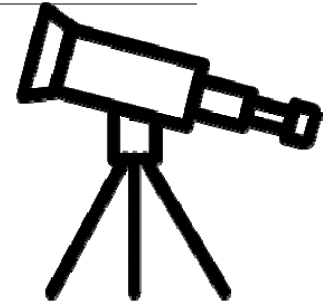




# Explorable Resources for Communication Forecasting

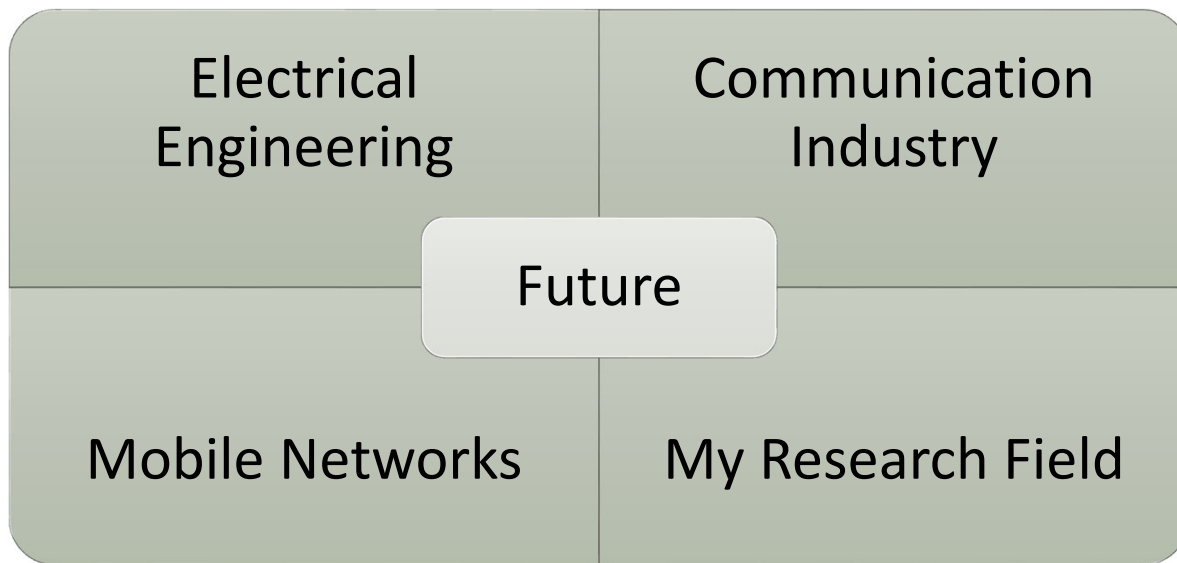
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MOHAMMAD HADI  
WINTER 2022



# Fundamental Question!

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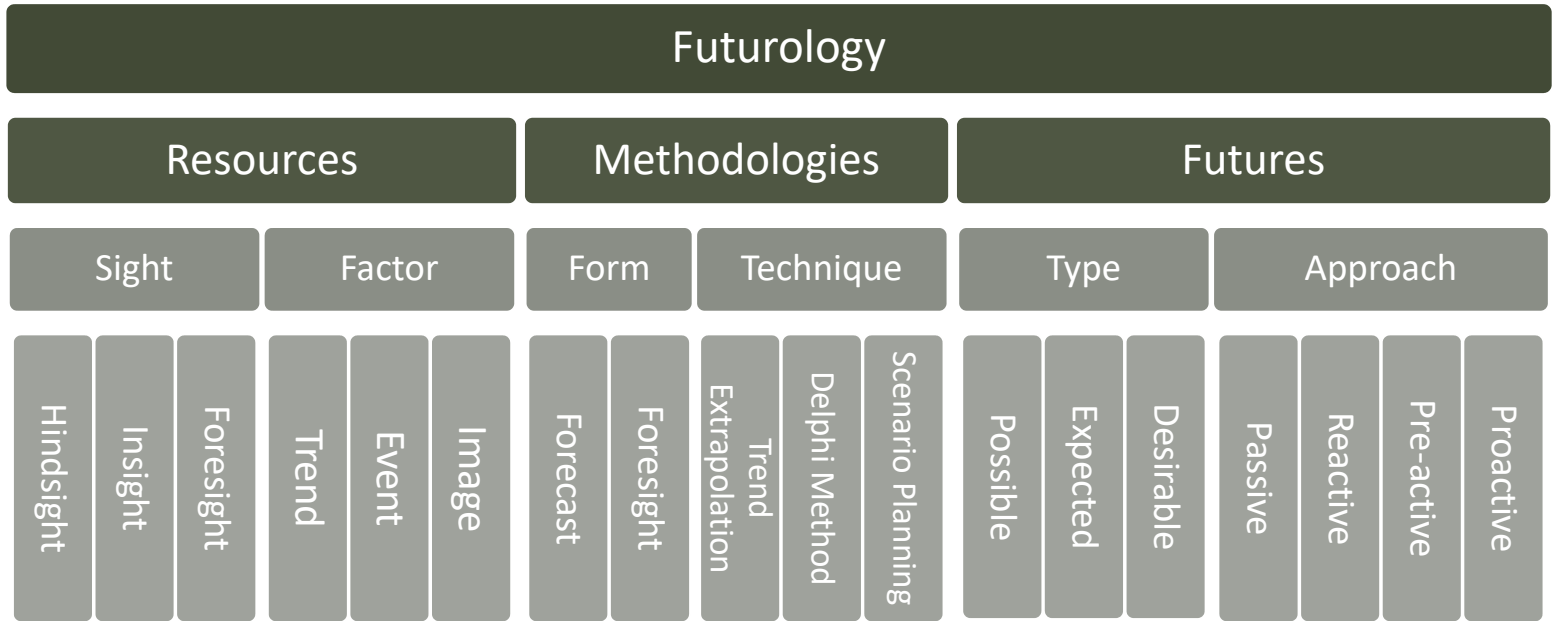


# Futurology Steps

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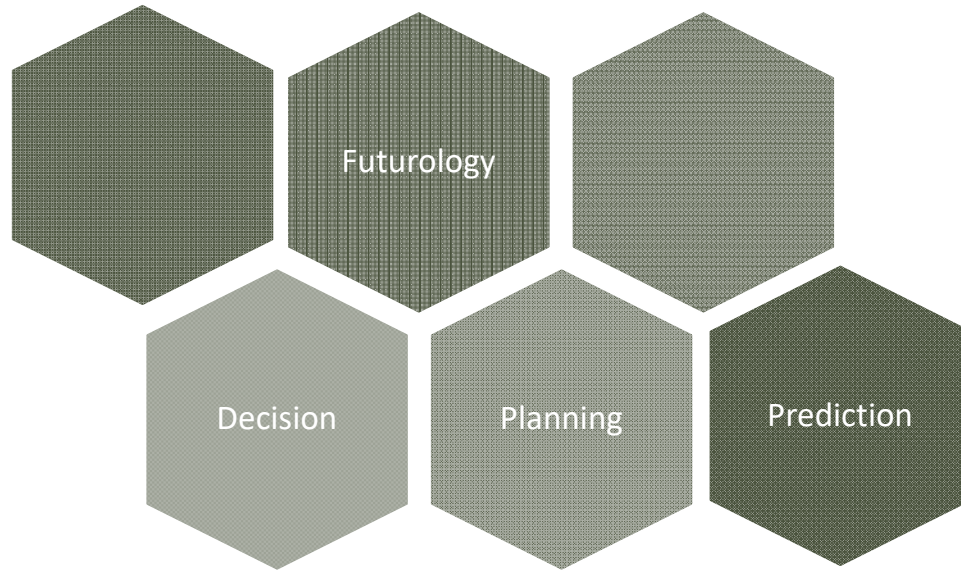


# Futurology Hierarchy



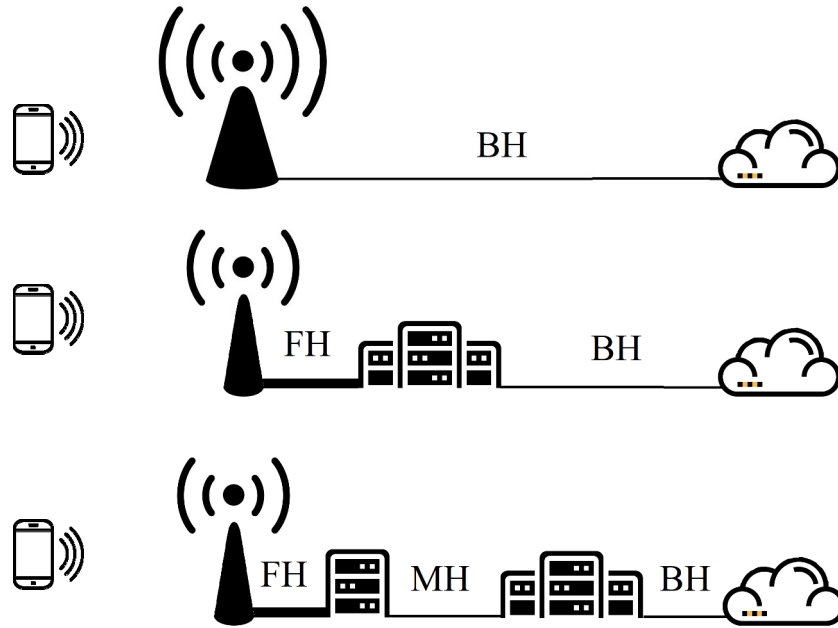
# Relative Terminologies

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# xHaul in Radio Access Network

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# Explorable Resources

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# Notebook

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## xHaul Keywords

Radio access network (**RAN**), Fronthaul (**FH**), Backhaul (**BH**),  
Midhaul (**MH**)

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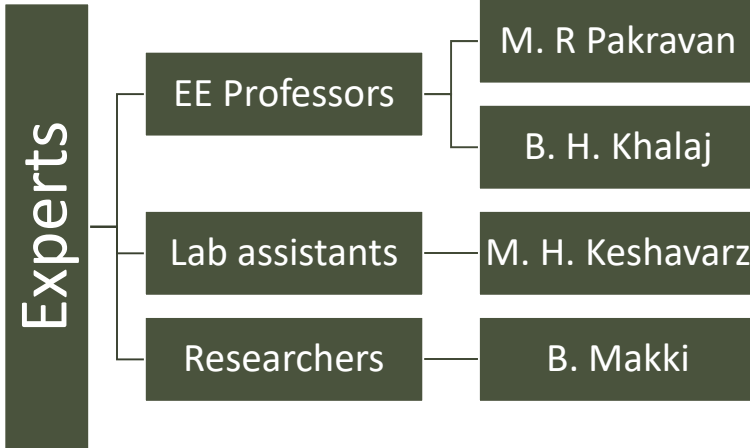
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# Experts



# Experts

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ReACT<sub>2021</sub>



Behrooz Makki  
ERICSSON INC.



## ABSTRACT

The number of devices requesting for wireless communications is growing exponentially. Network densification via the deployment of many base stations (BSs) of different types is one of the mechanisms that can be employed to satisfy the ever-increasing demand for bandwidth/capacity in wireless networks. However, deploying fiber to the small cells may be expensive and impractical when the number of small cells increases. For this reason, as well as because of the traffic jams and infrastructure displacements caused by fiber optic installation, millimeter wave (mmw)-based wireless backhaul is currently considered as an alternative, providing (almost) the same rate as fiber optic with significantly less price and no digging. With this background, integrated access and backhaul (IAB) networks, where



# Experts

---

## How to find experts

- Check GoogleSchlar/Linkedin/Researchgate/Publons **profiles**
- Surf university/department/personal **websites**
- Read **abstract texts** at conferences/papers/libraries
- See faculty introduction **board**
- Ask your **friends!**

## Hints

- Attend available **events/conferences/talks**
- Have short (online) **talks** with experts
- **Record** talks
- Audit introductory **lectures**
- Capture **keywords**



# Notebook

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## xHaul Keywords

Radio access network (**RAN**), Fronthaul (**FH**), Backhaul (**BH**),  
Midhaul (**MH**)

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mmWave (**mmW**) BH, integrated access & BH (**IAB**)

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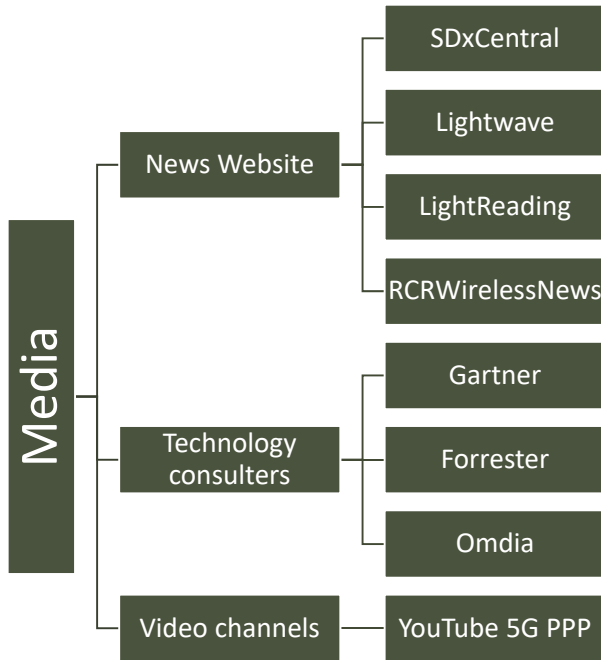
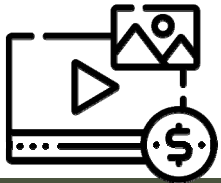
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# Media



**RCRWirelessNews**  
INTELLIGENCE ON ALL THINGS WIRELESS



5G PPP  
583 subscribers



**LightReading**

**LIGHTWAVE**

**Gartner**

**sdxcentral**

**FORRESTER**

**OMDIA**

# Media



5G | 6G | The Edge | Open RAN | The Cloud | Security | AI/Automation | Cable Tech | Optical/IP | SD-WAN

Beyond residential FTTH, Kunstler sees “huge opportunities” for service providers using XGS-PON. According to Omdia, 10G PON ONTs/ONUs will be used in enterprises, smart city, campus and **xHaul** transport applications.

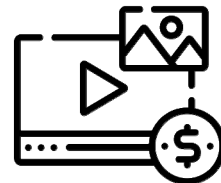


Editorial Report

## THE ROLE OF HYPERSCALERS IN ENTERPRISE 5G AND EDGE

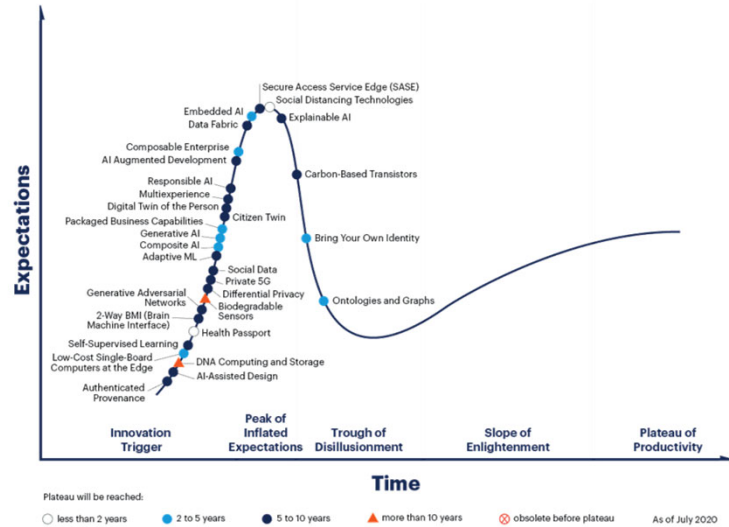
### Samsung exec: ‘Networks are becoming more agile with SDN technology in the 5G era’

Samsung Electronics said that it’s expanding its portfolio of Software-Defined Networking (SDN) solutions to add new capabilities designed with 5G network management flexibility in mind. The full lineup of **SDN** will now support mobile access (**xHaul**), which refers to fronthaul, midhaul and backhaul transport networks.



# Media

## Hype Cycle for Emerging Technologies, 2020



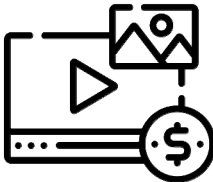
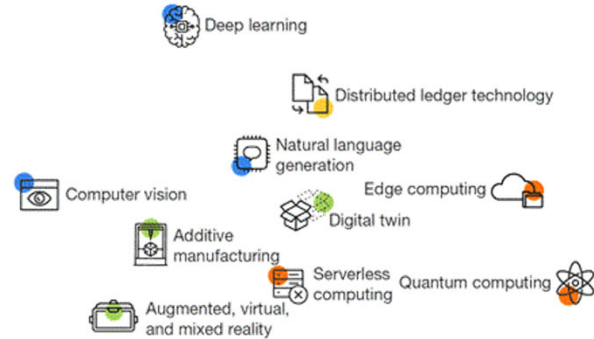
Broadly Implemented

Narrowly Implemented

Not New

Very New

● Physical/digital ● New compute paradigm ● Digital ecosystem ● Artificial intelligence (AI)



# Media

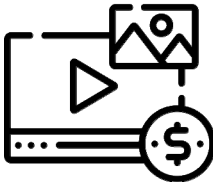
---

## How to find relevant media

- Search related keywords in **Google/Yahoo/MSN/...**
- Use **sitelike.org**
- Follow **linked news**
- Search **Youtube**

## Hints

- Use **advanced search** option
- Check **recent news**
- Think about the influence of **technology trends**
- Find **similar media**
- Capture **keywords**





# Notebook

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## xHaul Keywords

Radio access network (**RAN**), Fronthaul (**FH**), Backhaul (**BH**),  
Midhaul (**MH**)

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mmWave (**mmW**) BH, integrated access & BH (**IAB**)

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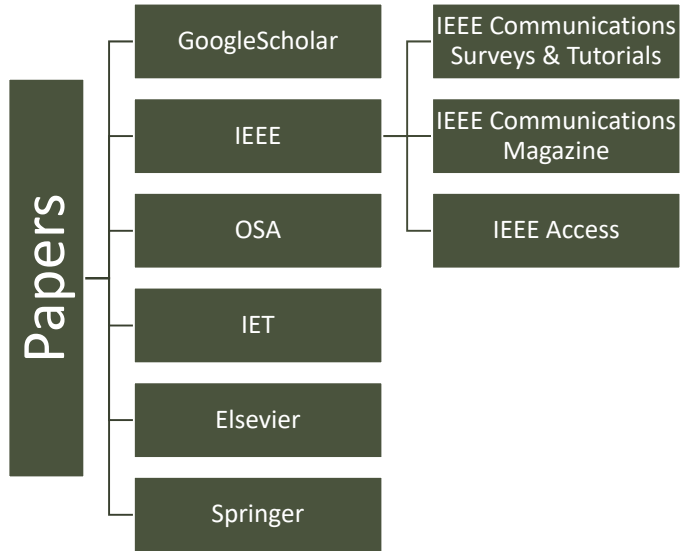
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# Papers



ELSEVIER



# Papers

## A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks

Publisher: **IEEE**

[Cite This](#)

[PDF](#)

Line M. P. Larsen  ; Aleksandra Checko ; Henrik L. Christiansen  [All Authors](#)

141

Paper

[Citations](#)

9084

Full

[Text Views](#)



 [Open Access](#)

### Abstract

#### Document Sections

[I. Introduction](#)

[II. Protocol Stack Overview](#)

[III. Functional Splits Survey](#)

[IV. Work in Progress](#)

[V. Impact on Fronthaul Network](#)

[Show Full Outline](#) ▾

[Authors](#)

[Figures](#)

### Abstract:

Paving the way toward 5G has lead researchers and industry in the direction of centralized processing known from Cloud-Radio Access Networks (C-RAN). In C-RAN research, a variety of different functional splits is presented by different names and focusing on different directions. The **functional split** determines how many base station functions to leave locally, close to the user, with the benefit of relaxing **fronthaul network** bitrate and delay requirements, and how many functions to centralize with the possibility of achieving greater processing benefits. This paper presents for the first time a comprehensive overview systematizing the different work directions for both research and industry, while providing a detailed description of each functional split option and an assessment of the advantages and disadvantages. This paper gives an overview of where the most effort has been directed in terms of functional splits, and where there is room for further studies. The standardization currently taking place is also considered and mapped into the research directions. It is investigated how the fronthaul network will be affected by the choice of functional split, both in terms of bitrates and latency, and as the different functional splits provide different advantages and disadvantages, the option of flexible functional splits is also looked into.

Published in: [IEEE Communications Surveys & Tutorials](#) ( Volume: 21 , Issue: 1, [Firstquarter 2019](#) )



# Papers

## 5G-XHaul: A Novel Wireless-Optical SDN Transport Network to Support Joint 5G Backhaul and Fronthaul Services

Publisher: **IEEE**

[Cite This](#)

[PDF](#)

Daniel Camps-Mur; Jesus Gutierrez; Eckhard Grass; Anna Tzanakaki; Paris Flegkas; Kostas Choumas; Dimitris Giatsios; Arash Farhadi Bel... [All Authors](#)

21

Paper

Citations

1249

Full

Text Views



### Abstract

#### Document Sections

- » Introduction
- » The 5G-XHaul Architecture
- » Experimental Evaluation of the 5G-XHaul Architecture
- » Conclusions

[Authors](#)

[Figures](#)

[References](#)

### Abstract:

The increased carrier bandwidth and the number of antenna elements expected in 5G networks require a redesign of the traditional IP-based backhaul and CPRI-based fronthaul interfaces used in 4G networks. We envision future mobile networks to encompass these legacy interfaces together with novel 5G RAN **functional splits**. In this scenario, a consistent transport network architecture able to jointly support **backhaul** and 4G/5G fronthaul interfaces is of paramount importance. In this article we present **5G-XHaul**, a novel transport network architecture featuring wireless and optical technologies and a multi-technology software defined control plane, which is able to jointly support backhaul and fronthaul services. We have deployed and validated the 5G-XHaul architecture in a city-wide testbed in Bristol.

Published in: **IEEE Communications Magazine** ( Volume: 57 , Issue: 7, July 2019)

Page(s): 99 - 105

INSPEC Accession Number: 18831706

Date of Publication: **27 May 2019**

DOI: [10.1109/MCOM.2019.1800836](https://doi.org/10.1109/MCOM.2019.1800836)



# Papers

## A Comprehensive Survey of RAN Architectures Toward 5G Mobile Communication System

Publisher: IEEE

[Cite This](#)

[PDF](#)

Mohammad Asif Habibi  ; Meysam Nasimi  ; Bin Han  ; Hans D. Schotten [All Authors](#)

96

Paper  
Citations

10357

Full  
Text Views



Open Access



Comment(s)

### Abstract

#### Document Sections

[I. Introduction](#)

[II. The 5G Mobile  
Communication](#)

[III. The Evolution of RAN  
Architectures](#)

[IV. Cloud-Radio Access  
Network](#)

[V. Heterogeneous Cloud  
Radio Access Network](#)

[Show Full Outline](#) ▾

[Authors](#)

[Figures](#)

[References](#)

### Abstract:

The fifth generation (5G) of mobile communication system aims to deliver a ubiquitous mobile service with enhanced quality of service (QoS). It is also expected to enable new use-cases for various vertical industrial applications-such as automobiles, public transportation, medical care, energy, public safety, agriculture, entertainment, manufacturing, and so on. Rapid increases are predicted to occur in user density, traffic volume, and data rate. This calls for novel solutions to the requirements of both mobile users and vertical industries in the next decade. Among various available options, one that appears attractive is to redesign the network architecture-more specifically, to reconstruct the radio access network (RAN). In this paper, we present an inclusive and comprehensive survey on various RAN architectures toward 5G, namely cloud-RAN, heterogeneous cloud-RAN, virtualized cloud-RAN, and fog-RAN. We compare them from various perspectives, such as energy consumption, operations expenditure, resource allocation, spectrum efficiency, system architecture, and network performance. Moreover, we review the key enabling technologies for 5G systems, such as multi-access edge computing, network function virtualization, software-defined networking, and network slicing, and some crucial radio access technologies (RATs), such as millimeter wave, massive multi-input multi-output, device-to-device communication, and massive machine-type communication. Last but not least, we discuss the major research challenges in 5G RAN and 5G RATs and identify several possible directions of future research.

Published in: [IEEE Access](#) ( Volume: 7)

Page(s): 70371 - 70421

Date of Publication: 28 May 2019 

INSPEC Accession Number: 18732009

DOI: [10.1109/ACCESS.2019.2919657](https://doi.org/10.1109/ACCESS.2019.2919657)



# Papers

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How to **find** relevant papers

- Search related keywords in **GoogleScholar/IEEE/IET/...**
- See **university publication libraries**
- Check **Researchgate/Linkedin** profile

## Hints

- Use **advanced search** option
- Check **recent papers**
- Prioritize **survey/magazine/tutorial/white papers**
- See relevant **conference proceeding**
- Read **abstract, conclusion, and introduction** parts of the **research papers**
- Read **preface** of books
- Track paper **references**
- Know **acknowledged agencies**
- Check other publications of the paper **authors**
- Capture **keywords**



# Notebook

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## xHaul Keywords

Radio access network (**RAN**), Fronthaul (**FH**), Backhaul (**BH**),  
Midhaul (**MH**)

---

mmWave (**mmW**) BH, integrated access & BH (**IAB**)

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Software-defined networking (**SDN**), Passive optical network  
(**PON**), Mobile edge computing (**MEC**), Machine learning (**ML**)

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Functional split (**FS**), Virtualized radio access network (**VRAN**)

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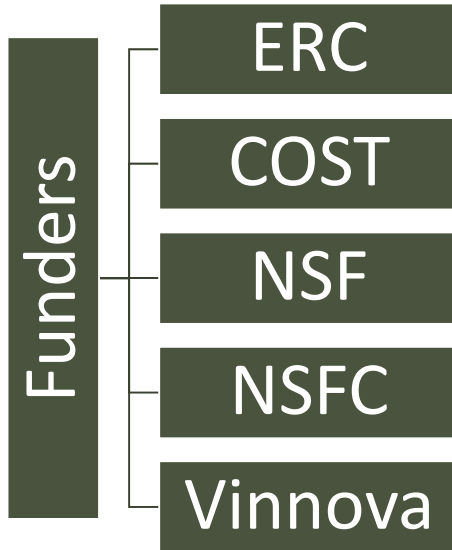
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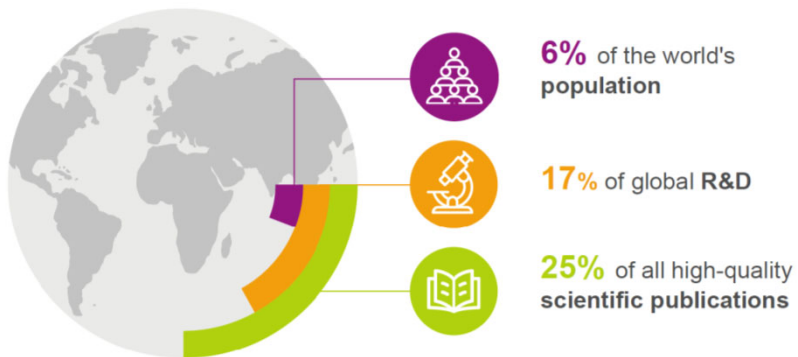


# Funders





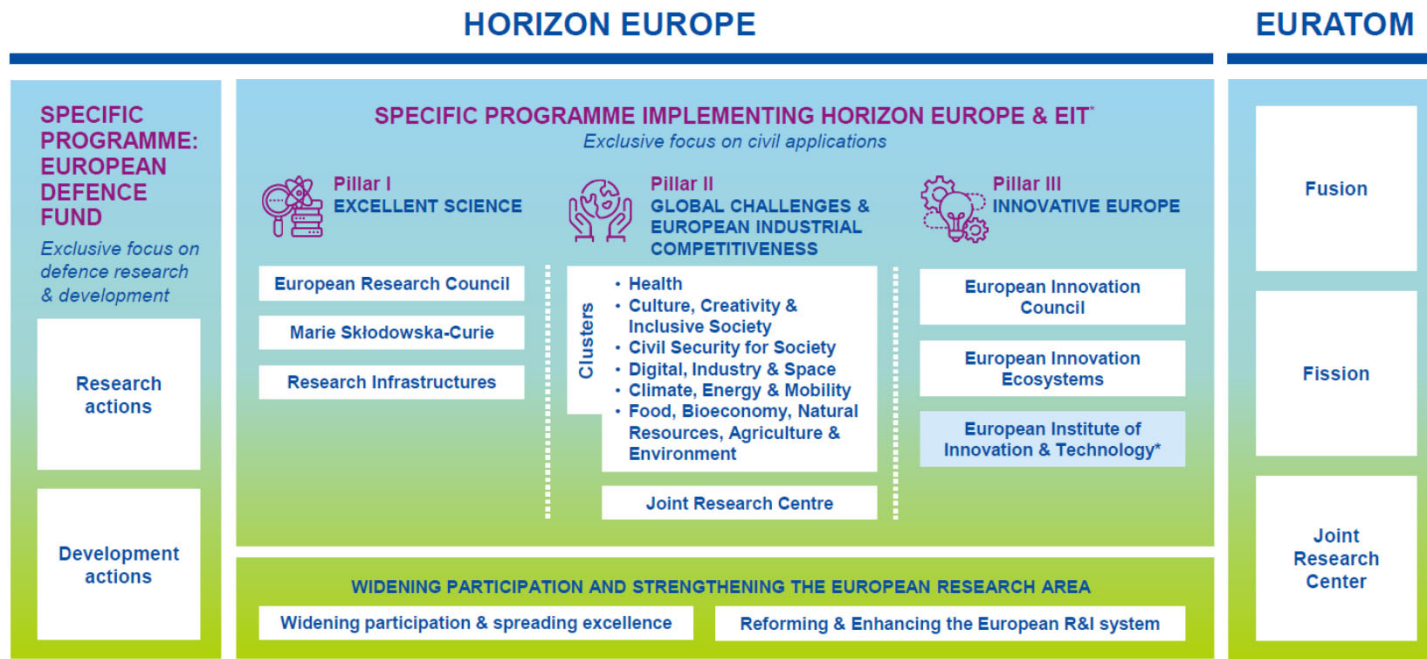
# Funders



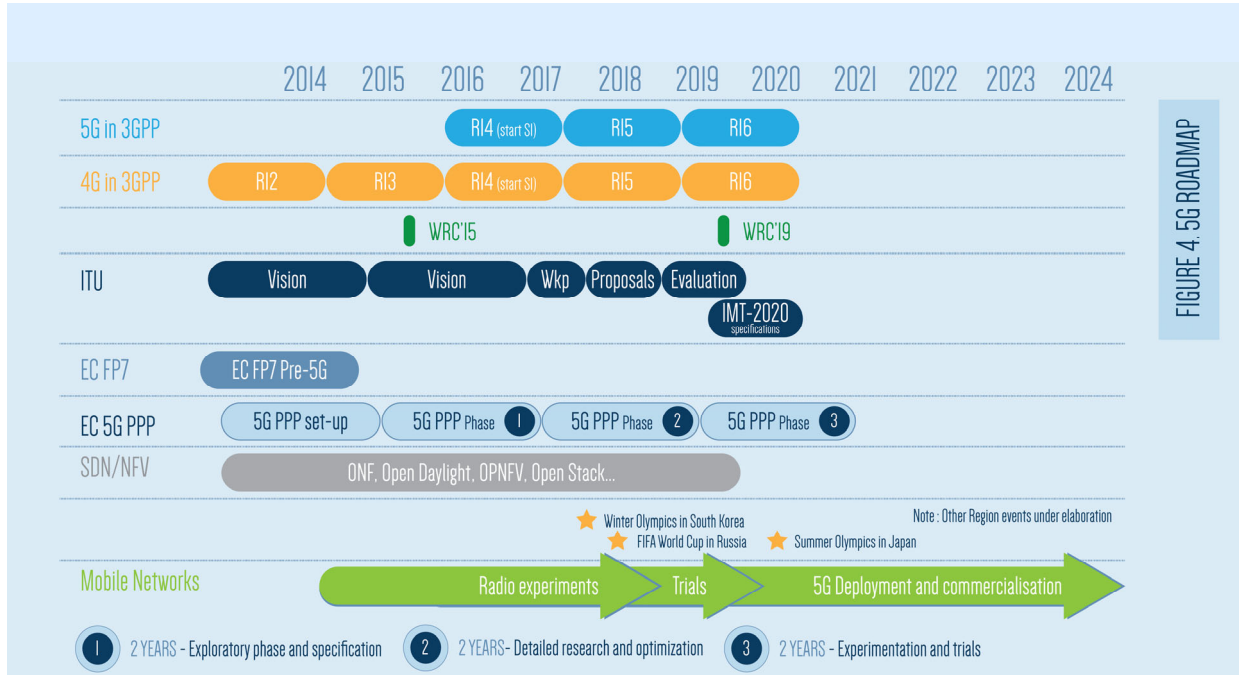
| ID  | Framework Program | Period    | Budget (billions of €) |
|-----|-------------------|-----------|------------------------|
| FP1 | First             | 1984–1987 | 3.8                    |
| FP2 | Second            | 1987–1991 | 5.4                    |
| FP3 | Third             | 1990–1994 | 6.6                    |
| FP4 | Fourth            | 1994–1998 | 13.2                   |
| FP5 | Fifth             | 1998–2002 | 15.0                   |
| FP6 | Sixth             | 2002–2006 | 16.3                   |
| FP7 | Seventh           | 2007–2013 | 53.2                   |
| FP8 | Horizon 2020      | 2014–2020 | 77                     |
| FP9 | Horizon Europe    | 2021–2027 | 95.5                   |



# Funders



# Funders



# Funders

| Phase          | Name                               | Proposals | Projects | Period    | Budget (millions of €) |
|----------------|------------------------------------|-----------|----------|-----------|------------------------|
| Phase 1        | Exploratory and specification      | 83        | 19       | 2015-2017 | 129                    |
| Phase 2        | Detailed research and optimization | 101       | 21       | 2017-2019 | 150                    |
| Phase 3-Part 1 | Infrastructure Projects            | 18        | 3        | 2019-2021 | 100                    |
| Phase 3-Part 2 | Automotive Projects                | 6         | 3        | 2019-2021 |                        |
| Phase 3-Part 3 | Advanced 5G validation             | 32        | 8        | 2019-2021 |                        |
| Phase 3-Part 4 | G Long Term Evolution              | 66        | 8        | 2019-2021 |                        |
| Phase 3-Part 5 | 5G Core Technologies               | 23        | 11       | 2019-2021 |                        |
| Phase 3-Part 6 | 5G innovations                     | 110       | 29       | 2019-2021 |                        |





# Funders

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# Funders

## Project Information

### 5G-Crosshaul

Grant agreement ID: 671598



Closed project

#### Start date

1 July 2015

#### End date

31 December 2017

#### Funded under

H2020-EU.2.1.1.3.

#### Overall budget

€ 8 492 038,61

#### EU contribution

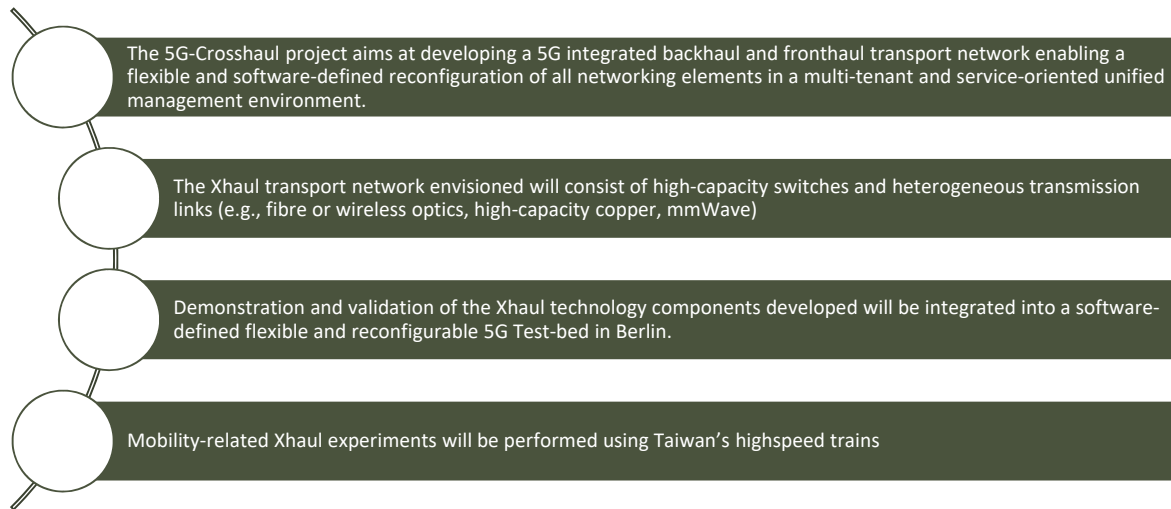
€ 7 942 521



#### Coordinated by

UNIVERSIDAD CARLOS III DE MADRID

 Spain



# Funders

## Project information

### 5G-XHaul

Grant agreement ID: 671551

[Project website](#)

Status

Closed project

Start date

1 July 2015

End date

30 June 2018

Funded under:

H2020-EU.2.1.1.3.

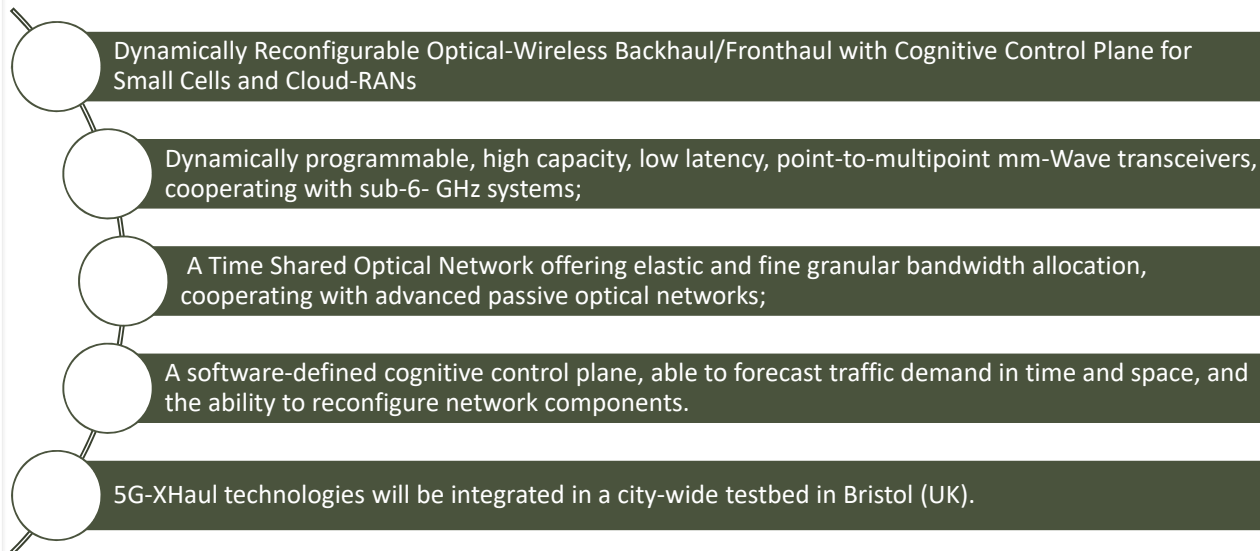
Overall budget:  
€ 7 233 887,50

EU contribution  
€ 7 233 887,50



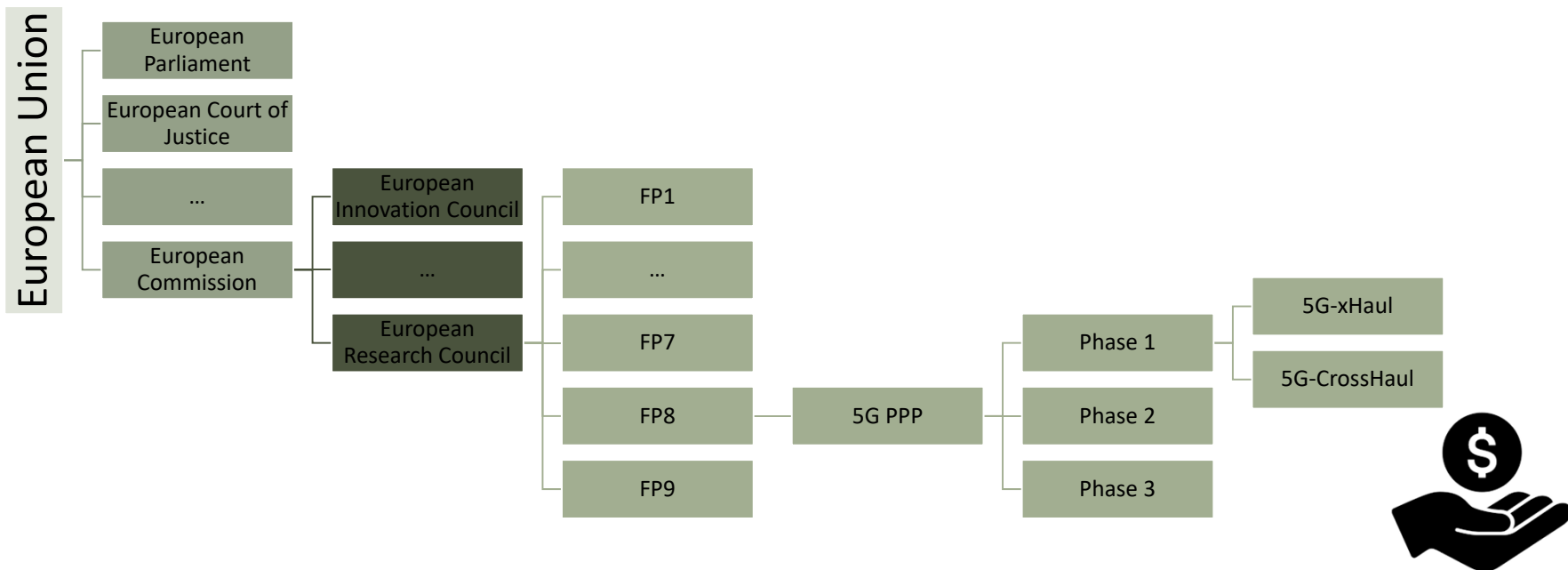
Coordinated by:

IHP GMBH - INNOVATIONS FOR HIGH  
PERFORMANCE  
MICROELECTRONICS/LEIBNIZ-INSTITUT  
FUER INNOVATIVE MIKROELEKTRONIK





# Funders



# Funders

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## How to **find** relevant papers

- Visit <https://www.aje.com/arc/research-funding-agencies-international-collaboration/>
- Consult with [https://en.wikipedia.org/wiki/Funding\\_of\\_science](https://en.wikipedia.org/wiki/Funding_of_science)

## Hints

- Watch demonstration **videos**
- Review **presentation**
- Visit project **websites**
- Look at **project summary/objectives/participants/results**
- Read **proposals/contracts**
- Extract **collaboration networks**
- Trace **money path**
- Capture **keywords**



# Notebook

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## xHaul Keywords

Radio access network (**RAN**), Fronthaul (**FH**), Backhaul (**BH**),  
Midhaul (**MH**)

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mmWave (**mmW**) BH, integrated access & BH (**IAB**)

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Software-defined networking (**SDN**), Passive optical network  
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Functional split (**FS**), Virtualized radio access network (**VRAN**)

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**Sub-6G**, Time-shared optical network (**TSON**), Flexible resource  
allocation (**FRA**)

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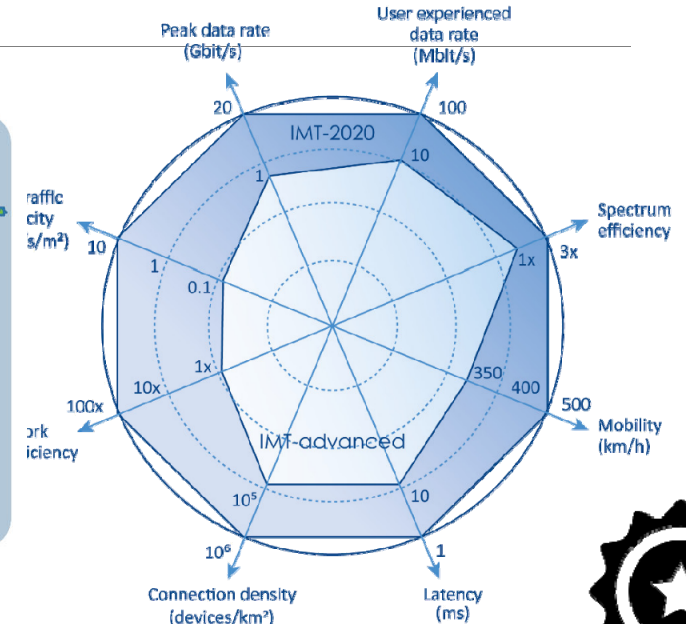
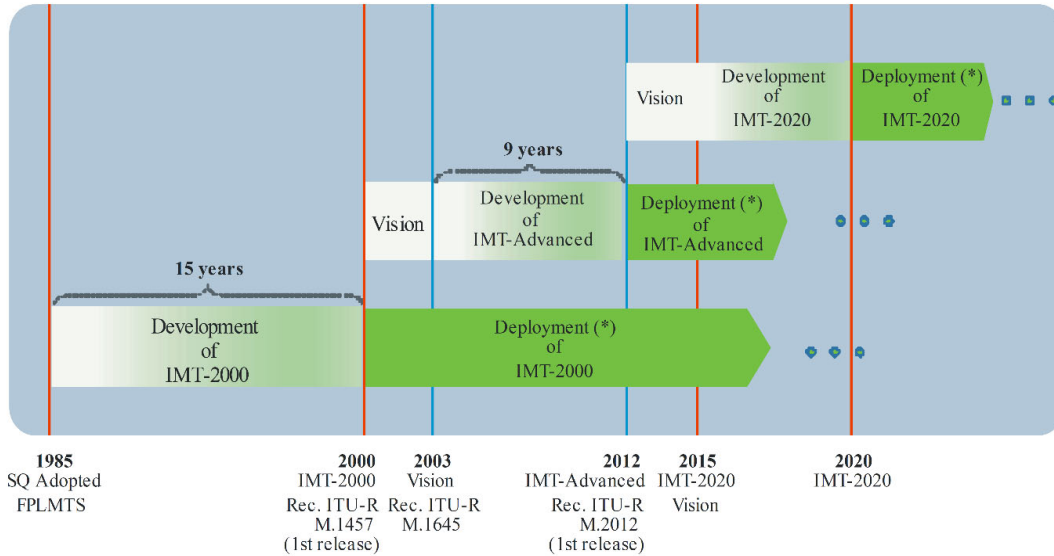
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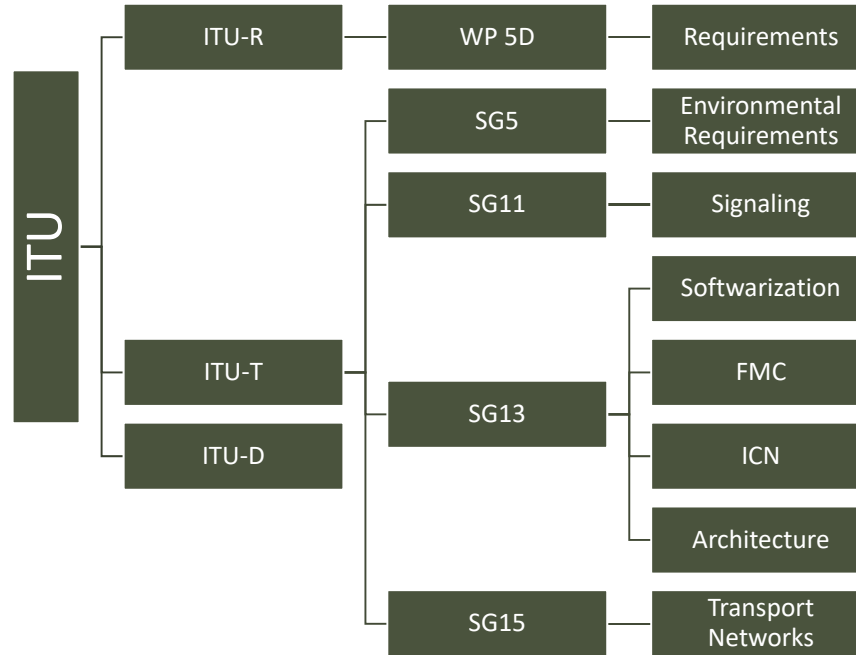
# Standards



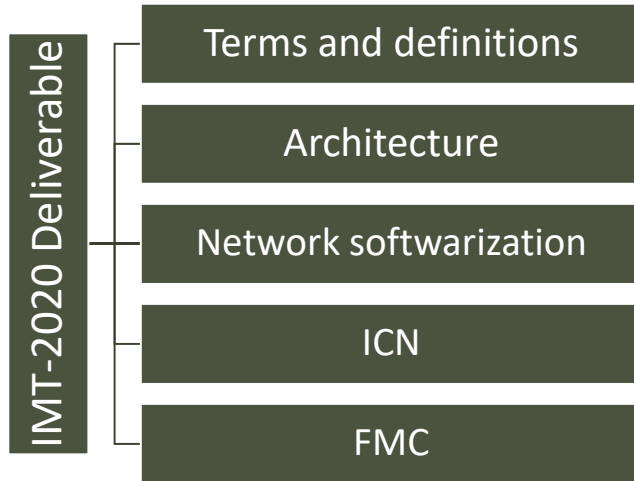
# Standards



# Standards

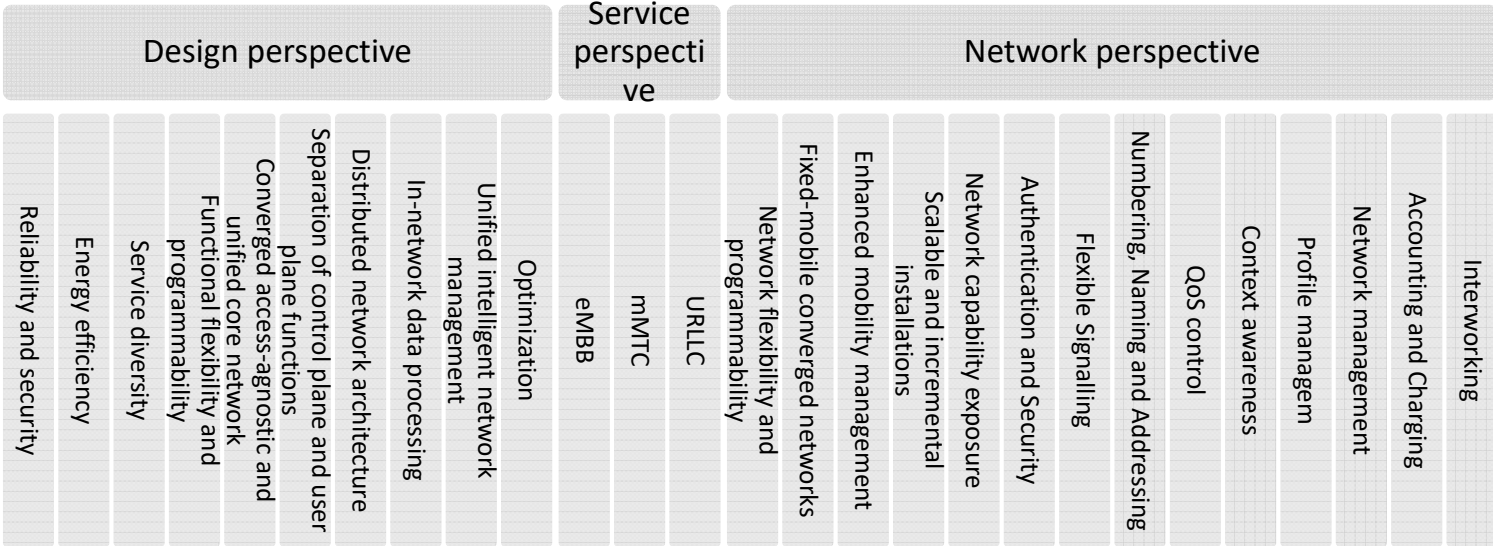


# Standards



# Standards

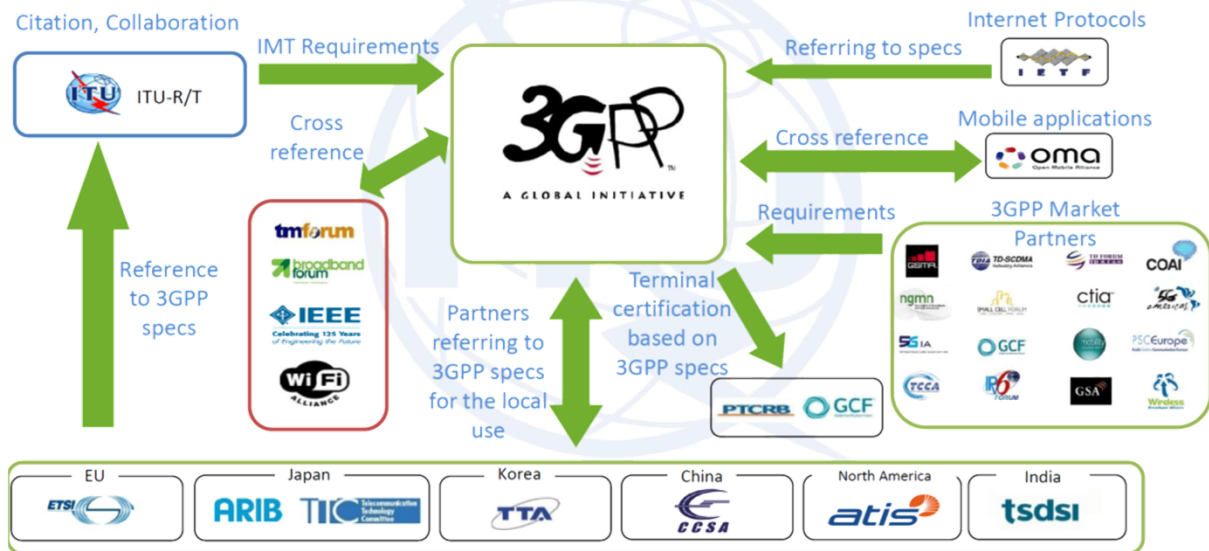
## High-level network architecture





# Standards

## Collaboration with SDOs, general



# Standards

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This document contains supplemental information referenced by the European Rolling Plan for ICT Standardisation.

## **IEEE Standards Activities in 5G**

### **Overview**

IEEE-SA provides a global, open, and collaborative platform for wireless communities that engage in, and enable the development of new, innovative, and relevant use cases and standards which, in turn, accelerate the time to market of consensus-developed technologies with regards to fifth-generation wireless systems (5G) and beyond.



# Standards

---

## How to **find** relevant standards

- Consult with [https://en.wikipedia.org/wiki/List\\_of\\_technical\\_standard\\_organizations](https://en.wikipedia.org/wiki/List_of_technical_standard_organizations)
- Check **collaboration** webpages

## Hints

- Use **advanced search** option
- Understand **organization** of the standardizing agency
- Check **introductory/listing** documents
- See **presentation** slides and videos
- Read general **specifications/requirements/recommendation**
- Skim **standard** documents
- Know **study/working** groups
- Know **partners, collaborators,** and **invertors**
- Capture **keywords**



# Notebook

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## xHaul Keywords

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mmWave (**mmW**) BH, integrated access & BH (**IAB**)

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Functional split (**FS**), Virtualized radio access network (**VRAN**)

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**Sub-6G**, Time-shared optical network (**TSON**), Flexible resource  
allocation (**FRA**)

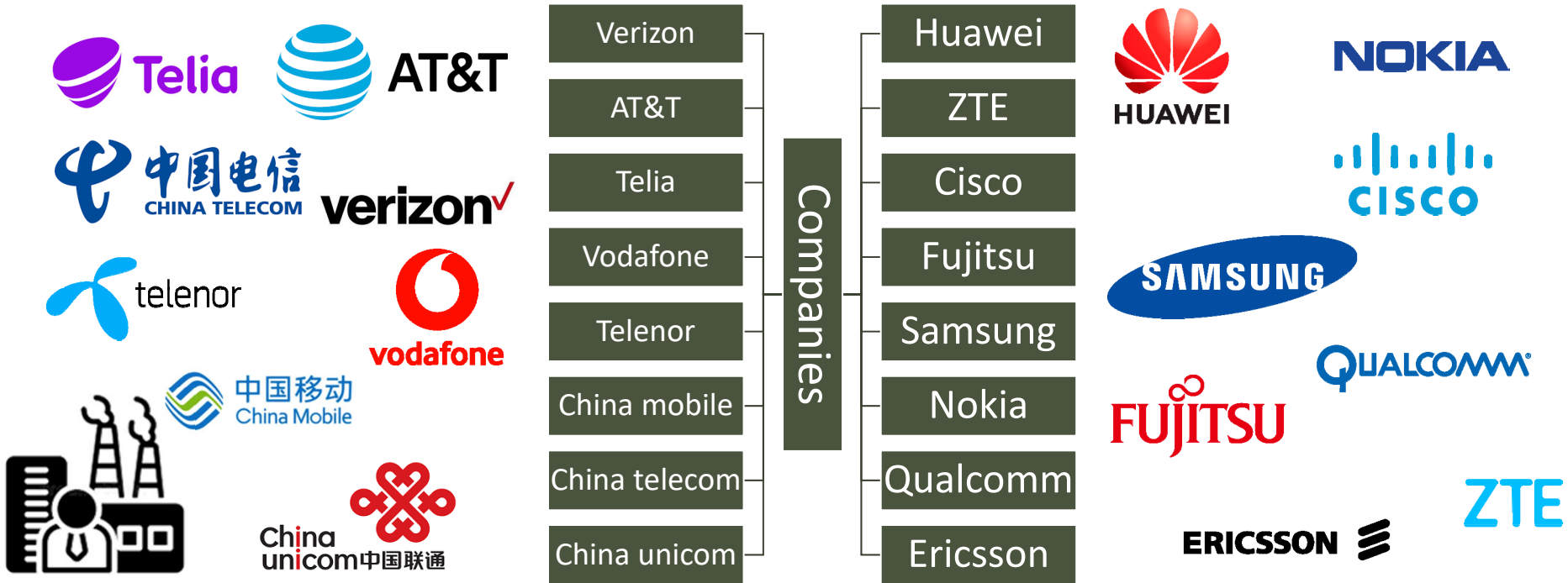
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Radio over fiber (**RoF**), Fixed mobile convergence (**FMC**),  
Network function virtualization (**NFV**)

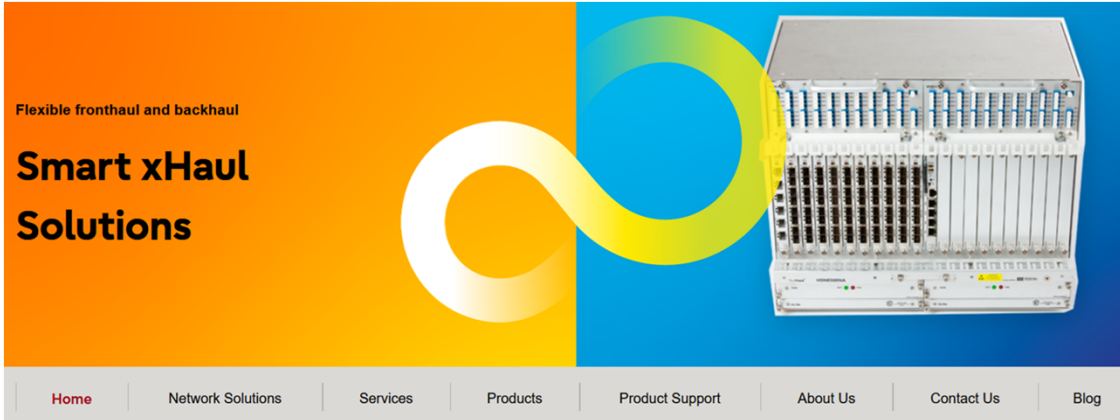
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# Companies



# Companies

The banner features a split background of orange and blue. On the left, the text 'Flexible fronthaul and backhaul' is above 'Smart xHaul Solutions'. A large, stylized infinity symbol in white and yellow is centered. On the right, a photograph of a server rack is shown.

Flexible fronthaul and backhaul

## Smart xHaul Solutions

[Home](#) | [Network Solutions](#) | [Services](#) | [Products](#) | [Product Support](#) | [About Us](#) | [Contact Us](#) | [Blog](#)

### An End-to-End Solution for Migration to SDN/NFV and 5G Transport

The Smart xHaul family allows 4G and 5G services to coexist on the same platform and fiber paths. Service coexistence includes CPRI up to CPRI-8 for **radio over Ethernet (ROE)** operation and eCPRI, along with Ethernet up to 25 Gbps coexisting on the same platform and fiber facility. This comprehensive end-to-end solution can also incorporate other Fujitsu platforms, including the FLASHWAVE CDS and 9500, managed using the NETSMART 1500 system, or Fujitsu **SDN/NFV** platforms such as the 1FINITY S100 Switching platform and Virtuora SDN/NFV control and management software. This complete portfolio addresses fronthaul, midhaul, backhaul and core transport requirements with a fully managed, end-to-end solution—from small-cell poles to central core point of presence (PoP) transport.

### Smart xHaul Highlights

Leverages an existing 4G network to quickly and efficiently support transport for 5G services.

Fixed and modular systems offer temperature-hardened network elements for 4G and 5G coexistence in **fronthaul** (with TSN options), midhaul, and backhaul architectures.



# Companies

## Cisco 5G xHaul Transport Vision and Strategy



### Converged SDN Transport

Converged • Simple (E2E XR)  
• Mass Scale • Resiliency •  
Secure • Flexible Service  
Placement



### Network Slicing

Differentiated Services • Robust  
SLA • Optimal Infrastructure  
Efficiency



### Open vRAN and Packet- Based Fronthaul

Stat-muxing • Wireline and  
Any-G Mobile • A la Carte  
RAN Procurement



# Companies

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Chenguang Lu

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## CATEGORY

Research

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## HASHTAGS

#5G-PPP #TransportNetworks

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# 5G RESEARCH

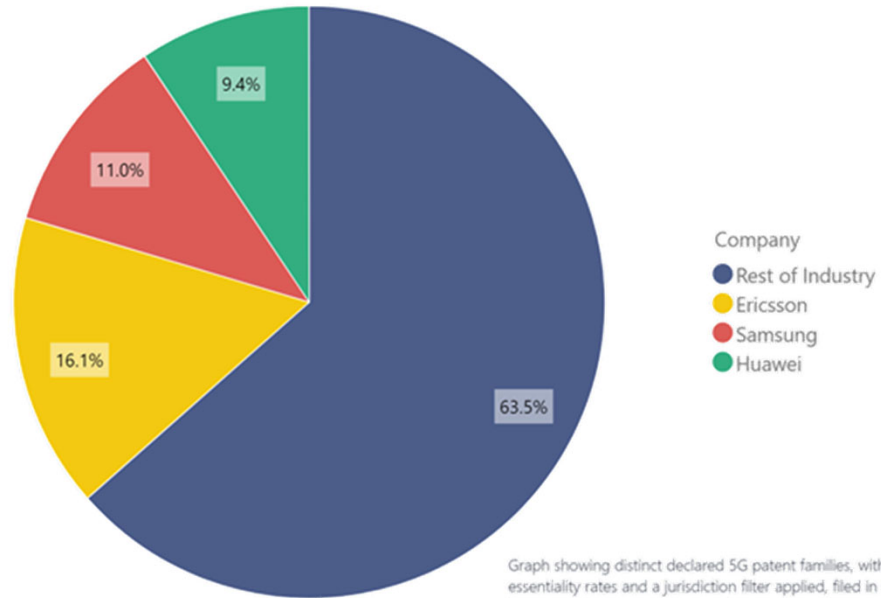
- The Xhaul project, part of the European H2020 5G Public-Private Partnership (5G PPP) Infrastructure, will define and develop the next generation of integrated fronthaul and backhaul networks that will respond to the needs of the future 5G communications system.
- The Xhaul consortium comprises 21 partners including leading telecom industry vendors, operators, IT companies, small and medium-sized enterprises and academic institutions.





# Companies

Company shares of essential 5G patent families



Graph showing distinct declared 5G patent families, with essentiality rates and a jurisdiction filter applied, filed in at least one of the US and Europe, by company group



# Companies

## 170 commercial 5G agreements or contracts with unique operators

We're proud to say that communication service providers all around the world have chosen to deploy 5G using our leading network technology. Our list of commercial agreements and contracts with unique operators is growing rapidly.

Click the link to explore our live 5G networks across the globe.

[Explore our live networks](#)



**170**  
Commercial 5G agreements

**88**  
Publicly announced 5G contracts

**109**  
Live 5G networks



# Companies

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## Publicly announced 5G contracts

### Americas

- AT&T
- GCI
- RINA Wireless
- Sprint
- T-Mobile
- U.S. Cellular
- Verizon
- Nex-Tech
- Bell Canada
- Telus Canada
- Rogers Canada

### Europe

- Telia Norway
- Telenor Norway
- Telenor Sweden
- Three Ireland
- Eir
- Telenor Denmark
- Vodafone UK
- TDC
- Orange France
- Polkomtel (Plus)
- Swisscom
- Vodafone Germany

### Middle East

- Ooredoo
- Mobily
- Batelco
- STC
- Zain
- Etisalat
- Omantel

### Africa

- MTN

### North East Asia

- LG U+
- KT
- SK Telecom
- SoftBank
- KDDI
- Far EasTone
- Chunghwa Telecom
- SmarTone
- China Mobile
- China Telecom
- China Unicom
- APT



# Companies

## Deutsche Telekom, Cosmote and Ericsson look beyond 100GHz to boost 5G backhaul capacity

As 5G deployments scale up, so does the need for capacity. Communications service providers need additional spectrum to expand the reach of their 5G services. Ericsson has partnered with Deutsche Telekom and Cosmote to trial and test an answer to the challenge – using W-band as 5G backhaul spectrum.

NEWS | APR 06, 2021

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# Companies



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IP Encyclopedia > QoS

## What Is QoS?

QoS improves network resource utilization and allows different types of traffic to compete for network resources based on their priorities, so that voice, video, and important data applications are preferentially processed on network devices.

### Contents

Importance of QoS

QoS Counters

Application Scenarios of QoS

Service Models

More <sup>»</sup>



### Related Topics

HQoS

### About This Topic



# Companies

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How to **find** relevant companies

- Check the list of operators at [https://en.wikipedia.org/wiki/List\\_of\\_mobile\\_network\\_operators](https://en.wikipedia.org/wiki/List_of_mobile_network_operators)
- See a list of top 5G companies at <https://www.greyb.com/5g-companies/>

## Hints

- Find **application notes/white papers**
- Read **catalogues/guides/manuals**
- Look at **contracts/SLAs**
- Read **patent** specifications
- Use technical **encyclopedias** and **courses**
- Watch demonstration **videos**
- Capture **keywords**



# Notebook

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## xHaul Keywords

Radio access network (**RAN**), Fronthaul (**FH**), Backhaul (**BH**),  
Midhaul (**MH**)

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mmWave (**mmW**) BH, integrated access & BH (**IAB**)

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Software-defined networking (**SDN**), Passive optical network  
(**PON**), Mobile edge computing (**MEC**), Machine learning (**ML**)

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Functional split (**FS**), Virtualized radio access network (**VRAN**)

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Sub-6G, Time-shared optical network (**TSON**), Flexible resource  
allocation (**FRA**)

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Radio over fiber (**RoF**), Fixed mobile convergence (**FMC**),  
Network function virtualization (**NFV**)

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Open radio access network (**ORAN**), Network slicing (**NS**)

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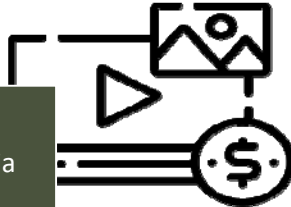
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# End

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MOHAMMAD HADI

WINTER 2022

