5G Mobile Communications

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Innovation of Mobile Communications

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BW	200 kHz	Up to 5 MHz	Up to 20 MHz	Up to 100 MHz
RAT	TDMA, CDMA, GSM	WCDMA	OFDMA	Post OFDMA
NW	Circuit Network	Packet Network	All-IP Network	Software Defined Network

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5G Service Vision

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Everything on Cloud

- Giga-bit data rate
- Ultra low latency

Immersive Experience *

- Giga-bit data rate
- Ultra low latency

Ubiquitous Connectivity

- Massive connectivity
- Ubiquitous coverage

Tele-Presence

- Giga-bit data rate
- Ultra low latency

(*) See also: Ian Harvey, "Virtual Reality", Twentieth Century Fox , MPEG WS on 5G /Media.

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5G Service Scenarios

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Mobile Cloud Service

Internet of Things

VR Remote Machine Control

Mobile Giga Internet Service

Autonomous Driving and V2X

Wireless Backhaul Service

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5G Use Cases & Requirements

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Mobile Cloud Computing

UHD Streaming

enhanced Mobile-Broadband

Peak 20 Gbps
Edge 100 Mbps

Ultra-Reliable & Low Latency

10^{-9} Error-rate
1ms Latency

Smart Vehicle

Industrial Automation

massive Machine-Type Communications

10^6 Connections/km^2
10 year Battery-life

Smart Home/ Smart City

U-Health/ Wearables

※ ITU-R document 5D/TEMP/625

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5G System Design

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Ultra Wideband & Gbps Support

High Freq. / Ultra-Wideband
mmWave BF Technology

Flexible & Scalable System

Flexible Spectrum Usage
New Waveform
New Multiple Access
Dynamic TDD

Low Power/ Low Complexity

LDPC
Low PAPR Waveform
Lean Design Principle

Spectrum Efficient System

Massive MIMO Technology
New Modulation & Coding

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New Spectrum Opportunities

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"Below 6 GHz" and "Above 6 GHz" Spectrum Bands Considered for 5G

- Much larger bandwidths available in spectrum bands above 6 GHz
- FCC NPRM : 28 / 37 / 39 / 64-71 GHz considered for mobile radio services

※ WRC-15 Results

- Above 6 GHz : **[WRC-19 Candidates]** (24.25-27.5), (31.8-33.4), (37-43.5), (45.5-50.2), (50.4-52.6), (66-76), (81-86) [GHz]
- Below 6 GHz : **[Public Safety]** (694-894)MHz, **[IMT Spectrum]** (1.427-1.518)GHz, (3.4-3.6)GHz

Frequency Ranges Below/Above 6 GHz of Regional Preparatory Groups for WRC-15

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mmWave Challenges and Opportunities

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Path Loss Model in Urban Environment

Many Identified Challenges for mmWave

- Larger path-loss at high frequency bands
- Atmosphere loss, rain attenuation, foliage blocking
- Outdoor-to-indoor penetration loss
- Semiconductor readiness, PA efficiency, power consumption

Realizing mmWave Mobile in 5G

- Samsung developed the world's first mmWave mobile prototype to verify the feasibility of mmWave mobile communications
- Global collaborative effort on mmWave channel modeling

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mmWave Channel Modeling

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Leading Channel Modeling Activity toward Outdoor Cellular Deployment

- Gbps data rate support envisioned by mmWave propagation analysis

Measurement and Simulation

- Measurement Campaign

28 GHz Channel Sounder [TX]

[RX]

NYU campus

2018 Winter Olympic Resort

Channel Modeling

- Calibration

- Channel modeling

Samsung's Activity on Channel Modeling

- Universities & research centers
  - NYU, USC, KAIST
- Research projects
  - 5G PPP mmMAGIC, COST IC1004
- Standard
  - 3GPP 5G Channel Model SI Rappaporteur

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mmWave Testbed / Chipset Development

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World's 1st mmWave Testbed and Antenna/RFIC for Mobile Device

Base Station

Array Antenna
8x6 (=48) Antenna Elements

RF + Array Antenna

Mobile Station

Array Antenna
4x1 (=4) Antenna Elements

	BS	MS
Carrier Frequency	27.925 GHz	
Bandwidth	800 MHz	
FFT Size	4096-FFT	
Power (EIRP)	59dBm	30dBm
Beam Width	10°	20°(AZ) /60°(EL)

Baseband Modem

28 GHz Antenna/RFIC

28GHz Array Antenna Module

Horizontal-Pol. Antenna

Vertical-Pol. Antenna

Beamforming CMOS RFIC / GaAs FEM

CMOS RFIC

GaAs FEM

One-Cable Connection

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World's 1st mmWave Multi-Cell Handover

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Handover Tests in 3-Cell Network (Average ISD : 178m)

- Handover Latency of 21 ms
- Average Throughput of 1.67 Gbps at Driving Speed of 25 km/h

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5G New Waveform (Post-OFDM)

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Post-OFDM Multicarrier Technology

Spectrum efficiency enhancement and flexible spectrum utilization through new waveform design

Needs for New Waveform Technology

- Service-specific commun. in a limited freq. band
  - Need for a new waveform enabling efficient spectrum utilization

5G New Waveform Benefits

- Efficient spectrum utilization examples
  - Well-localized spectrum

  - Efficient spectrum usage for multiple services

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5G New Waveform (Post-OFDM)

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QAM-FBMC : A Post-OFDM Multicarrier Technology

QAM-FBMC Overview

- Post-OFDM multicarrier technology
  - Well-localized spectrum by per-subcarrier filtering
  - QAM transmission
- Main benefits
  - Well-localized spectrum ➔ Efficient coexistence with other RATs
  - Time/frequency overhead reduction ➔ Enhanced spectral efficiency

QAM-FBMC Testbed

- Spectrum fragmentation performance test
  - RB-unit in-band spectrum nulling
  - Spectrum comparison between OFDM and QAM-FBMC
  - Interference suppression gain (>23dB) against OFDM

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5G Flexible Network Architecture

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Flexible Architecture based on SDN and NFV

- Virtual NW function : easy upgrade by software change
- Scalable/flexible architecture : dynamic instantiation of NFs

Flexible Function Location
Support for low latency applications

Flexible Architecture
Support divergent network requirements

Open network API
Network as a platform for innovative service

5G Network Architecture

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5G Flexible Network Architecture

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Network Slicing using NFV/SDN technology

- Enable logically independent networks for different services
- Support divergent requirements by instantiating required network functions on demand

Network Slicing

Specialized Service for OTT

- OTT can manage the end to end connection by leasing the slice
- UE may access multiple slices based per App's needs

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Low Complexity Channel Coding : LDPC

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A Promising Channel Coding Scheme for Multi-Gbps Support with Low Power Consumption

- 5G peak data rate is 10 Gbps to 20 Gbps
- Low power consumption and small implementation area is essential

Lower Power Consumption

- LDPC shows 10 times lower power w.r.t. Turbo

Smaller Area

- LDPC shows 5 times smaller area for decoder implementation

[1] M. May, T. Ilnseher, N. Wehn, and W. Raab, "A 150Mbit/s 3GPP LTE tubo code decoder," in Proc. DATE, Mar. 2010.
[2] S. Belfanti, etc., "A 1Gbps LTE-advanced turbo-decoder ASIC in 65nm CMOS," in Symposium on VLSI Circuits Digest of Technical Papers, 2013.
[3] Y. Sun, J.R. Cavallaro, "Efficient hardware implementation of a highly-parallel 3GPP LTE/LTE-advance turbo decoder," INTEGRATION, the VLSI journal, 2011.
[4] M. Weiner, B. Nikolic, and Z. Zhang, "LDPC decoder architecture for high-data rate personal-area networks," IEEE Symp. Circuits and Systems, 2011.
[5] S.-Y. Hung, etc., "A 5.7Gbps row-based layered scheduling LDPC decoder for IEEE 802.15.3c applications," IEEE Asian Solid-State Circuits Conference, Nov. 2010.

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Power Efficient Modulation : FQAM

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Combines the Virtues of QAM and FSK modulation

- Energy efficient & good performance in a low SNR region, useful for coverage extension
- Low PAPR when combined with OFDMA due to small number of active subcarriers

FQAM Transmission

- A QAM symbol transmission on a single tone selected a mong a group of tones

Example of an FQAM Constellations

FQAM Benefits

- Inherits the energy efficient nature of FSK
- Low PAPR when combined with OFDMA

Normalized Throughput over AWGN Channels

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Massive MIMO Technology

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FD-MIMO with Massive Antenna Technologies

- 2D array based adaptive beamforming at the base station
- Higher-order MU-MIMO with 3D beamforming

FD-MIMO Overview

- 3D-Beamforming
  - Elevation and azimuth beamforming
  - Full-dimension MIMO/BF support with 2D massive array
- Higher-order MU-MIMO
  - Increased order of Multi-users supported simultaneously

FD-MIMO Enhancements

- Support of larger number of antenna ports
- MIMO/beamforming enhancements for both TDD & FDD

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Massive MIMO Technology

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FD-MIMO

High order (≥8 UEs) MU-MIMO demonstration by FD-MIMO System at 3.5 GHz

Key Features

- LTE pre-release small-cell FD-MIMO
  - 20MHz BW TDD @3.5GHz, 32-TRX ports
  - Compact eNB with fully integrated array antenna, RF, and baseband
  - Novel antenna calibration network and compact array architecture
- Support of adaptive 3D-Beamforming and high-order MU-MIMO
  - Support of multi-user MIMO up to 8~12 UEs simultaneously

Inside
(RF/Antenna Board)

FD-MIMO MU-MIMO Test Results

- High-order multi-user MIMO with FD-MIMO PoC
  - 12-UE MU-MIMO indoor test: 422Mbps DL aggregated throughput
  - Realtime demo at NIWeek2015 (Aug. 2015, Austin TX)

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Expected 5G Timelines

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Standardization and Spectrum Allocation

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Global 5G R&D Activities

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Global 5G Initiatives with Samsung's Active Engagements

5G PPP Association (Full Member)
Leading and Participating the EU Flagship 5G Projects

5GIC Founding Member

5G Forum Executive Board Member

Member of Giga KOREA Project

NYU Wireless Center (Board Member)

Proposed NPRM (28/37/39/64-71 GHz)

IMT-2020 Promotion Group

Member of Future Forum

Contributor to 863 Project

5GMF (5G Mobile Promotion Forum)

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Thank you

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