CORNING

Demystifying 5G

More than just faster cellular

Unlike its predecessors, the fifth generation of wireless network technology will do more than just make cell phones work faster. The collection of technologies that are architected together to enable 5G will fundamentally change the way we interact with devices and how they interact with each other.

Expected to be up to 10x faster than current LTE with greatly reduced latency,* 5G will help turn data-hungry technologies where reliability is critical, like VR, AR, AI, remote surgery, driverless vehicles, IoT, and more, into everyday realities.

Are you ready for the future of wireless communication?

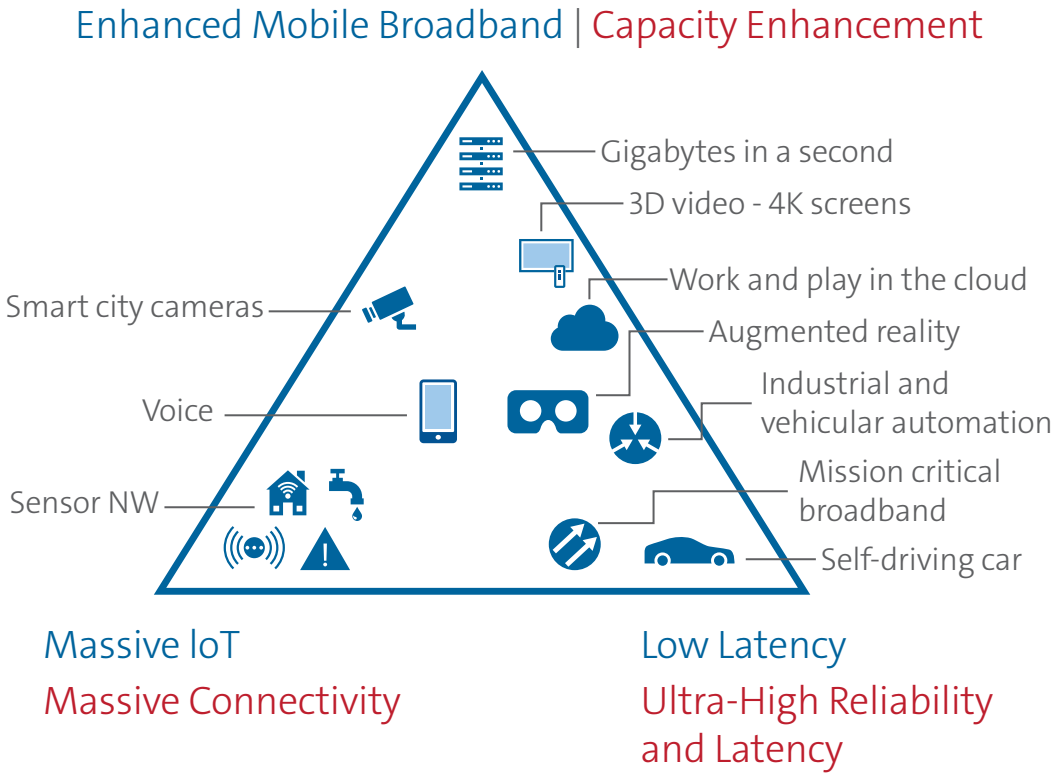
Visit **Corning.com/JustRight** to learn more about 5G and our 5G RAN products or contact your Corning representative to explore solutions that are right for your applications.

*ITU-R IMT 2020

Introduction to 5G

The new world of 5G

Beyond simply offering a faster network, 5G will answer pent-up demand for a faster, more flexible, and more reliable broadband wireless service, enabling the deployment of a whole new class of wireless services.



What is the main benefit of 5G?

A significant performance increase over LTE that will support the massive expected increase in connected devices to about an average of one million per square kilometer by the mid-2020s vs. about 100,000 today.*

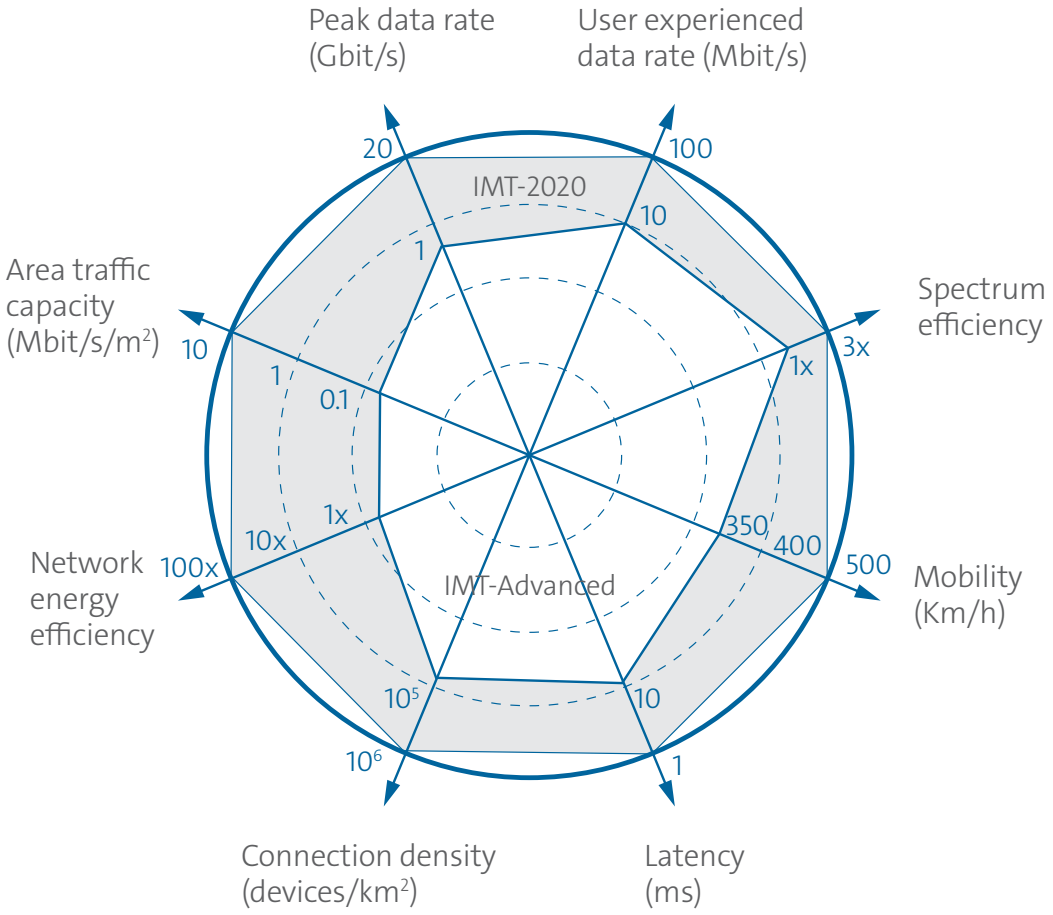
*ITU-R IMT 2020

Who defines 5G?

The 5G standards for networks, devices, and services were released in 2015 as the International Mobile Telecommunications-2020 (IMT-2020 Standard). They were developed by the ITU Radiocommunication Sector (ITU-R) of the International Telecommunication Union (ITU).

What are the goals of 5G?

The radar diagram from the IMT-2020 standards illustrates the eight dimensions of improvement over IMT-Advanced (also known as LTE). It shows, for example, that 5G has a latency goal of 1 millisecond which represents a 10-times improvement over current LTE.



What technologies will be used to meet 5G's goals?

5G-NR Air Interface, an improved LTE waveform

Ultra-Reliable Low-Latency Computing (URLLC) Edge Computing

Massive MIMO Antennas

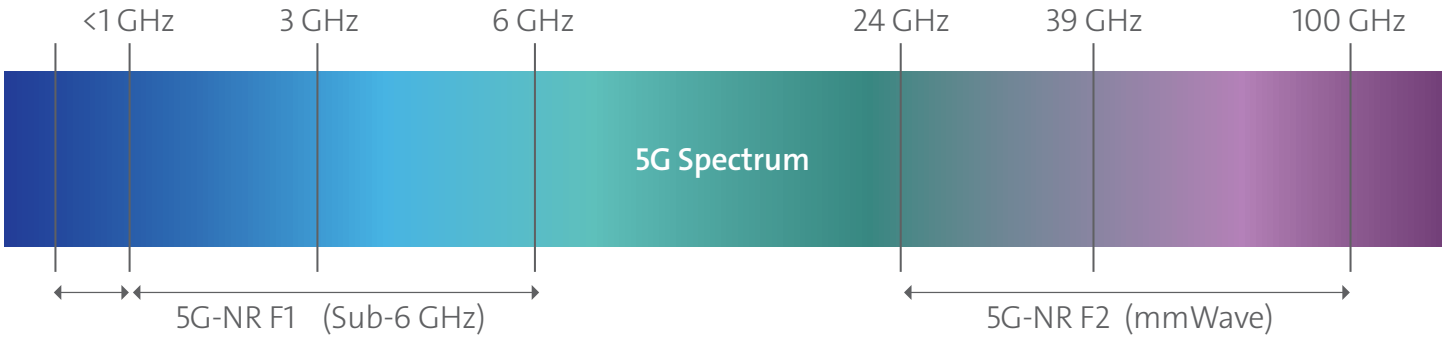
Network Slicing to Create Multiple End-to-End Performance Classes

Introduction to 5G-NR

What is 5G-NR?

A descendant of the LTE air interface that offers:

- A maximum spectrum bandwidth of 400 MHz — LTE has 20 MHz.
- Two implementation modes called F1 and F2:
  - F1 supports spectrum under 6 GHz, also referred to as sub-6 GHz.
  - F2 supports spectrum from 24 GHz and up, also referred to as millimeter wave or mmWave.

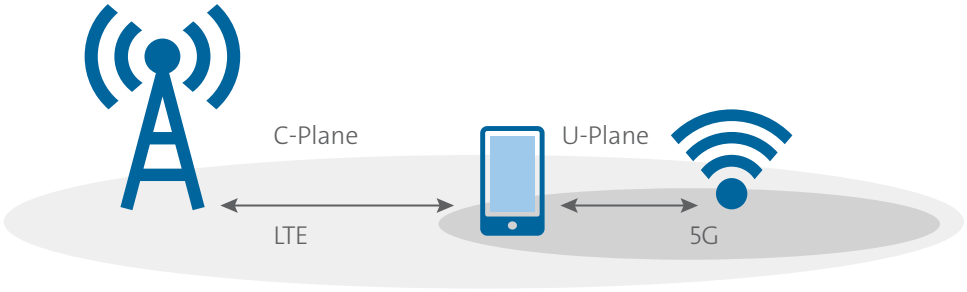


What's the maximum speed of 5G-NR?

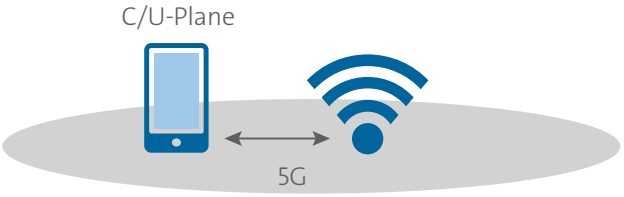
Maximum speed is a complex question. It depends on the spectrum available to the mobile operator and how they configure their 5G network. Best case peak network rates are expected to be 20 Gbps (20x today's LTE) and user-experienced data rates of 100 Mbps (10x current LTE).

Is it true that 5G also uses LTE?

Yes. Because the country is too large to activate 5G everywhere at the same time, U.S. mobile operators are implementing 5G-Non-Standalone (5G-NSA), a system that uses an existing LTE channel for 5G signaling and a 5G-NR channel for user data between a 5G-NSA cell and attached mobile devices. 5G-NSA was selected because it will continue to provide a positive user experience as the 5G network is being rolled out nationwide. The alternative mode is 5G-Standalone or 5G-SA that carries all signaling traffic and user data on 5G-NR channel(s).



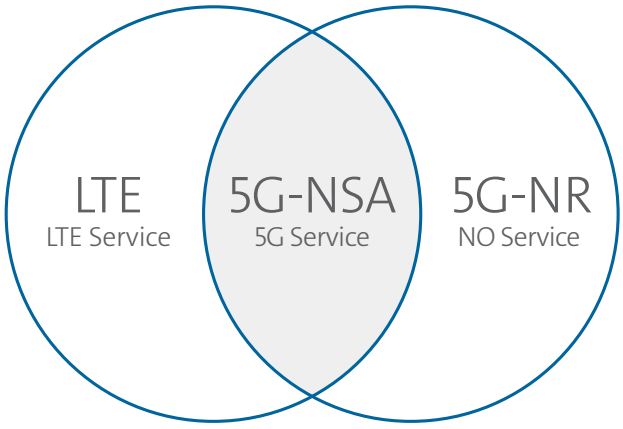
NSA (Non-Standalone, LTE Anchor)



SA (Standalone)

Since 80% of cellular traffic is generated indoors, does 5G-NSA work there?

To enable service, 5G-NSA requires adequate coverage by both LTE and 5G-NR channels. That means that where there is no LTE coverage, there cannot be 5G service, even if the 5G-NR channel has coverage. However, where there is no 5G-NR coverage, there can be LTE service, if LTE coverage exists. Ideally, buildings with indoor LTE systems will implement 5G-NSA by adding a 5G-NR overlay network that matches the existing LTE coverage and marrying the 5G-NR and LTE base stations together.



Introduction to MIMO

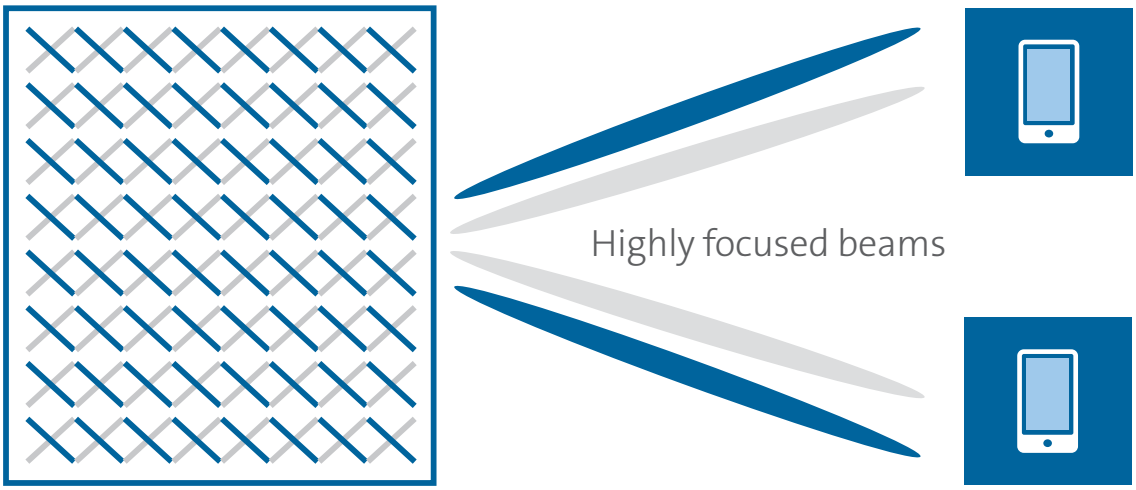
What is MIMO?

Multiple input and multiple output (MIMO) — pronounced "my-moe" — is a method for multiplying the capacity of a radio link by using multiple transmission and receiving antennas. MIMO is used extensively in Wi-Fi and LTE to provide better service to laptops and mobile devices. Typically, the antenna count is from two to eight on the Wi-Fi access point or cell site.

What is massive MIMO?

Massive MIMO consists of:

- **Antenna panels:** Each panel can contain hundreds of antennas.
- **Beamforming:** Each antenna in a panel is digitally steered. This means that rather than emitting a broad, undirected signal, the internal controllers group multiple antennas together to focus a cellular energy beam directly at a specific mobile device. The beam greatly increases the signal quality which enables much higher data rates. The antenna grouping that created the beam is also better able to receive signal back from the mobile device.
- **Spatial diversity:** Because the focused beams don't cross, beamforming allows massive MIMO panels to use the same frequency to support all the devices, so you need less spectrum to serve more devices.
- **Multiuser MIMO:** Areas where multiple 5G mobile devices are clustered can be served with a packet flow that contains messages for all the devices inside single data packets, increasing network efficiency.



What are the benefits of massive MIMO?

The primary benefits to the network and mobile owners are:

- **Increased network capacity:** Many more people can be on the network at the same time without negatively affecting performance.
- **Improved coverage:** Mobile owners will enjoy a more uniform experience across the network and can expect high-data-rate service almost everywhere, even at the cell edge.
- **Happy mobile owners:** Capacity and coverage improvements will result in a better overall mobility experience.

Introduction to Ultra-Reliable Low-Latency Communication (URLLC)

What is URLLC?

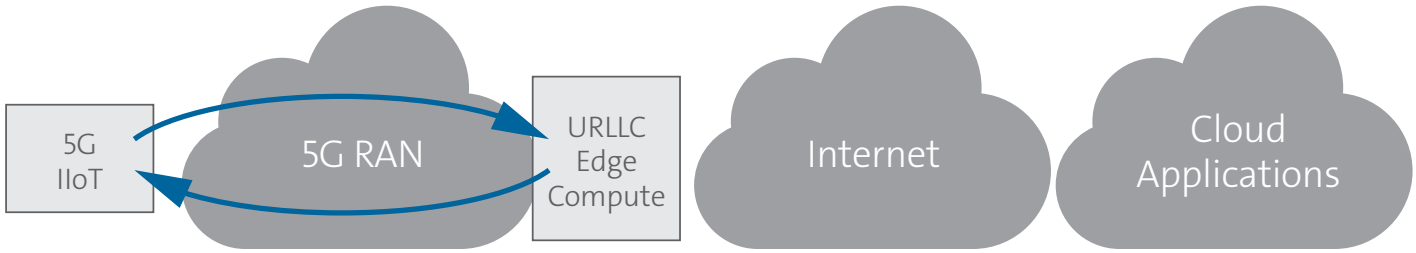
URLLC is a collection of software and hardware techniques to enable high-availability, low-latency, and, in some cases, bounded jitter for critical application performance needs.

How does URLLC support fast application response times?

URLLC is defined in the 3GPP Release 16 and 17 specifications. Among the techniques included in these specifications are:

- Massive MIMO antenna spacial diversity capability to maintain multiple connections to an attached device
- Multiple connections to an attached device by multiple antennas
- Enable privileged flows to have priority access to radio uplink/downlink
- Allocation of reservations in the systems for privileged flows
- Edge computing to support fast application responses by either hosting stand-alone edge application or a subset of a cloud application

Requirements example: In a remote surgery scenario, the feedback to the surgeon must be as immediate as possible to ensure that the surgeon's actions are not slowed or limited by network latency. Haptic feedback to the surgeon where they "feel" the resistance of their tool as it cuts has a round-trip time requirement of as low as 1 ms. Edge computing, privileged flows, and resource reservations all combine to meet this critical 1-ms requirement.



What are the benefits of URLLC?

At its debut, URLLC will provide a platform for application developers to build services in mobile networks that deliver the fast, local response required for industrial robotics, remote surgery, factory 4.0, and other time-sensitive/high-value scenarios.

Commercial release of systems is anticipated in the 2021-2022 time frame. The URLLC technology framework is anticipated to continuously evolve over time as experience with it develops.

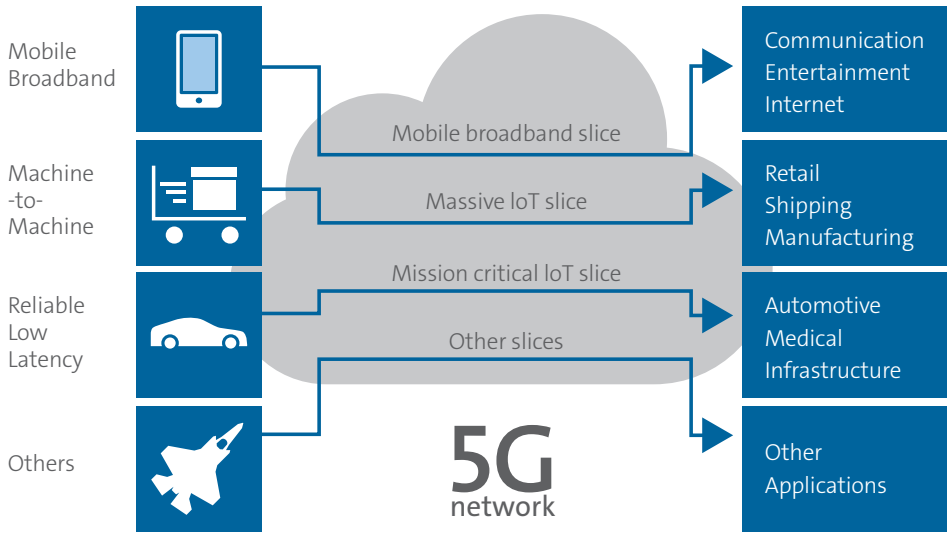
Introduction to Network Slicing

What is network slicing?

Network slicing creates multiple virtual networks on top of a common shared physical infrastructure. Each virtual network is customized to meet the specific needs of applications, services, devices, or customers.

5G network slicing

5G network slicing enables service providers to build virtual end-to-end networks tailored to application requirements.



What's in a network slice?

A slice is an end-to-end logical network that is created with resources from the 5G device, RAN, URLLC, backhaul, core network, and even cloud services. Each slice will have its own programmed behavior when it is created for a specific use or application.

What are the benefits of network slicing?

Network slicing divides a single physical network infrastructure into multiple isolated, end-to-end virtual networks that support a wide range of services and applications and can be optimized for specific business purposes.

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