Cognitive Radio Network and Network Service Chaining towards 5G: challenges and requirements

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ABSTRACT

Cognitive radio is a promising technology that answers the spectrum scarcity problem arising with the growth of usage of wireless networks and mobile services. Cognitive Radio Network Edge Computing will enhance the Cognitive Radio Network (CRN) capabilities and along with some adjustments in its operation will be a key technology for 5G Heterogeneous Network deployment. This paper presents current requirements and challenges in CRN, a review of the limited research work on the CRN Cloud which will take off CRN capabilities and 5G Network requirements and challenges. The paper proposes a Cognitive Radio Edge Computing Access Server deployment for Network Service Chaining in Access Layer level.

INTRODUCTION

Cognitive radio is a promising technology that answers the spectrum scarcity problem arising with the growth of usage of wireless networks and mobile services. Based on the Software Defined Radio (SDR) that can reconfigures 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 the Cognitive Radio Network (CRN) Users to transmit. In case of the licensed spectrum when the licensed users, i.e. Primary Users (PUs), vacate the spectrum the CRN users, also called Secondary Users (SUs), can access it. There are limitations to the interference the Secondary Users can cause to the Primary Users. On the other hand, the underutilized spectrum resulted in an immense need for Dynamic Spectrum Access that exploits spectrum opportunistically.

Dynamic Spectrum Access includes amongst others sensing, spectrum management, spectrum sharing and spectrum mobility. For spectrum sensing - Primary Users 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 Primary User, the Secondary User has to vacate the channel immediately and continue transmission in another vacant channel. Spectrum sharing is essential for avoiding overlapping of multiple cognitive radios as well as handoff (loss of connection for mobile Secondary User or poor Quality of Service).

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 OSI layer (Software Defined Radio - 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 networks needs. A high degree of interaction takes place within the CRN to achieve optimal network performance. Thus, the paper considers Cognitive Radio Cloud and proposes a Cognitive Radio Edge Computing architecture to expand the CRN's capabilities and performance whilst by placing Network Service Chaining for the Access level as a key technology for an increasing Cognitive Radio Access diversity. The proposed solution would support the 5G Heterogeneous Networks as well – an analysis of challenges and requirements of 5G Network is provided to justify the former considerations and proposals within 5G. Although current research work on Cognitive Radio Network Cloud (CRNC) has started to unveil, this paper goes beyond and bypass the existing limitations in Cognitive Radio Network with enhancements on Radio Access capabilities to respond to the vast needs of future Wireless/Mobile Networks - the 5G example was presented.

The paper is organized as follows: section (II) is an introduction to Mobile Cloud and Mobile Edge Computing, section (III) presents the CRN requirements and challenges, the CRNC, current research work on this field and proposes a server-based architecture for Cognitive Radio Access for Network Service Chaining on the Access Layer Level. Section (IV) is a brief discussion on the 5G requirements and challenges whilst section (V) combines the Cognitive Radio Access Network Service Chaining solution to the 5G Heterogeneous Network deployment.

MOBILE CLOUD AND MOBILE EDGE COMPUTING

MOBILE CLOUD

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 data storage away from

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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 the 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 they 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% for numerical computations
- Improve Data storage and processing power
- Improve reliability.

MOBILE-EDGE COMPUTING AND NETWORK SERVICE CHAINING

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.

The work of ETSI MEC –RAN aims to provide IT and cloud-computing capabilities within the Radio Access Network (RAN). The key element of Mobile-edge Computing (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 VM back to the physical interface. Cloud and virtualization technologies (Network Functions Virtualization-NFV) are key enablers for Mobile-edge Computing.

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's 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 Cognitive Radio Network are storing of large amount of data, processing them in real time and the exchanging 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 arise. Cognitive Radio Network Cloud (CRNC) is an infra-structure consisting of mobile nodes and the cloud whose primary goal is to keep an up-to-date status of the spectrum availability in the network for all (Primary and Secondary Users) to access. The network status will be maintained in the cloud and updated by the networks nodes. The need for intense and accurate sensing made 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 on the existing research work on this field is presented along with the arising Cognitive Radio Network Cloud 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. So, CRNC should also be able of running the cognition cycle for the network. The nodes will continually report to the cloud their status, store and process their data and plan. Thus the control messages exchange between the mobile nodes will be eliminated and only data transfer will occur.

In [4] the data transfer between a mobile node *A* and *B* will occur after the cloud has reserved the resources in the multi-hop cognitive network path: $A\text{->}C_i\text{->}B$ (where C_i denotes all the rest 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 Primary User arrival.

Actually, there are two options of implementing data transmission:

- the cloud will reserve the resources along the transmission path and then transmission will occur between the wireless nodes without the cloud's interception

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- the data will be send to the cloud and then will be copied to the destination node.

In the latter case, there will be no data loss upon Primary User arrival as they will be stored in the cloud instead. The Secondary Users' 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, hidden terminal node problem or 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 - whilst the handoff will be seamless. Common Control Channel (CCC) was the solution in ad-hoc networks to handle the coordination and resources management between the nodes as well as the hidden terminal problem. When all the control messages of the network are transmitted via one channel, this make the network 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 (CR) Infrastructure Networks and Cognitive Radio Infrastructure-less Networks (Figure 1). Cognitive Radio Infrastructure-less networks, although they are self-organized and implement distributed resources allocation, still suffer the limited storage, processing ability and power supply. Demanding tasks, e.g. signal intelligence, could be off-loaded 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 CR 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 use 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 tradeoff 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, Database and the Knowledge Database. A Game Theoretic Resources Allocation in the CRNC is presented in [6], where the Secondary Users 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 the timestamp, are reported to the cloud server. The decision for a channel availability is taken upon 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 Cognitive Radio Networks where the SUs are equipped with a GPS - sensing by the SUs is avoided at all.

The authors in [9] introduce powerful mobile devices which act as resources providers serving the Cognitive Radio Network 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 are volatile wireless nodes e.g. in terms of jamming. Cooperative sensing and localization for Power Map reconstruction are proposed in [11] [12].

Multiple-input/multiple-output (MIMO) systems are capable of achieving a capacity gain and/or increasing link robustness in CRN but they increase processing time, energy consumption and processing 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.

A necessity for a Cognitive Medium Access Control on the Cloud arises: as the Primary Users can utilize the spectrum anytime, continuous sensing and storage of the huge amount of sensing data as well as real-time processing are required. A Mobile Edge Computing architecture and Cognitive Radio Network Virtualization would make feasible Lower layers' Services and Applications that could decrease latency, increase the QoE and security. Lower layer Cognitive Radio Services and applications on the Edge Computing would increase capabilities not only within the RAN but within 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 Figure 3 with the Cognitive Radio Edge Computing (CREC) Server to offload storage and processing at the Radio Access Network (RAN) or at the local powerful nodes in the form of access services provision for the Cognitive Radio Network 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's and resources' virtualization i.e. Software Defined Radio (SDR) and resources, which are infrastructure-oriented
- the application platform that supports the services such as Local Network Access Control, Handover etc. for the applications that would respond to e.g. QoS
- the virtual machines with the applications. Each virtual machine with the 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 Medium Access Control is available as a service and adapts to the wireless nodes' requirements. The SU node will run the corresponding Virtual Machine for each Cognitive Medium Access Control service and its application. Virtual Machines communicate via the application platform which run on the server. The server would connect to the cloud for further support. The

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proposed architecture is flexible, reduces latency and easily adaptable as more services and applications are adjusted in a simple way.

Services can connect through the network composing a powerful Network Service Chaining for Cognitive Radio Networks controlling access and providing high level QoE to the network users.

In Figure 4 we can see an 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 e.g. for an IoT network. In Figure 5 (a) we can see the Service, Application Registration and Data sending for computations and processing to the CREC Server operating at a powerful node of a local Network A. Later the CREC Server decides to initiate the handover process for the SU and sends a handover request to the local Network B. The SU is notified and registers to Network B. In Figure 5 (b) 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 Cognitive Radio Network.

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 would also characterize 5G technology. A vastly diverse range of things (IoT) would be connected that imply new functions to be developed. Millions of low cost connected devices and sensors that need to operate on battery would require low energy consumption reduced by a factor of 1000 to improve connected device battery lifetime. 1,000 times the today’s traffic volume would be supported in an affordable, sustainable way, cost and energy efficiently.

Next generation wireless-access networks would need to support fiber-like data rates at 10 Gbps to make possible ultra-high definition visual communications and immersive multimedia interactions and support mobile cloud service; 100 Mbps should be generally available whilst 1 Mbps should be the baseline everywhere (Figure 2).

Ultra large data rates, latency of one millisecond, always-on users per cell reaching several millions and signaling loads to almost 100% would be included in performance requirements. Another challenges for 5G network are: less than one millisecond latency for real-time mobile applications and communications, maximum ten milliseconds switching time between different radio access technologies for seamless delivery of services would be included, too. On the quest for efficient usage of radio link, modulation techniques like non-linear-multiple-user-pre-coding, joint modulation and coding, physical network coding and advanced physical layer adaptation are tested. For example, Non-Orthogonal-Multiple Access (NOMA) for multiple access 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 Radio Access Network (RAN) would accommodate massive capacity, extremely large amount of connections, 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 RAT with new numerology - wider subcarrier spacing - will achieve shortened Transmission Time Interval (TTI) and thus reduced latency to 1ms.

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

5G unlike previous mobile networks technologies will have to proceed not only to flexible and efficient use of available non—contiguous spectrum but extend the operation range for wireless access into higher frequencies above 10GHz (the spectrum from 10GHz to 100GHz i.e. the mmW range is considered so that the multi-Gbps data rates to be 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 would 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 resources could be reused by different groups of users of the cellular network, if the interference occurred within those groups is tolerable. Advanced Small Cell technology will utilize higher frequencies 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.

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 would 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 human-machine and will coordinate network resources for inter-RAT, inter-frequency, inter-site radio access for efficient network management. Virtualization and Software Defined Networking are technologies that can simplify and optimize the 5G network. Multi-Radio Access Technologies (RAT) convergence and intelligent management would lie on the cloud. Not only that but in the 5G, network capabilities such as bandwidth, latency, QoS would be configurable allowing the access to a wider range of services. 5G Network would integrate also existing and heterogeneous networks with diverse requirements.

CRNC FOR 5G HETEROGENEOUS NETWORK

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 the capacity of the order of 10 and more
- can be put together with the help of low power and less costly components
- decrease latency on the air interface
- encompass simple multiple access layer
- increase the signal strength against interference. The proposed Cognitive Radio Access Server (Figure 3) which is supported by the cloud would be an appropriate architecture for fast processing of the computational load of the Massive MIMO technology.

There are mainly two spectrum sharing techniques that enable mobile broadband systems to share spectrum i.e. distributed solutions and centralized solutions in 5G. Distributed spectrum sharing techniques is more efficient as it 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 (Figure 4, Figure 5). Access and Backhauling convergence would be easily 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, then it will be on the device level (device-to-device communication). So 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 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. Network Service Chaining would be realized enabling end-user to make 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 paper makes a revision of Cognitive Radio Network requirements and challenges - including Cognitive Radio Network Cloud, Mobile Edge Computing, Network Service Chaining - and provides a review of current research work on CRNC that would support all the rest. Distributed resources/spectrum management (devices as resources providers), centralized resources/spectrum management (cloud) and processing offloading would be easily feasible with the proposed Cognitive Radio Edge Computing Access Server paradigm. Furthermore, an Cognitive Radio Access Server will support the 5G Heterogeneous Network operating as a platform service providing Radio Access i.e. in case of a highly capacity backhaul when the cloud support is needed. Otherwise the resources/spectrum management will be performed locally, effectively enabling Network Service Chaining in end-user-oriented mode in the diverse wireless environment of 5G Network. Thus bypassing its limitations Cognitive Radio Network will respond to the vast needs of future Wireless/Mobile networks - the 5G example was presented.

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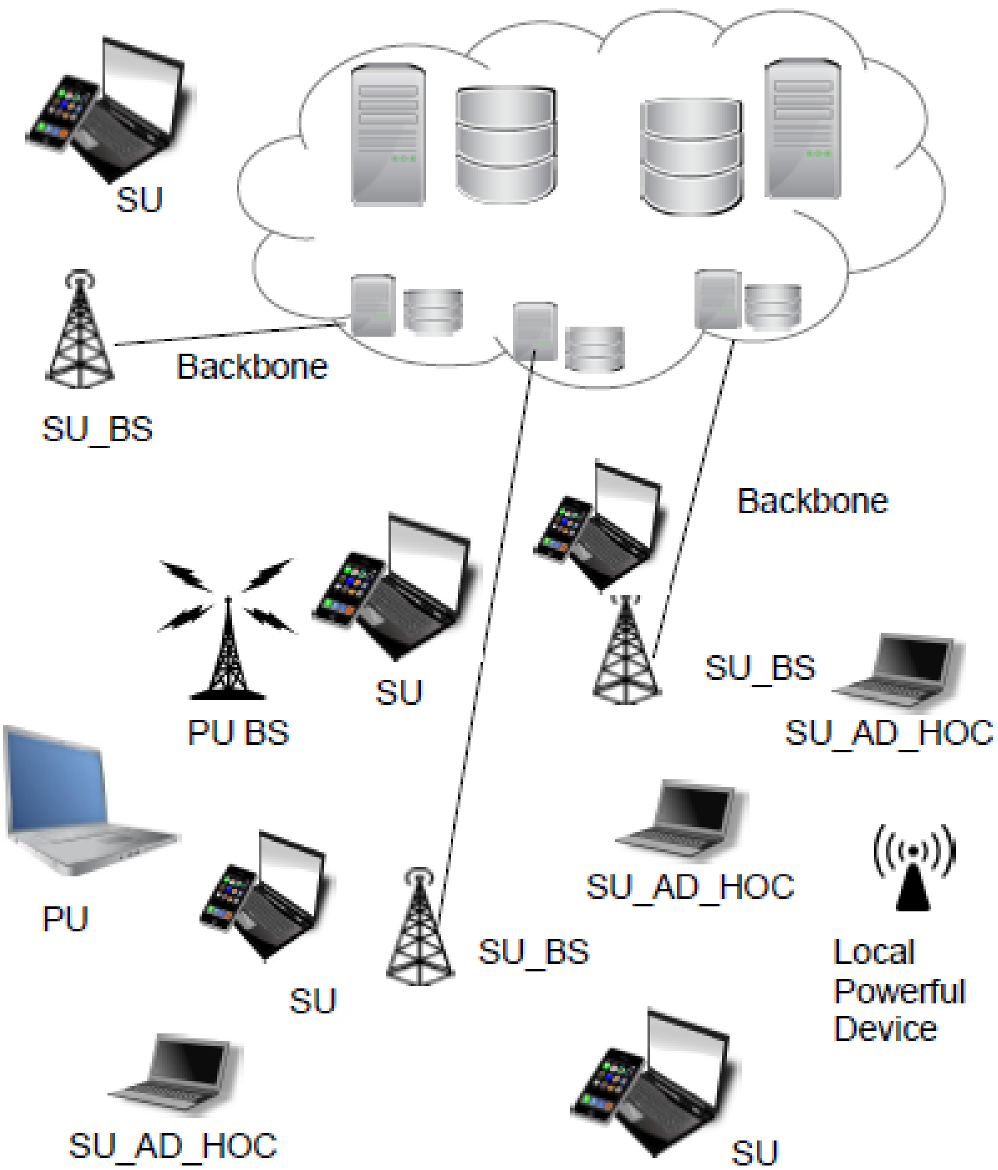

Figure 1: The Cognitive Radio Network Cloud

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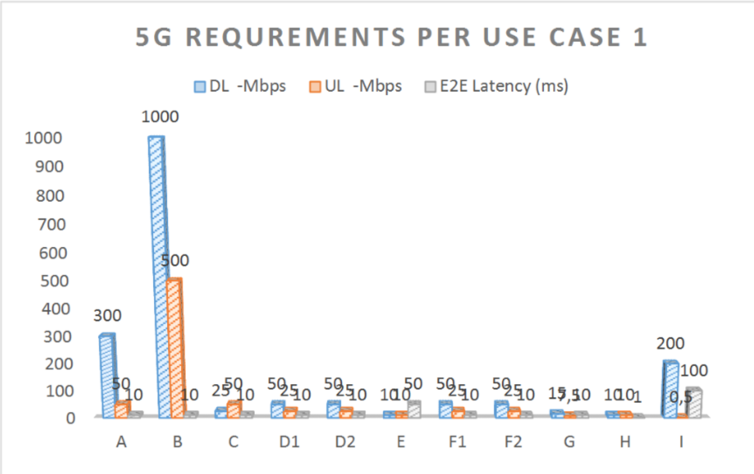

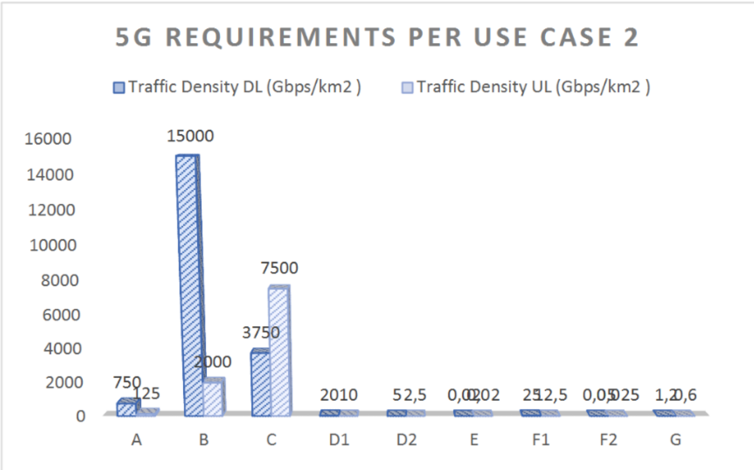

A: Broadband access in dense areas
B: Indoor ulrta high broadband access
C: Broadband access in crowd
D1: 50+Mbps everywhere/suburban
D2: 50+ Mbps everywhre/rural
E: Ultra low cost broadband for ARPU areas
F1: Mobile broadband per train
F2: Mobile broadband per car
G: Airplane connectivity
H: Ultra high reliability -ultra low latency
I: Broadband like services

Figure 2: 5G requirements per Use Case

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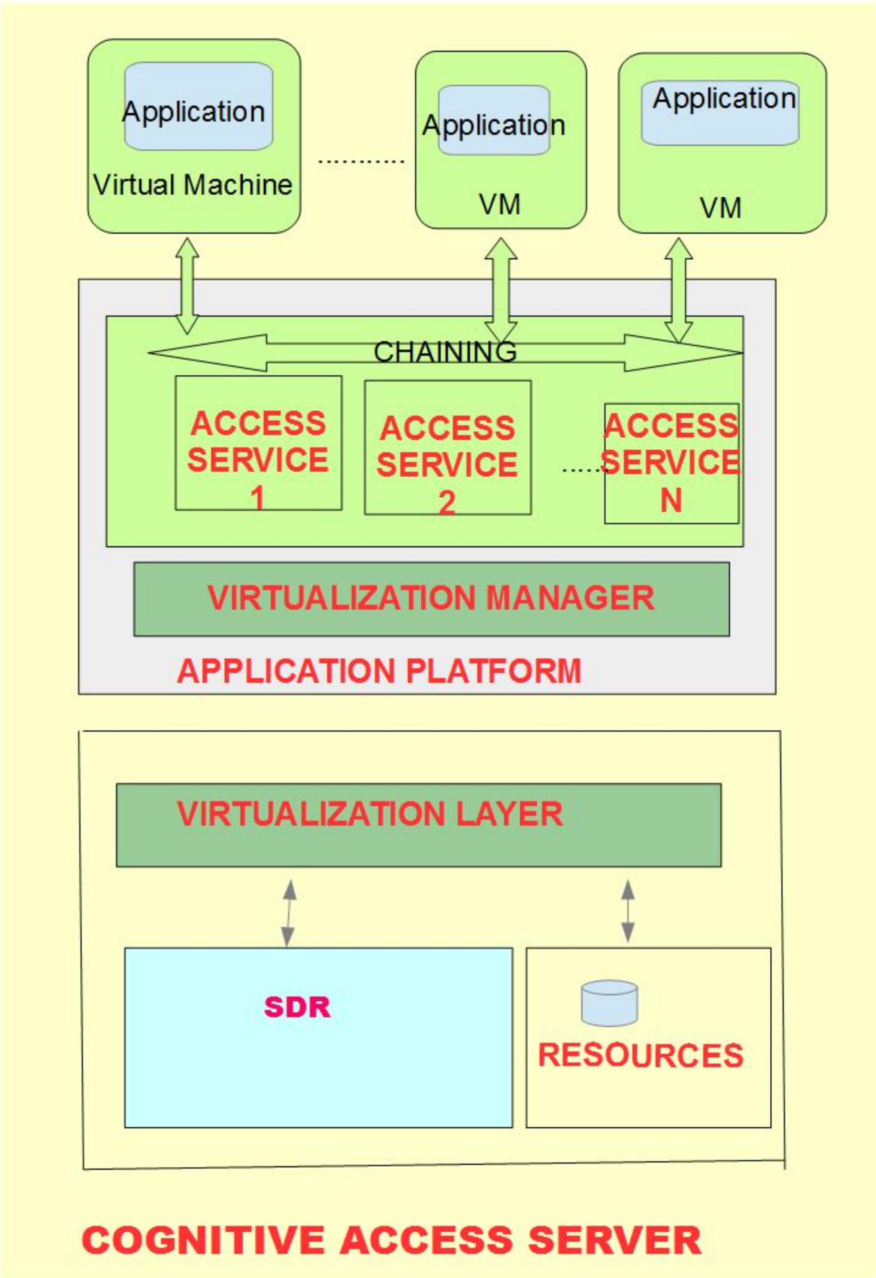

Figure 3: The Cognitive Radio Access Server

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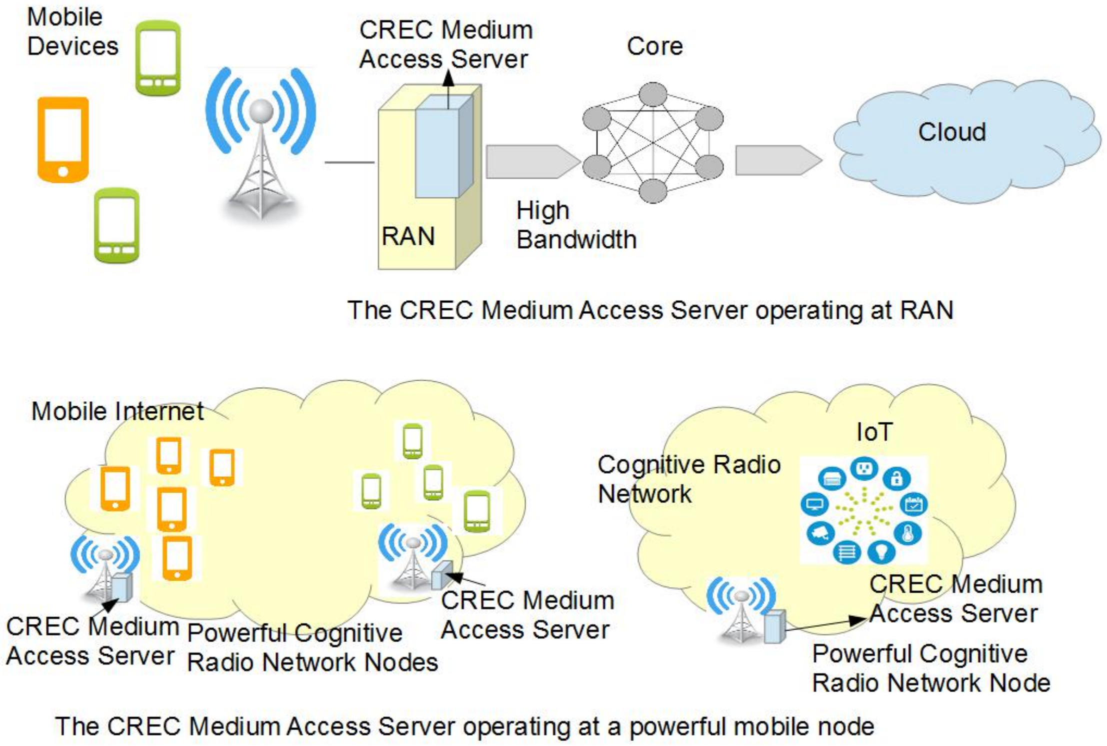
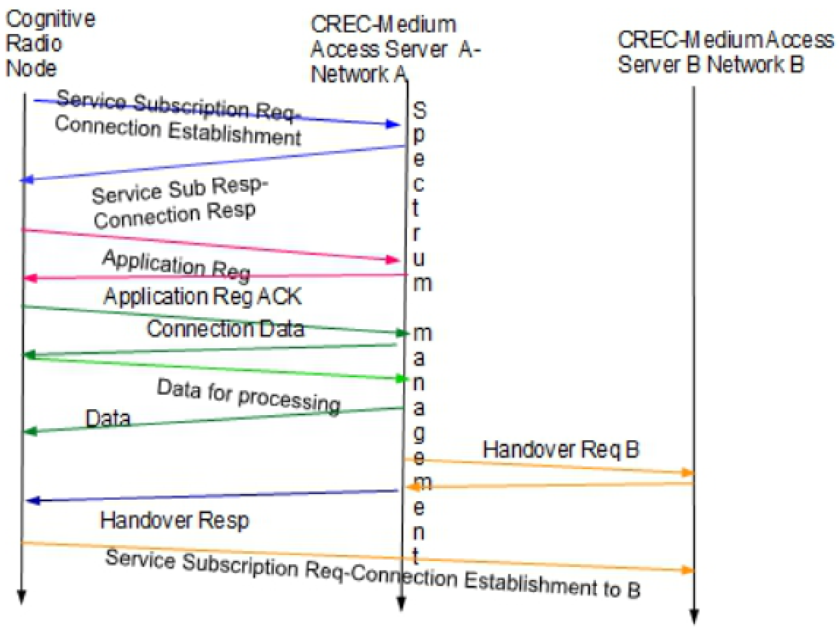
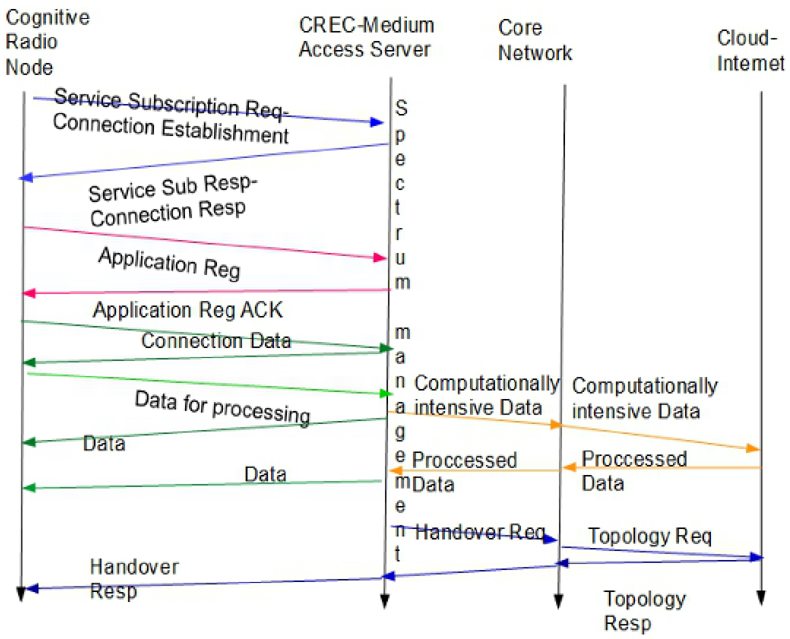


Figure 4: The CREC Medium Access Server deployed on the RAN and locally



(a) CREC Server operating locally



(b) CREC Server operating at the RAN

Figure 5: CREC- Medium Access Server operating: a) at a powerful local node; b) on the RAN.

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