Cognitive Radio Network and Network Service Chaining toward 5G: Challenges and Requirements

Ioanna Kakalou, Kostas E. Psannis, Piotr Krawiec, and Radu Badea

ABSTRACT

Cognitive radio is a promising technology that answers the spectrum scarcity problem arising from the growth of usage of wireless networks and mobile services. Cognitive radio network edge computing will enhance the CRN capabilities and, along with some adjustments in its operation, will be a key technology for 5G heterogeneous network deployment. This article presents current requirements and challenges in CRN, and a review of the limited research work on the CRN cloud, which will take off CRN capabilities and 5G network requirements and challenges. The article proposes a cognitive radio edge computing access server deployment for network service chaining at the access layer level.

INTRODUCTION

Cognitive radio is a promising technology that answers the spectrum scarcity problem arising from the growth of usage of wireless networks and mobile services. Based on software defined radio (SDR), which can reconfigure its parameters (modulation, frequency, etc.) , it adds a cognitive cycle [1] in order to observe the environment, orient, plan, design, act, and learn from past experiences. Cognitive radio senses the spectrum for vacancies, so called "spectrum holes," for cognitive radio network (CRN) users to transmit. In the case of the licensed spectrum, when licensed users (primary users, PUs), vacate the spectrum, CRN users, also called secondary users (SUs), can access it. There are limitations to the interference SUs can cause to PU. On the other hand, the underutilized spectrum has resulted in an immense need for dynamic spectrum access, which exploits spectrum opportunistically.

Dynamic spectrum access includes, among other factors, sensing, spectrum management, spectrum sharing, and spectrum mobility. For spectrum sensing — PU detection — cognitive radio uses filter detection, energy detection, and feature detection. The spectrum management includes characterization, selection, and reconfiguration of the spectrum (channel, modulation, bandwidth, power, and transmission time). On appearance of the PU, the SU has to vacate the channel immediately and continue transmission in another vacant channel. Spectrum sharing is essential to avoid overlapping of multiple cognitive radios as well as handoff (loss of connection for a mobile SU or poor quality of service, QoS).

CRN uses machine learning, genetic algorithms, game theory techniques, knowledge representation, and optimization techniques for efficient resources allocation. Further, the CRN learns the network conditions [2] and encompasses past experiences to its cognitive cycle.

The cognitive radio uses the first open systems interconnection (OSI) layer (SDR) and second OSI layer (cognitive medium access control, MAC) basically, but actually relies on the whole OSI stack, and the decisions made in the CRN have to meet the whole network's needs. A high degree of interaction takes place within the CRN to achieve optimal network performance. Thus, this article considers cognitive radio cloud and proposes a cognitive radio edge computing architecture to expand the CRN's capabilities and performance while placing network service chaining at the access level as a key technology for increasing cognitive radio access diversity.The proposed solution would support 5G heterogeneous networks, and an analysis of challenges and requirements of 5G networks is provided to justify the former considerations and proposals within 5G. Although current research work on CRN cloud (CRNC) has started to emerge, this article goes beyond and bypasses the existing limitations in CRN with enhancements of radio access capabilities to respond to the vast needs of future wireless/mobile networks. The 5G example is presented.

The article is organized as follows. An introduction to mobile cloud and mobile edge computing is given; then we present the CRN requirements and challenges, the CRNC, and current research work in this field, and propose a server-based architecture for cognitive radio access for network service chaining at the access layer level. We give a brief discussion on the 5G requirements and challenges, while we combine the cognitive radio access network (RAN) service chaining solution to the 5G heterogeneous network deployment.

This article presents current requirements and challenges in CRN, and a review of the limited research work on the CRN cloud, which will take off CRN capabilities and 5G network requirements and challenges. The article proposes a cognitive radio edge computing access server deployment for network service chaining at the access layer level.

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Mobile edge computing provides a highly distributed computing environment that can be used to deploy services and delay-sensitive and context-aware applications to be executed in close proximity to mobile users. This creates an ecosystem where new services are developed in and around the base station.

Mobile Cloud and Mobile Edge Computing

Mobile Cloud

The Mobile Cloud Computing Forum introduced cloud computing leveraging to the mobile network. "Mobile Cloud Computing at its simplest refers to an infrastructure where both the data storage and the Data Processing happen outside of the mobile device. Mobile cloud applications move the computing power and at a storage away from mobile phones and into the cloud, bringing applications and mobile computing to not just smart phone users but a much broader range of mobile subscribers" — Mobile Cloud Computing Forum (MCC-Forum, 2011).

There are several existing definitions of mobile cloud computing" and different concepts of the mobile cloud: applications run as thin clients to powerful remote servers on one hand, and on the other hand mobile devices may establish peer-to-peer connections locally with other powerful devices providing resources without the cost of latency and bandwidth issues. These systems are self-organized [3] and could offload jobs on local mobile resources. A cloudlet may be a cluster of multi-core computers connected to the cloud, and if it is not available, the mobile device will have to be served by the cloud. A virtual machine is built in the cloudlet to which the mobile devices connect as thin clients. Open issues are the distribution of processing, storage and networking capacity, the trade-off between QoS and cost for cloudlet providers, and security. The CloudClone is another implementation of local service infrastructure that creates a clone of an application. CloudClones do not virtualize native resources.

Mobile cloud has to address, besides the basic requirements of the cloud (i.e., scalability, availability, and self-awareness), the loss of connectivity, mobility, and power issues.

Cloud computing can serve mobile cloud in many aspects [3]:
- Extend battery life. Actually, remote application execution can save energy up to 45 percent for numerical computations.
- Improve data storage and processing power.
- Improve reliability.

Mobile Edge Computing and Network Service Chaining

Mobile edge computing (MEC) provides a highly distributed computing environment that can be used to deploy services and delay-sensitive and context-aware applications to be executed in close proximity to mobile users. This creates an ecosystem where new services are developed in and around the base station.

The work by the European Telecommunications Standards Institute (ETSI) on MEC-RAN aims to provide IT and cloud computing capabilities within the RAN. The key element of MEC is the MEC application server, which is integrated at the RAN element. The MEC-RAN provides computing resources, storage capacity, connectivity, and access to user traffic, radio, and network information.

Mobile edge computing allows cloud application services to be hosted alongside mobile network elements, and also facilitates leveraging of the available real-time network and radio information. The MEC-RAN delivers information from the radio network relating to users and cells, and is based on network-layer signaling messages. MEC-RAN also provides measurement and statistics information related to the user plane.

Multiple virtual machines (VMs) can be deployed in a single platform to share the hardware resources. Traffic can be routed to a VM from a physical interface and from a VM back to the physical interface. Cloud and virtualization technologies (network functions virtualization, NFV) are key enablers for MEC.

The ETSI MEC-RAN covers network layer signaling only and does not infiltrate to the lower layers. As a consequence, the traffic shaping service is a basic service.

Network service chaining is a key technology enabling automated provisioning of network applications with different characteristics. The "chain" in service chaining represents the services that can be connected across the network using software provisioning. New services can be instantiated as software-only, running on commodity hardware.

Network service chaining capabilities mean that a large number of virtual network functions can be connected together in an NFV environment. Because it is done in software using virtual circuits, these connections can be set up and torn down as needed with service chain provisioning through the NFV orchestration layer.

Cognitive Radio Network Cloud

The current challenges in CRN are storing large amounts of data and processing them in real time, and the exchange of nodes' current status on the fly. These challenges are in contrast to the limited storage and processing ability (plus battery lifetime) of cognitive devices; thus, the need for additional capabilities arises. Cognitive radio network cloud (CRNC) is an infrastructure consisting of mobile nodes and the cloud whose primary goal is to keep up-to-date status of the spectrum availability in the network for all (PUs and SUs) to access. The network status will be maintained in the cloud and updated by the network nodes. The need for intense and accurate sensing makes multiple-input multiple-output (MIMO) technology appropriate for cognitive radio. The large amount of sensing data and processing of MIMO antennae as well as the signal intelligence as a whole can be mitigated to the cloud. Current research on cognitive radio mobile cloud is limited. In the following paragraphs, a review of the existing research work in this field is presented along with the arising CRNC challenges and requirements.

A CRNC prototype, as proposed in [4],collects sensing data, processes them in real time, and provides the results to all nodes. Hence, CRNC should also be capable of running the cognition cycle for the network. The nodes will continually report their status to the cloud, and store and process their data and plan. Thus, the control message exchange between the mobile nodes will be eliminated, and only data transfer will occur.

In [4] the data transfer between mobile nodes A and B will occur after the cloud has reserved the resources in the multihop cognitive network path: $A \rightarrow C_i \rightarrow B$ (where C_i denotes all the rest of the cognitive nodes in the path), or the data transfer will take place directly between node *A* and node *B* as soon as the necessary resources reservation has been made by the cloud. Another issue that will be answered by the cloud architecture is that there will be no data loss upon PU arrival.

Actually, there are two options for implementing data transmission:
- The cloud reserves the resources along the transmission path, and then transmission occurs between the wireless nodes without the cloud's interception.
- The data is sent to the cloud and then copied to the destination node.

In the latter case, there will be no data loss upon PU arrival as they will be stored in the cloud instead. The SUs' requests for spectrum access will arrive to the cloud in first come first served (FCFS) order, but policies can be applied on the queue for implementing QoS classes.

Overlapping,the hidden terminal node problem, and the exposed terminal problem will be avoided [5] as the cloud keeps the geolocation position of each node — the overlapping nodes will be well known for a given data transmission — while the handoff will be seamless. Common control channel (CCC) was the solution in ad hoc networks to handle the coordination and resource management between the nodes as well as the hidden terminal problem. When all the control messages of the network are transmitted via one channel, the network is vulnerable to congestion and attacks (there are protocols [2] that deal with this problem though). The cloud overcomes the CCC problem.

CRNC should cover both cognitive radio infrastructure networks and cognitive radio infrastructure-less networks (Fig. 1). Cognitive radio infrastructure-less networks, although they are self-organized and implement distributed resources allocation, still suffer from limited storage, processing ability, and power supply. Demanding tasks (e.g., signal intelligence) could be offloaded to powerful nodes locally, allowing the local network to be self-organized. A critical issue in CR Infrastructure-less network deployment on the cloud would be the standard interface operability for cognitive radio users to connect to the cloud or local powerful nodes.

The CRNC should accommodate databases for past experience information and databases for the sensing data. Cognitive radio uses the past experience to learn its environment and plan.The cognitive nodes will connect to cloud front devices playing the broker's role to provide their sensing reports as proposed in [4] or data for processing. Those devices will split data and the processing load to the intermediate cloud computers. There is a trade-off between the degree of parallelism and the data exchange. In [4] they use a scalable method to partition the geographical area according to the SUs' density in order to eliminate the processing time and then call the Map/Reduce; the time and location are the keys for Map and location the key for Reduce.The Sparse Bayesian Learning Algorithm is used in [4] to estimate the cooperative sensing outcome. The CRNC architecture in [5] includes the interface, the controller, the query processor, the database, and the knowledge database. A game theoretic resources allocation in the CRNC is presented in [6], where

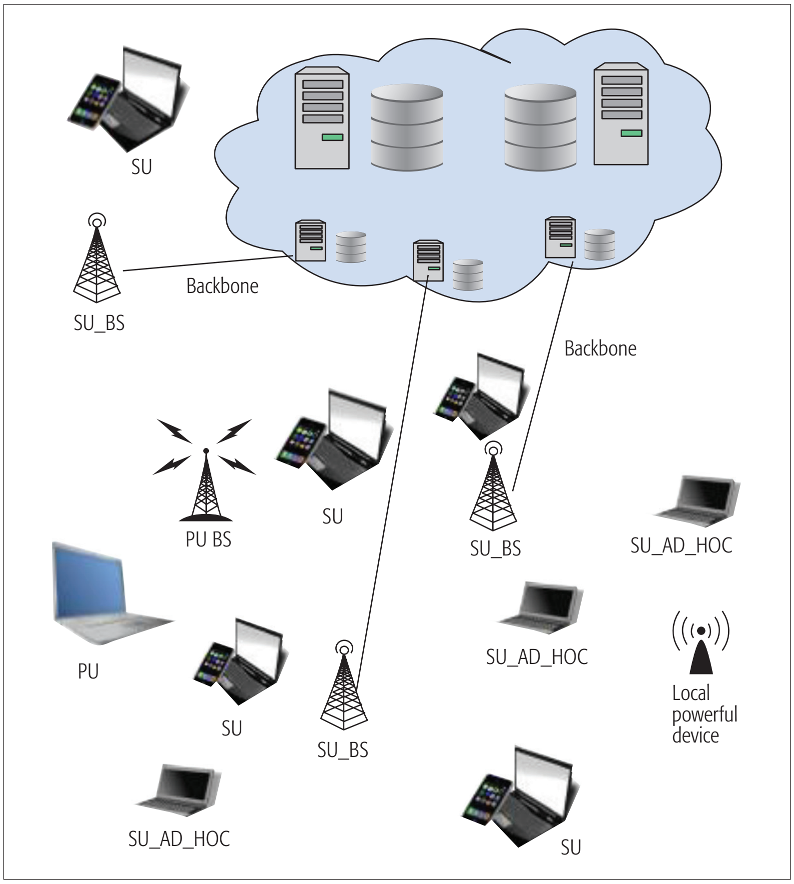

Figure 1. The cognitive radio network cloud.

the SUs adapt their power in a distributed manner and the greedy behavior is controlled by the cloud manager.

In [7] the geolocation of idle bands and the SUs' transmission requirements, such as data rate and timestamp, are reported to the cloud server. The decision regarding channel availability is made at the energy detection threshold and the bandwidth threshold. The cloud server reports the available channels to the nodes, which then select the channel that satisfies their transmission requirements best. The authors consider both device-to-device and device-to-infrastructure communication.The authors in [8] propose a cloud architecture for CRNs where the SUs are equipped with a GPS; sensing by the SUs is completely avoided.

The authors in [9] introduce powerful mobile devices that act as resource providers serving the CRN when the application data size and complexity is below a threshold; otherwise, they are served by the cloud. They have also developed a technology called MapReduce on Opportunistic Environments or Opportunistic Cloud to ensure job completion and good performance of MapReduce [10] by building a private cloud where dedicated nodes in the cloud supplement volatile wireless nodes (e.g.,in terms of jamming). Cooperative sensing and localization for power map reconstruction are proposed in [11, 12].

MIMO systems are capable ofachieving a capacity gain and/or increasing link robustness in CRN, but they increase processing time, energy

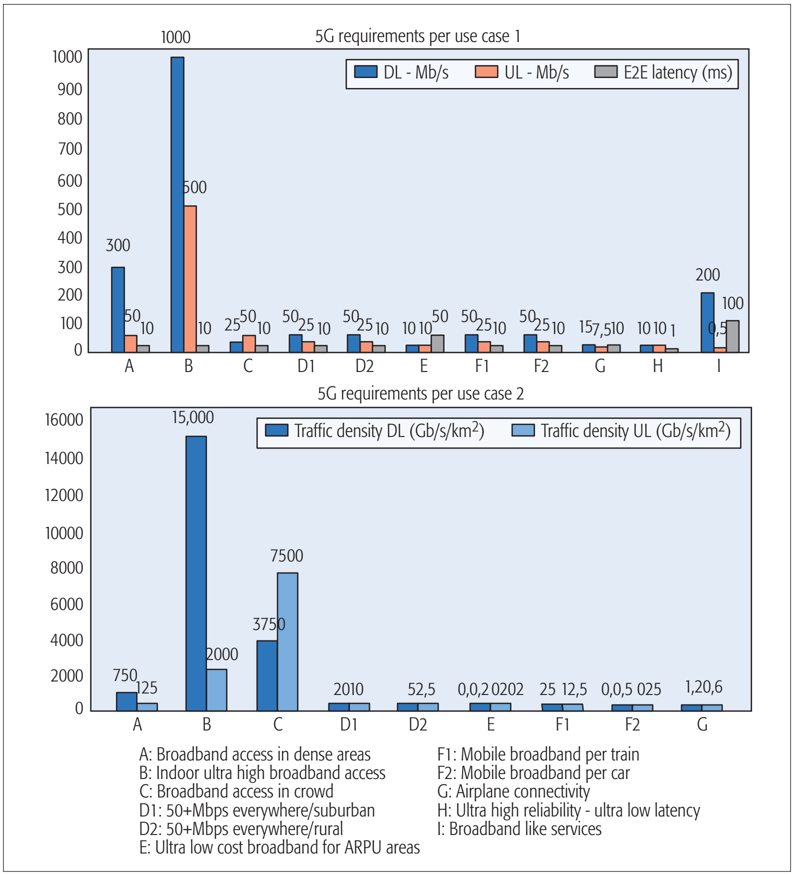

Figure 2. 5G requirements per use case.

consumption, and processed data amount. In [13] they propose a sub-optimal solution with parallel QR-factorization algorithms to establish an adaptive transmitter system by dynamically selecting the antennae — making use of the parallel computing of the cloud.

The necessity for a cognitive MAC on the cloud arises: as the PUs can utilize the spectrum any time,continuous sensing and storage of the huge amount of sensing data as well as real-time processing are required. An MEC architecture and CRN virtualization would make feasible lower-layer services and applications that could decrease latency, and increase the quality of experience (QoE) and security. Lower-layer cognitive radio services and applications on the edge computing would increase capabilities not only within the RAN but within the local mobile network on a peer-to-peer basis for access and backhauling. In the latter case, ad hoc networks or vehicles would leverage powerful local nodes, allowing them to be self-organized. A proposal for such an architecture is presented in Fig. 3 with the cognitive radio edge computing (CREC) server to offload storage and processing at the RAN or at the powerful local nodes in the form of access services provisioned for the CRN by virtualizing the lower layer's functionality and resources and leveraging the connection to the core network and the cloud connection.

We can distinguish three parts of the CREC access server:

- The basic one covers the lower layers' functionality and resource virtualization (i.e., SDR and resources, which are infrastructure-oriented).
- The application platform supports services such as local network access control and handover for the applications that would respond to, say,QoS.
- Each VM with an application will run at the SU node.

Network service chaining allows the creation of new access capabilities and is performed at the application platform. The server may run at a RAN or at a powerful local/wireless node to which other nodes can connect on a peer-to-peer basis (device-to-device communication), reducing latency. The cognitive MAC is available as a service and adapts to the wireless nodes' requirements. The SU node will run the corresponding VM for each cognitive MAC service and its application. Virtual machines communicate via the application platform that runs on the server. The server connects to the cloud for further support. The proposed architecture is flexible, reduces latency, and is easily adaptable as more services and applications are adjusted in a simple way.

Services can connect through the network composing powerful network service chaining for CRNs, controlling access and providing high-level QoE to the network users.

In Fig. 4 we can see a CREC server being part of the RAN and connected to the core network and the cloud, and in the second case being part of powerful nodes operating locally, for example, for an Internet of Things (IoT) network. In Fig. 5a we can see the service, application registration, and data sending for computations and processing to the CREC server operating at a powerful node of local network A. Later, the CREC server decides to initiate the handover process for the SU and sends a handover request to local network B. The SU is notified and registers with network B. In Fig. 5b the server operates at the RAN, and the SU registers its service and application and sends data to the server for processing. The server processes the amount of data that are not computationally intensive, and the rest are passed to the cloud for processing. Later, a handover process is initiated, and the request is passed to the cloud (e.g.,to update the network topology database of the CRN).

5G: Challenges and Requirements

Mobile networks will become the primary means of network access for person-to-person and person-to-machine connectivity where access to information and data sharing are possible anywhere, anytime. An increasingly diverse set of services, applications, and users with diverse requirements and flexible spectrum use of all non-contiguous spectrum will also characterize 5G technology. A vastly diverse range of things (IoT) will be connected, which implies new functions to be developed. Millions of low-cost connected devices and sensors that need to operate on batteries would require low energy consumption reduced by a factor of 1000 to improve connected device battery lifetime. A thousand times today's traffic volume will be supported in an affordable, sustainable way, cost- and energy-efficiently.

Next generation wireless access networks will need to support fiber-like data rates at 10 Gb/s to make possible ultra-high definition visual communications and immersive multimedia interactions and support mobile cloud service; 100 Mb/s should be generally available, while 1 Mb/s should be the baseline everywhere (Fig. 2).

Ultra large data rates, latency of 1 ms, always-on users per cell reaching several millions, and signaling loads to almost 100 percent will be included in performance requirements. Other challenges for a 5G network are: less than 1 ms latency for real-time mobile applications and communications, and maximum 10 ms switching time between different radio access technologies for seamless delivery of services. On the quest for efficient usage of radio link, modulation techniques like nonlinear multiple-user precoding, joint modulation and coding, physical network coding, and advanced physical layer adaptation are being tested. For example, non-orthogonal multiple access (NOMA), which is an intra-cell multi-user multiplexing scheme using the power domain, and faster than Nyquist (FTN) are included in research efforts. Air interface and RAN will accommodate massive capacity, extremely large amount of connections, and high speeds for new network deployments. Latency reduction will improve user experience, so techniques such as pre-scheduling, local gateway, local breakout, local server, local cache, shortened transmission time interval (TTI), faster decoding, and QoS will control network delay, backhaul delay, radio access delay, and terminal delay. The new radio access technology with new numerology — wider subcarrier spacing — will achieve shortened TTI and thus reduced latency to 1 ms.

Advanced antenna solutions with multiple elements (massive MIMO) including beamforming and spatial multiplexing will achieve high data rates and capacity. Massive MIMO technologies experience small interference and consequently higher throughput.

5G, unlike previous mobile network technologies will have to not only proceed to flexible and efficient use of available non-contiguous spectrum, but also extend the operation range for wireless access into higher frequencies above 10 GHz (the spectrum from 10–100GHz, i.e., the millimeter-wave range is considered so that multi-gigabits-per-second data rates are feasible). Advances in waveform technologies, multiple access, coding, and modulation would improve spectral efficiency so as to support scalability of massive IoT connectivity and decrease latency. Computationally intensive and adaptive new air interfaces are necessary. Single-frequency full-duplex radios will increase spectrum efficiency, reduce network cost, and increase energy efficiency. Plug-and-play will be essential in deployment, allowing nodes to self-organize spectrum blocks for access and backhauling.

The extension of mobile devices' capabilities will be necessary for device-based on-demand mobile networking for services like device-to-device communications. Advanced device-to-device communication would enhance spectrum efficiency and reduce latency as the offloading of network data locally will minimize processing cost and signaling. A single radio resource could be reused by different groups of users of the cellular network if the interference occurring within those groups is tolerable. Advanced small cell technology will utilize higher frequency bands; taking advantage of the vast bandwidth makes it suitable for dense small cell deployment, where massive MIMO will be essential. Furthermore, user-centric virtual cells that consist of a group of BSs are introduced for 5G. In-band wireless backhaul can be used between the BSs for cooperative communication, reducing cost and complexity for the network backhaul.

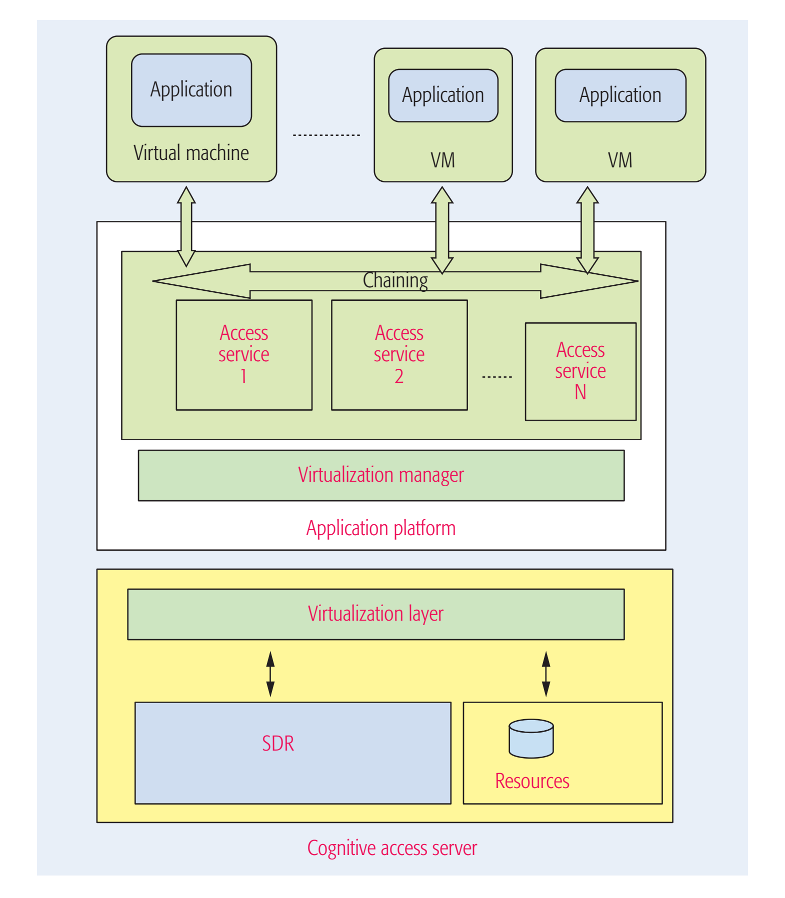

Figure 3. The cognitive radio access server.

Service requirements need to be mapped to the best combinations of frequency and radio resources by spectrum access and programmable air interface technologies. Software defined networking and cloud architectures will enable customization of mobile technologies and QoS guarantees. Cloud computing will allow leveraging of new services and applications and provide on demand processing, storage, and network capacity. The cloud will enable seamless connections between people and between humans and machines, and will coordinate network resources for inter-RAT, inter-frequency, inter-site radio access for efficient network management. Virtualization and SDN are technologies that can simplify and optimize the 5G network. Multi-radio access technologies (RAT) convergence and intelligent management will lie on the cloud. Not only that but in the 5G, network capabilities such as bandwidth, latency, and QoS will be configurable, allowing access to a wider range of services. The 5G network will also integrate existing and heterogeneous networks with diverse requirements.

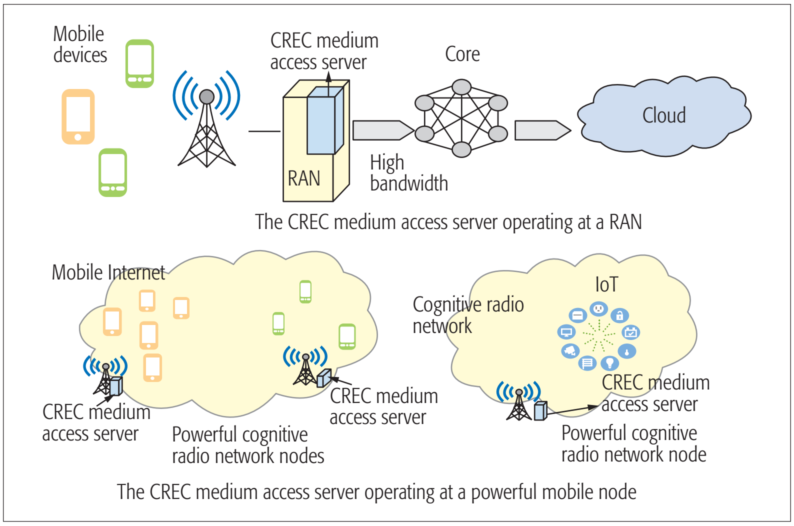

Figure 4. The CREC medium access server deployed on the RAN and locally

CRNC for 5G Heterogeneous Networks

In general, massive MIMO is an evolving technology of next generation networks, which is energy-efficient, robust, secure, and spectrum-efficient [14]. According to [14], massive MIMO technology would:

- Improve energy efficiency by 100 times and capacity on the order of 10 and more
- Be put together with the help of low-power and less costly components
- Decrease latency on the air interface
- Encompass a simple multiple access layer
- Increase the signal strength against interference

The proposed cognitive radio access server (Fig. 3), which is supported by the cloud, would be an appropriate architecture for fast processing of the computational load of massive MIMO technology.

There are mainly two spectrum sharing techniques that enable mobile broadband systems to share spectrum in 5G: distributed solutions and centralized solutions. Distributed spectrum sharing techniques are more efficient as they can take place in a local framework. Besides the centralized and distributed spectrum sharing considerations, cognitive radio with dynamic spectrum management will enhance the network and application performance in 5G [14]. The proposed cognitive radio access server would accommodate centralized solutions and distributed solutions at local powerful nodes (Figs. 4 and 5). Access and backhauling convergence would easily be deployed. Furthermore, full-duplex cognitive radios will be empowered to support 5G.

If a device links directly to another device or apprehends its transmission through the support of other devices, it will be on the device level (device-to-device communication). Thus, the combined resources of the numerous mobile devices and other available stationary devices in the local area will be exploited. This method supports user mobility and identifies the potential of mobile clouds to perform collective sensing [14]. Cognitive radio access as a platform service will enable the 5G network to accommodate heterogeneous networks with diverse requirements, such as small cell dense environments when the cognitive radio access server runs the adaptive access services in the local vicinity and wireless backhaul between base stations for cooperative communication. Network service chaining will be realized, enabling end users to make the best choices, introducing high-level QoE based on the enhanced air interfaces and capabilities of 5G, signifying a new era in network infrastructures.

Conclusion

This article makes a revision of cognitive radio network requirements and challenges — including cognitive radio network cloud, mobile edge computing, and network service chaining — and provides a review of current research work on CRNC that will support all the rest. Distributed resource/spectrum management (devices as resource providers), centralized resource/spectrum management (cloud), and processing offloading would be easily feasible with the proposed cognitive radio edge computing access server paradigm. Furthermore, a cognitive radio access server will

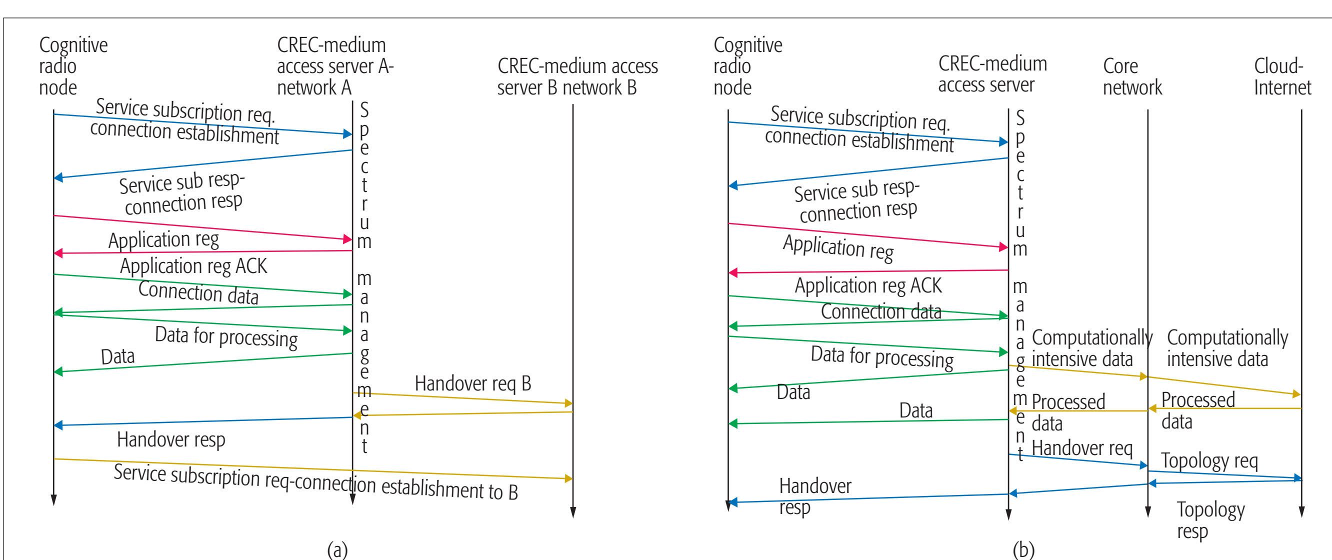

Figure 4. CREC— medium access server operating: a) at a powerful local node; b) on the RAN.

support the 5G heterogeneous network operating as a platform service providing radio access in the case of a high-capacity backhaul when cloud support is needed. Otherwise, resource/spectrum management will be performed locally, effectively enabling network service chaining in end-user-oriented mode in the diverse wireless environment of the 5G network. Thus, bypassing its limitations, the cognitive radio network will respond to the vast needs of future wireless/mobile networks; the 5G example has been presented.

Cognitive Radio Access as a platform service will enable 5G network to accommodate heterogeneous networks with diverse requirements e.g., for small cell dense environments when the Cognitive Radio Access Server runs the adaptive access services on the local vicinity and wireless backhaul between BSs for cooperative communication.

References

[1] J. Mitola and G. Q. Maguire, Jr., "Cognitive Radio: Making Software Radios More Personal," *IEEE Personal Commun.*, vol. 6, no. 4, Aug. 1999, pp. 13–18.

[2] I. Kakalou *et al.*, "A Reinforcing Learning-Based Cognitive MAC Protocol," *IEEE ICC 2015*, London, U.K., 2015, pp. 5608–13.

[3] H. D. Thai *et al.*, "A Survey of Mobile Cloud Computing: Architecture, Applications and Approaches," *Wireless Commun. and Mobile Computing*, vol. 13, no. 18, 2013, pp. 1587–1611

[4] C. H. Co, D. H. Huang, and S.-H. Wu, "Cooperative Spectrum Sensing in TV White Spaces: When Cognitive Radio Meets Cloud, Workshop on Cloud Computing," *IEEE INFOCOM 2011*, 2011, pp. 683–88.

[5] B. Y. Reddy, "Solving Hidden Terminal Problem in Cognitive Networks Using Cloud Technologies," *Proc. 6th Int'l. Conf. Sensor Technologies and Applications*, 2012, pp. 235–40.

[6] D. B. Rawat, S. Shetty, and K. Raza, "Game Theoretic Dynamic Spectrum Access in Cloud-Based Cognitive Radio Networks," *Proc IEEE Int'l. Conf. Cloud Engineering 2014*, 2014, pp. 586–91.

[7] D. B. Rawat, "ROAR: An Architecture for Real-Time Opportunistic Spectrum Access in Cloud-Assisted Cognitive Radio Networks," *Proc.13th IEEE Annual Consumer Commun. & Net. Conf. 2016*, Las Vegas, NV, 2016.

[8] D. B. Rawat *et al.*, "Cloud-Assisted GPS-Driven Dynamic Spectrum Access in Cognitive Radio Vehicular Networks for Transportation Cyber Physical Systems," *Proc. IEEE Wireless Commun. and Networking Conf. 2015*, New Orleans, LA, 2015.

[9] F. Ge *et al.*, "Cognitive Radio Rides on the Cloud," *Proc. MILCOM 2011*, 2011, pp. 1448.

[10] H. Lin *et al.*, "MOON: MapReduce on Opportunistic Environments," *Proc. ACM Int'l. Symp. High Performance Distributed Computing 2010,* Chicago, IL, 2010, pp. 95–106.

[11] S.-H. Wu *et al.*, "A Cloud Model and Concept Prototype for Cognitive Radio Networks," *IEEE Wireless Commun.*, vol. 19, no. 4, 2012, pp. 49–58.

[12] D. Huang, S.-H. Wu, and P.-H. Wang, "Cooperative Radio Source Positioning and Power Map Reconstruction: A Sparse Bayesian Learning Approach," *IEEE Trans. Vehic. Tech.*, vol. 64, no. 6, 2015, pp. 2318–32.

[13] S. Y. Chang and H. C. Wu, "Adaptive Antenna Selection by Parallel QR-Factorization for Cognitive Radio Cloud Network," *Proc. IEEE GLOBECOM 2014, Cognitive Radio and Networks Symp.*, Austin TX, 2014, pp. 882–87.

[14] A. Gupta and R. K. Jha, "A Survey of 5G Network:Architecture and Emerging Technologies," *IEEE Access*, vol. 3, 2015, pp. 1206–32.

[15] J. M. Batalla *et al.*, "ID-Based Service-Oriented Communications for Unified Access to IoT," *Computers & Electrical Engineering*, Elsevier, vol. 52 , no. C, 2016, pp. 98–113.

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