5G~ The Hype is Real (Look at the history)

Flash back to 2009 (Bangalore, India)
- Facebook is a new website you visit on your desktop during lunch
- Sometimes you spend the afternoon uploading vacation photos.
- When it’s time to head home, you walk outside to hail an auto rickshaw.
- Home Delivery from local stores – make a call, SMS or pick on your way back.
- Order a Movie from DVD/CD Store.
- Watch Setup Box based content – Browse Channels.

Fast Forward to 2019 (Bengaluru, India) ~ 10 years
- Facebook is now the world’s second largest advertising platform.
- Mobile/Smartphone has replaced Desktops (Personal Usage).
- Uber/Ola/Ride Sharing Apps are common place.
- Digital Wallets/Rise or PayTm, Instant Messaging apps.
- HyperLocal Delivery at fingertips.
- Netflix/Amazon Prime; world of streaming entertainment.

→ The mobile applications driving today’s digital economy.

What enabled the ideas of 2009 to become integral to today’s digital economy?

The answer is simple: Advent of 4G LTE wireless technology.
Mega Trends – 5G Requirements

• 7.2 billion cellular gadgets, multiplying 5X over humans
  (Source: GSMA)

• More Content, More Social, More Gaming, More Multimedia, More Data

• Rise of Green Consumption

• Instant – ‘Want it now’

• Rise of Automation, Connected life (human in the center of smart connected devices)

5G: Requirements & Performance

Key PHY Features

- **Beamforming & Massive MIMO** for Coverage & Spectral Efficiency Enhancements
  - With Dynamic Beam Management
- **Adaptive Bandwidth** for Enhanced Power Savings
- **Advanced Channel Coding** for Multi-Gbps (LDPC) and Small Control Data (Polar)
- **Lean System Design** for reducing Overhead & increasing Energy Efficiency

**Beamforming & Massive MIMO**
- mmWave Hybrid-BF based Transceiver
- Beamformed data/control traffic
- Beam Management & Tracking
- Massive MIMO Sub-6GHz

**Flexible Multi-numerology Support**
- Slot/minislots with multiple numerologies
- Flexible utilization of resources for different service requirements
- Dynamic eMBB and URLLC Multiplexing

**Advanced Channel Coding**
- LDPC for data channels
  - Efficient for High data rates
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Key MAC Features

- **Fast Data Processing** for Multi-Gbps Data Rate
- **New Sublayer** for Packet Level Quality-of-Service

**Service Data Adaptation Protocol**

**On Demand System Information (SI)** for reducing signaling overhead
**New RRC State (“Inactive”)** for Energy Efficiency

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**On Demand System Information (SI)** for reducing signaling overhead
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### 5G NR vs 4G LTE: Radio

**5G NR vs 4G LTE: Radio**

**5G NR to Support High Speed/Low Latency Services with Low CAPEX/OPEX**

<table>
<thead>
<tr>
<th>Carrier Frequency</th>
<th>5G NR</th>
<th>LTE</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 6GHz / Below 6GHz</td>
<td>Above 6GHz / Below 6GHz</td>
<td>Below 6GHz only</td>
<td>Wider Spectrum Higher System Capacity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beamforming /MIMO</th>
<th>5G NR</th>
<th>LTE</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>mmWave Hybrid BF/Digital</td>
<td>Digital only</td>
<td>High Spectral Efficiency Longer Range [mmWave]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel Coding</th>
<th>5G NR</th>
<th>LTE</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data: LDPC</td>
<td>Data: Turbo Control: TBCC</td>
<td>Low Complexity</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Carrier BW</th>
<th>5G NR</th>
<th>LTE</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 6 - Max. 400 MHz (max: 16 carriers ~ 6.4 GHz bw)</td>
<td>Max. 20 MHz (max: 5 carriers ~ 100 MHz bw)</td>
<td>High Peak Throughput</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Slot Length</th>
<th>5G NR</th>
<th>LTE</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0625/0.125/0.25ms</td>
<td>1ms</td>
<td>Low Latency</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RAN Function Split</th>
<th>5G NR</th>
<th>LTE</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU-DU Split (Centralized/Distributed)</td>
<td>DU-RU Split (CPRI)</td>
<td>Low Backhaul Capacity</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Adaptive Bandwidth</th>
<th>5G NR</th>
<th>LTE</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need based RF Bandwidth at UE</td>
<td>Fixed BW for UE</td>
<td>Reduced Power Consumption</td>
<td></td>
</tr>
</tbody>
</table>

### mMTC ~ Outlook

**mMTC ~ Outlook**

**Low Device Cost essential for IoT should benefit from a mature technology**
- **Cat-M1** (*enhanced MTC*)
  - Extension of LTE in R13
  - Reduced bandwidth (20 MHz → 1.25 MHz)
  - Enhanced coverage (+15 dB)
  - Longer Battery Life with eDRX
- **NB-IoT (R14)**
  - Separate air-interface that is spectrum compatible with LTE
  - 200 KHz bandwidth
  - Standalone, in band, guard band deployment
- **NR-Lite (R17 SI Planned)**
  - Use cases with IoT-type of requirements that cannot be met by eMTC and NB-IoT:
    - Higher data rate & reliability and lower latency than eMTC & NB-IoT
    - Lower cost/complexity and longer battery life than NR eMBB
    - Wider coverage than URLLC (+10 ~ 15 dB)
  - Requirements and use cases –
    - Data rates up to 100 Mbps to support e.g. live video feed, visual production control, process automation
    - Latency of around [10-30] ms to support e.g. remote drone operation, cooperative farm machinery, time-critical sensing and feedback, remote vehicle operation
5G: 3GPP Standard Evolution

- Apr 04: South Korea launches first national 5G networks
- Apr 05: Verizon launches in USA (cities)

Agenda

- Technology Trends and Products
  - Image Sensor/Camera
  - Processors
  - Memory and Storage
  - Neural Engine
  - Samsung Solutions for 5G and IoT

- Beyond 5G
  - Possibilities (2025 and Beyond)
Mobile Usage Trend, IoT - “$” trend

- Taking photos: 30%
- Text Messaging: 40%
- Internet Browsing: 60%
- Sending photos: 80%
- E-mailing: 90%
- App downloads: 90%
- Gaming: 90%

2014: Survey on Mobile Usage Pattern (Samsung Marketing)

2014: Comtech study on Smartphone buying decision

IoT 2019 spending per technology category – services, hardware, software and connectivity – source IDC

Imaging ~ Hot bed for innovation

- In October 2019, Mi CC9 Pro (Xiaomi’s) first-ever 108MP camera smartphone.
- Samsung’s ISOCELL HMX image sensor 108MP Quad-Bayer sensor
- 4K @ 30fps, slo-mo HD @ 960fps; Penta-camera

5G & IoT will fuel this growth and innovation further

- Outdoor Surveillance cameras to be biggest market for 5G IoT solutions in next 3 years (Gartner)
- To represent ~ 70% of the 5G IoT endpoint installed base in 2020
**Imaging ~ 2019 and Beyond!**

- More lenses and megapixel madness
  - Telephoto, monochrome, color, and multi-lens pixel synthesis
- Refinements: AI, computational photography, and portraits
  - AI to process multiple images and deliver better results
  - smartHDR, HDR+, Night Sight feature (Low Light)
- Portrait lighting effects

- 3D sensors and AR
- Time-of-Flight (ToF) sensor
- Active Stereo Vision, Structured Light (SL)
- Improvements in video
  - Fused stabilization
  - Stereo audio capture in videos
  - 8K @ 30 fps, and 4K videos @ 150 fps
- More Zoom

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**Processing ~ High Performance, Low Power**

**CPU Processing Trends (Edge, Fog, Cloud)**

- 3D sensors and AR
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**IoT Processor Trends**

- One size doesn’t fit all: healthcare, consumer, industrial, automotive, BFSI, Retail, SmartCity, Automation etc.
- Low Power/Ease of deployment is key driver
- 5G & IoT will fuel this growth and innovation further
Memory and Storage innovation

Comparison of Memory Technologies

<table>
<thead>
<tr>
<th>Memory Type</th>
<th>DRAM (Nanometer)</th>
<th>Flash (Nanometer)</th>
<th>DRAM (Density)</th>
<th>Flash (Cell Type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency</td>
<td>30 ns - 50 ns</td>
<td>10 ns - 20 ns</td>
<td>10 ns - 30 ns</td>
<td>20 ns - 40 ns</td>
</tr>
<tr>
<td>Endurance</td>
<td>10^8 - 10^10</td>
<td>10^9 - 10^10</td>
<td>10^10 - 10^11</td>
<td>10^11 - 10^12</td>
</tr>
<tr>
<td>Reliability</td>
<td>10 years</td>
<td>15 years</td>
<td>10 years</td>
<td>30 years</td>
</tr>
</tbody>
</table>

Low power mobile DRAM on Samsung Galaxy

<table>
<thead>
<tr>
<th>Samsung Galaxy</th>
<th>DRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note 7</td>
<td>LPDDR4</td>
</tr>
<tr>
<td>Note 8</td>
<td>LPDDR4</td>
</tr>
<tr>
<td>Note 9</td>
<td>LPDDR4</td>
</tr>
<tr>
<td>Note 10</td>
<td>LPDDR4</td>
</tr>
<tr>
<td>Note 10 Edge</td>
<td>LPDDR4</td>
</tr>
<tr>
<td>Galaxy S8</td>
<td>LPDDR4</td>
</tr>
<tr>
<td>Galaxy S9</td>
<td>LPDDR4</td>
</tr>
<tr>
<td>Galaxy S10</td>
<td>LPDDR4</td>
</tr>
<tr>
<td>Galaxy S10+</td>
<td>LPDDR4</td>
</tr>
</tbody>
</table>

Samsung's top class dual-core NPU and improved DSP can perform over ten-trillion operations per second (TOPS)
Samsung Neural SDK is designed to accelerate neural network models to improve performance and provide the best use of underlying hardware components.
- Bixby Vision, AI Gallery, Selfie Focus Live, Shot Suggestion, Avatar, Scene Optimizer.

5G & IoT - touted as early adopters

Neural Engine ~ New kid on the block

NPUs ~ (TPU), Neural Network (NNP), Intelligence Processing (IPU), Vision (VPU)

Edge AI Use cases

Flexible, Scalable Mt. Solutions

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Edge AI is key for future products on 5G & IoT
Samsung Exynos Modem (5G)

Strong LTE leadership is key to 5G success

2009
CMC220

2014
Exynos Modem 300/303

2017
Exynos 9

2018
Prototype

2019
Exynos 5G

World 1st
Commercial LTE

LTE Advanced
(100Mbps)
Carrier Aggregation

LTE Advanced Pro
(1Gbps)
LTE cat 26, 6x 80MHz CA

5G Trial
Sub-6GHz/mmWave

5G New Radio
GigaBps+ Ultra high data rate, latency

Source: Thomas Byunghak Cho, Samsung, "5G SUMMIT 2017" THE SILICON VALLEY 5G SUMMIT, 2017
Samsung 5G NR First Solution

Exynos Modem 5100

- **High data rate and low latency**
- **Global bands for sub-6GHz and mmWave**
  - 2Gbps in sub-6GHz, and 6Gbps in mmWave
  - 25G-QAM for sub-6GHz and up to 64-QAM for mmWave
- **All legacy RATs (2/3/4G)**
- **Compatibility with 3GPP Rel.15 NR standard**
  - URLLC: Ultra Reliable and Low Latency
  - eMBB: Multi Giga bps data rate
  - Hybrid beamforming: fast beam search/tracking
- **10-nm process Technology**

Pairs with RF and supply modulator solutions, Exynos RF 5500 and Exynos SM 5800

Samsung 5G NR Modem & IntegAP (2019+)

- Exynos 980 (ModAP): (8nm LPP): Full Stack ~ VoNR/IMS
  - sub-6GHz 2.55Gbps DL/1.28Gbps(UL) (NR)
  - (EN-DC), which combines 5CC LTE and NR 3.55Gbps (DL)/ 1.38Gbps (UL).
  - LTE Cat.16 5CA 1Gbps (DL) / Cat.18 2CA 200Mbps (UL)
  - Octa-core, (Dual A77/ Hexa A55), AI (NPU+DSP)
    - On Device AI: user authentication, content filtering, mixed reality, intelligent camera, etc.
- Exynos Modem 5123: (7nm LPP): Full Stack ~ VoNR/IMS
  - 7.35Gbps in mmWave (NR)
  - 5.1Gbps in sub-6Ghz setting
  - Upto 8x CA (NR)
  - 4G LTE mode ~3Gbps of DL, 422 Mbps UL.
  - Supports E-UTRA-NR Dual Connectivity (EN-DC) (LTE and 5G connectivity)
  - Couples with Exynos 990 (AP)
    - Dual (Custom CPU) + Dual (A76) + Quad (A55)
    - Dual-core NPU
Samsung Exynos i (IoT) Solutions

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Beyond 5G ~ Requirements

- **Super-high-definition Video**
  - 8K Super Hi-VISION TV
  - 64 X Digital Cinema

- **Super-immersive Multimedia**
  - High-fidelity audio
  - Immersive 3D images

Beyond 5G ~ Requirements (2)

- **Zero Perceived Latency**
  - Internet of Things
  - Millimeter-wave wireless technologies

- **Super-Precision Positioning**
  - N laboratories

- **Everything Connected at 2030**
  - 500B Devices Connected
  - 3X Growth
  - 40% MUI
Thank You

tusharv@samsung.com