive network: the selfishness of the cognitive elements, their degree of ignorance, and the amount of control they have over the network. To evaluate the impact of these decisions, they created a metric called the price of a feature, defined as the ratio of the network performance with a certain design decision to the performance without the feature. Moreover, they developed cognitive networks for two open problems in resource management for self-organizing networks, validating and illustrating the cognitive network approach. For the first problem, a cognitive network was shown to increase the lifetime of a wireless multicast route by up to 125%. For this problem, they showed that the price of selfishness and control are more significant than the price of ignorance. For the second problem, a cognitive network minimized the transmission power and spectral impact of a wireless network topology under static and dynamic conditions.

3. Cognitive Networks

Here, a new model is proposed for establishing and managing cognitive wireless networks with the help of trainable and adaptive radio systems. The notion of cognition in cognitive networks implies a number of intelligent tasks including perception, acting and planning, learning, reasoning, and decision making, all of which require a robust knowledge representation that facilitates the sharing and reuse of knowledge. Cognitive wireless networks are capable of reconfiguring their infrastructure, based upon experience, in order to adapt to continuously changing network environments Machine Learning techniques. Learning engines have been proposed to support decision making for context-aware services and applications. Challenges remain in turning these learning models into viable commercial products. There are also a mix of open issues regarding the implementation of cognition, including distributed learning, decision fusion and robust decision making, dynamic adaptation of parameters, iterative numerical algorithms, and complex adaptive behavior, among others.

In the proposed system, cognitive radios will obtain an estimate of the power spectral density (PSD) of the radio spectrum to determine which frequencies are used and which frequencies are unused. In order to accurately measure the spectrum, a highly sensitive radio will be required to measure signals at their cell edge. Machine learning and reasoning play a key role in fuelling and driving the advance of our cognitive network. Main function components of auto-learning that are implemented by means of network-aware middleware and normally distributed across the network components. A cognitive network-enabled system can respond in intelligent ways to various stimuli and help automated agents make human-like decisions about their assigned tasks.

Proposed system includes large numbers of autonomous sensor and actuator nodes. Using a large number of specialized sensors and actuators in a dense network enable us to acquire localized and situated information of certain metrics gathered from the physical and/or digital environment. This collection of situated measurements are used to recognize and control certain events in the physical and/or the digital world, for promoting health, safety, communications and knowledge. Sensor networks are used to monitor environmental phenomena and identify emerging threats, and to monitor the functionality of different networks and be able to foresee and cope with emerging problems. The main components and their functions of the proposed system are listed below:

1) Hardware: Includes radio frequency circuitry and signal processing devices for enabling self-configuration.
2) Software: Programming code written with a common language loaded into digital signal processors (DSPs) or other related hardware to define the devices' identity to others on the network.
3) Logical layer: For configure and program hardware and software components to to act like multiple radio links.
4) Management & Administration Module: 2 sub-modules exist, one for equipment/devices and another one for configuration. Equipment module loads radio configurations into the hardware components and sets-up the logical radios. Configuration module determines which radio configurations are available on the physical radio for rapid loading into the hardware.
5) Repository: Including collections of radio fuctions. Developed with different tools including general purpose and cross compilers, assembly, low level programming, etc.
6) Regulation & Control Module: To limit the operation of the radio due to regulatory, geographical, or physical constraints. Used for defining rules for hardware, software, logical layer and repository and controlling their operations and functions.

4. Conclusion

Today's computer networking technology will not be able to solve the complex problems that arise from increasingly bandwidth-intensive applications competing for scarce resources. Cognitive networks have the potential to change this trend by adding intelligence to the network. Cognitive radio introduces a new level of sophistication to wireless communications technology. Basic cognitive radios operate autonomously and depend on highly sensitive receivers and device learning to know when and how spectrum can be accessed. Cognitive radio offers hope with a system that is compatible with existing deployed wireless systems, stimulates new innovation, reduces regulatory burden, encourages market competition, preserves the rights of incumbent spectrum license holders, and benefits the populace overall.

Cognitive networks are the future, and they are needed simply because they enable users to focus on things other than configuring and managing networks. Without cognitive networks, the pervasive computing vision calls for every consumer to be a network technician. The applications of cognitive networks enable the vision of pervasive computing, seamless mobility, ad-hoc networks, and dynamic spectrum allocation, among others. As secondary spectrum usage is rapidly approaching, it is important to study the potential of cognitive radios and cognitive transmission from a network perspective. Future work in the areas of opportunistic spectrum access, cross-layer optimization, reconfigurable protocol layers and policy-based reasoning in cognitive networks will be facilitated by the reconfigurable platform. A driving feature of future network architectures will be the mobile user. Users increasingly will access information resources while on the move, whether when in a vehicle, attending a business meeting, or working in remote locations. Wireless technology is necessary to support the mobile user and adaptive and efficient use of radio spectrum is an important aspect of developing future network architectures.

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