Towards Future 5G Mobile Networks
- from Research to Standardization to Implementation

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The evolution towards 5G: compute and communications

1G-4G were focused on improving communications

Market demands lead to 5G:
- Communications & processing are diffused across networks and mobile devices
- Scalability, Versatility, Energy Efficiency
- Capacity, Intelligence and User Experience

5G = compute & communications
5G goals

5G dynamically integrates compute and communication for future generations of applications and services

5G requires new network architecture to support massive number of devices, and efficient SW/HW platforms for both devices and networks
5G scaling

Network and device scaling

- 10x
- 100x
- 1,000x
- 10,000x

Edge cloud shortens the distance between an user and his contents/services. Data traffic, information, and intelligence intensify around user.

Ecosystem scaling

Ecosystem expands beyond traditional wireless industry. Convergence of consumer electronics and intelligent things.
Performance targets

<table>
<thead>
<tr>
<th></th>
<th>IoT</th>
<th>4G</th>
<th>mmWave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data rate</td>
<td>Can be very low</td>
<td>100s Mbps</td>
<td>1-10 Gbps</td>
</tr>
<tr>
<td>Latency</td>
<td>From 2 ms to hours</td>
<td>Moderate</td>
<td>2 ms</td>
</tr>
<tr>
<td>Battery life</td>
<td>Up to 10 years</td>
<td>Smart phone</td>
<td>Depends on app</td>
</tr>
<tr>
<td>Link budget</td>
<td>Penetration</td>
<td>Coverage</td>
<td>High data rate</td>
</tr>
<tr>
<td>Multiple access</td>
<td>Massive # of devices</td>
<td>Smart phones</td>
<td>Bursty/opportunistic</td>
</tr>
<tr>
<td>Network</td>
<td>Overlay</td>
<td>Hetnet</td>
<td>Hetnet/underlay</td>
</tr>
</tbody>
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- 5G has to be designed as a system
- Compute + communication becomes a necessity
- Platform innovations enable applications/services innovations
Wireless technology is at a turning point. Future performance is measured in bit/s/Hz/m²/joule.

5G trend 1: Overlay networks for high frequency bands and energy saving

Avoid excessive handovers in traditional heterogeneous networks

Control plane anchored at macro-cell, user plane from small cells

User experience for now, new RAT @ high frequency bands for future

Incremental small cell deployment according to traffic growth

Turn off selected cell sites at light traffic hours

Coverage for now, network energy saving for future
5G trend 2: Underlay networks for things/wearables and proximity services

One big intelligent and information network
Compute, storage, networking

Many devices, types of devices, connections
Many moving underlay network clusters
5G trend 3:
Cloud Expansion to Network Edge and to Devices

Remote Cloud / Basic Terminal

CDN / Cooperative Radio

Edge Cloud / Underlay Net Clusters

Logos shown represent categories of common Internet content and are used for conceptual illustration only.
Future standards development focus

Cross industries
Open industry implementation
Virtualization technology

Edge cloud/tight device coupling
New bands/new air interface
Underlay network clusters
Cloud evolution of 5G networks

- Cloud RAN architecture plays a pivot role in network densification and cooperative networking.
- Real time workload for air interface related signal processing requires complete hardware + software platform solutions.

5G network capacity scaling

- Edge cloud shortens the distance between an user and his contents/services, matches 5G air interface capability.
- Data, information, and intelligence intensify around user. Edge cloud efficiency becomes crucial.

General Performance disclaimer: For more complete information about performance and benchmark results, visit Performance Test Disclosure.
Virtualization of 5G device and access

- Future applications require intensified compute and communication but often smaller device form factor
- 5G high data rate + low latency radio links enable mobile device + access virtualization across the air interfaces
- 5G services are immersive. Sensing, intelligence and contents require edge cloud and device + access virtualization
- Breaking computing barrier through communication may transform consumers’ relationship with network
New frequency bands and spectrum sharing

“Channel Model for millimeter-Wave Communications Based on Geometry Statistics”, IEEE GLOBECOM 2014
5G research and technology development

- Hi-K Metal Gate
- Strained Silicon

Intel Strategic Research Alliance on 5G

P5: Efficient Hardware/Software and Platforms for 5G Network Elements and Devices
Summary

We are at a technology turning point

Future generation wireless technology development needs broader collaboration amongst industries and with universities

Compute and communications need to come together to deliver unprecedented user experience