Making 5G a commercial reality

Mikko.Uusitalo@nokia-bell-labs.com
5G will change the world

- "Unlimited experience" with >10 Gbps peak data rates
- "For everything" with 1,000,000 devices per km² and 10 years on battery
- "Instant action" with Ultra low cost for massive machine coms.
- Ultra reliability with <1 ms radio latency and <10⁻⁵ E2E outage
- Zero mobility interruption
- 100 Mbps whenever needed
- 10,000 x more traffic
- <1 ms radio latency
- Ultra reliability
Differences between 5G and LTE
Two: Stretched Performance

Key Metrics
- 10Gbps
- 1ms RAN
- 5ms e2e
- 99.999%
- 1M/km²

Latency
- 80%
  25 → 5ms

Reliability
+ 90%
  4 → 5 9’s

Service Intro
- 93%
  90 days → 90 min

Data Volume
1000x
10Gb/s/km² → 10Tb/s/km²

Peak Rates
100x
100Mbps → 10Gbps

5G

LTE

Mobility
500km/h

IoT Density
1000x
1K → 1M/km²

Energy
- 90%
  10% of current

Public
Key to the programmable world
Key to the programmable world
5G for people and things
Expanding the human possibilities of technology

- **Give back 2hrs/day**... never be in a rush
- **Everyone is an innovator** – easier and faster to innovate
- Towards **zero road fatalities**, > half a million lives saved
- **Zero loss** water distribution
- **Healthier** people with connected wearables, remote medics
- **Less transport costs** and fuel consumption
- **Never lost** – always find an address – always on time
- **50% higher industry productivity** by connected cyber physical systems
- **Safer** in connected homes

**Individual**

**Society**

**Economy**
The use case evolution towards 5G
Markets need preparation

<table>
<thead>
<tr>
<th>Business driver</th>
<th>Pre-5G</th>
<th>5G</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Automotive</strong></td>
<td><strong>Assisted / basic automated driving</strong></td>
<td><strong>Advanced automated driving</strong></td>
</tr>
<tr>
<td>• 1.2 million lost lives</td>
<td>• Vehicle hazard warnings</td>
<td>• CACC with emergency braking</td>
</tr>
<tr>
<td>• 90% of crashes by human error</td>
<td>• HD location updates, situat. awareness</td>
<td>• Vulnerable road user protection</td>
</tr>
<tr>
<td>• Time and energy waste by traffic</td>
<td>• Cruise control, platooning, lane automation</td>
<td>• Smart intersection control</td>
</tr>
<tr>
<td><strong>Health</strong></td>
<td><strong>Predictive health surveillance</strong></td>
<td><strong>Remote diagnosis and treatment</strong></td>
</tr>
<tr>
<td>• 52 million deaths by non communicable diseases in 2030</td>
<td>• Remote diagnostic surveillance and risk assessment</td>
<td>• Robot assisted examination and tele-consultation in 4D and 5D</td>
</tr>
<tr>
<td>• Aging societies</td>
<td>• Early disease forecasting</td>
<td>• Remote surgery</td>
</tr>
<tr>
<td><strong>Events and tourism</strong></td>
<td><strong>Augmented location experience</strong></td>
<td><strong>Freely selectable 3D views</strong></td>
</tr>
<tr>
<td>• Tourism is 9.8% of world GDP with growing competition and expectations</td>
<td>• Location finder</td>
<td>• Freepoint viewing</td>
</tr>
<tr>
<td></td>
<td>• Video replay on-demand</td>
<td>• Player perspective</td>
</tr>
<tr>
<td></td>
<td>• Augmented reality (AR)</td>
<td>• Advanced (e.g. interactive) AR</td>
</tr>
<tr>
<td><strong>Industry 4.0</strong></td>
<td><strong>Cognitive maintenance</strong></td>
<td><strong>Artificially intelligent production</strong></td>
</tr>
<tr>
<td>• 50% higher productivity</td>
<td>• Sensor connectivity for monitoring and predictive maintenance</td>
<td>• Wireless zero latency robot collaboration</td>
</tr>
<tr>
<td>• Mass individualization</td>
<td>• Augmented (AR-supported) maintenance</td>
<td>• Complex autonomous cyber-physical systems</td>
</tr>
<tr>
<td>• Defragmentation of comm. sys.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

< 25 ms E2E latency, 99,99% reliability

< 5 ms E2E latency, 99,999% reliability, E2E network slicing
Key to the programmable world
One versatile and self-configurable radio for everything

Diverse use cases

- OFDMA-based waveform
- Scalable carrier bandwidth
- Sub frame lengths

Diverse spectrum and deployments

- Same for uplink & downlink
- 5MHz → 2GHz
- Adjusted to latency requirements

(Low power) Wide area
Crowd
Outdoor
Ultra-dense
Indoor
Unlocking new spectrum assets | Foundation for 5G
Leveraging all bands, ranging from ~400MHz - 100GHz

Different characteristics, licensing, sharing and usage schemes

- Carrier BW
  - $n \times 20$ MHz
  - $n \times 100$ MHz
  - 1-2GHz

- Duplexing
  - FDD
  - TDD

- Cell size
  - Macro
  - Small
  - Ultra small

- Coverage

Higher capacity and massive throughput

Leading METIS I & II spectrum work package

Pre-commercial 73GHz system, 15Gbps over 2GHz

World’s 1st trials on shared spectrum access
5G Enables Extreme Traffic Density 1 Tbps/km²

- LTE today: 1 Gbps/km²
- 5G/LTE at <6 GHz: 10 Gbps/km²
- 5G at cm: 100 Gbps/km²
- 5G at mm: >1 Tbps/km²

Per operator in downlink:
- 200 MHz: 20 Gbps/km²
- 600 MHz: 250 Gbps/km²
- 150 MHz: 300 Gbps/km²
- 300 MHz: >1 Tbps/km²

Site density [#/km²]:
- 20/km²
- 50/km²
- 150/km²
- 300/km²
Multi-Connectivity | Perception of infinite capacity
Multiple radio technologies collaborating as one system

- Extreme mobility robustness and ultra reliability
- >100 Mbps anywhere
- >30 Gbps throughput*
- Massive Capacity combining any kind of mobile and fixed access

*Combining any access
Native massive MIMO | Let the capacity follow the demand
Chip-scale antennas, high beamforming & multiplexing gain

Controllable antenna elements
16, 32, 64, 256,...

Exploiting high frequency bands with chip scale antenna array research
→ Compensating path loss with high antenna gain

- 700% Cell edge gain
- +80% Spectral efficiency
- Cooperation with top-notch industry and university partners
- mmWave trials with DOCOMO
- >20Gbps at 8x8 MIMO with SKT

10,000 x  >10 Gbps  100 Mbps  <1 ms  10-100 x  ultra low  10 years
1ms Radio | Enabling a new generation of latency critical services
E2E latency aware scheduler

Latency optimized frame structure

Dynamic uplink-downlink

Pipeline processing

W/o wireless communications (e.g. propagation of sensor reaction only)

802.11p 50ms

LTE-A D2D (public safety) 42ms

LTE-A D2D ~10ms

[Rel. 13 pot.]

5G ~1ms

D2D only

D2D + D-Infra-D

5G ~2.5ms

~10ms

E2E latency

0-100x

10 years

<1 ms latency on commercial AirScale radio access

Autonomous driving and Industry 4.0

Tactile internet services

DMRS = Demodulation Reference Signal; GP = Guard Period

© Nokia 2016
Dynamic resource management | Bandwidth deployment cost savings
Precise on-demand RRM - downlink, uplink and self-backhaul

Public

Smart local traffic routing e.g. D2D on top of local cellular
SC/UDN low cost deployment e.g. via self-backhauling
Dynamic TDD cmW and mmW air IF blue prints and PoC
Part of eLA concept adopted in METIS
Reduced CO2 footprint and flattened energy bill

Energy aware cognitive networks

Dynamic adaptation of active resources & network wide multi-layer, multi-technology energy management

30-40% energy savings

Network energy consumption research jointly with key operators

Power amplifier innovations driving energy efficiency

Baseband

Deactivated carrier

Rural
3G Macro cell

Offices
5G local area cell

Shopping mall
5G local area cell

Urban outdoor
4G medium cell

Public

© Nokia 2016
Key to the programmable world
Network Slicing | Optimized service delivery for heterogeneous use cases

Multiple independent instances on one physical network

Slicing across radio, transport, core edge and central clouds

Cloud scalability and efficiency

Flexibility to meet diverse requirements

10,000 x >10 Gbps 100 Mbps <1 ms 10-100 x ultra low 10 years

Dynamic e2e network slicing

*5G Novel Radio Multiservice adaptive network Architecture
Dynamic Experience Management | Superior quality at less resources
Automated QoE optimization of each application session

Full QoE awareness of application sessions

Immediate QoE degradation prediction
Root cause analysis

Immediate action before problems arise

Decision making powered by self-learning

4 x QoE compared to today
100% successful sessions in congested networks
+20-30% capacity*

Unique Nokia solution available TODAY

10,000 x >10 Gbps 100 Mbps <1 ms 10-100 x ultra low 10 years
Service-determined connectivity | Latency, resilience and FMC
Any-to-any connectivity, path selection according to actual service demand

- Multi-homed device
- User plane processing function
- Local switching
- 5G AP
- Local IP anchor
- CDN site
- Central IP anchor
- Broadband Internet

Optimal path routing
New network services e.g. Any-to-Any FMC
Higher resilience
C and U plane separation demo with SKT
Car to Infra trial

- 10,000 x
- >10 Gbps
- 100 Mbps
- <1 ms
- 10-100 x
- ultra low
- 10 years
Fast traffic forwarding | Enabling a new generation of latency critical services
Lowest latency packet forwarding to UEs

- Moving virtual networks
- Mission-critical services, e.g. in V2X or industrial applications

<table>
<thead>
<tr>
<th>Service Type</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central cloud based</td>
<td>&gt; 50 ms latency</td>
</tr>
<tr>
<td>Mobile Edge LTE</td>
<td>≈ 10 ms</td>
</tr>
<tr>
<td>5G Edge</td>
<td>≈ 2.5 ms</td>
</tr>
<tr>
<td>5G D2D</td>
<td>≈ 1 ms</td>
</tr>
</tbody>
</table>

- Vehicle2Infra trial on German motorway
- Pioneer in Mobile Edge Computing
- Autonomous driving live demo
- ETSI ISG Chair

- Native D2D
- Mobile Edge cloud computing
- Core Cloud
Operability | Flexibility in running 5G radio with LTE or 5G core
Multi-connectivity leveraging LTE coverage and early 5G high throughput

- LTE-based 5G adoption
- Robustness and extreme throughput
- Efficient site reuse – collocation 5G and legacy LTE
- Lower latency user plane booster
- Improved robustness for capacity, link and mobility
- Driving standardization
5G

Key to the programmable world

Possibilities
Versatile radio
System of systems
Practicalities
Potentials
Fundamental Architecture evolution is required
Cognitive + converged + cloud-optimized network evolution
Driving the global 5G end-to-end ecosystem

Business partners and verticals

Leading contributor to standardization and research

Early engagements with 30+ world technology leaders

Shaping 5G NAR with all major operators

3GPP contributions, Jan-Aug 2016
Nokia demonstrates world’s first 5G-ready network, London June 2016

After successful 5G call on AirScale Radio Platform (Feb, 16), Nokia advances commercialization with 5G radio access connected to a cloud packet core including MME, HSS, and SAE Gateway all running on Nokia AirFrame datacenter

• DoCoMo and Nokia May 2016: World first real time 8K video over 5G
• Nokia first to take 5G testing from lab to the field with Verizon
• 1,2 Gbps using CA on Airscale platform with DT in Poland
• First live 5G system at large scale public event with Sprint (73 GHz)
Verizon Specs Available http://www.5gtf.org/

VERIZON 5G TECHNICAL FORUM

ACCELERATING THE PACE OF INNOVATION.

The Verizon 5G Technology Forum (V5GTF) was formed in late 2015 in cooperation with ecosystem partners Cisco, Ericsson, Intel, LG, Nokia, Qualcomm and Samsung. The V5GTF has created a common and extendable platform for Verizon’s 28/39 GHz fixed wireless access trials and deployments.

The V5GTF forum partners collaborated to create the 5G technical specifications. The 5G radio interface is composed of Layers 1, 2 and 3 and defines the interfaces between the User Equipment (UE) and the network. These specifications promote interoperability among network and UE/Chipset manufacturers. The initial release included the V5G.200 series which describes Layer 1 (the Physical Layer), the V5G.300 series describing Layers 2 and 3 (Medium Access Control, Radio Link Control, Packet Data Convergence Protocol, and Radio Resource Control) are also released.
5G standards and spectrum roadmap
Enabling regional trials in 2017, fulfilling full vision around 2022

5G standards roadmap

5G industry roadmap

5G spectrum availability

- US 28, 39 GHz
- Korea 28 GHz
- EU/CN 3.5 GHz
- Japan 4.5 GHz
- Korea 3.5 GHz
- US/EU 600/700MHz
- Global availability > 24 GHz
Fast 5G commercialization with Nokia’s approach

Go to market approach

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>Highlights</th>
<th>Proof of concept with lead customers</th>
<th>Pre-standard (FWA, Mobility trials)</th>
<th>3GPP compliant (commercial) Initial Wave</th>
<th>3GPP compliant (commercial) 2nd Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>e2e 5G PoC solution</td>
<td>e2e 5G PoC solution</td>
<td>Pre-standardized extreme broadband to the home solution, Mobility and mMimo trials</td>
<td>3GPP compliant mobile solution for early adopters</td>
<td>3GPP compliant cost optimized products for mass rollout (worldwide)</td>
<td></td>
</tr>
<tr>
<td>Advanced Antenna System</td>
<td>Fixed Wireless Access products (5GTF)</td>
<td>Frequency bands: 3.5, 4.5, 28, 39 GHz</td>
<td>First 3GPP compliant radio access products (Non-standalone &amp; Standalone mode)</td>
<td>First 3GPP compliant mobile devices</td>
<td></td>
</tr>
<tr>
<td>5G ready AirScale radio access</td>
<td>Pre-standardized mobile access products</td>
<td>Frequency bands: 3.5, 4.5, 28, 39 GHz (others acc. market needs)</td>
<td>2nd gen. radio access products supporting further use cases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airframe data center</td>
<td>Frequency bands: 3.5, 4.5, 28, 39 GHz</td>
<td>Phase 1 Network slicing Analytics for 5G</td>
<td>Further frequency bands dependant on market demand (FDD, TDD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud packet core</td>
<td>Various frequency bands</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5G acceleration services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Various frequency bands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ecosystem

Prototype devices (reverse BTS)

First fixed devices
First pre-standard mobile devices

First 3GPP compliant mobile devices

Further commercial mobile devices
Key to the programmable world
Business models powered by network performance, data and slicing

**Network Performance**

**Data**

**Slice**

**Connectivity +**

- Connected home
- Real time work in cloud
- 8K Video beamer
- 4K Video
- Virtual presence
- Advanced monitoring

"+" = content + tariffing / packaging

**Information brokering**

- Augmented gaming
- Augmented dashboard
- Self driving
- T. mgmt.
- Logistics
- Factory automation
- Waste mgmt.
- Smart grids
- Traffic systems
- Advanced logistics & production
- Massive metering

**Network as a Service**

- Safety & Security
- Mobile living
- Utility & Energy
- Traffic Mgmt.
- Automotive
- Health
- Communication
- Logistics

Tailored vertical XaaS solutions