5G: A Technology Vision

5G wireless networks will support 1,000-fold gains in capacity, connections for at least 100 billion devices, and a 10 Gb/s individual user experience capable of extremely low latency and response times. Deployment of these networks will emerge between 2020 and 2030. 5G radio access will be built upon both new radio access technologies (RAT) and evolved existing wireless technologies (LTE, HSPA, GSM and WiFi). Breakthroughs in wireless network innovation will also drive economic and societal growth in entirely new ways. 5G will realize networks capable of providing zero-distance connectivity between people and connected machines.

HUAWEI

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1. Next Wave of Digital Society

The advent of 5G technologies and ICT networks signify the coming next wave of a globally connected Digital Society:

- Right now, all over the world, mobile access to the internet is becoming wholly fundamental to doing business in all industries. Flexible working practices facilitated by mobile networks and devices are already essential, and are allowing enterprises to conduct operations across boundaries that previously inhibited growth.

- Growing mobile access to the internet, cloud-based services and Big Data analytics is allowing anyone, anywhere to leverage "Big Wisdom" – a whole new kind of globally connected and shared knowledge base.

- The continuing rise in the relevance of social media as an important part of how we interact with the internet is also opening up new kinds of intelligent analytics ready to be harnessed for tangible business and everyday life benefits.

- Transformation and convergence of ICT network infrastructure is driving business innovation and growth. Not only is ICT an increasingly effective tool for enhancing efficiency, but it is now a vital driver of economic and societal growth.

The development of 5G technologies is a cornerstone for realizing breakthroughs in the transformation of ICT network infrastructure. Ultra-broadband and intelligent-pipe network features that achieve near-instantaneous, "zero distance" connectivity between people and connected machines – no matter where they are – are just the first step.

A changing telecoms landscape

The current generation of mobile networks continues to transform the way people communicate and access information. Further developing and implementing technologies that enable true human-centric and connected machine-centric networks will come to redefine end user mobility along with the entire landscape of the global telecoms industry.

5G will herald an even greater rise in the prominence of mobile access for

realizing total ICT network growth and expansion. Over time, any mobile app and any mobile service will be given the potential to connect to anything at anytime – from people and communities to physical things, processes, content, working knowledge, timely pertinent information and goods of all sorts in entirely flexible, reliable and secure ways.

This is the promise of 5G: to expand the possibilities of what mobile networks can do, and to extend upon what services they can deliver.

Internet evolution

5G will drive the future evolution of the internet itself. What we mean when we refer to the "internet" is likely to change:

- Implementing the next generation of ubiquitous ultra-broadband network infrastructure will require a rethinking, restructuring and redesigning of approaches to mobile network construction and expansion.
- Integration of mass-scale cloud architectures will infuse mobile networks with capabilities for flexibly delivering services at unprecedented speeds while meeting forecasts for tremendous growth in mobile data traffic, diversification of mobile app innovation, IoT connectivity, and security.

To achieve these goals, developments in 5G will primarily focus on two fundamental aspects for eliminating infrastructure bottlenecks: massive capacity and massive connectivity.

Immediacy and adaptability

Massive capacity for delivery of services will allow connections between end users and the network to be made at "faster than thought" speeds – so fast that the apparent distance between connected people and connected machines will shrink to a virtual "zero distance" gap.

An instant immediacy in mobile services will lay the foundation for a whole new set of mobile apps to proliferate and push the capabilities of communications beyond what is currently possible.

A more massive capacity for managing connections will better enable a greater widespread adoption of M2M services and interactions, and will facilitate innovation in localized mobile service delivery.

The next wave of the Digital Society will be characterized by an ICT network's capability for service immediacy and on-demand adaptability.

2. Challenges and Requirements

The three fundamental requirements for building 5G wireless networks are:

- Capabilities for supporting massive capacity and massive connectivity
- Support for an increasingly diverse set of services, application and users – all with extremely diverging requirements for work and life
- Flexible and efficient use of all available non-contiguous spectrum for wildly different network deployment scenarios

Mobile networks will increasingly become the primary means of network access for person-to-person and person-to-machine connectivity. These networks will need to match advances in fixed networking in terms of delivered quality of service, reliability and security. To do so, 5G technologies will need to be capable of delivering fiber-like 10 Gb/s speeds to make possible ultra-high definition visual communications and immersive multimedia interactions. These technologies will depend on ultra-wide bandwidth with sub-millisecond latencies.

Smart cities

5G will provide the foundational infrastructure for building smart cities, which will push mobile network performance and capability requirements to their extremes.

Low latency and extremely high reliability, however, will also be essential requirements for the likes of mobile industrial automation, vehicular connectivity, and other IoT applications. Applications like smart sensors and text-based messaging are examples of extremely high volume applications that will require very low data rates and will not be sensitive to latency.

Complex performance requirements

An increasingly diverse and wide range of mobile services will have differing performance requirements:

- Latency from one millisecond to a few seconds
- Always-on users per cell from a few hundred to several millions
- Duty cycles from mere milliseconds to entire days
- Signaling loads from less than 1% to almost 100%

The "5G HyperService Cube" below gives a multi-dimensional overview in terms of throughput, latency and number of connections required for the many types of services 5G networks will need to run:

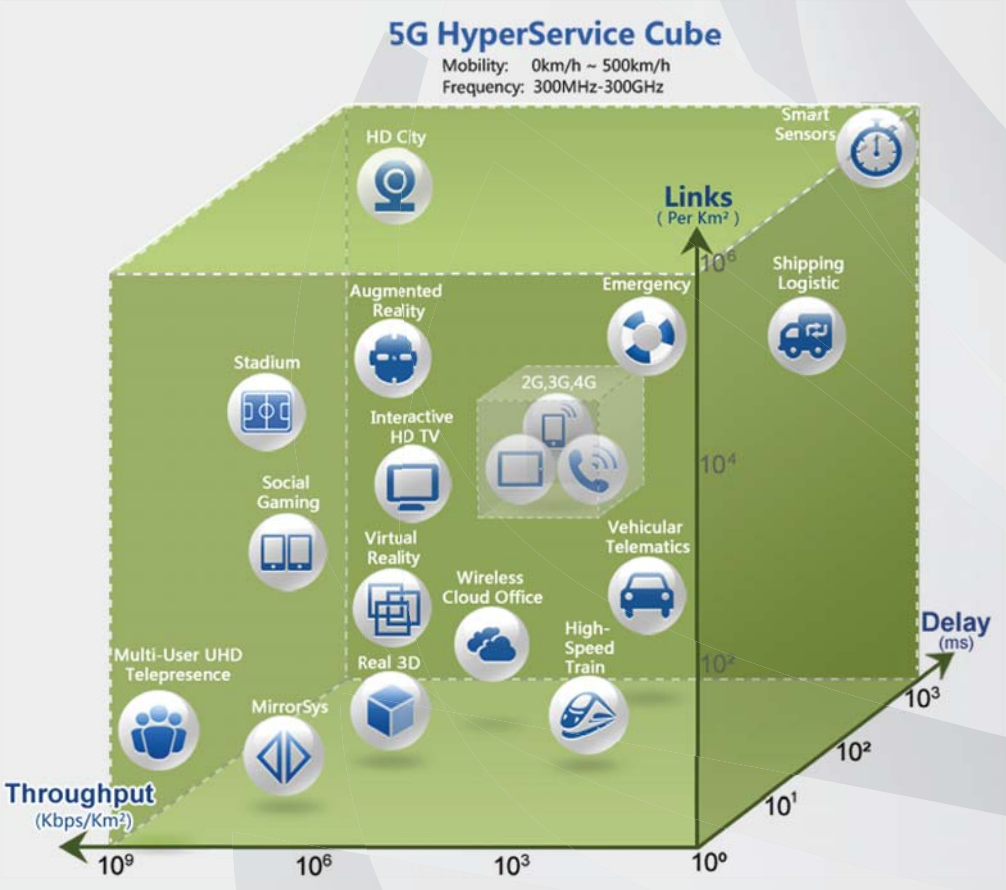

Figure 1 5G service and scenario requirements

5G networks faces significant design challenges to simultaneously meet all of the above service requirements. They must be built to meet a number of individual user and enterprise needs:

- Immersive experience: at least 1 Gb/s or more data rates to support ultra-high definition video and virtual reality applications
- Fiber-like user experience: 10 Gb/s data rates to support mobile cloud service
- Zero latency and response times: less than one millisecond latency to support real time mobile control and vehicle-to-vehicle applications and communications
- Zero-second switching: max 10 millisecond switching time between different radio access technologies to ensure a consistently seamless delivery of services
- Massive capacity and always-on: current mobile network systems already support 5 billion users, this will need to expand to also support several billions of applications and hundreds of billions of machines
- Energy consumption: energy-per-bit usage should be reduced by a factor of 1,000 to improve upon connected device battery life

Spectrum impact

Other than flexible and efficient use of all available non-contiguous spectrum in different network deployment scenarios, freeing up additional spectrum will also be required to support thousand-fold capacity increases by 2020 – and even higher increases looking forward to 2040 and beyond.

But while a global consensus is forming that 500MHz to 1GHz bandwidth of additional mobile spectrum is needed, the following considerations will be need to be addressed:

- Spectrum bands availability by region and the local laws that govern their usage will need to be harmonized so the global circulation and economies-of-scale for mobile devices are not negatively impacted.
- Exactly how all available and new IMT bands will be used to achieve 10 Gb/s for an individual end user is a major challenge for designing working 5G systems.

To sufficiently maximize spectrum efficiency, all-spectrum access and programmable air interface technologies will need to be capable of mapping service requirements to the best suitable combinations of frequency and radio resources. The continuing deep integration of SDN and cloud architecture technologies will help realize this, and will facilitate the on-demand customization of mobile network technologies that better ensure QoS, increase network TVO, decrease network TCO, and reduce energy consumption.

3. Key Technology Drivers and Innovations

Key 5G technology drivers are as follows:

- While previous generations of wireless networks were characterized by fixed radio parameters and spectrum blocks, 5G will allow utilization of any spectrum and any access technology for the best delivery of services.

- Air-interface and RAN systems will need to be completely redesigned to accommodate a new mobile access paradigm of massive capacity, huge numbers of connections, and ultra-fast network speeds.

- 5G will feature native support for new kinds of network deployments, including ultra-dense radio networking with self-backhauling, device-to-device communications, dynamic spectrum refarming and radio access infrastructure sharing.

Necessary breakthroughs

The development of 5G will require several breakthroughs:

- New breakthroughs in multiple access and advanced waveform technologies combined with advances in coding and modulation algorithms are essential for realizing continuing improvements in spectral efficiency. This will accommodate the necessary scalability for massive IoT connectivity and drastic reductions in access latency.

- New breakthroughs in the baseband and RF architecture are required to enable computationally intensive and adaptive new air interfaces. A significantly more advanced baseband computation is required to meet the complex requirements of new solutions like mass-scale MIMO. A singular, integrated design for combining an unprecedented number of RF radio and antenna elements into one unit (a "Radiotenna") will be needed to support these new air interfaces.

- New breakthroughs in advanced RF domain processing will bring benefits to the efficient and flexible usage of spectrum; single-frequency full-duplex radio technologies will be a major contributor to increasing spectrum efficiency. Improvements in these areas will help drive overall network costs down while achieving improved energy efficiency.

- New breakthroughs in the integrated access node and backhaul design are required to enable the very dense networking of radio nodes. Plug-and-play will become essential to deployment where such nodes will need to access and self-organize available spectrum blocks for both access and backhauling. This capability will be key for enabling high-frequency spectrum radio access.

- New breakthroughs in radio technologies for mobile devices are required to support a vast range of capabilities, from ultra-low energy sensors to ultra-fast devices with long-lasting battery life. Miniaturized multi-antenna technologies will be critical for enabling Gb/s-level access speeds with less spectrum and lower power consumption. Further extending the capability of mobile devices is also of great importance to support certain base station functionalities. This will allow device-based, on-demand mobile networking for services like instant device-to-device communications.

Virtualized architectures

Radio access infrastructures based on cloud architecture technologies will provide on-demand resource processing, storage and network capacity wherever needed. Software-defined air interface technologies will be seamlessly integrated into 5G wireless access network architectures. The evolution of RAN sites will develop toward a “hyper transceiver” approach to mobile access, and will help realize the joint-layer optimization of how radio resources are efficiently utilized.

Core network evolution will revolve around how to enable more flexibility for the creation of new services and new applications. Cloud computing will become the foundation of core networks, and will open the network to allow the leveraging of innovations as they are developed. 5G core networks will also be equipped to seamlessly integrate with current 3G and 4G core networks.

All-spectrum access

New designs for all-spectrum radio access nodes will require breakthroughs in fundamental radio technologies like the air interface, RAN, radio frequency transceiver and devices. New radio backhaul and new fiber access for the fixed network will be an integral part of next generation commercial network solutions. The following figure gives a basic overview of such a 5G radio access architecture:

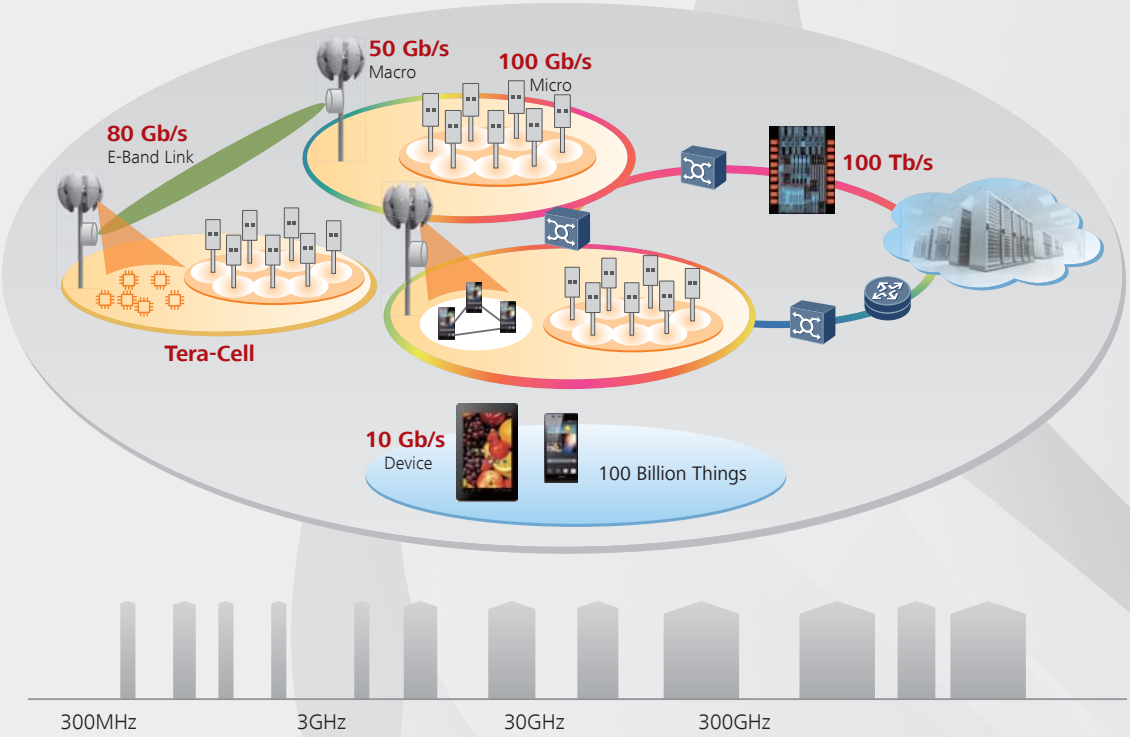

Figure 2 5G All-spectrum access RAN

4. Timeline

5G is presently in its early research stages. New IMT spectrum is expected to be agreed upon for the World Radio Communication Conference (WRC) in 2015. ITU is currently at work on IMT spectrum requirements for 2020 and beyond. After WRC-15, ITU will have a clearer path for determining network system and technology requirements.

The figure below shows one possible roadmap for 5G technology evolution:

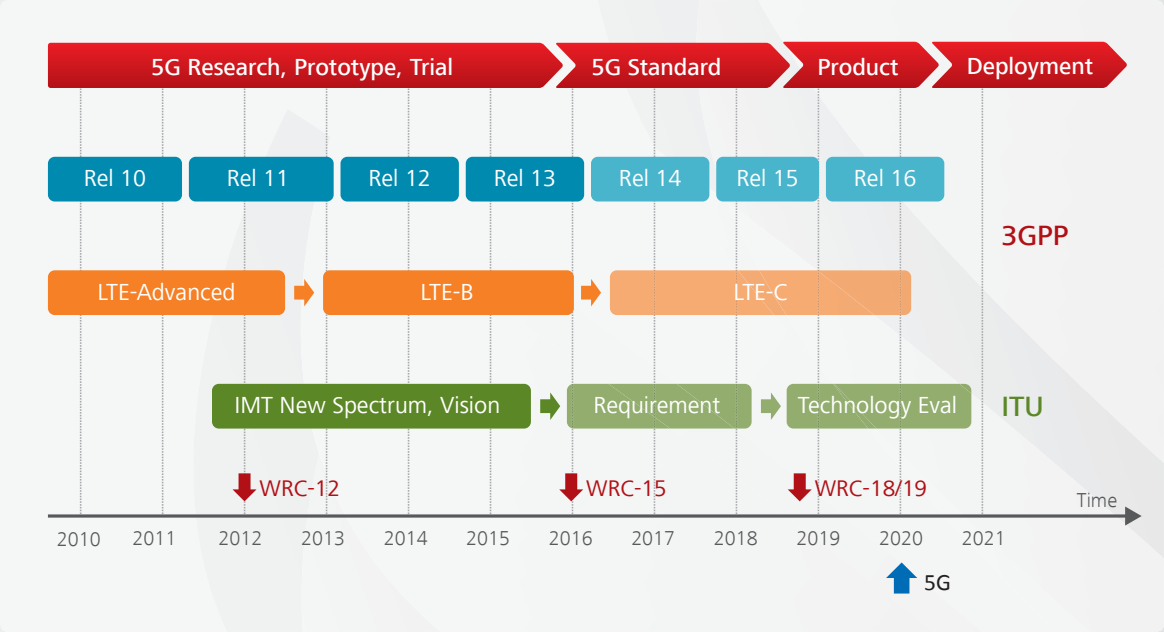

Figure 3 5G roadmap and timeline

5. Collaborating Globally

Huawei's R&D commitments to 5G are undisputed. Since 2009, Huawei has been a key player in establishing essential 5G technologies and innovations.

Huawei will collaborate globally with multiple ecosystem partners, international trade associations, universities, governments and private sector companies to promote and develop 5G technologies. The company has already partnered with more than 20 universities worldwide and has been actively working with organizations like METIS, ITU, China IMT-2020 and 3GPP.

The success of 5G can only be built upon the success of the entire ICT ecosystem. Entire ICT ecosystem innovation will be the real driver in creating a bigger market for 5G.

6. Summary

5G is the next frontier of innovation for entire mobile industry.

The three major design objectives for 5G:

- Implementation of massive capacity and massive connectivity
- Support for an increasingly diverse set of services, applications and users – all with extremely diverging requirements
- Flexible and efficient use of all available non-contiguous spectrum for wildly different network deployment scenarios

An adaptive network solution framework will become a necessity for accommodating both LTE and air interface evolution; Cloud, SDN and NFV technologies will reshape the entire mobile ecosystem; and 5G will speed up the creation of massive-scale services and applications.

The next decade promises breakthrough developments in several fundamental RAN technologies that will be required for implementing commercial-ready 5G network solutions:

- Multiple access and advanced waveform technologies combined with coding and modulation algorithms
- Interference management
- Access protocols
- Service delivery architecture
- Mass-scale MIMO
- Single frequency full duplex radio technologies
- 5G devices
- Virtualized and cloud-based radio access infrastructure

5G success depends on the entire ICT ecosystem. Its growth will be built upon global LTE success. ICT ecosystem innovation will also be a major driver in creating a bigger 5G market.

Appendix-A Acronyms

Gb/s	Giga Bits per Second
GSM	Global System for Mobile Communications
HSPA	High Speed Packet Access
ICT	Information and Communications Technology
IMT	International Mobile Telecommunication
IoT	Internet of Things
ITU	International Telecommunication Union
LTE	Long Term Evolution
M2M	Machine to Machine
METIS	Mobile and wireless communications Enablers for the Twenty-twenty (2020) Information Society
NFV	Network Function Virtualization
RAT	Radio Access Technology
RAN	Radio Access Network
RF	Radio Frequency
SDN	Software Defined Networking
TCO	Total Cost of Ownership
TVO	Total Value of Ownership
WRC	World Radio Communication Conference

Appendix-B Reference

[1]. Outlook: Visions and research directions for the Wireless World, WWRF, Oct 2011

[2]. Roadmap and workplan on future technologies(2020) from 3GPP, ITU, WRC, APT, CJK, China IMT2020, etc.

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