

# Fronthaul Design in Cloud Radio Access Networks: A Survey

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**Abstract**—Cloud Radio Access Networks (C-RAN) was proposed as a solution to overcome the challenges faced by the current Radio Access Networks (RAN). C-RAN was introduced as a change in the architecture of the Base station (BS). Fronthaul is a communication link between the BS entities of the proposed architecture. The change in BSs' architecture places some technical challenges to utilize the benefits offered by C-RAN. Fronthaul capacity limitation and delay are the major bottlenecks of the C-RAN practical implementation. To prevail over these limitations, various C-RAN models in terms of functional splits are proposed. But none of the architectures is finalized among the industry and academia. In this paper, exhaustive literature is presented on the advantages offered by C-RAN architecture. To make full utilization of these advantages, different C-RAN architectures and fronthaul architectures were proposed. Fronthaul compression is crucial for bringing sustainability to C-RAN architecture. As part of the study, different compression techniques are discussed in this literature. Besides the theoretical study, various practical implementation of C-RAN testbeds is examined.

**Index Terms**—C-RAN, Fronthaul Compression, Resource Allocation, CoMP, Precoding.

## I. INTRODUCTION

Data explosion in the era of smart-phones is skyrocketing. According to the Cisco report, the global mobile data traffic for 2016 became 7.2 exabytes per month, and it will increase 7-fold approximately by 2021 [1]. To support users' growing appetite for higher data rates, traditional Radio Access Network (RAN) has to improve its network throughput. The most prominent way to achieve high throughput is by deploying more Base Stations (BSs) for the densification of cell coverage [2]. But, each new BS deployment will increase the Total Cost of Ownership (TCO), which has to be bear by the Telecom Network Operator (TNO). The Average Revenue Per User (ARPU) for the TNOs is not increasing at the expected rate. There is a chance network cost may surpass the revenue if no remedial actions are taken. Traditional RAN has other drawbacks, such as resource sharing is not possible; resources are not effectively utilized as the BS is working all the time irrespective of load conditions, and the tidal effect problem [3]. To address the above challenges faced by traditional RAN, a change in architecture for BSs is proposed, which is popularly known as Cloud Radio Access Network (C-RAN) [4].

Under C-RAN, the traditional BS (eNodeB) is decoupled into two main components: 1) Remote Radio Heads (RRHs), 2) Base-Band Processing Units (BBUs) [5]. The RRHs include light-weighted Radio Frequency (RF) units and antennas to provide a wireless interface for User Equipment (UE).

Whereas the BBUs include all signal processing units and all functional blocks of L2 and L3 protocol stack, located centrally like data centers. The function split between RRH and BBU follows a fully centralized structure [6]. Fig. 1 depicts the architectural difference between traditional RAN and C-RAN [7]. Centralization of BBUs at the BBU pool has many advantages like feasibility of resource sharing, on-demand resource allocation, the possibility of implementing advanced technologies like joint processing and Coordinated Multi-Point (CoMP), etc. [8].

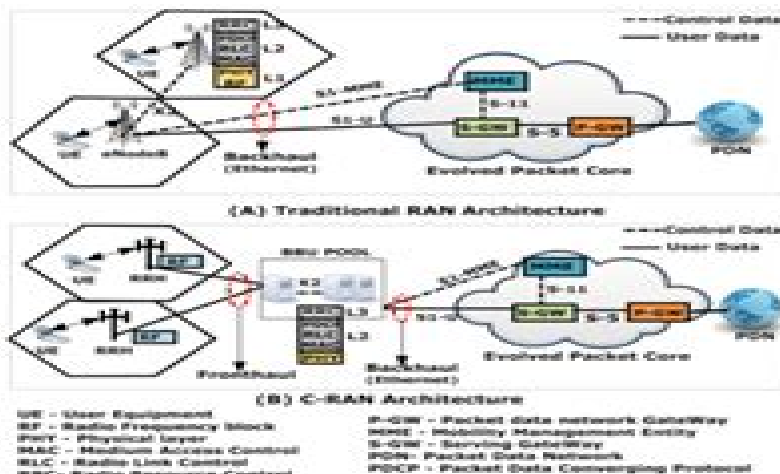


Figure 1. Architectural difference between traditional RAN and C-RAN. (A) traditional RAN architecture, (B) C-RAN architecture.

Due to the full centralized structure of C-RAN, there is a vast communication overhead between RRH and BBU. Being only RF section at RRH, I/Q samples are sent over the fronthaul to the BBU for further processing. The required fronthaul data rate is directly proportional to the number of antennas used at RRH, due to which the use of C-RAN in 5G with massive MIMO seems to be hypothetical [9]. There are two possible directions to address the above problem, which are fronthaul compression and baseband functional

# Fronthaul Design For Radio Access Networks Using Multicore

**Abdelgader M. Abdalla, Jonathan  
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Teixeira**



## **Fronthaul Design For Radio Access Networks Using Multicore:**

*Optical and Wireless Convergence for 5G Networks* Abdelgader M. Abdalla, Jonathan Rodriguez, Issa Elfergani, Antonio Teixeira, 2019-10-07 The mobile market has experienced unprecedented growth over the last few decades Consumer trends have shifted towards mobile internet services supported by 3G and 4G networks worldwide Inherent to existing networks are problems such as lack of spectrum high energy consumption and inter cell interference These limitations have led to the emergence of 5G technology It is clear that any 5G system will integrate optical communications which is already a mainstay of wide area networks Using an optical core to route 5G data raises significant questions of how wireless and optical can coexist in synergy to provide smooth end to end communication pathways Optical and Wireless Convergence for 5G Networks explores new emerging technologies concepts and approaches for seamlessly integrating optical wireless for 5G and beyond Considering both fronthaul and backhaul perspectives this timely book provides insights on managing an ecosystem of mixed and multiple access network communications focused on optical wireless convergence Topics include Fiber Wireless FiWi Hybrid Fiber Wireless HFW Visible Light Communication VLC 5G optical sensing technologies approaches to real time IoT applications Tactile Internet Fog Computing FC Network Functions Virtualization NFV Software Defined Networking SDN and many others This book aims to provide an inclusive survey of 5G optical wireless requirements architecture developments and technological solutions

*Futuristic Communication and Network Technologies A.* Sivasubramanian, Prasad N. Shastry, Pua Chang Hong, 2021-10-11 This book presents select proceedings of the International Conference on Futuristic Communication and Network Technologies CFCNT 2020 conducted at Vellore Institute of Technology Chennai It covers various domains in communication engineering and networking technologies This volume comprises of recent research in areas like optical communication optical networks optics and optical computing emerging trends in photonics MEMS and sensors active and passive RF components and devices antenna systems and applications RF devices and antennas for microwave emerging technologies wireless communication for future networks signal and image processing machine learning AI for networks internet of intelligent things network security and blockchain technologies This book will be useful for researchers professionals and engineers working in the core areas of electronics and communication

Open Radio Access Network (O-RAN) Systems Architecture and Design Wim Rouwet, 2025-05-15 Open Radio Access Network O RAN Systems Architecture and Design 2nd edition gives a jump start to engineers developing O RAN hardware and software systems providing a top down approach to O RAN systems design from an author with a silicon software and system background It gives an introduction into why wireless systems look the way they do today before introducing relevant O RAN and 3GPP standards The remainder of the book discusses hardware and software aspects of O RAN system design including dimensioning and performance targets and some practical use case examples that include 5G advanced topics This edition includes comprehensive updates in key areas such as postquantum security and radio unit design Additionally it

addresses emerging 5G advanced topics including Industrial URLLC nonterrestrial networking the role of artificial intelligence 5G reduced capabilities for IoT and self organizing networks Strong emphasis on implementation in hardware and software Presents O RAN and 3GPP standards Provides a top down approach to O RAN systems design Includes practical examples of relevant elements of detailed hardware and software design to provide tools for development Gives a few practical examples of where O RAN designs play in the market and how they map to hardware and software architectures

*Photonic Applications for Radio Systems Networks* Fabio Cavaliere, Antonio D'Errico, 2019-09-30 This hands on practical new resource provides optical network designers with basic but necessary information about radio systems air interface and radio access network architecture protocols and interfaces using 5G use cases as relevant example The book introduces mobile network designers to the transmission modeling techniques for the design of a radio access optical network The main linear and non linear propagation effects in optical fiber are covered The book introduces mobile network designers to the optical technologies used in digital and analog radio access networks such as optical amplifiers and transmitters and describes different deployment scenarios including point to point fiber systems wavelength division multiplexing systems and passive optical networks New integrated photonic technologies for optical switching are also discussed The book illustrates the principles of optical beamforming and explains how optical technologies can be used to provide accurate phase and frequency control of antenna elements The new architecture of the optical transport network driven by the new challenging requirements that 5G poses in terms of high capacity high energy efficiency low latency and low cost is discussed The use of photonic devices to perform tasks as radio frequency generation and beamforming with improved accuracy and cost compared to traditional electronic systems especially when moving to mm waves is also explored Readers also learn the replacement of electric interconnect systems with higher speed and more energy efficient optical lines to perform more effectively computationally demanding baseband processing in 5G All presented propagation models can be implemented in a spreadsheet in order to provide the designer with simple rules of thumbs for network planning [Research Anthology on Developing and Optimizing 5G Networks and the Impact on Society](#) Management Association, Information

Resources, 2020-11-27 As technology advances the emergence of 5G has become an essential discussion moving forward as its applications and benefits are expected to enhance many areas of life The introduction of 5G technology to society will improve communication speed the efficiency of information transfer and end user experience to name only a few of many future improvements These new opportunities offered by 5G networks will spread across industry government business and personal user experiences leading to widespread innovation and technological advancement What stands at the very core of 5G becoming an integral part of society is the very fact that it is expected to enrich society in a multifaceted way enhancing connectivity and efficiency in just about every sector including healthcare agriculture business and more Therefore it has been a critical topic of research to explore the implications of this technology how it functions what industries it will impact

and the challenges and solutions of its implementation into modern society Research Anthology on Developing and Optimizing 5G Networks and the Impact on Society is a critical reference source that analyzes the use of 5G technology from the standpoint of its design and technological development to its applications in a multitude of industries This overall view of the aspects of 5G networks creates a comprehensive book for all stages of the implementation of 5G from early conception to application in various sectors Topics highlighted include smart cities wireless and mobile networks radio access technology internet of things and more This all encompassing book is ideal for network experts IT specialists technologists academicians researchers and students

**Opportunities and Challenges of Industrial IoT in 5G and 6G Networks** Yu, Poshan,Hu, Xiaohan,Prakash, Ajai,Misuko, Nyaribo Wycliffe,Haiyue, Gu,2023-06-07 Modern communication technologies such as 5G and 6G and the industrial internet of things have important attributes to meet the requirements of industries and with the rapid development of the fourth industrial revolution and beyond it is unavoidable that these will fulfill the necessary requirements of this important part of modernization Opportunities and Challenges of Industrial IoT in 5G and 6G Networks ranges from the application of recently ratified communication standards theoretical knowledge that provides tangible insight for understanding the principles of operation design implementation and planning to the outcomes from deployment of industrial projects Covering topics such as 5G network programmability industry policies and optical networking technologies this premier reference source is a valuable resource for computer scientists IT specialists industry consultants and professionals business leaders libraries students researchers and academicians

Handbook of Radio and Optical Networks Convergence Tetsuya Kawanishi,2024-10-02 This handbook provides comprehensive knowledge on device and system technologies for seamlessly integrated networks of various types of transmission media such as optical fibers and millimeter and THz waves to offer super high speed data link service everywhere The seamless integration of the knowledge of radio and optical technologies is needed to construct wired and wireless seamless networks High frequency bands such as millimeter wave and THz wave bands where super wideband spectra are available can offer high speed data transmission and high resolution sensing However the expected coverage is limited due to large wave propagation loss Thus convergence of radio and optical links is indispensable to construct worldwide networks The radio and optical technologies share the same physics and are closely related to each other but have been developed independently Therefore there is a big gap between these two fields Bridging the two fields this handbook is also intended as a common platform to design integrated networks consisting of wireless and wired links Full coverage of wireless and wired convergence fields ranging from basics of device and transmission media to applications allows the reader to efficiently access all the important references in this single handbook Further it also showcases state of the art technology and cases of its use

The Road towards 6G: Opportunities, Challenges, and Applications Valeria Loscri,Luca Chiaraviglio,Anna Maria Vegni,2024-03-19 The proposed book will provide a comprehensive picture of the journey from 5G networks towards 6G Different aspects ranging from theoretical foundations

to existing platforms and technologies will be presented and analysed by critically highlighting the real opportunities and the challenges. The first chapters are to describe the general transitioning aspects from 5G to 6G. After that an overview on the different technologies is provided to present at the end the security aspects, the new applications and an analysis of the electromagnetic exposure above all in terms of comparative in respect of 5G. Security and Application will be straightforward better explained after the big picture on the different technologies is detailed in the previous chapters. 6G is an emerging complex paradigm with some important new concepts that would enable an extremely high reliability and low latency. The main purpose is to provide the reader a thorough vision of the enabling technologies, their potential and what is still needed to fill the gap in terms of sustainability and coexistence of the different technologies. Since different emerging technologies will be considered and detailed in the book, it will be interesting for the reader to infer the major opportunities of each and the main limitations. This kind of information will mainly boost the potential interactions of different technologies to provide a more reliable system.

*Joint Design of Access and Fronthaul Uplinks in Cloud Radio Access Networks* Jens Steven Bartelt, 2017      **Fronthaul-constrained Uplink Cloud Radio-access Networks** Yuhua Zhou, 2016. This thesis considers the uplink of a cloud radio access network (C-RAN) in which base stations (BSs) are connected to a cloud computing based central processor (CP) via noiseless fronthaul links with finite capacities. The compress and forward strategy is employed where the BSs compress the received signals and send the quantized bits to the CP. Then the CP performs either joint decoding of both the quantization and message codewords simultaneously or generalized successive decoding of quantization and message codewords in an arbitrary order. Under this setup, this thesis establishes several information theoretic results and proposes a number of practical algorithm designs. From a theoretical perspective, this thesis first proves that under joint decoding and Gaussian input, Gaussian quantization maximizes the achievable rate region. Second, it is shown that generalized successive decoding achieves the identical rate region as joint decoding under a sum fronthaul capacity constraint. Third, a particular successive decoding scheme in which quantization codewords are decoded first followed by message codewords, referred to as the virtual multiple access channel (VMAC) scheme, achieves the same maximum sum rate as joint decoding under individual fronthaul constraints. Furthermore, it is shown that under a sum fronthaul constraint, Wyner-Ziv coding quantized at the background noise level can achieve the sum capacity to within a constant gap. A similar constant gap result is shown for single user compression under a diagonally dominant channel condition. From an optimization perspective, this thesis investigates the optimization of beamforming design and fronthaul compression for the VMAC schemes. First, under a sum fronthaul constraint, this thesis proposes a novel alternating convex optimization algorithm to maximize the weighted sum rate for single antenna uplink C-RAN. It is shown that setting the quantization noise levels to be proportional to the background noise levels is near optimal when the signal to quantization noise ratio is high. Second, under individual fronthaul constraints, this thesis develops a weighted minimum mean square error successive convex approximation algorithm to jointly

optimize beamforming and fronthaul compression for multi antenna uplink C RAN The performances of the proposed algorithms are verified under practical multicell and heterogeneous networks through numerical evaluation *Optical and Wireless Convergence for 5G Networks* Abdelgader M. Abdalla, Issa Elfergani, Jonathan Rodriguez, Antonio

Teixeira, 2019-08-02 The mobile market has experienced unprecedented growth over the last few decades Consumer trends have shifted towards mobile internet services supported by 3G and 4G networks worldwide Inherent to existing networks are problems such as lack of spectrum high energy consumption and inter cell interference These limitations have led to the emergence of 5G technology It is clear that any 5G system will integrate optical communications which is already a mainstay of wide area networks Using an optical core to route 5G data raises significant questions of how wireless and optical can coexist in synergy to provide smooth end to end communication pathways *Optical and Wireless Convergence for 5G Networks* explores new emerging technologies concepts and approaches for seamlessly integrating optical wireless for 5G and beyond Considering both fronthaul and backhaul perspectives this timely book provides insights on managing an ecosystem of mixed and multiple access network communications focused on optical wireless convergence Topics include Fiber Wireless FiWi Hybrid Fiber Wireless HFW Visible Light Communication VLC 5G optical sensing technologies approaches to real time IoT applications Tactile Internet Fog Computing FC Network Functions Virtualization NFV Software Defined Networking SDN and many others This book aims to provide an inclusive survey of 5G optical wireless requirements architecture developments and technological solutions **Coordination Inside Centralized Radio Access Networks**

**with Limited Fronthaul Capacity** Jialong Duan, 2017 Centralized Cloud Radio Access Network C RAN is a promising mobile network architecture which can potentially increase the capacity of mobile networks while reducing operators cost and energy consumption However the feasibility of C RAN is limited by the large bit rate requirement in the fronthaul The objective of this thesis is to improve C RAN performance while considering fronthaul throughput reduction fronthaul capacity allocation and users scheduling We first investigate new functional split architectures between Remote Radio Heads RRHs and Baseband Units BBU on the uplink to reduce the transmission throughput in fronthaul Some low layer functions are moved from the BBU to RRHs and a quantitative analysis is provided to illustrate the performance gains We then focus on Coordinated Multi point CoMP transmissions on the downlink CoMP can improve spectral efficiency but needs tight coordination between different cells which is facilitated by C RAN only if high fronthaul capacity is available We compare different transmission strategies without and with multi cell coordination Simulation results show that CoMP should be preferred for users located in cell edge areas and when fronthaul capacity is high We propose a hybrid transmission strategy where users are divided into two parts based on statistical Channel State Informations CSIs The users located in cell center areas are served by one transmission point with simple coordinated scheduling and those located in cell edge areas are served with CoMP joint transmission This proposed hybrid transmission strategy offers a good trade off between users

transmission rates and fronthaul capacity cost      *Backhauling / Fronthauling for Future Wireless Systems* Kazi Mohammed Saidul Huq, Jonathan Rodriguez, 2016-09-26 The recent widespread use of mobile Internet together with the advent of numerous smart applications has led to the explosive growth of the mobile data traffic in the last few years This momentum of mobile traffic will continue due to the emerging needs of connecting people machines and applications through mobile infrastructure As a result the current and projected dramatic growth of mobile data traffic necessitates the development of fifth generation 5G mobile communications technology As a result there is significant interest in the development of innovative backhaul and fronthaul solutions for ultra dense heterogeneous networks This book brings together mobile stakeholders from academia and industry to identify and promote technical challenges and recent results related to smart backhaul fronthaul research for future communication system such as 5G Moreover it presents a comprehensive analysis on different types of backhaul fronthaul technology and topology It considers already available topology for backhauling fronthauling and explains all fundamental requirements for deploying future smart and efficient backhauling fronthauling infrastructure from an architectural technical and business point of view and presents real life applications and use cases Expanding on standardization activities this book consists of multiple channels on specific research topics The chapters are logically organized as the authors approach the subject from overview to specifics and from a lower to higher layer direction

**Cloud-Radio Access Networks** Niezi Mharsi, 2019 Cloud Radio Access Network C RAN has been proposed as a promising architecture to meet the exponential growth in data traffic demands and to overcome the challenges of next generation mobile networks 5G The main concept of C RAN is to decouple the BaseBand Units BBU and the Remote Radio Heads RRH and place the BBUs in common edge data centers BBU pools for centralized processing This gives a number of benefits in terms of cost savings network capacity improvement and resource utilization gains However network operators need to investigate scalable and cost efficient algorithms for resource allocation problems to enable and facilitate the deployment of C RAN architecture Most of these problems are very complex and thus very hard to solve Hence we use combinatorial optimization which provides powerful tools to efficiently address these problems One of the key issues in the deployment of C RAN is finding the optimal assignment of RRHs or antennas to edge data centers BBUs when jointly optimizing the fronthaul latency and resource consumption We model this problem by a mathematical formulation based on an Integer Linear Programming ILP approach to provide the optimal strategies for the RRH BBU assignment problem and we propose also low complexity heuristic algorithms to rapidly reach good solutions for large problem instances The optimal RRH BBU assignment reduces the expected latency and offers resource utilization gains Such gains can only be achieved when reducing the inter cell interference caused by the dense deployment of cell sites We propose an exact mathematical formulation based on Branch and Cut methods that enables to consolidate and re optimize the antennas radii in order to jointly minimize inter cell interference and guarantee a full network coverage in C RAN In addition to the increase of inter



cell interference the high density of cells in C RAN increases the amount of baseband processing as well as the amount of data traffic demands between antennas and centralized data centers when strong latency requirements on fronthaul network should be met Therefore we discuss in the third part of this thesis how to determine the optimal placement of BBU functions when considering 3GPP split option to find optimal tradeoffs between benefits of centralization in C RAN and transport requirements We propose exact and heuristic algorithms based on combinatorial optimization techniques to rapidly provide optimal or near optimal solutions even for large network sizes

### **Open Radio Access Network (O-RAN) Systems**

**Architecture and Design** Wim Rouwet,2022-02-26 Open Radio Access Network O RAN Systems Architecture and Design gives a jump start to engineers developing O RAN hardware and software systems providing a top down approach to O RAN systems design It gives an introduction into why wireless systems look the way they do today before introducing relevant O RAN and 3GPP standards The remainder of the book discusses hardware and software aspects of O RAN system design including dimensioning and performance targets Presents O RAN and 3GPP standards Provides a top down approach to O RAN systems design Includes practical examples of relevant elements of detailed hardware and software design to provide tools for development Gives a few practical examples of where O RAN designs play in the market and how they map to hardware and software architectures

### **Cloud Radio Access Networks** Tony Q. S. Quek,Mugen Peng,Osvaldo

Simeone,Wei Yu,2017-02-02 This unique text will enable readers to understand the fundamental theory current techniques and potential applications of Cloud Radio Access Networks C RANs Leading experts from academia and industry provide a guide to all of the key elements of C RANs including system architecture performance analysis technologies in both physical and medium access control layers self organizing and green networking standards development and standardization perspectives Recent developments in the field are covered as well as open research challenges and possible future directions The first book to focus exclusively on Cloud Radio Access Networks this is essential reading for engineers in academia and industry working on future wireless networks

### **Energy-efficient Resource Allocation in Limited Fronthaul Capacity**

**Cloud-radio Access Networks** Phuong Thi Thu Luong,2018 **Cloud Radio Access Network in Constrained Fronthaul**

Rui Lei,2017 **Cloud-radio Access Network Functional Split Over Ethernet-based Fronthaul** Ghizlane

Mountaser,2021 Fog Radio Access Networks (F-RAN) Mugen Peng,Zhongyuan Zhao,Yaohua Sun,2021-08-14 This book provides a comprehensive introduction of Fog Radio Access Networks F RANs from both academic and industry perspectives The authors first introduce the network architecture and the frameworks of network management and resource allocation for F RANs They then discuss the recent academic research achievements of F RANs such as the analytical results of theoretical performance limits and optimization theory based resource allocation techniques Meanwhile they discuss the application and implementations of F RANs including the latest standardization procedure and the prototype and test bed design The book is concluded by summarizing the existing open issues and future trends of F RANs Includes the latest theoretical and

technological research achievements of F RANs also discussing existing open issues and future trends of F RANs toward 6G from an interdisciplinary perspective Provides commonly used tools for research and development of F RANs such as open resource projects for implementing prototypes and test beds Includes examples of prototype and test bed design and gives tools to evaluate the performance of F RANs in simulations and experimental circumstances

This book delves into Fronthaul Design For Radio Access Networks Using Multicore. Fronthaul Design For Radio Access Networks Using Multicore is an essential topic that must be grasped by everyone, from students and scholars to the general public. This book will furnish comprehensive and in-depth insights into Fronthaul Design For Radio Access Networks Using Multicore, encompassing both the fundamentals and more intricate discussions.

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  - Chapter 5: Conclusion
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