Fog Computing for 5G/IoT Development

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Shanghai Research Center for Wireless Communications

Key Lab of Wireless Sensor Network and Communication

SIMIT, Chinese Academy of Sciences

Current Computing Paradigm Inadequate

Cloud   **Cloud**   **Cloud**   **Cloud**   **Cloud**

Internet of Things
Seeking to connect more things and provide more services/applications

Network Bandwidth Constraints

Intermittent Network Connectivity

Stringent Latency Constraints

New Operational Environments: Distributed, Remote, Highly Vulnerable, Un-Managed, …

Vast #, Wide Variety of Devices and Systems, Many Are Resource-Constrained

Vast Amount of Data Generated by the Things

Cyber-Physical Systems: Unique Requirements and Challenges

Need New Capabilities to Enable Mobile Computing at the Edge of 5G Networks

Small Company vs. Big Company

Small Company
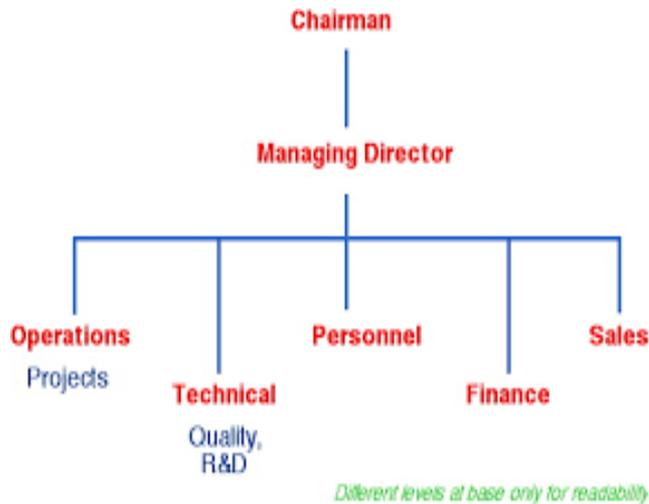
Big Company
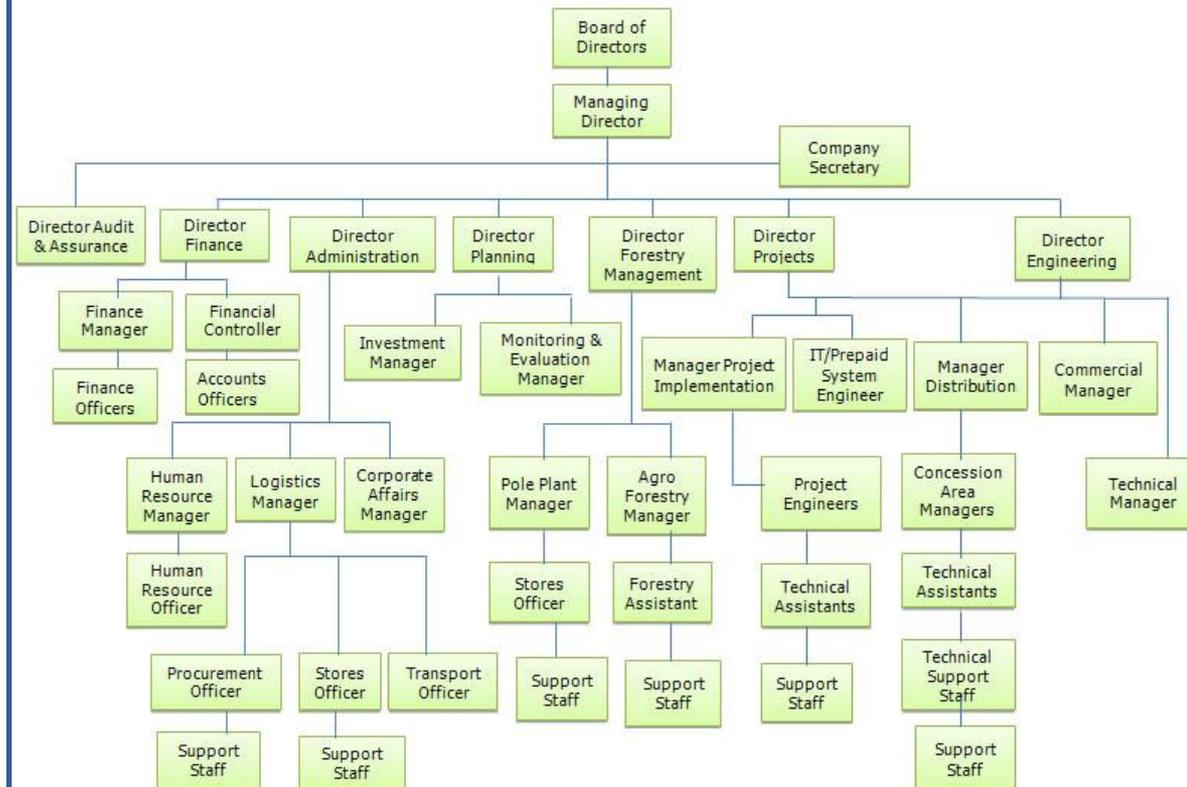
People-centric network **vs.** IoT-oriented network

4 billion connected people

Gartner forecasts that 8.4 billion connected things in 2017, and 20.4 billion by 2020
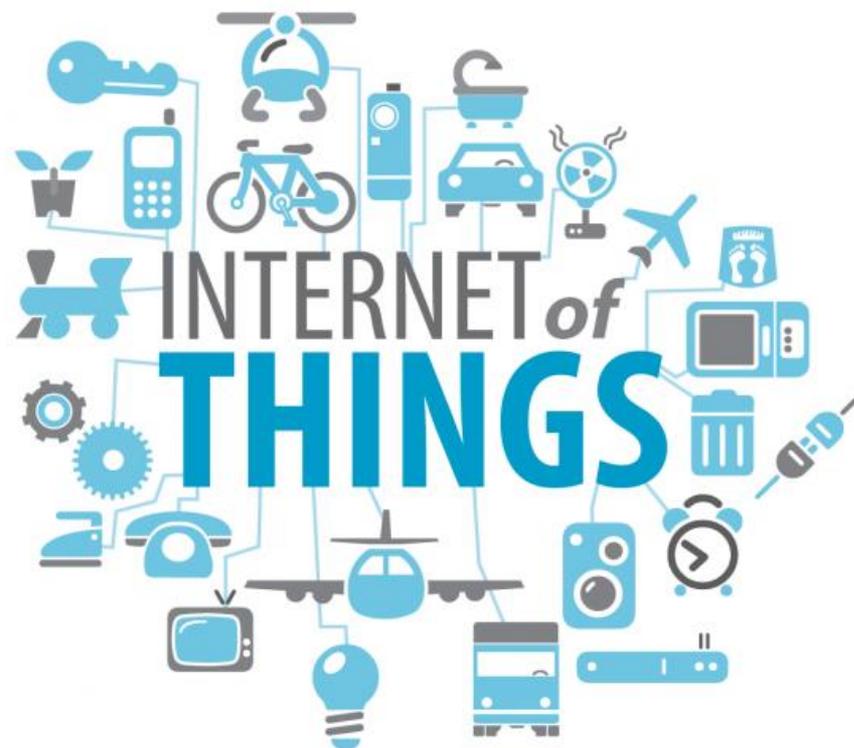
Fog Computing is the Future

Fog
*Enables Computing anywhere along the Cloud-to-Thing Continuum*

Cloud Cloud Cloud Cloud Cloud

Fog Fog Fog
Fog Fog
Fog Fog Fog

Internet of Things
Seeking to connect more things and provide more services/applications

Fog Fog
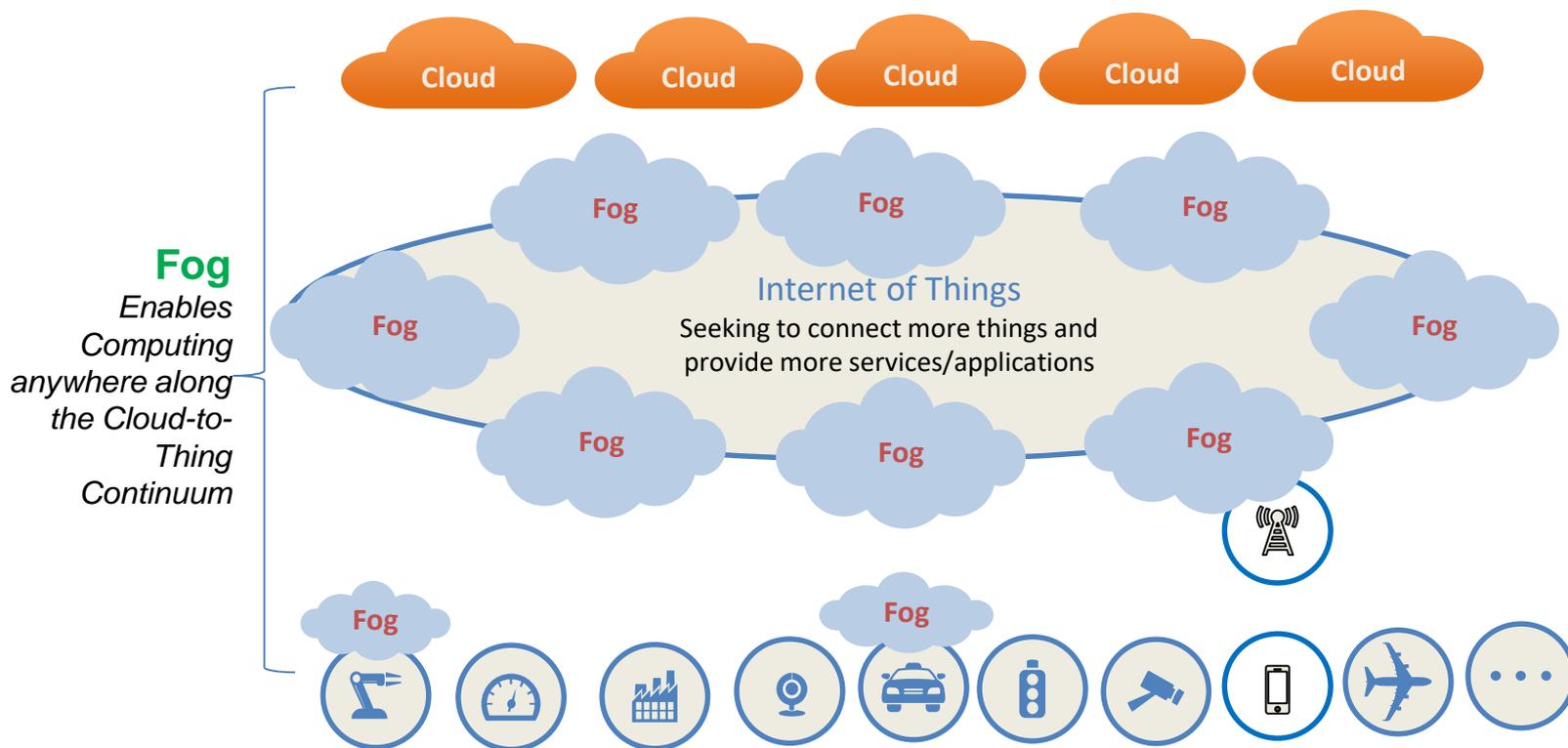
Cloud, Fog, Edge and Things

What is Fog Computing?

Cloud

FOG

A **horizontal**(3) **system-level**(4) **architecture**(1)
that **distributes**
computing, storage, control, & networking functions
closer to the users
along the **Cloud-to-Thing continuum**(2)
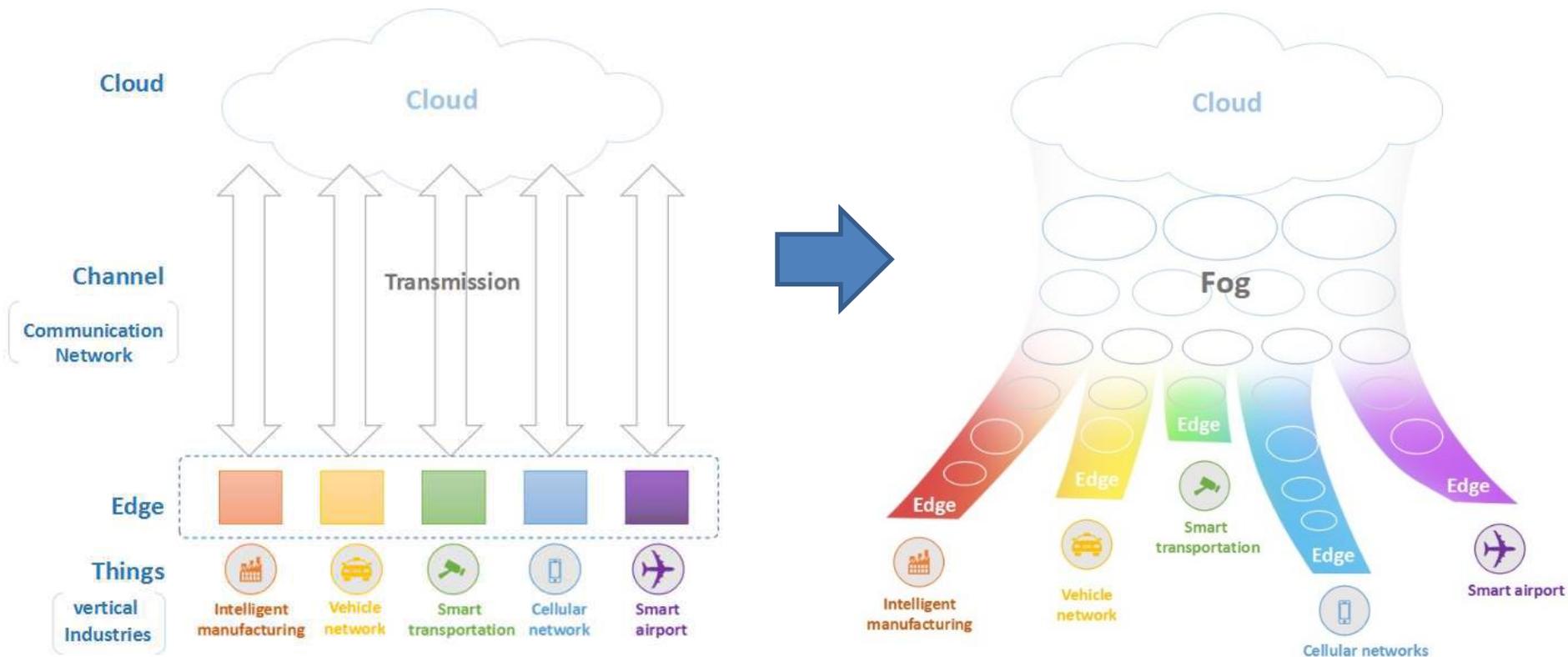
3. Horizontal

Supports multiple industries
(not limited to any specific industry, network type, or application domain)

4. System-Level

from Things to the Edge, and over the Core to the Cloud, spanning multiple protocol layers
(works over and inside wireless and wireline networks along the Cloud-to-Thing Continuum)
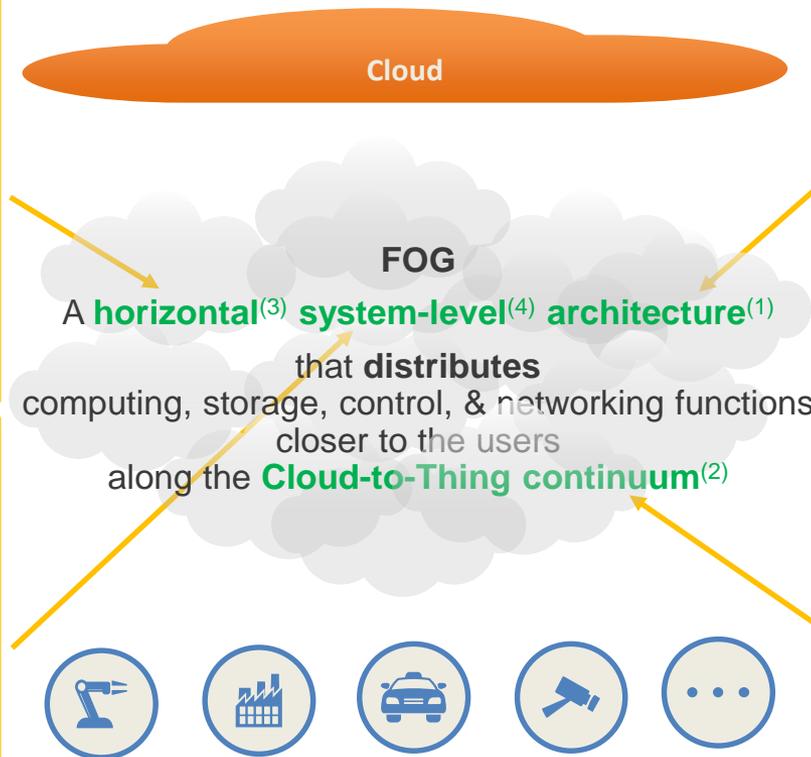
1. Architecture

with its enabling **tools** for distributing, orchestrating, managing, securing resources and services
(not just placing servers, apps, or small clouds at the edge)

2. Cloud-to-Thing Continuum

Distributes resources and services to anywhere along the continuum
(not just at the edge)
Converged Cloud/Fog services
(not just isolated edge computing devices / apps)

Fog Is Needed Everywhere

Real-Time Adaptive Traffic Control,
Connected/Autonomous Car Apps (safety,
Internet access, …)

Positive Train Control,
Real-Time Monitoring,
Internet Access, …

Industrial Control Applications,
Local Data Analytics, …

Local Control and Data Analytics with
Intermittent Internet Connectivity

5G,
Oil & Gas,
Smart Cities and Homes,
Internet Services,
Robotics,
Smart Grid,
Visual Security,
Drones,
Virtual/Augmented Reality,
Embedded AI,
…

Fog is Analogous to TCP/IP

TCP/IP

A standard and universal framework
to
distribute packets

Fog

A standard and universal framework
to
distribute resources and services

plus
Manage, orchestrate, and secure
the distributed resources and
services

Why Must We Care About Fog Now?

We Need Fog Now

Demanding network functions & apps to be distributed

Enabled network elements, apps, and other SW to be distributed more efficiently

AI and Machine Learning
Wisifying things, computing, and networking

Container
Portablized applications more efficiently

NFV
Virtualized network elements

Virtualization
Abstracted OSs away from HW

SDN
Separated control and data planes.
Softwarized control functions.

Cloud
Centralized computing and data storage

Computing and Networking Technology Progression

User Needs and Business Demands

Emerging systems & use cases are constrained by cloud-only models

Many new operating requirements cannot be adequately met by cloud alone

Many resource-constrained devices require local off-board support

More cyber-physical systems need open, standards-based, real-time local control

More applications need time-critical local processing

More data created at the edge

Fog Fills Critical Technology Gaps and Enable New Services

Address Challenges in Emerging Systems/Apps (IoT, 5G, Imbedded AI, …)

- Stringent latency/delay requirements
- Resource constraints (endpoints, network bandwidth, …)
- Intermittent network connectivity
- Large # and many types of "Things"
- Distributed, remote operations by non-IT experts

Empower the Cloud

- Fog as proxy of Things to connect more Things to Cloud
- Fog as proxy of Cloud to deliver services to Things

Enable New Services

- Fog-based services
- Fog-enabled 5G
- Converged Cloud-Fog platforms and services
- User controlled Fog services
- Fog-enabled dynamic networking at the edge

Fog Will Disrupt Existing Business Models

Reshaping Industry Landscape	• Routers, switches, application servers, and storage servers converge into unified fog nodes
Disruptive New Service Models	• Players of all sizes, not just massive cloud operators, build/operate fogs and offer fog services → "WiFi Model" and the rise of local/regional fog eco-systems and operators?
Integrated/Converged Cloud–Fog Services	• For a business to function as a cohesive whole, cloud and fog will converge into one common infrastructure for integrated and unified cloud <u>and</u> fog services: development, deployment, monitoring, management, security, …
Rapid Development and Deployment of Fog Systems and Applications	• Rapid deployment of localized applications → shifting from "build the cloud and see what services we can put on it" to "find what customers want and quickly put together a fog for them"

5G: a Game Changer

5G Technical Requirements

- Can **one** 5G network satisfy **all** diversified requirements?
- How to make 5G networks super flexible and adaptive?
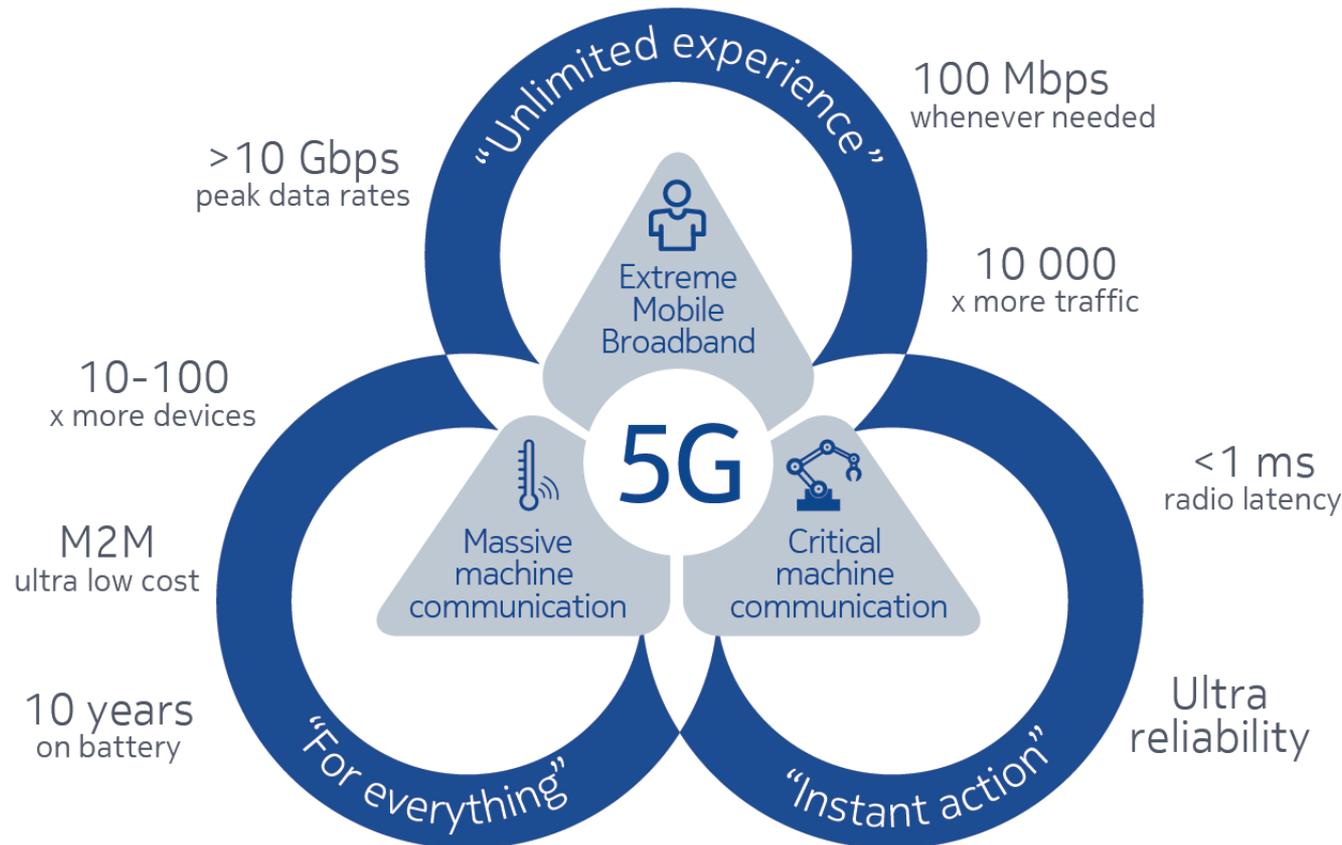
Source: Nokia

TIP, February 22, 2016

- The Telecom Infra Project (TIP) is an engineering-focused initiative driven by operators, infrastructure providers, system integrators and other technology companies that aim to reimagine the traditional approach to building and deploying telecom network infrastructure.

- Focus areas: access, backhaul, and core and management.

- Open and collaboration!

Members (growing)		
AMN	ACACIA	IP access
ADVA	Amarisoft	Juniper
ASOCS	Aricent	LEMKO
AW2S	Athonet	Lumentum
Axiata	BaiCells	MTN
Bandwidth	BlueStream	Nexius
Broadcom	Coriant	Nokia
EE	T-Mobile	Quortus
Equinix	Facebook	Radisys
Globe	Harman	Horizon
HCL	SK Telecom	iDirect
SS7	Starsolutions	Sysmocom
Intel	Indosat	Telefonica

FCC, July 14, 2016

- U.S. leadership in 5G is a national priority.

- There are others around the world who are saying, "No, we want to figure out what the standards are and then figure out how to do the spectrum." We think that's backwards.

Tom Wheeler, FCC Chairman

Licensed			Unlicensed
27.5GHz-28.35GHz	37GHz-38.6GHz	38.6GHz-40GHz	64GHz-71GHz

Source: FCC

White House, July 15, 2016

- Advanced Wireless Research Initiative, USD 400 million, led by the NSF.

- **Deployment of four city-scale testing platforms for advanced wireless research.**

- (To) allow academics, entrepreneurs, and the wireless industry to test and develop advanced wireless technology ideas, some of which may translate into key future innovations for 5G and beyond.

Strong support from public and private sectors	
NSF	DARPA
NIST	NTIA
AT&T	Carlson Wireless
HTC	CommScope
Intel	InterDigital
NI	Juniper Networks
Nokia	Keysight
Oracle	Qualcomm
Viavi	Samsung
Sprint	Shared Spectrum
Verizon	T-Mobile
ATIS	CTIA
TIA	Source: White House

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Google: target at 5G networks

- Google is partnering with leading mobile network operators globally to build a platform for operators to run their network services

- Google will bring their expertise in **SDN**, **NFV** and **Cloud** to the carrier ecosystem, thus accelerate the transition to 5G and enable new features such as the application of machine learning

- The platform will provide plenty of APIs which will enable new operational models and help operators bring new features

- The platform is based on **commodity hardware** instead of **dedicated hardware** provided by telecom manufacturers

EMBB	MIoT	MCS
APIs		
SDN	NFV	Cloud
Fabric	Backbone network	Edge nodes

Commodity hardware

Google Edge Nodes

Map of metros where at least one Edge node (GGC) is present.
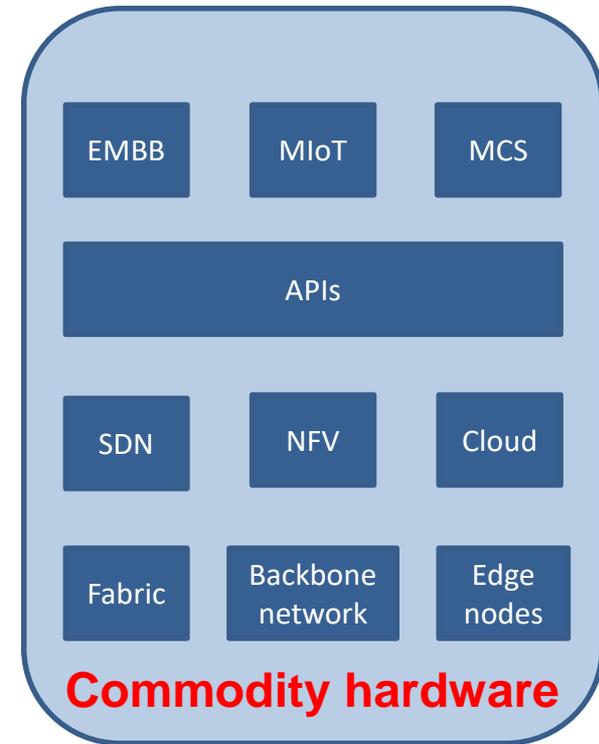
Intel's 5G Strategy

- Provide a full suite of products for covering almost every part of the new networks that will all seamlessly interact

- 5G networks will have to be designed to be more flexible, relying on **software** that can be reprogramming to handle different tasks running on more **generic hardware**, instead of being built on more **customized hardware** dedicated to specific tasks

- Links between different parts of the 5G network all made by Intel will be able to interact more efficiently and quickly, while Intel software gives users a **smooth experience**
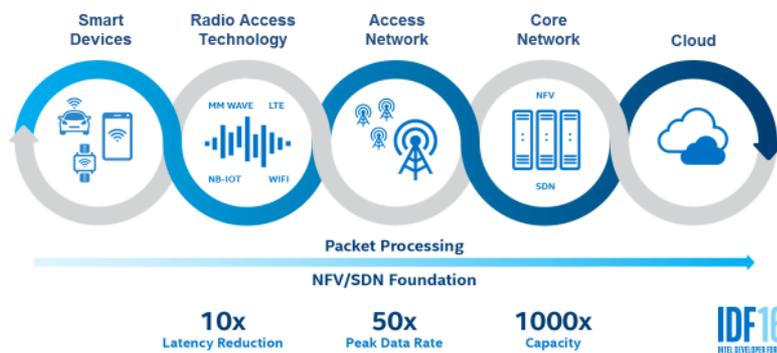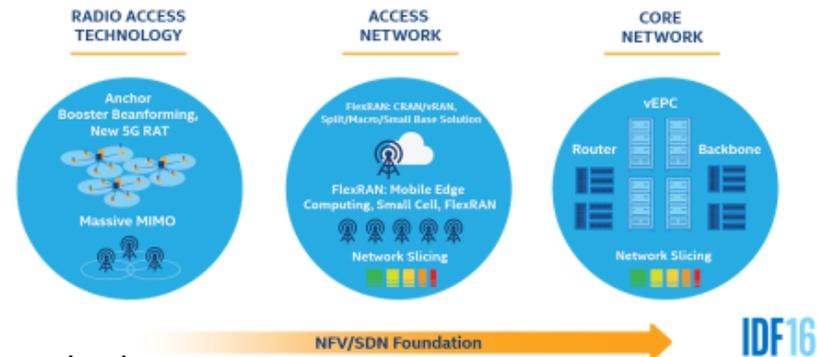
Source: Intel

Intel 5G Modem (Codenamed GoldRidge) 5G Stand-alone and Dual-connectivity

- World's first global 5G modem with ultra-high throughput operation and low latency

- Operation in both sub-6 GHz and mm-Wave bands with compact chip kit

- Pairs with the world's first 5G sub-6 GHz and 28 GHz RFICs

- Supports key 5G NR technology features, including low latency frame structure, advanced channel coding, massive MIMO and beamforming

- Pairs with LTE modems such as Intel's XMM™ 7360 LTE modem for 4G/5G dual connectivity
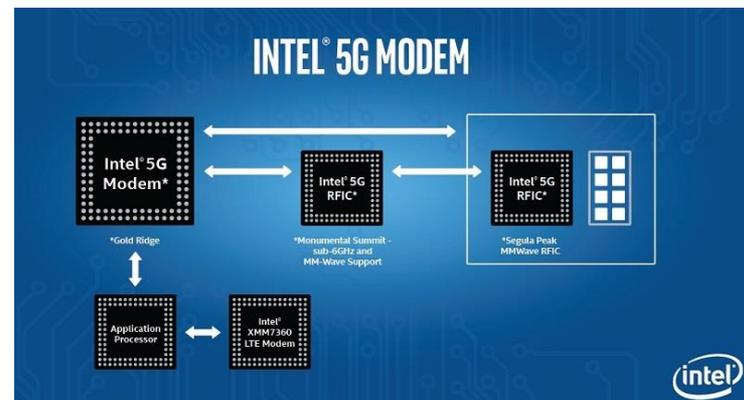
Intel aims to cover all the bases for 5G. (Image: Intel)

Qualcomm: maintain its Modem and RFFE leadership in 5G era

- Qualcomm's 5G vision: a unifying connectivity fabric, including enhanced mobile broadband, Mission-critical services, Massive Internet of Things

- Qualcomm has a strong background of wireless communication technology and mobile chipset design base on ARM architecture

- Qualcomm is driving 4G and 5G in parallel to their fullest potential, pushing LTE towards 5G with its end-to-end system approach

- Qualcomm announces X16 and X50 modems for Gigabit LTE and 5G Connectivity

5G Vision: GPP-based Platform

- Software defined mobile network and resource/network function virtualization could meet different diversified 5G use cases and business models, i.e. eMBB, mMTC and uMTC.
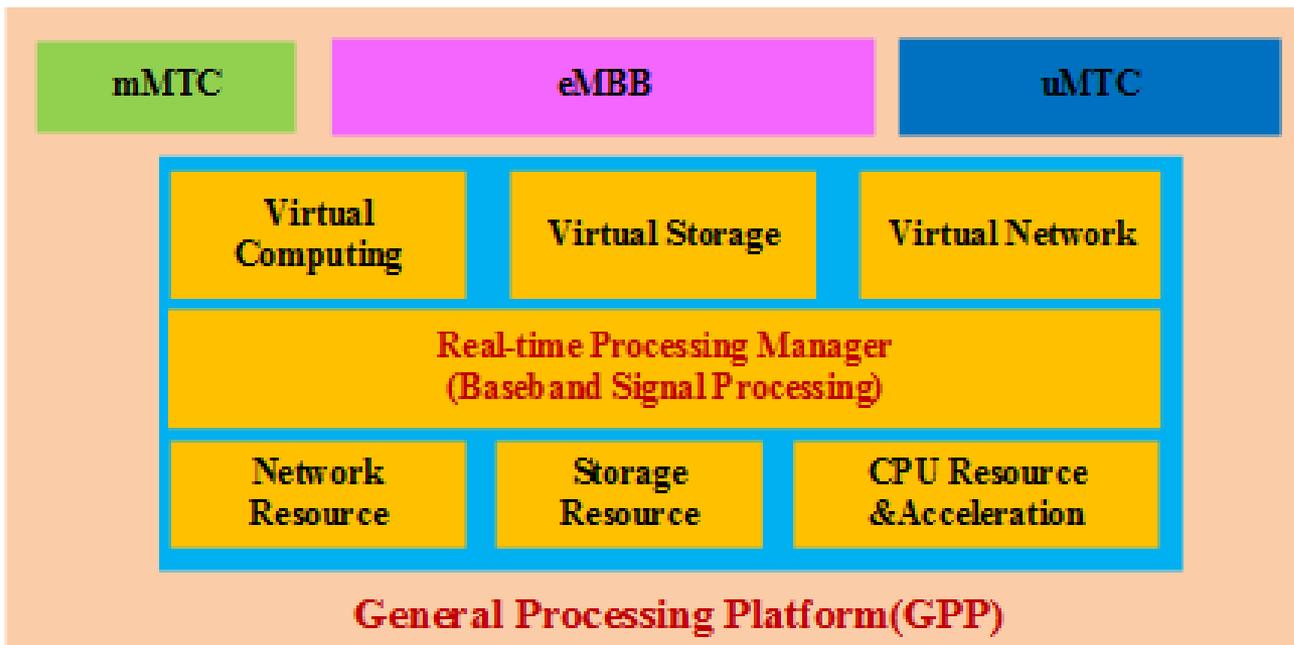
Virtualized Network Slices

Motivation: Flexible and Adaptive

- To decouple software and hardware designs
- To realize flexible deployment of network functions

Current: Dedicated Hardware Platform → **Future: GPP-based Platform**
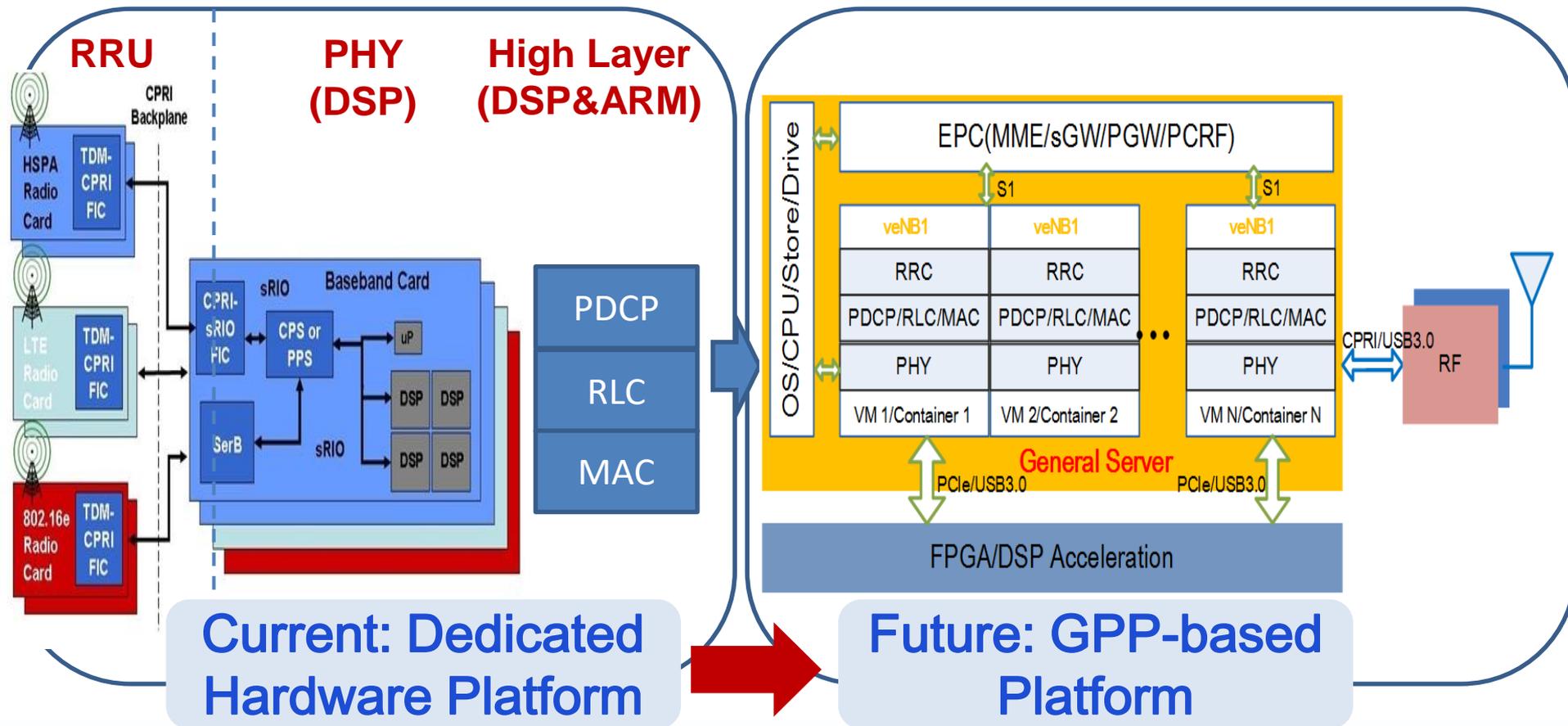
Software Defined RAN

Making up the weakness of general processor, providing standard function of CODEC, MDM, resource mapping, FFT/IFFT/DFT and etc.

CPRI Interface

10G Ethernet Connection

Decoder/MDM/Resources and aerial mapping.etc

Specialized Hardware（SoC）

Specialized Hardware（SoC）

Exchange

VM Multi-mode BMU

VM LTE BMU

VM GSM BMU

...

VM Edge App BMU
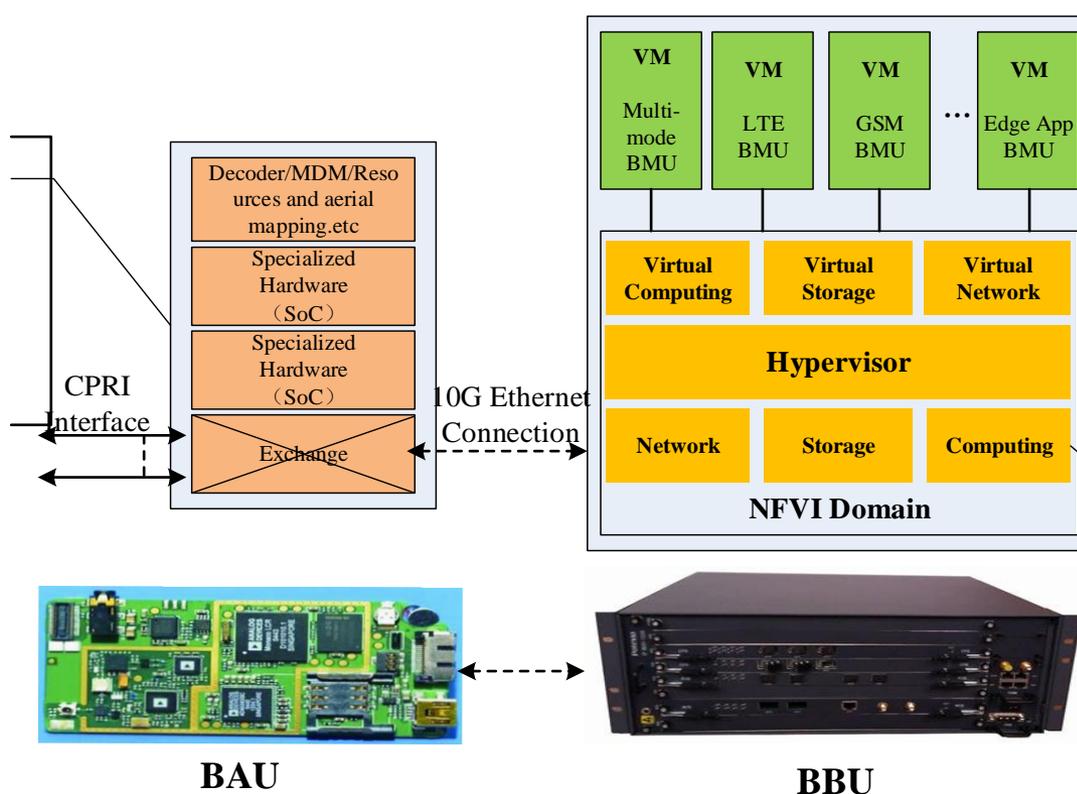
Virtual logic applications provide support to GSM, TD-LTE and other wireless protocols.

Virtual Computing

Virtual Storage

Virtual Network

Hypervisor

Network

Storage

Computing

NFVI Domain

Based on multi-core CPUs and general purpose servers, virtual logic applications provide physical computing, network and storage resources.

BAU

BBU

Dedicated accelerations with FPGA and DSP

Virtualization of baseband resources

Source: Alcatel-Lucent Shanghai Bell

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Facebook OpenCellular: an Open Source Wireless Access Platform

- **Radio:** Radio with integrated front-end, which is based on SDR/SoC and supports network-in-a-box or access point.

- **GBC:** General Baseband Computing

- **Function:** SMS messages, voice calls, basic data connectivity using 2G implementation.
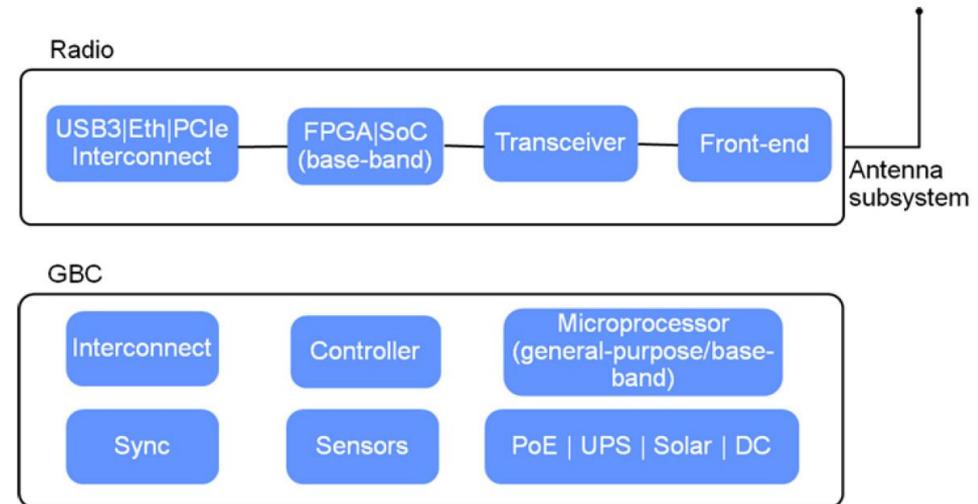
Source: Facebook

it is a just mini PC

Intel NUC 5i7RYH
Core i7-5557U
3.1 GHz-3.4 GHz
Dual-core
4 MB cache
Price: < 600 USD

Futuremark PCMark 7
Overall PCMark Score
Intel NUC5i7RYH - Core i7-5557U
Higher Scores = Better Performance

	Score
Intel Core i5-4670K	6401
Intel NUC NUC5i7RYH (i7-5557U)	5515
Intel Core i5-3470	5379
Intel NUC5i5RYK (i5-5250U - Samsung SSD)	5268
Intel NUC5i5RYK (i5-5250U - Intel SSD)	5139
AMD A10-6800K	4585
Intel NUC DC3217BY (i3-3217U)	3483

0   2000   4000   6000   8000

19V ⎓   ⊞P   ⊒品   SS←   HDMI

Source: Internet

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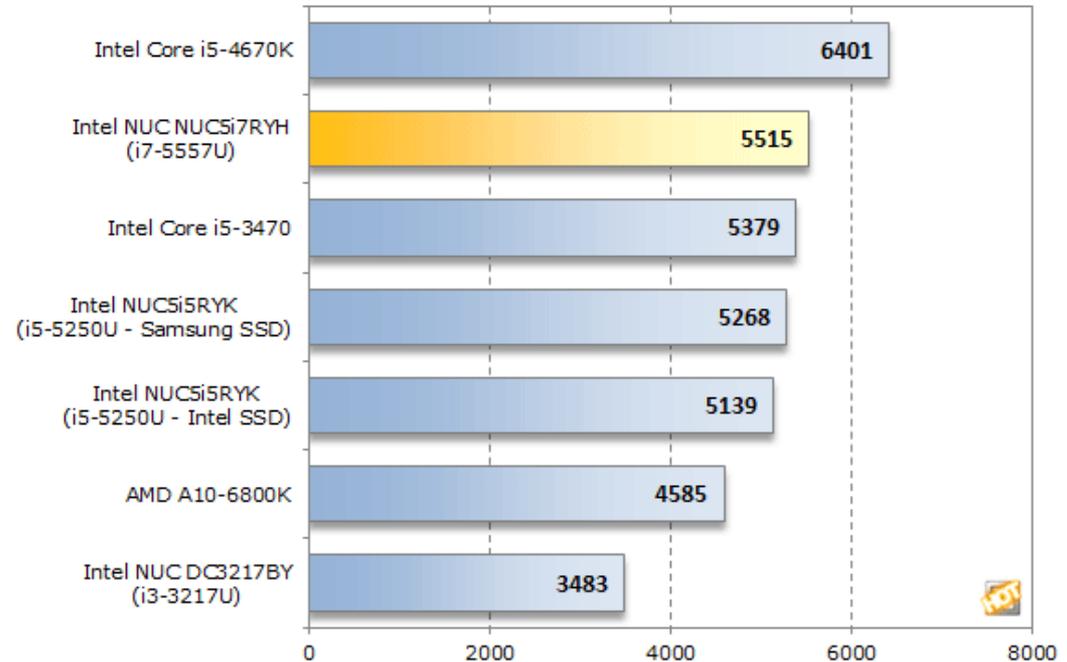
You think it is a just mini PC

eNodeB   **EPC**

Intel NUC 5i7RYH
Core i7-5557U
3.1 GHz-3.4 GHz
Dual-core
4 MB cache
Price: < 600 USD

=   **+**

Radio Access Network (RAN)   Core Network (EPC)

SGW — PGW

External Network

MME   PCRF
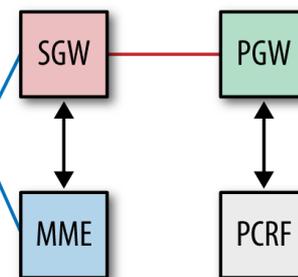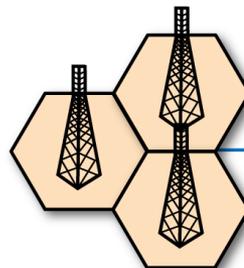
Source: Internet

Software Defined Mobile Network

- Based on OAI open-source LTE platform

- Real-time software defined LTE network (including RAN and EPC) on a multi-core GPP-based platform

- FDD and TDD modes

- Support multiple commercial LTE mobile terminals for each eNB

- Support video streaming and web browsing traffic
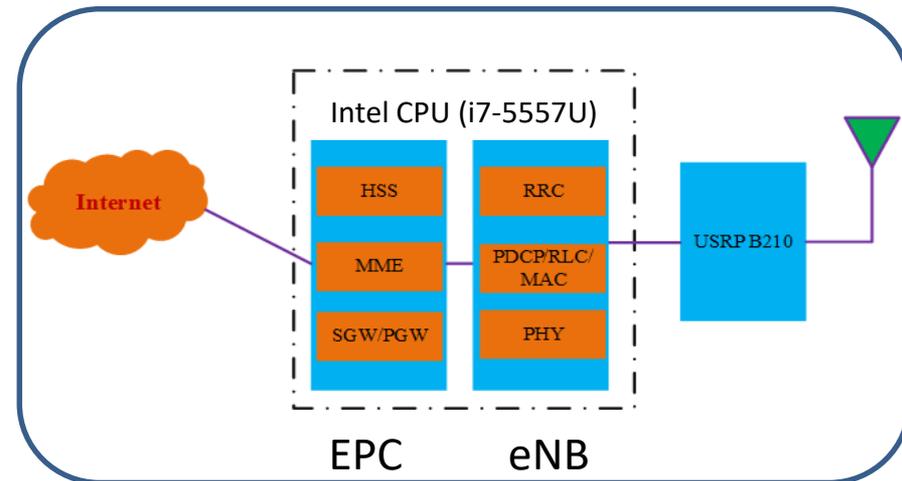
Delay of baseband signal processing

- TD-LTE uplink and downlink on a GPP-based platform;

- Multi-core parallel computing achieves real-time requirements.
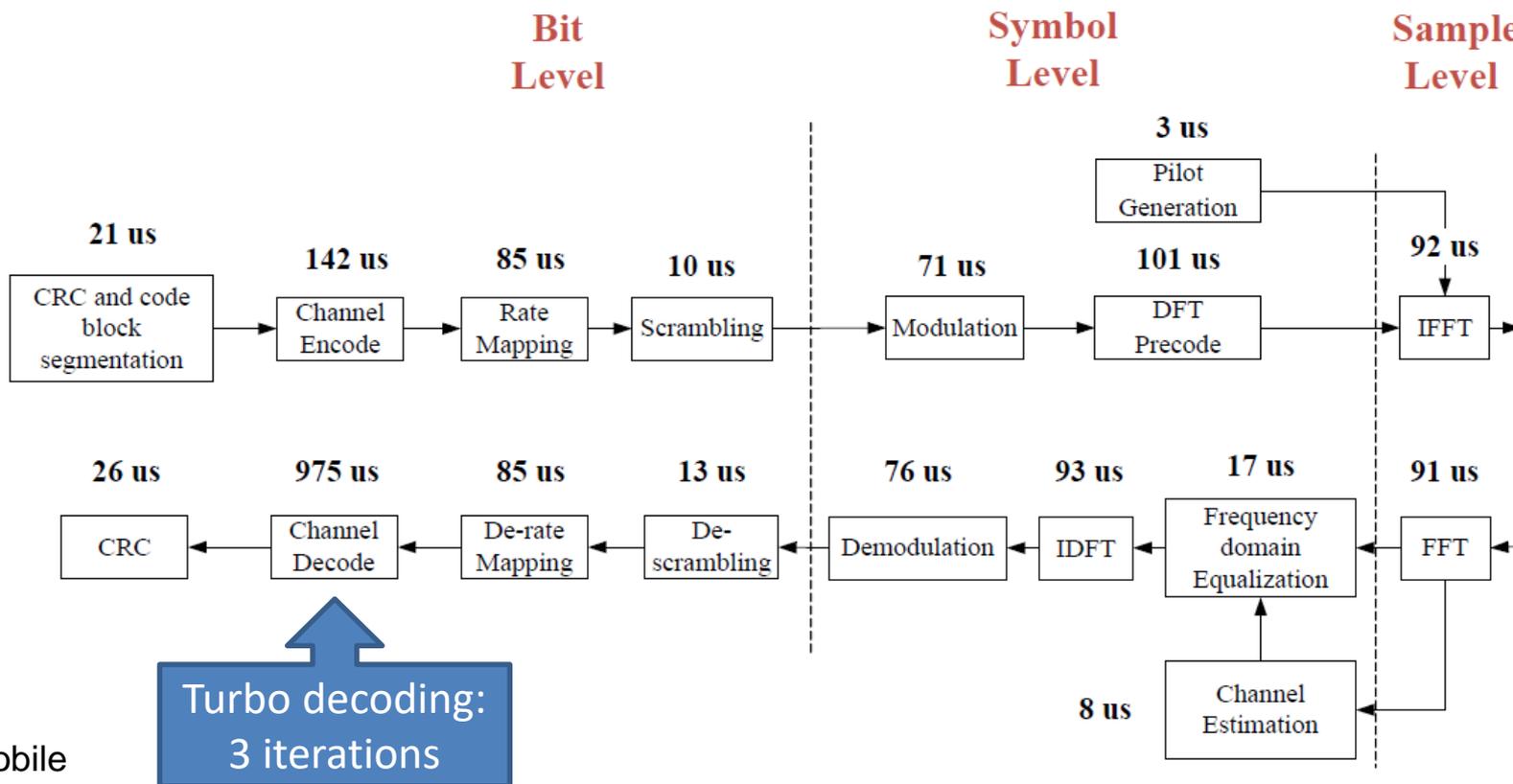

Source:
China Mobile

Delay of baseband signal processing

- **Our GPP-based platform:** IBM System x3400 M3 with 2.13GHz CPU, quad-core Intel Xeon E5606, 4G RAM, 256G HDD, Linux Debian 7 OS with the version 64 bits Ubuntu 14.04 DeskTop.

- **Turbo decoding** is the bottleneck for real-time processing.

Processing Time(µs) / Function \ Rate (Mbps)	2.152	8.76	13.536	17.56
De-scrambling	7.96	21.93	33.38	43.26
De-modulation	7.89	13.72	15.94	17.84
De-interleaving	6.27	30.19	48.68	72.11
Turbo decoding	113.44	465.01	734.86	1047.61

Network Slicing for Various Use Cases

Unified Infrastructure

Slice 1: Wide-area Coverage

Slice 2: Hot Area

Slice 3: Low power consumption& Massive connection

Network Slicing

Signaling
Data

Control Function   Data Function   Content Appreciation
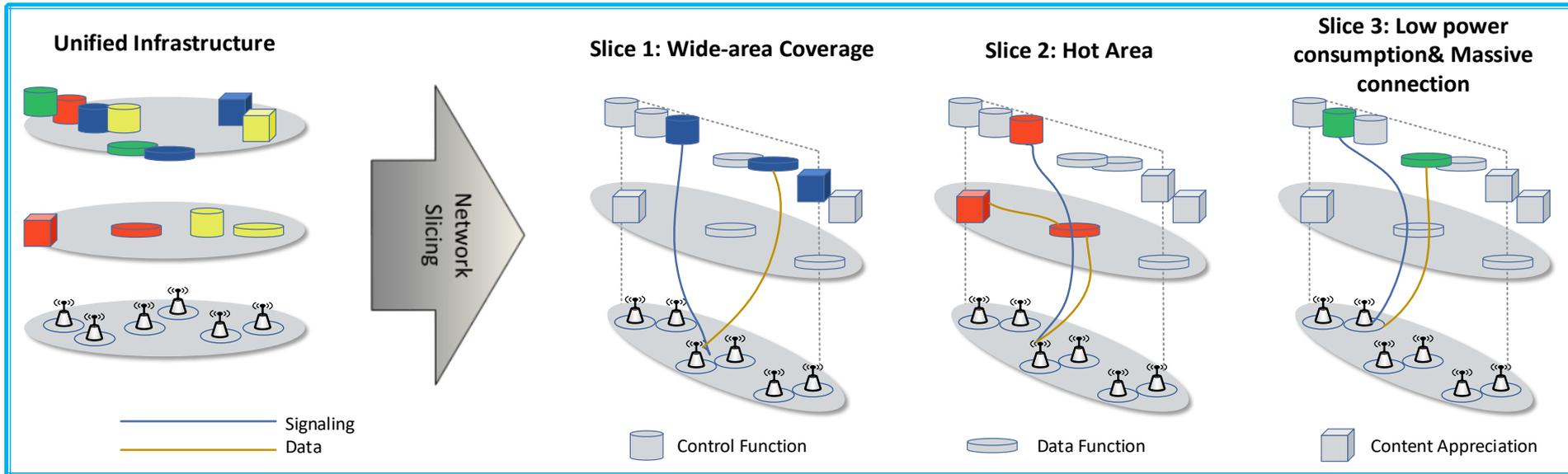
- **Open Source Software:** to build a collaborative community and ecosystem for innovations in EPC, eNB and terminals.

- **GPP-based Hardware:** to replace dedicated hardware (e.g. ASIC), thus enabling flexible and adaptive service creations and deployments for various use cases and business models.

Fog-enabled 5G Platform
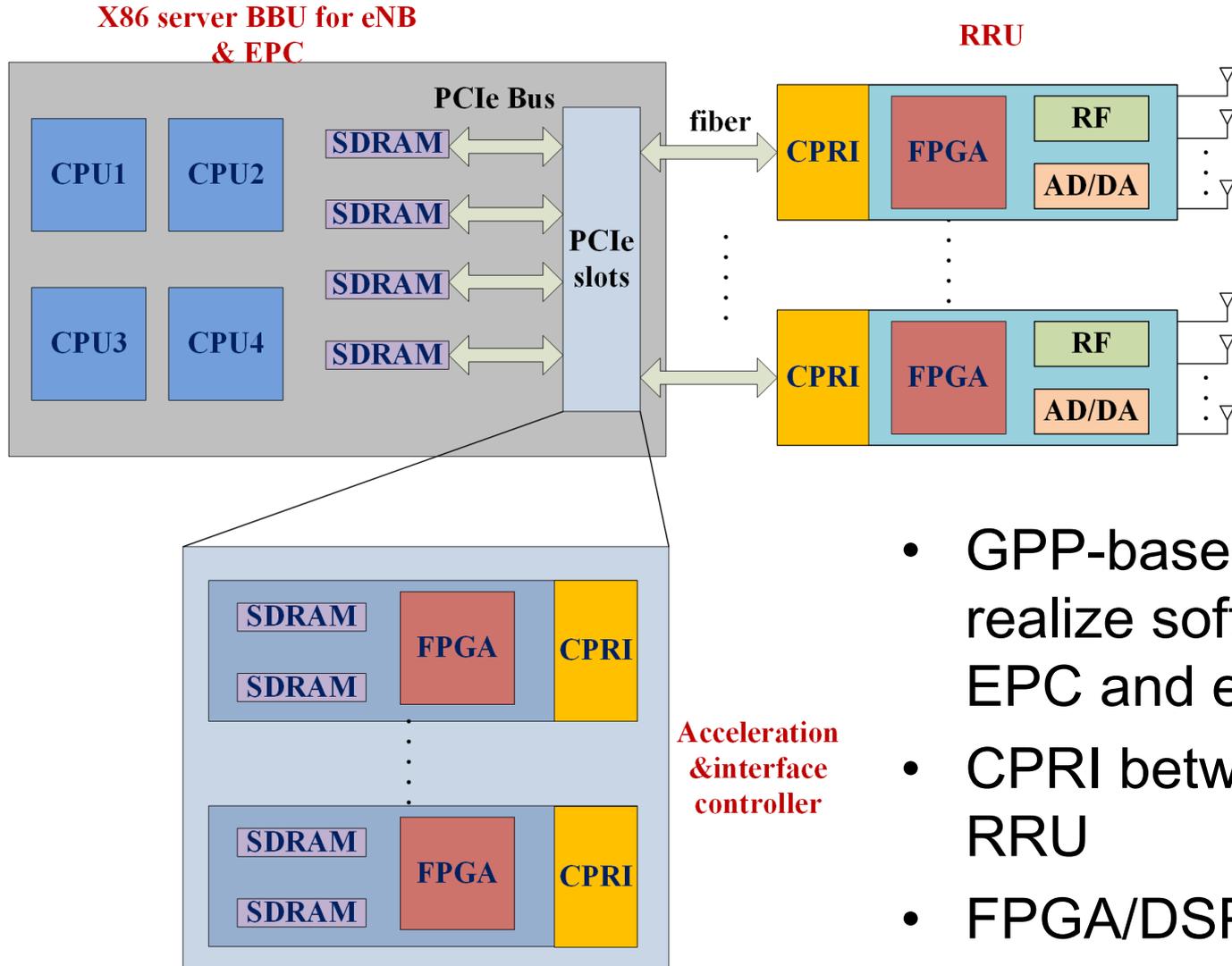
- GPP-based platform to realize software defined EPC and eNB BBU
- CPRI between BBU and RRU
- FPGA/DSP Acceleration

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Chapter 2: ShanghaiTech Fog Node
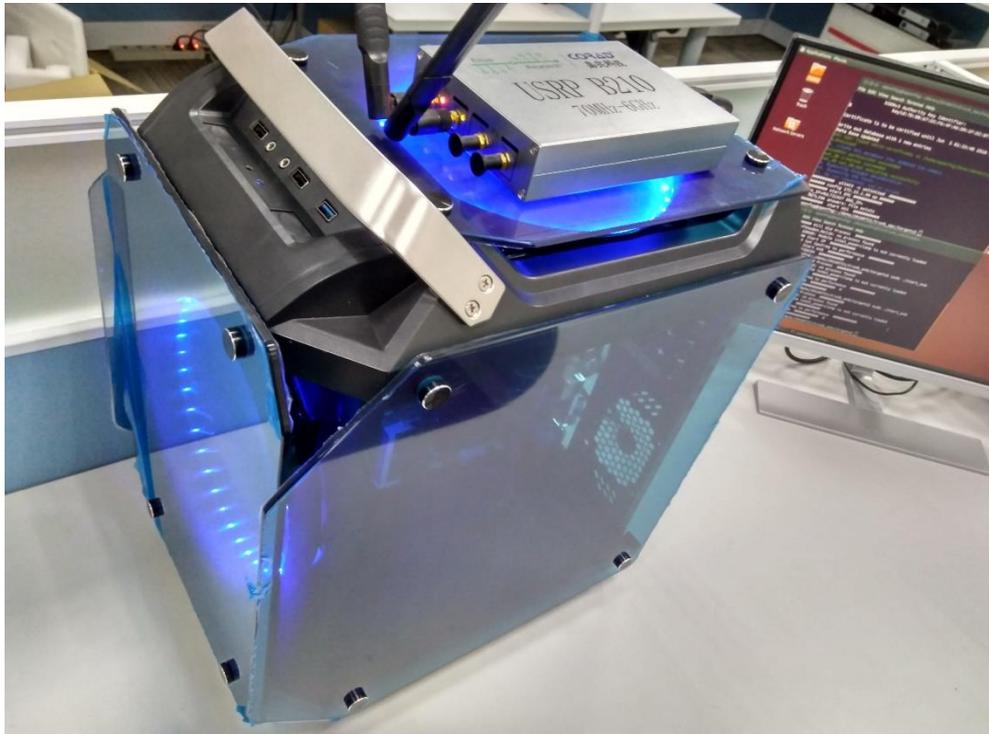
- Four Intel core i7-4700EQ CPU

- 16GB DDR3

- 240G SSD

- 2TB HDD

- USRP B210 RF Module

Chapter 2: ShanghaiTech Fog Node

- Highly aligning with OpenFog Reference Architecture
- Fog application support: management, storage, etc

Application Services	F-RAN / Auto-driving / Robots / …
Application Support	Fog Application Support
Node Management (IB) & Software Backplane	Linux OS, SDN-eNB, SND-EPC, node & service discovery, node management software Virtualization, software Container
Platform Hardware	Inter i7 CPU, USPR, RF HW, FPGA, Sensor/Actuators/Cameras…
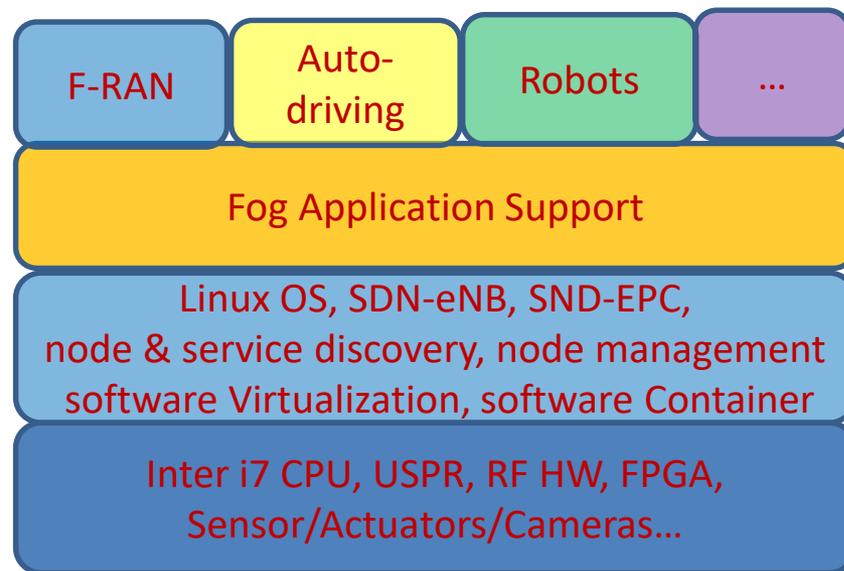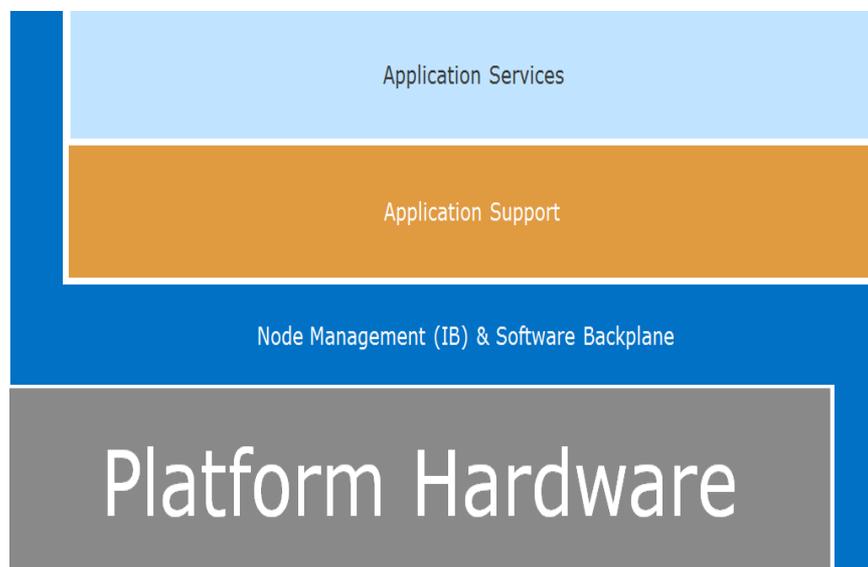
OpenFog Testbed for 5G/IoT R&D

➢ **LTE + 5G hierarchical network architecture**

- 6 macro-cell base stations
- 10~20 micro-cell base stations
- 100+ small base stations
- Trial of GPP-based BSs

➢ **802.11ac high speed WLAN**

- 100~200 outdoor APs
- 1000~10000 indoor APs
- UDN, multi-carriers
- Trial of GPP-based APs

ShanghaiTech University
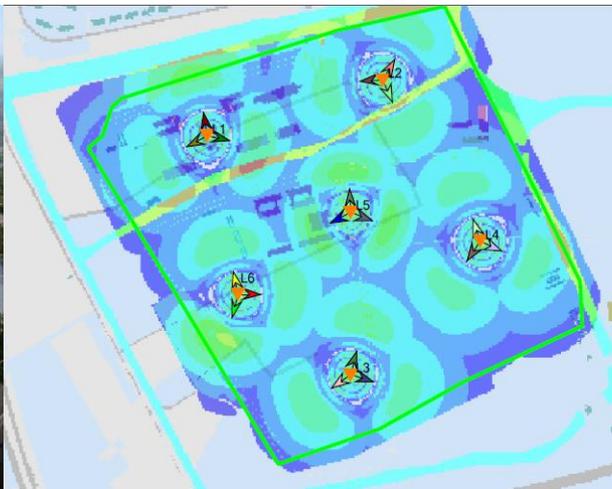

LTE+5G macro-cell BSs
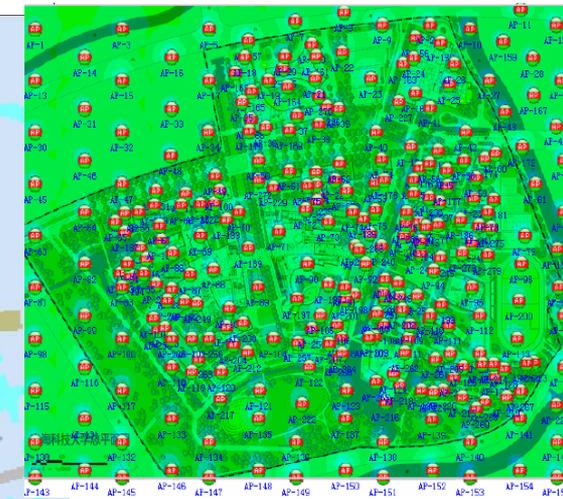
802.11ac outdoor APs

Fog-enabled 5G Platform for Various Vertical Applications

Data Analysis

Business Platform
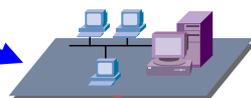
Monitor Center

Example

Fog

Autonomous Car

Fog

Network Management

Fog

Fog

Fog

Fog

Fog

Video Surveillance

Environment Monitoring

Smart Grid

www.jiading.gov.cn

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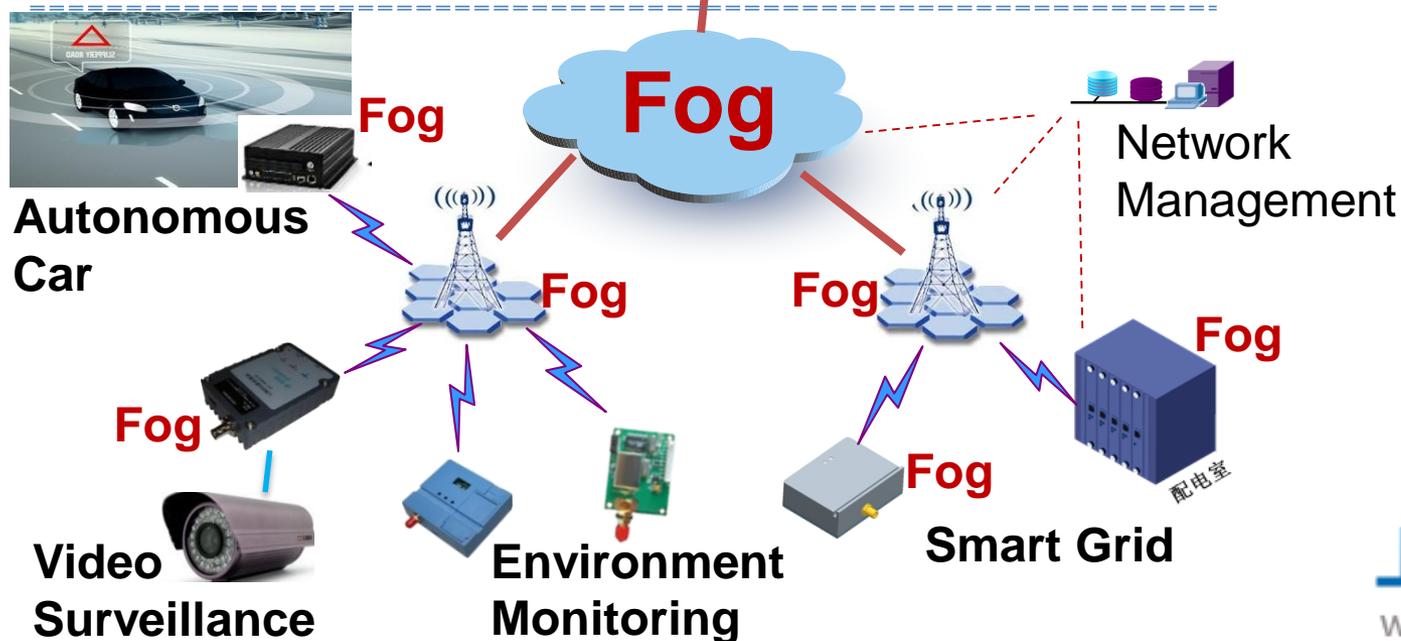
Fog-enabled Network for 5G/IoT Applications
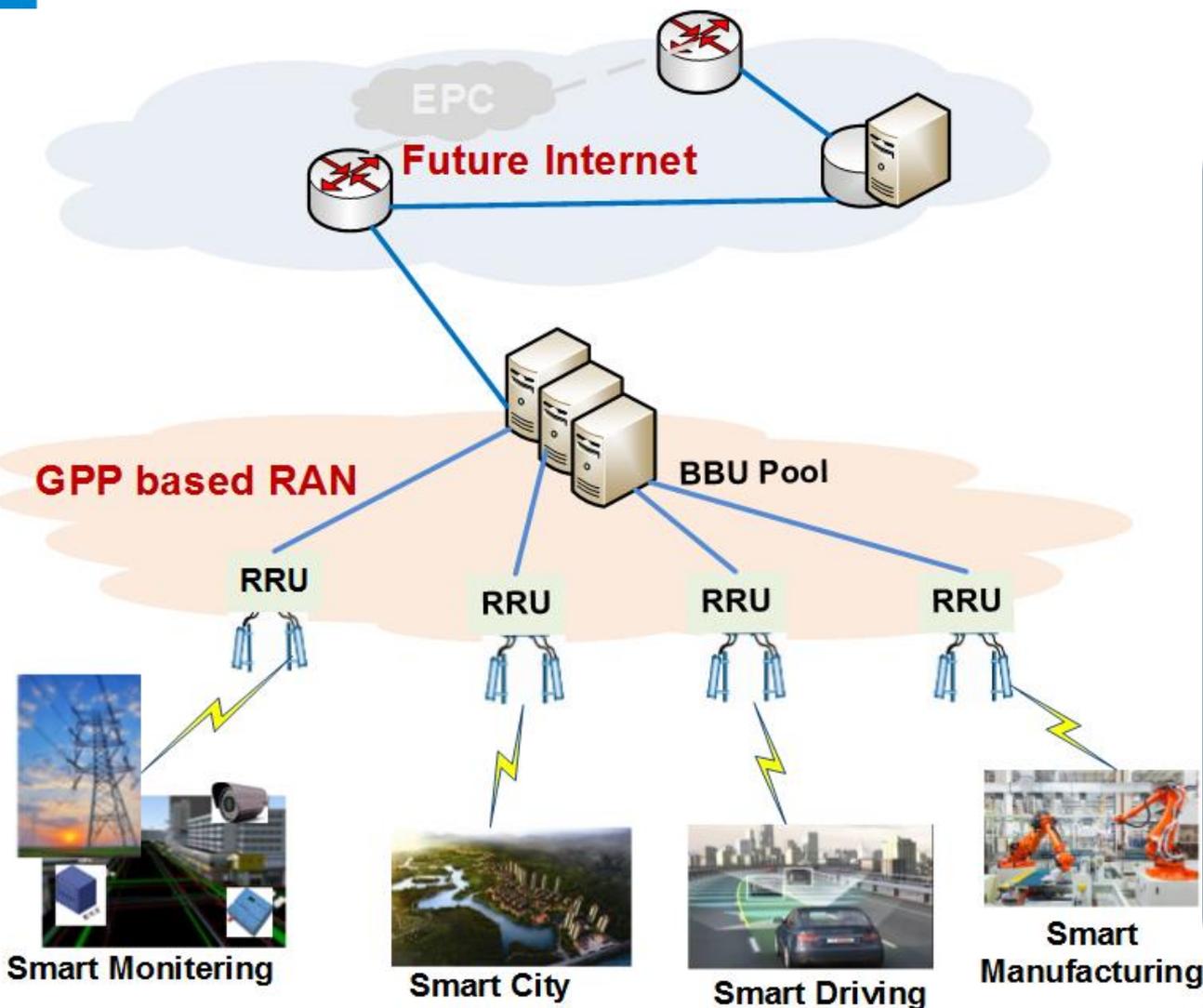
- **Fog-based network supports various 5G/IoT applications**

- **Massive and low rate connections**

- **Low power consumption and depth coverage**

- **Low latency and high reliability**

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Join the OpenFog Consortium!
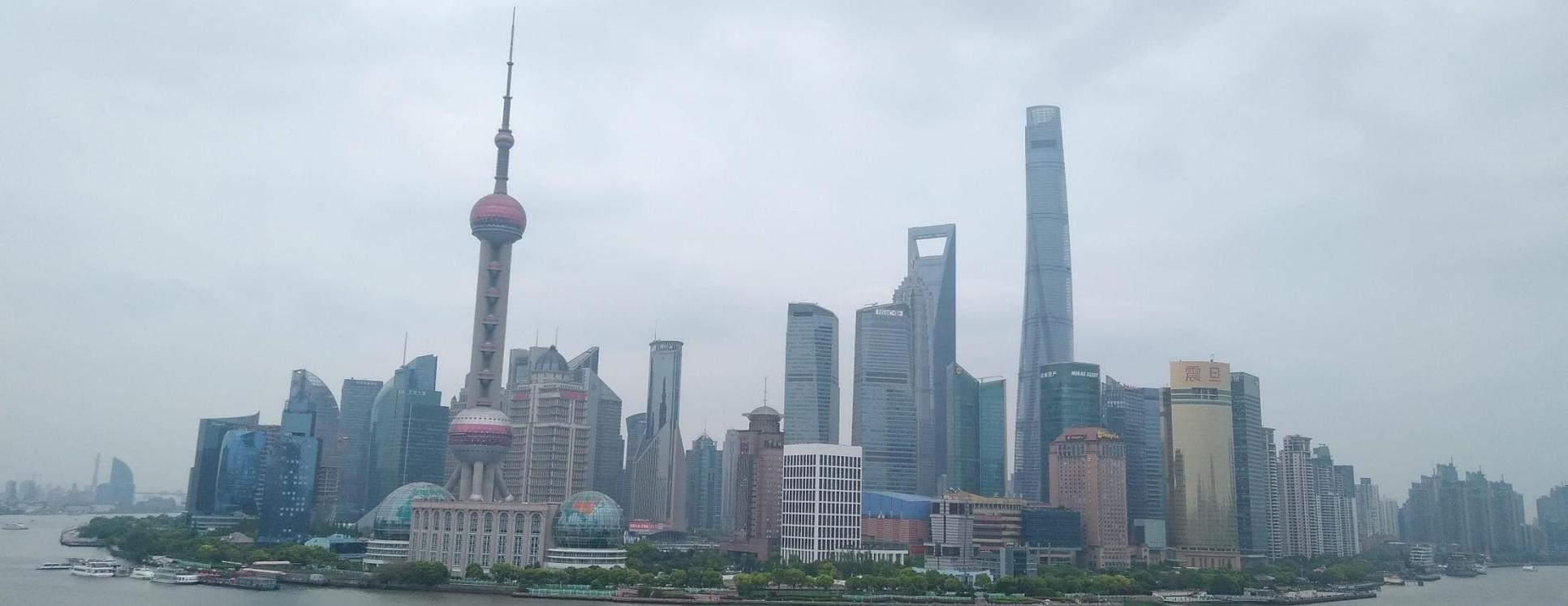
Thanks you!

Dr. Yang Yang

Email: Yang.Yang@wico.sh

OpenFog Consortium Greater China Region

GCR Committee Charter

1. Build, advocate, and help drive OpenFog Operational Models
2. Be one of the global thought leaders on the OpenFog technologies and solutions
3. Be the champion of all the regional related issues
4. Promoting OpenFog Technology/Solution and Membership to Industry Vertical, Operator, Government, Academic, etc.
5. Play the regional technical leader role assisting regional members in
   - Resolve regional related technical issues
   - Help regional member to participate global F2F discussions, developing technical competency.
   - Help regional investment community to identify/assess business value of a technical solution
   - Help to abstract business and technical challenges for academic research
6. Establish liaison relationship with Regional Government, SDO/Industry Consortium, Academic for business opportunity announcement and technology sharing. Collaborating research project with regional academic institutions.
7. Facilitating the opportunities for the investment community and OpenFog technology stakeholder to explore the opportunity of accelerating OpenFog Technology adoption.

GCR Committee Structure

Deputy Liaison Dr. Tao Zhang

Technology Sub-Committee:
Architecture FR Group
Communication Group
SW Infrastructure Group
Security Group
Computing Arch Group
Test-bed Group

GCR Director Dr. Yang Yang

Liaison/Admin/PR Sub-Committee

Marketing Sub-Committee

Standardization Sub-Committee

Research/innovation Sub-Committee

GCR Committee

Government

Academic/Education Sub-Committee

Affiliations/ Local Consortia

SME

Fognomics Ad Hoc Committee

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GCR Web Site and WeChat Publicity ID

www.OpenFogConsortium.cn

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- **SHIFT: S**hang**h**ai **I**nstitute of **F**og Computing **T**echnology
- http://**shift**.shanghaitech.edu.cn

We are recruiting: Tenure-Track & Tenured Faculty Positions in Fog Computing

ShanghaiTech University invites highly qualified candidates to join our newly established Shanghai Institute of Fog Computing Technology (SHIFT), which is a joint lab between ShanghaiTech University and Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, to lead the following research areas in fog computing and networks.

- Fog computing architecture and theory
- Big data processing in fog computing
- Security in fog computing
- Low-power sensors for fog computing
- Fog computing for Internet-of-Things (IoT)
- Next-generation communication with fog computing
- Fog computing test-beds

Contact:
Professor Xiliang Luo,
luoxl@shanghaitech.edu.cn

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