What comes next? Is there a need for a new generation after 5G?

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Docent, University of Oulu, Finland

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(B)5G Evolution (Revolution)

Communication = Transport
Wireless
Hardware (10y)

Communication = Transport
Storage
Computing
Wireless (10y), 5G + Wired (1d), IETF
Much less Hardware + More Software

Then Law of Even Numbers: Success in only generations with even numbers

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Just checking what the press is saying …

6G will achieve terabits-per-second speeds

Initial, upcoming 5G is going to be a disappointment, a University of Oulu researcher says. 6G, with frequencies up to terahertz, will be needed for true microsecond latency and unlimited bandwidth.

NETWORKWORLD FROM IDG

5G is too slow → terahertz

SDN software architecture is too slow

MEC/AI is the key

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NETWORKWORLD FROM IDG

5G is too slow → terahertz	SDN software architecture is too slow	MEC/AI is the key
Too slow for what? Control packets with 40 B @ 10 Gbps 32ns	Correct But this has nothing to do with 5G or 6G	Correct Heavily used in 5G (ML used in 3G)

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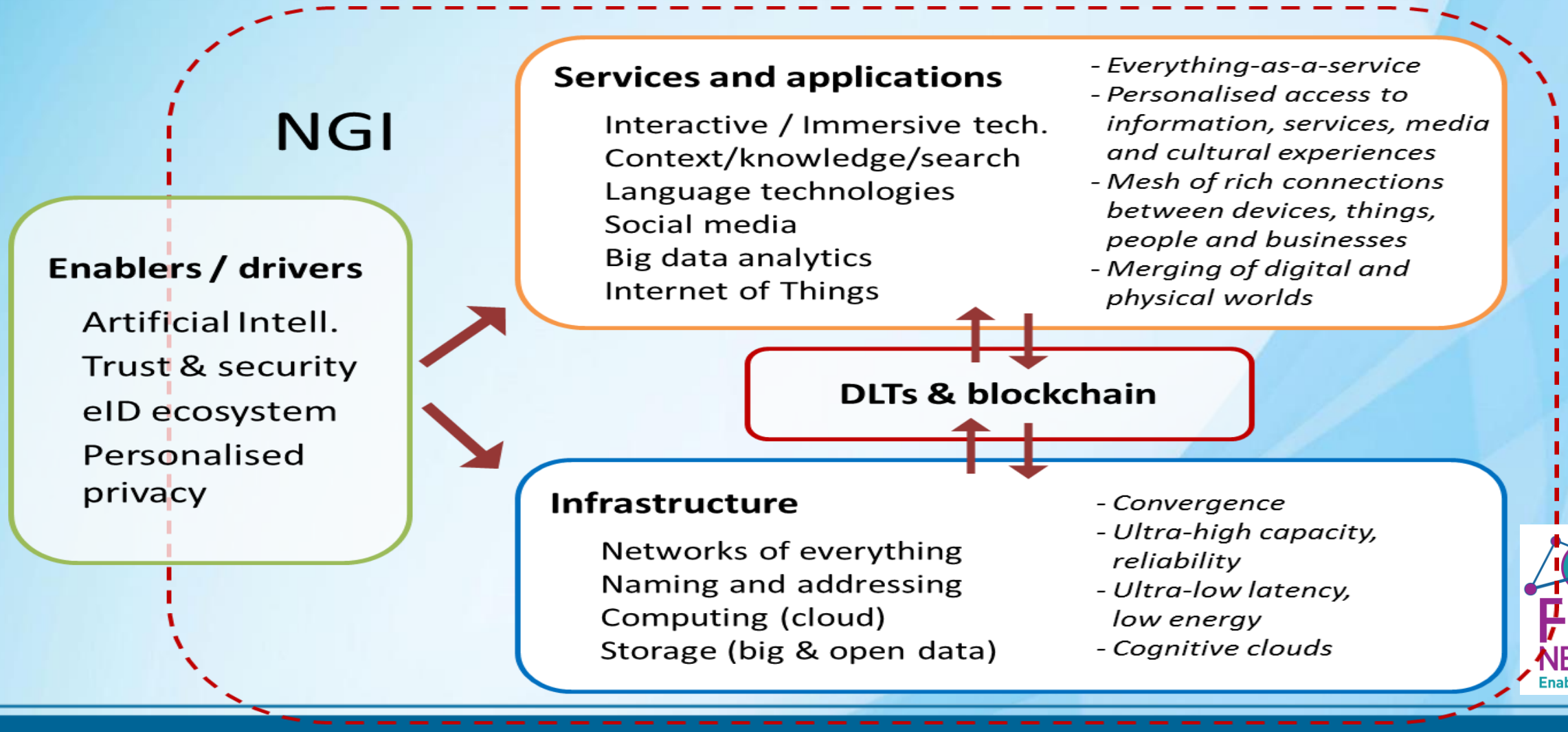
So, what is 6G next ??

- Software will dominate the communication systems
- Hardware is still needed for generic platform running software, the link level, security, and acceleration
- New frequencies might be given out now on the fly
- Just Terahertz communication → why 6G why not 5G++ ?
- Therefore 6G will be a great marketing tool, but technically we will focus on Release 16, 17, 18, …
- Any argument for 6G?
  - 5G was quite conservative in the technology chosen
  - 5G must deliver low latency communication NOW

- What might be better questions? -- (1) Will the future be cellular?
  (2) How can we make 5G more interesting for industry?
  (3) Security !!!
  (4) Cost structure
  (5) Availability

NGI Proposed Structure



Two approaches

(1) Evolutionary B5G and no new generation

(1) Paradigm-shifting 6G

(1) Advancing beyond 5G – the call is 5G+ or 5G Advanced

IEEE view defined in their Technology Roadmap document:

(a) SDN/NFV to expand to e2e framework with distributed system software to management, control and UE equipment,

(b) Finish industry transformation to a software centric vision with COTS enabled by AI/ML to achieve agility as part of the life-cycle management

(c) User integration and enablement, security, spectral and energy efficiency, and agility

Other views: THz, VLC, satellite, include technologies left out of 5G,

Technologies: ML/AI, Blockchain, dynamic spectrum allocation, CR, UCI's innovation to develop a 4.4 mm square transceiver chip increases speed by a factor of 2 at in the range of 100 GHz

Issues in 5G to be fixed in 5G+: Coverage, applications challenges, KPIs, D2D, MEC, Open and smart RAN, network orchestration and slicing,

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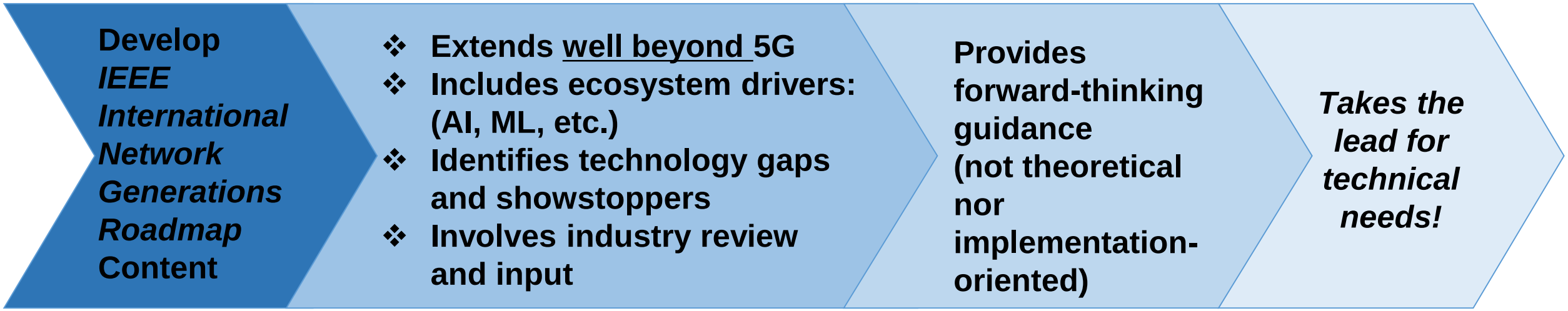
The IEEE International Network Generations Roadmap (INGR) identifies new infrastructure needs for future generations (6G, 7G, etc.)

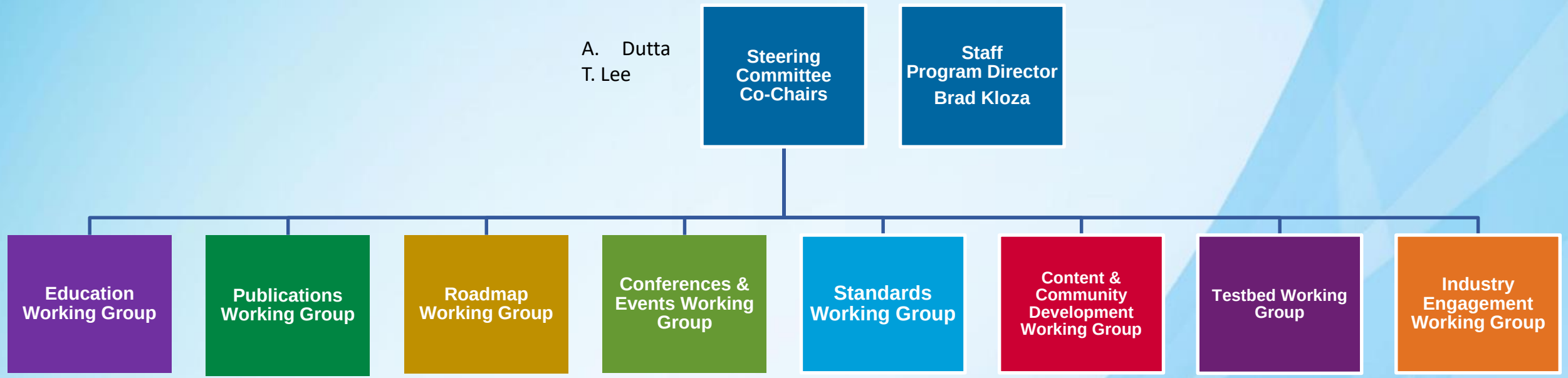
Broad vision = "IEEE International Network Generations Roadmap (INGR)"



The INGR projects the next 10 years: 2019 – 2029, with Key Timeframe points at 3, 5, and 10 years.

IEEE: What "5G and Advanced Communication Systems" is About

IEEE Future Networks Initiative Organization Structure



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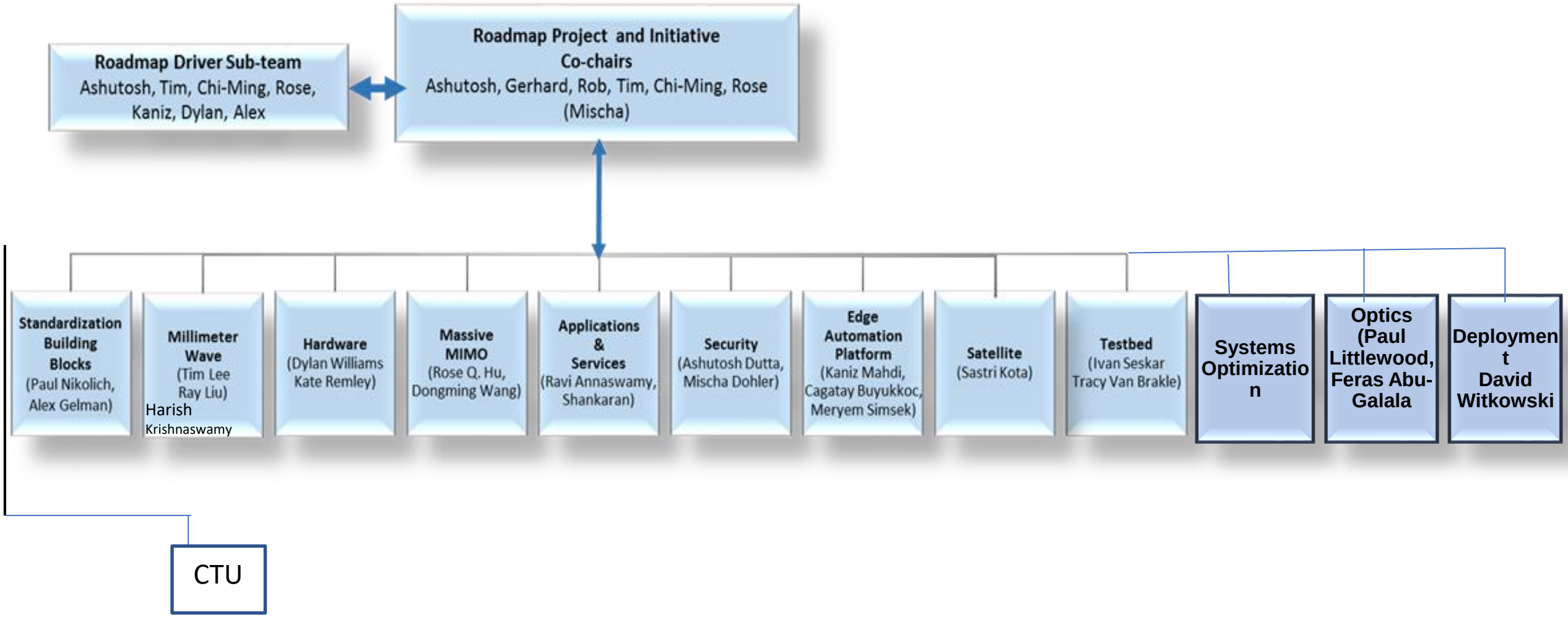
IEEE 5G and Beyond Roadmap Working Group



INGR 1st Edition Release Announcement

December 2019

1st Edition Chapters and Executive Overview

Applications and Services	mmWave and Signal Processing	Hardware
Edge Automation Platform	Standardization Building Blocks	Satellite
Massive MIMO	Security	Testbed

Additional **white papers to follow in Q1' 2020**

• Deployment • Optics	• Energy Efficiency • AI/ML	• Systems Optimization • Connecting the Unconnected

INGR 1st Edition Release

- Access the documents online at

  futurenetworks.ieee.org/roadmap

- INGR is a program of the **IEEE Future Networks Initiative**

2019 INGR Roadmap Teams

WORKING GROUP TEAM	CHAIRS : Chi-Ming Chen, Rose Hu, Narendra Mangra	EMAIL TO CONTACT TO PARTICIPATE : 5Groadmapinfo@ieee.org
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Systems Optimization – New for 2019	Ashutosh Dutta, Kaniz Mahdi, Lyndon Ong, Meryem Simsek	5GRM-sysopt@ieee.org
Optics – New for 2019	Feras Abou-Galala, Prakash Ramchandran	5GRM-optics@ieee.org
Connecting the Unconnected – New for 2019	Sudhir Dixit, Ashutosh Dutta	5GRM-ctu@ieee.org
Energy Efficiency – New for 2019	Brian Zahnstecher	5GRM-energy@ieee.org
AI/ML – New for 2019	Mahmoud Daneshmand, Honggang Wang, Chonggang Wang	5GRM-AIML@ieee.org

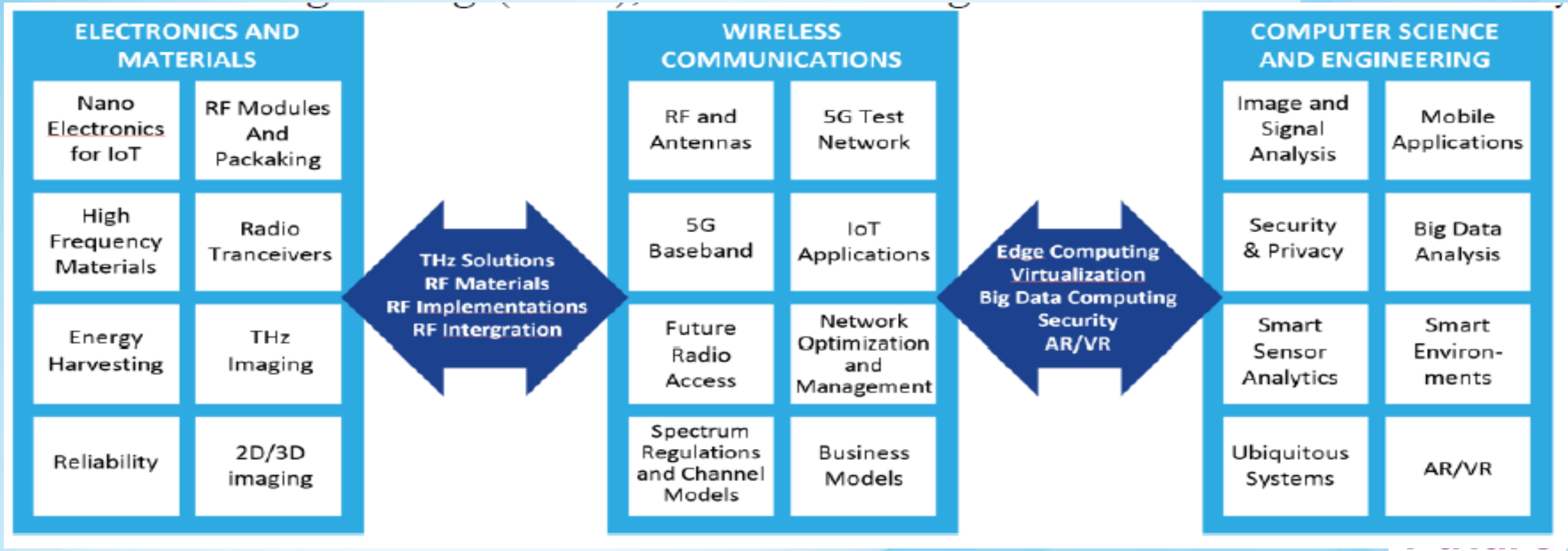
The Second Approach

New generation standard like in the past, call it 6G – no universally accepted definition, but here are some..

1) Finnish 6G Flagship project[1]: “6G will emerge around 2030 to satisfy the expectations not met with 5G, as well as, the new ones fusing AI inspired applications in every field of society with ubiquitous wireless connectivity.”
   - ✓ Transformation from “5G Engineering to 6G humanity” – meet 17 SDG goals from United Nations Vision 2030 Agenda
   - ✓ Wireless connectivity; Devices and circuit technology; Distributed computing with cost and energy efficiency; Services and apps; Techno-economic; Cyber security; Co-creation infrastructures; SDN/NFV; Transformation toward IT
   - ✓ Transmission up to 1 Tbps per user, photonics, AI, ML, Modulation techniques beyond QAM and OFDM, Network embedded security, privacy and trust
   - ✓ New KPIs in addition to 5G technical KPIs
   - ✓ https://www.youtube.com/watch?v=T6ubRoZCeVw

[1]Key drivers and research challenges for 6G ubiquitous wireless intelligence, 6G Research Visions 1 white paper, September 2019

Academy of Finland 6G Flagship



Flagship positioning in various research areas

The Second Approach (contd.)

2) Paper from CNIT/Univ of Bologna (Marco Chiani, Enrico Paolini, Franco Callegati) on Vision of 6G[2]

- ✓ More and more data
- ✓ Network intelligence
- ✓ Fast and flexible spectrum reallocation
- ✓ Enhanced senses
- ✓ Wireless-devices-as-a-service
- ✓ Battery life and energy
- ✓ Quantum computers and quantum networks
- ✓ Privacy, security and data manipulation
- ✓ Security and safety
- ✓ Virtual operators explosion

Technologies for 6G: ML/AI, DSA, Wireless energy transfer, FSO communication,Sub-terahertz and Terahertz communications, MIMO, High accuracy indoor localization, advanced techniques for access to massive wireless networks, Cybersecurity

[2]Open Issues and Beyond 5G, Marco Chiani, Enrico Paolini, Franco Callegati, 5G Italy,White e-book

Some First Thoughts about B5G

"6G Vision and requirements," IEEE VTS, September 2018, Klaus David and Hendrik Berndt

- ✓ Users PoV
- ✓ Spectrum regulation
- ✓ 6G service classes
- ✓ Innovations: FSO for indoor, charging via radio waves and/or laser beams, energy harvesting, integration of multi-sensory inputs
- ✓ New way of thinking, from a societal viewpoint – absorption of technology and its implications

General directions in 6G[3] – take aways!

(1) the transition from radio to subterahertz (sub-THz) and optical spectra,
i.e., laser, FSO, visible light communication

(2) the use of AI and ML to achieve intelligent network automation, robotics,

(3) the introduction of new network architectures

(4) new applications based on new enabling technologies, such as holography, 4D, multi-sensory.

[3]Special issue on 6G, IEEE VTM, August 2019

WWRF views on beyond 5G toward 6G

WWRF has identified the major technology challenges and relevant application and usage scenarios for systems B5G toward 6G

1) Technology enablers/new air interface
   - ❑ Molecular Communications
   - ❑ THz Communications
   - ❑ Large/massive antenna processing
2) New architectures/system concepts: machine learning, AI, blockchain
3) Privacy and trust
4) New business models
5) New deployment concepts (e.g. islands of BB, ..)
6) New apps/use cases (virtual reality, ..) for consumers and vericals
7) New / Critical challenges: Society impact, ‘endless’ battery life, cost of new technologies,..

What Is Driving This?

Verticals to drive development

- ❑Wireless connectivity offers unlimited opportunities

Major changes to network architectures

- ❑ Ultra dense networks (UDNs)
- ❑ Short range connectivity a crucial component of the e2e connectivity
- ❑ Varieties of network deployments
- ❑ Cloud distributed across the network from edge to the core
- ❑ Distributed AI and ML

New value chains to appear

- ❑ Context dependent content
- ❑ Micro operators and virtual operators to be integral part of the eco-system and potentially extending to the end users

Technology challenges for Network 2030

Low cost and affordable network solutions

- ❑Connecting the last 4B people
- ❑Must contribute to sustainable development and society
- ❑Must address the problem of backhauling to remote areas
- ❑Seamless integration of terrestrial, satellite and HAP-based networks

Networking converges with IT and cloud

- ❑Virtualization and cloud the largest disrupters to telecom
- ❑Software defined mobile network
- ❑Mobility management moves to edge of the network

Technology Challenges for Network 2030 (Contd.)

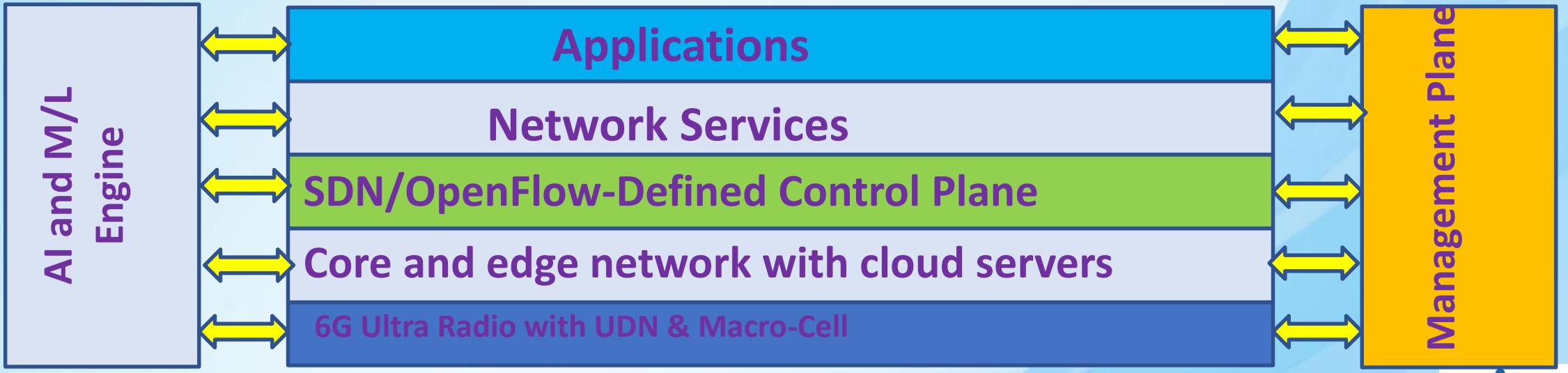
New spectrum allocation and spectrum refarming

- ❑Synergistic collaboration between unlicensed and licensed bands
- ❑Communication in the THz range

Advances in communications fundamentals

- ❑Channel modeling and propagation for mmWave and THz systems
- ❑Short range connectivity a crucial component of the e2e connectivity
- ❑Adaptive signal processing and beamforming algorithms
- ❑Analytical modeling and design of UDNs
- ❑Radio resource management

Potential IT-Driven Architecture



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Network 2030 (6G) Ultra Radio

- Exploiting the Spatial Dimension
  - ❑ Advanced MIMO and Massive MIMO
- Exploiting the untapped spectrum
  - ❑ mmWave & Terahertz communication systems
- Exploiting Cost Efficiency of Cloud and Distributed Computing
  - ❑ Multi-Technology HetNets (UDN)
  - ❑ Improved Cell Edge Coverage

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ieee-wf-5g.org

5G and Beyond:

a comprehensive look at future networks

10-12 September 2020 | Bangalore, India

bit.ly/5GWFcfp

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www.6Gsummit.com

Thank you!

Questions and inquiries?

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- More than 114,000 Student members
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- 2,806 student branches at colleges and universities in over 100 countries
- 1,159 student branch chapters of IEEE technical societies
- 459 affinity groups; IEEE affinity groups are non-technical sub-units of one or more Sections or a Council. The affinity group patent entities are the IEEE-USA Consultants' Network, Young Professionals (YP), Women in Engineering (WIE), and Life Members (LM)
- Has 46 Societies and seven technical councils representing the wide range of IEEE technical interests
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Electron Devices Society
Electromagnetic Compatibility Society
Engineering in Medicine and Biology Society
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Society on Social Implications of Technology
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Systems, Man, and Cybernetics Society
Systems Council
Technology Management Council
Ultrasonics, Ferroelectrics, and Frequency Control Society
Vehicular Technology Society

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2018 FDC Initiatives & Activities

Small Projects

- Environmental Engineering
- Roadmaps Strategy and Governance (IRSG)
- Quantum Computing

IEEE BLOCKCHAIN™

IEEE Future NETWORKS™

IEEE brain

IEEE rebooting COMPUTING

IEEE DigitalReality

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- 5G has promised us ultralow latency and record-breaking data speeds, which will enable advances in everything from small cell research to virtual reality applications. This technology will create tremendous growth opportunities, but it won't stop there. That is why, in August 2018, the IEEE 5G Initiative has rebranded to become the IEEE Future Networks Initiative. The Initiative will pave a clear path through development and deployment of 5G and beyond. We will accomplish this through the creation of:

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IEEE Societies (22 so far)

Industry

Academia, Students

IEEE OUs

IEEE STANDARDS ASSOCIATION

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Initiative Profile

- Launched August 2016
- Technical Activities Board Funded
- 20+ Participating Societies/OUs

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Dr. Ashutosh Dutta, Johns Hopkins University Applied Physics Labs (JHU/APL)
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Mitigating Thermal & Power Limitations to Enable 5G
Dr. Earl McCune, CTO, Eridan Communications
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IEEE Workshop on 5G Technologies for Tactical and First Responder Networks
View recordings and presentations of the workshop held 23 October 2018
Learn more.

Feature Article

MWC Barcelona 2019: Low Latency 5G Networks Could be a Game-Changer for AR and VR (But Not Until 2020)

New 5G service could enable multi-player VR games and maybe even eliminate nausea

Read more at IEEE Spectrum.

Wireless Predictions 2019

Read more at ECN.

Technology Spotlight

MWC Barcelona 2019: On the Road to Self-Driving Cars, 5G Will Make Us Better Drivers

Long before we have autonomous vehicles, 5G-enabled services could keep us more alert and informed

Read more at IEEE Spectrum.

Are you Ready to Look at 6G?

Read more at Telecoms.com.

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- IEEE Future Directions Newsletter
- IEEE ComSoc Technology Blog
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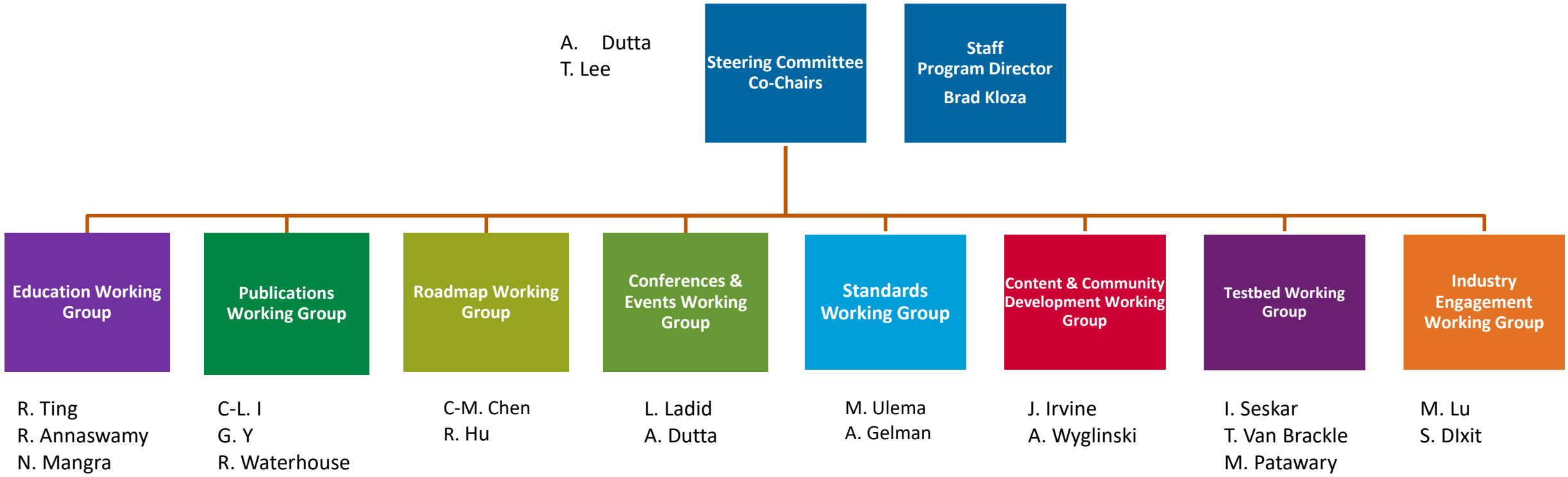

INGR Roadmap Teams Participation Opportunities

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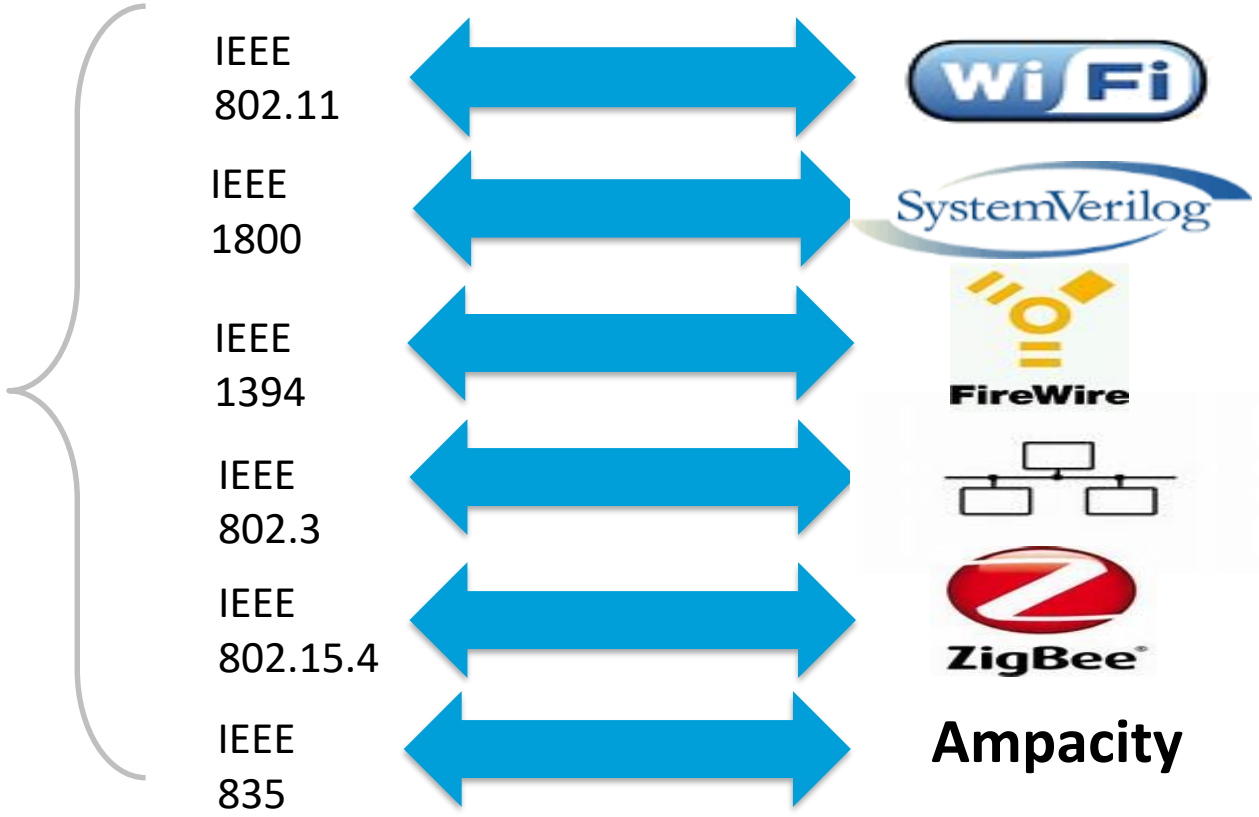
For more information: https://futurenetworks.ieee.org/roadmap

IEEE Standards

Consumers around the world enjoy the benefits of IEEE standards.

Here are a few you may recognize…

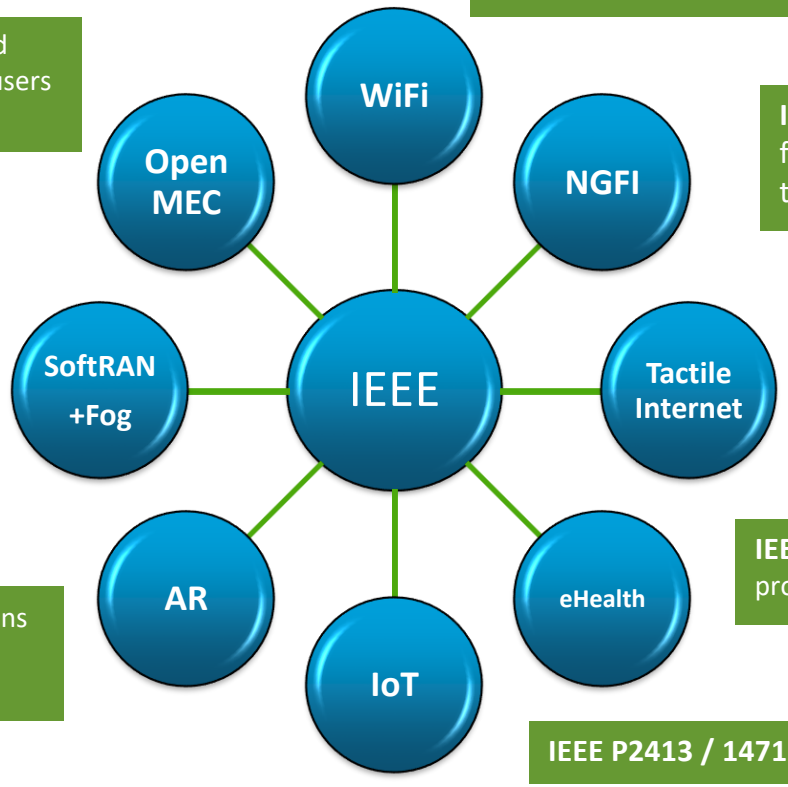


IEEE: Standards and Global Collaboration for 5G

IEEE provides a complete, end-to-end, collaborative framework today for accelerating the realization of 5G and its revolutionary use cases tomorrow.

IEEE 802.11
standard supported by almost any mobile device in the market today

Mobile Edge Cloud brings SDN/NFV frameworks and data path programmability to the proximity of end users as key enablers for service differentiation



IEEE 1914/1904
flexible, efficient and scalable packet-based fronthaul transport networks

SoftRAN is to create a SD RAN flexible enough to control applications with the wireline centric concepts of "fog" in a SD-controller

IEEE 1918
non/mission-critical applications (e.g. manufacturing, transportation, healthcare, mobility, edutainment, events)

IEEE P1589/P1587.6/P1857.9/P3333.2.4 Industry Connections the integration of computer-generated sensory content with the physical world

IEEE 11073
provides a global platform for eHealth stakeholders

IEEE P2413 / 1471 / 42010

Standards Applicable to 5G

Computer Society:

IEEE 802.1 - Higher Layer LAN Protocols Working Group

- IEEE P802.1CM Profile of Ethernet networks utilizing Time Sensitive Networking
- IEEE P802.1CF Netw. Ref. Model, and Func. Description of IEEE 802 Access Network

IEEE 802.3 - Ethernet Working Group

- IEEE P802.3bs 200 Gb/s and 400 Gb/s Ethernet
- IEEE P802.3ca 25 Gb/s, 50 Gb/s, and 100 Gb/s Ethernet Passive Optical Networks (EPON)
- IEEE P802.3cc 25 Gb/s Ethernet over Single-Mode Fiber
- IEEE P802.3cd 50Gb/s, 100 Gb/s, and 200 Gb/s Ethernet

IEEE 802.11 - Wireless LAN (aka Wi-Fi) Working Group

- IEEE 802.11ac-2013 Up to 7 Gbps in 5 GHz
- IEEE 802.11ad-2012 Up to 7 Gbps in 60 GHz
- IEEE P802.11ax Up to 10 Gbps in the 5 GHz
- IEEE P802.11ay Up to 20 Gbps in the 60 GHz band
- IEEE 802.11ah-2016 “HaLow”: Massive Machine Type Communications

Standards Applicable to 5G (Cont'd)

Computer Society:

•IEEE 1903–2011 Standard for the Function Architecture of Next Generation Overlay Network

IEEE 802.15 - Wireless Personal Area Network (WPAN) Working Group

- IEEE 802.15.6 Wireless Body Area Networks (BAN)
- IEEE 802.15.7 Visible Light Communications
- IEEE 802.15.12 Upper Layer Interface (ULI)

IEEE 802.16 - Broadband Wireless Access Working Group

IEEE 802.18 - Radio Regulatory Technical Advisory Group

IEEE 802.19 - Wireless Coexistence Working Group

- IEEE 802.19.1 TV White Space Coexistence Methods

IEEE 802.21 - Media Independent Handover Services Working Group

IEEE 802.22 Point-to-Multipoint Wireless Broadband

IEEE 802.11P Vehicular Communication System (amendment to 802.11)

Standards Applicable to 5G (Cont'd)

IEEE Vehicular Technology Society/ Intelligent Transportation Systems:

1609 Series - IEEE Wireless Access in Vehicular Environments (WAVE)

IEEE Antennas and Propagation Society/Antennas and Propagation:

P211 - Standard Definitions of Terms for Radio Wave Propagation

P149 - Recommended Practice for Antenna Measurements

1720-2012 - IEEE Recommended Practice for Near-Field Antenna Measurements

SASB/SCC39-SCC39 - International Committee on Electromagnetic Safety:

•1528-2013 - IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques

Instruments & Measurements:

- 1451 Series - Smart Transducer Interface for Sensors and Actuator Wireless Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats

Audio Video Coding Working Group:

- IEEE P1857.6™ - Standard for Digital Media Content
- IEEE P1857.9™ - Standard for Immersive Visual Content Coding

3D Based Medical Application Working Group:

- IEEE P3333.2.4™ - Standard for Three-Dimensional (3D) Medical Simulation

Standards in Development Applicable to 5G (Cont'd)

IEEE SA Design Automation Standards Committee (DASC)

- IEEE 1666 (SystemC) Modeling of 5G designs at a pre-implementation level
- IEEE 1666.1 SystemC AMS)
- IEEE 1800 (SystemVerilog) Design/Verification of 5G devices
- IEEE 1076 (VHDL)
- IEEE 1076.1.1 (VHDL AMS)
- IEEE 1647 (the e language)
- IEEE P1800.2 (UVM)
- IEEE 1801 (UPF) Low power hardware analysis 5G hardware designs
- IEEE 1685 (IPXACT) 5G Semiconductor IP design
- IEEE 1734 (IP quality)
- IEEE 1735 (IP encryption)

Standards in Development Applicable to 5G (Cont'd)

Communications Society

IEEE P1903.1	Content Delivery Protocols of Next Generation Service Overlay Network (NGSON)
IEEE P1903.2	Service Composition Protocols of NGSON
IEEE P1903.3	Self-Organizing Management Protocols of NGSON
IEEE P2413	Architectural Framework for the Internet of Things
IEEE P1914.1	Standard for Packet-based Fronthaul Transport Networks
IEEE P1915.1	SDN and NFV Security
IEEE P1916.1	SDN and NFV Performance
IEEE P1917.1	SDN and NFV Reliability
IEEE P1918.1	Tactile Internet
IEEE P1918.1.1	Haptic Codecs for the Tactile Internet
IEEE P1921.1	SDN Bootstrapping Procedures
IEEE P1930.1	Recommended Practice for (SDN) Middleware
IEEE 1931.1	Architectural "ROOF "Framework for the IoT

Standards in Development Applicable to 5G (Cont'd)

IEEE Microwave Theory and Techniques:

- IEEE P1765 Recommended Practice for Estimating the Uncertainty In Measurements of Modulated Signals for Wireless Communications with Application to Error Vector Magnitude and Other System-Level Distortion Metrics
- IEEE P1770 Recommended Practice for The Usage of Terms Commonly Employed In the Field of Large-Signal Vector Network Analysis
- IEEE P1785 IEEE Frequency Bands and Waveguide Dimensions

IEEE Instrumentation and Measurement Society:

- IEEE P287 Standard for Precision Coaxial Connectors at RF, Microwave and Millimeter-wave Frequencies
- IEEE P1415-99 Harmonization of Internet of Things (IoT) Devices and Systems

Augmented Reality Learning Experience Model:

- IEEE P1589 Standard for an Augmented Reality Learning Experience Model

Industry Input

AN INDUSTRY-WIDE DIALOGUE

You're invited to participate in the IEEE Beyond 5G Technology Roadmap effort *to help stimulate an industry-wide dialogue to outline a technology and innovation vision of the development and deployment of 5G and beyond*.

Your expertise as an industry subject matter expert is needed in the roadmap dialog regarding the evolution, the challenges faced, and identification of solutions and areas of innovation.

Ecosystem Stakeholders

- End users
- Application developers
- Service providers
- Equipment manufacturers
- Component suppliers
- Technology innovators
- Governments
- Standards and guidelines producing bodies

IEEE-SA

3GPP

ITU

Industry Interaction at Large

- The Roadmap effort will also include a series of meetings to gather additional inputs and feedback on trends related to:
- Business
- Technology
- Societal
- New fields
- Other industries

Connecting the Industry, Academic, Entrepreneurs and Government Around the World

GLOBAL

IS

WHAT IS NEEDED

LOCALLY EVERYWHERE

More than 50 Summits
IEEE 5G Summit Series – 2015 - 2019 (www.5gsummit.org)

50+ 5G Summits, More than 8500 attendees (onsite and online), 950 Speakers,
IEEE.TV Streaming available

Number of Summits
2015 – 3
2016 – 8
2017 – 19
2018 – 14
2019– 12+ (Planning underway)
Soliciting other chapters

IEEE Advancing Technology for Humanity

More than 60 Summits
IEEE 5G Summit Series – 2015 - 2019 (www.5gsummit.org)

60+ 5G Summits, More than 8500 attendees (onsite and online), 950 Speakers,
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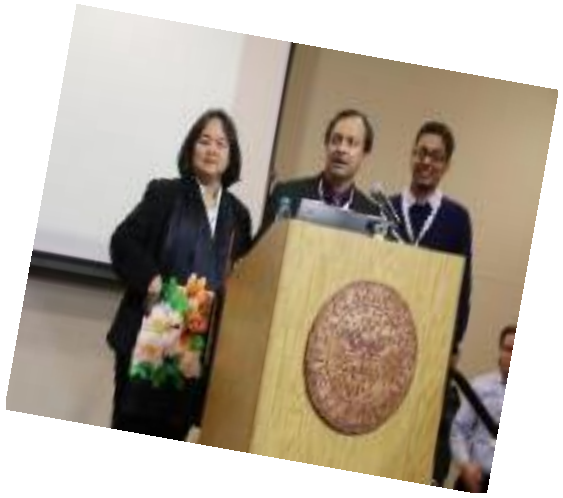
2015 – 3
2016 – 8
2017 – 19
2018 – 14
2019– 18

IEEE Advancing Technology for Humanity

First IEEE 5G Summit
Princeton University May 2015

IEEE
Advancing Technology for Humanity

SANTA CLARA SUMMIT, 2015



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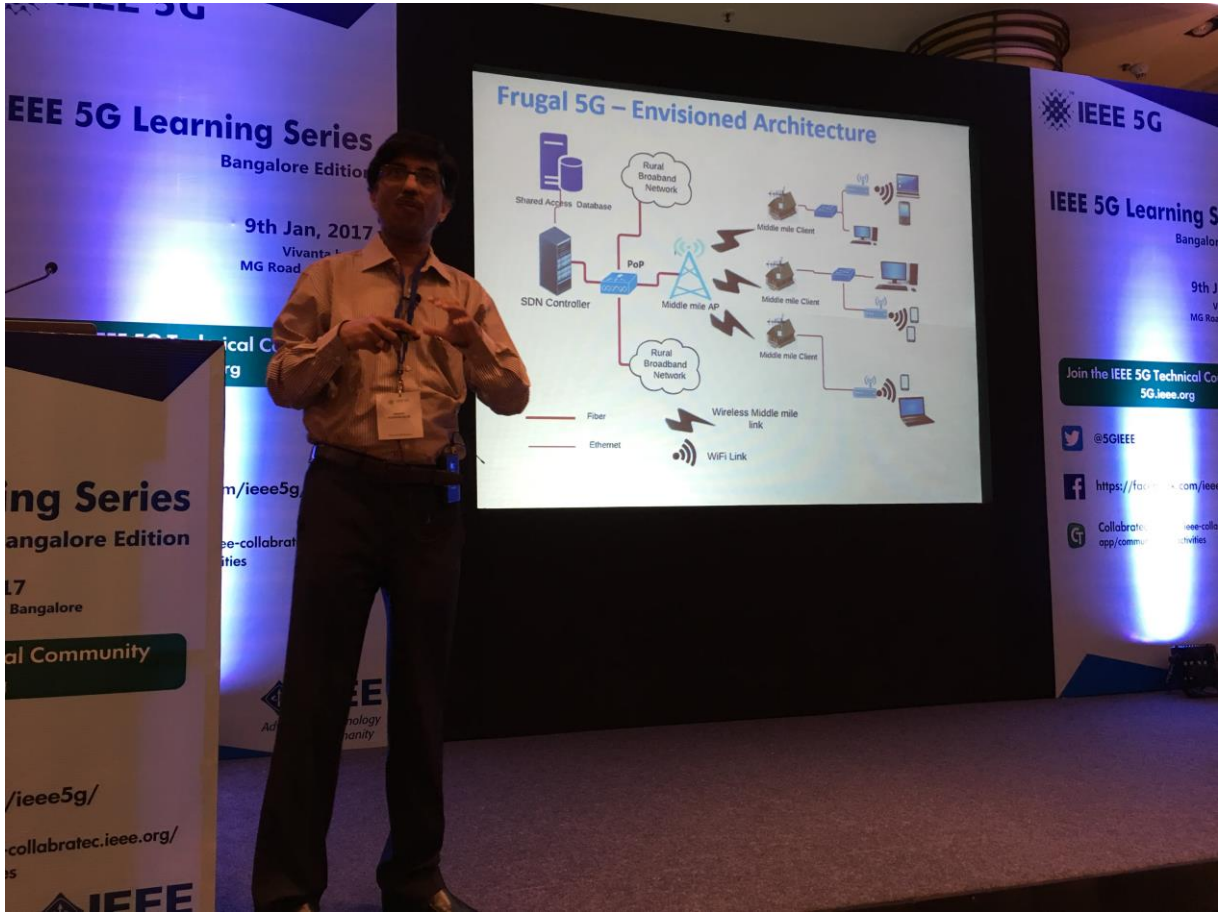
BANGALORE SUMMIT 2017



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IEEE 5G World Forum 2019 and 2020

5G World Forum 2019 – Dresden, Germany

5G World Forum July 2020, Bangalore India

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Whether you are a platform provider, operator, manufacturer, or service/ content provider, there is a path for you and your business to be seen, heard, and make an impact in 5G

…contribute to the inaugural IEEE 5G Initiative Roadmap Working Groups …

…contribute to our publication, IEEE 5G Tech Focus…

…lead an IEEE 5G use case or infrastructure project.

THANK YOU

and

JOIN US FOR THE INNOVATION REVOLUTION

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