

Assignment #1

5G

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What is 5G?

Ans.: 5G is the 5th generation mobile network. It will elevate the mobile network to not only interconnect people, but also interconnect and control machines, objects, and devices. It will deliver new levels of performance and efficiency that will empower new user experiences and connect new industries. 5G aims to deliver multi-Gbps peak rates, ultra-low latency, massive capacity, and more uniform user experience.

What are the other generations of mobile networks?

Ans.: The other mobile network generations are 1G, 2G, 3G, and 4G.

- 1G delivered analog voice.
- 2G introduced digital voice (e.g., CDMA).
- 3G brought mobile data (e.g., CDMA2000).
- 4G LTE ushered in the era of mobile Internet.

What are the benefits of 5G?

Ans.: 5G is a new kind of network: a platform for innovations that will not only enhance today's mobile broadband services but will also expand mobile networks to support a vast diversity of devices and services and connect new industries with improved performance, efficiency, and cost. 5G will redefine a broad range of industries with connected services from retail to education, transportation to entertainment, and everything in between. 5G is considered as technology as transformative as the automobile and electricity.

Through a landmark 5G Economy study, it is found that 5G's full economic effect will be realized across the globe by 2035, supporting a wide range of industries and potentially producing up to \$12 trillion worth of goods and services.

The study also revealed that the 5G value chain (OEMs, operators, content creators, app developers and consumers) could alone generate up to \$3.5 trillion in overall aggregate revenue by 2035 and support up to 22 million jobs, or more than one job for every person in Beijing, China. Of course, there are many emerging and new applications that are yet to be completely defined or even known today. That is why only time will tell what the full "5G effect" is going to be.

What services and use cases for 5G?

Ans.: In general, 5G use cases can be broadly categorized into three main types of connected services:

1. **Enhanced Mobile Broadband:** 5G will not only make our smartphones better, but it will also usher in new immersive experiences, such as VR and AR, with faster, more uniform data rates, lower latency, and cost-per-bit.

2. **Mission-Critical communications:** 5G will enable new services that can transform industries with ultra-reliable/available, low latency links—such as remote control of critical infrastructure, vehicles, and medical procedures.
3. **Massive Internet of Things:** 5G will seamlessly connect a massive number of embedded sensors in virtually everything through the ability to scale down in data rates, power and mobility to provide extremely lean/low-cost solutions.

How fast is 5G?

Ans.: Per IMT-2020 requirements, 5G is expected to deliver peak data rates up to 20 Gbps. Qualcomm Technologies' first 5G NR modem, the Qualcomm® Snapdragon™ X50 5G modem, is designed to achieve up to 5 Gbps in downlink peak data rate.

But 5G is more than about just how “fast” it is. In addition to higher peak data rates, 5G will provide much more network capacity by expanding into new spectrum, such as millimeter wave (mmWave). 5G will also deliver much lower latency for a quicker immediate response, and an overall more uniform user experience so that the data rates stay consistently high even when users are moving around. Moreover, the new 5G NR (New Radio) mobile network will be backed up by Gigabit LTE coverage foundation, which will provide ubiquitous Gigabit-class connectivity.

What are the key differentiating 5G technologies?

Ans.: 5G is bringing a wide range of technology inventions in both the 5G NR (New Radio) air interface design as well as the 5G NextGen core network.

The new 5G NR air interface introduces many foundational wireless inventions, and the top five are:

1. Scalable OFDM numerology with $2n$ scaling of subcarrier spacing
2. Flexible, dynamic, self-contained TDD subframe design
3. Advanced, flexible LDPC channel coding
4. Advanced massive MIMO antenna technologies
5. Advanced spectrum sharing techniques

How does 5G work?

Ans.: Like 4G LTE, 5G is also OFDM-based and will operate based on the same mobile networking principles. However, the new 5G NR (New Radio) air interface will further enhance OFDM to deliver a much higher degree of flexibility and scalability. For more details on 5G waveform and multiple access techniques. 5G will not only deliver faster, better mobile broadband services compared to 4G LTE, but it will also expand into new service areas, such as mission-critical communications and connecting the massive IoT. This is enabled by many new 5G NR air interface design techniques, such as a new self-contained TDD subframe design.

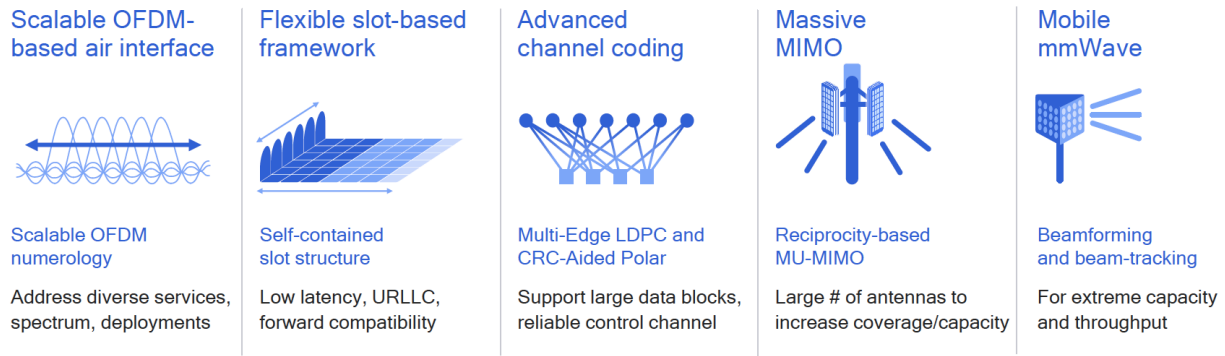


Figure 1: Specifications of 5G-NR

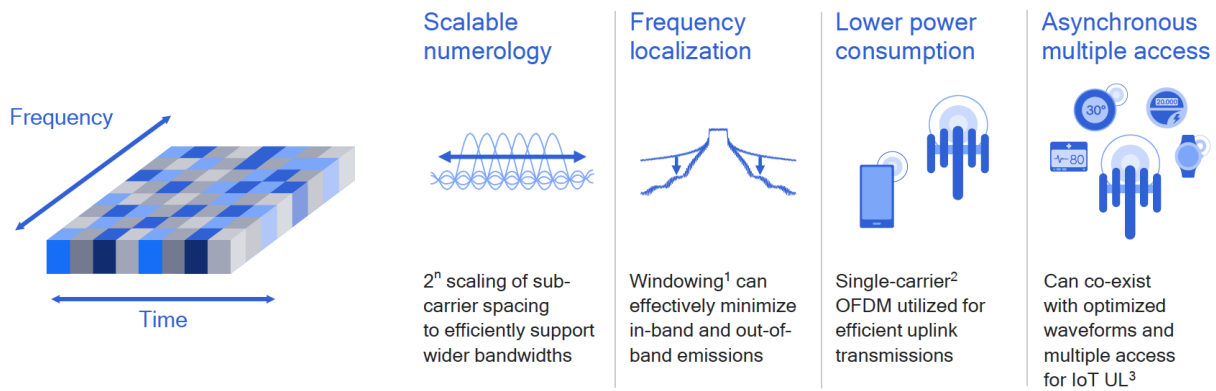


Figure 2: Scalable OFDM-based 5G-NR air interface.

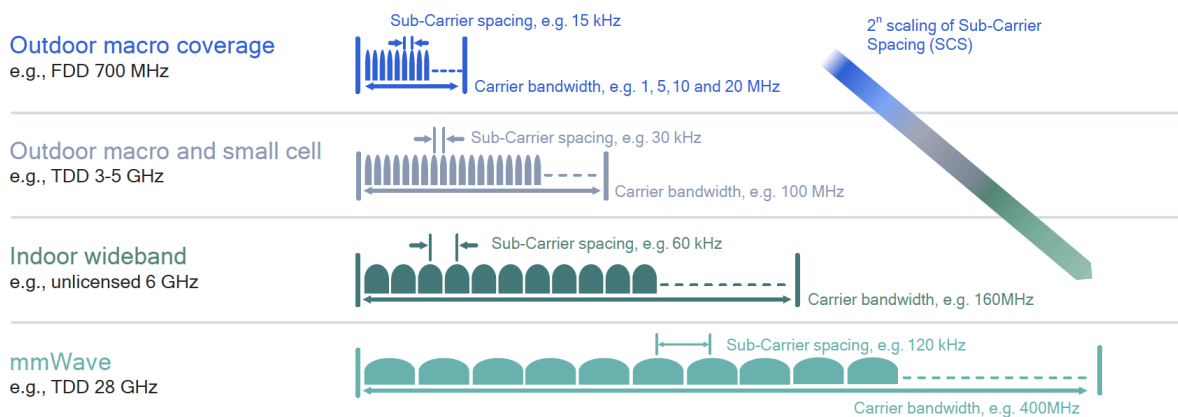


Figure 3: Scalable 5G-NR OFDM numerology-examples.

The diagram illustrates the 5G NR slot structure, showing a 3D perspective of a slot grid. The grid is divided into several regions: eMBB (enhanced Mobile Broadband) in blue, D2D (Device-to-Device) in green, Multicast in green, Blank subcarriers in white, and Blank slots in white. The grid is also divided into Self-contained slot structure (left) and Nominal traffic puncturing (right). The Self-contained slot structure shows a slot with DL Ctrl, eMBB transmission, and UL Ctrl. The Nominal traffic puncturing shows a slot with URLLC (Ultra-Reliable Low Latency Communication) and eMBB transmission. The diagram highlights the flexibility of the slot structure, allowing for efficient multiplexing of diverse latency and QoS requirements, and the ability to independently decode slots and avoid static timing relationships across slots.

Scalable slot duration
Efficient multiplexing of diverse latency and QoS requirements

Forward compatibility
Transmissions well-confined in time/frequency to simplify adding new features in future

Self-contained slot structure
Ability to independently decode slots and avoid static timing relationships across slots

Nominal traffic puncturing
To enable URLLC transmissions to occur at any time using mini-slots

Diagram illustrating the relationship between subframe and slot durations for different SCS values:

- 15 kHz SCS:** A 1ms subframe aligned with LTE is divided into 14 slots (0 to 13). The duration of one slot is 500 μs.
- 30 kHz SCS:** A slot is 500 μs. A mini-slot is 250 μs.
- 60 kHz SCS:** A slot is 250 μs.
- 120 kHz SCS:** A slot is 125 μs.

The diagram illustrates four TDD configurations, each showing the timing of Downlink (DL) and Uplink (UL) transmissions within a slot. A double-headed arrow at the top indicates the 'Slot-based scheduling/control interval'.

- TDD Self-Contained:** Shows a slot where DL and UL transmissions occur within the same slot. The DL transmission (blue) includes a 'DL Ctrl' (control) portion and 'DL Data'. The UL transmission (teal) includes a 'Guard' period, 'UL Data', and a 'UL Ctrl' (control) portion.
- Data-centric:** Shows a slot where DL and UL transmissions are separated. The DL transmission (blue) includes a 'DL Ctrl' (control) portion and 'DL Data'. The UL transmission (teal) includes 'UL Data' and a 'UL Ctrl' (control) portion.
- Mini-slot:** Shows a slot where DL and UL transmissions are separated. The DL transmission (blue) is a 'mini-slot' (e.g., 2-symbol mini-slot). The UL transmission (teal) is a 'mini-slot' (e.g., 4-symbol mini-slot).
- Blank slot:** Shows a slot where no transmissions occur.

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Much faster, more flexible TDD switching and turn-around than 4G LTE

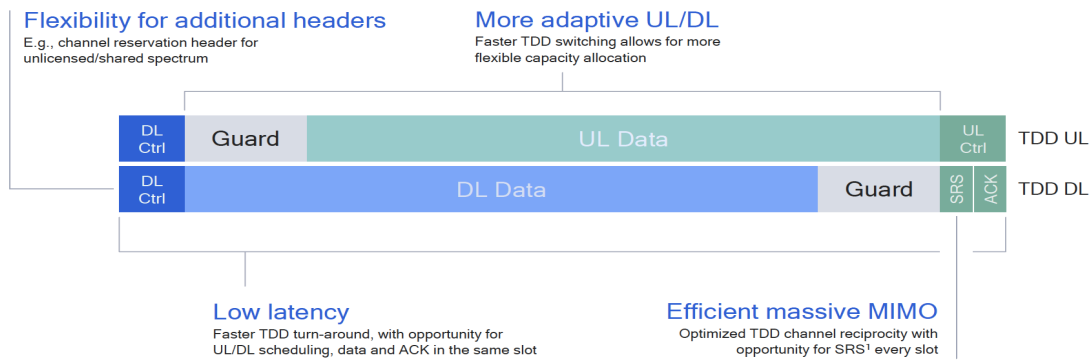


Figure 7: Benefits of the 5G-NR TDD self-contained slot.

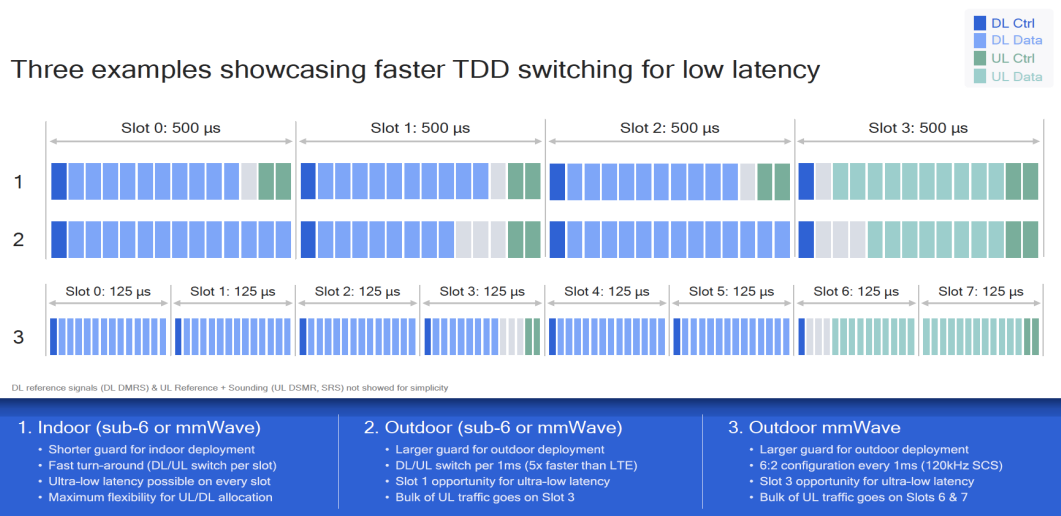
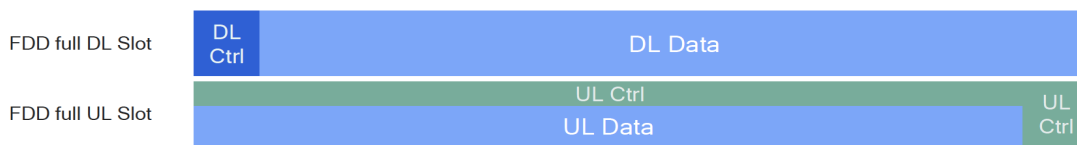


Figure 8: 5G-NR TDD self-contained slot structure in action.

Delivering low latency, extended coverage, and forward compatibility

FDD baseline for continuous transmission and extended coverage



FDD partial slot for faster DL/UL turn-around and efficient half-duplex FDD implementation



Figure 9: 5G-NR flexible FDD slot structure.

Key enabler for using higher spectrum bands, e.g. 4 GHz, with existing LTE sites

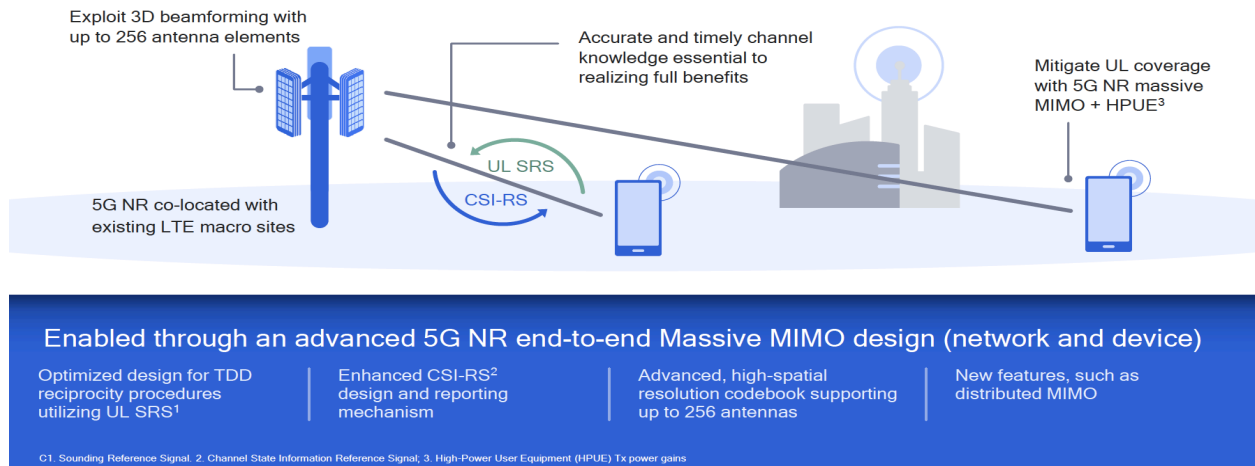
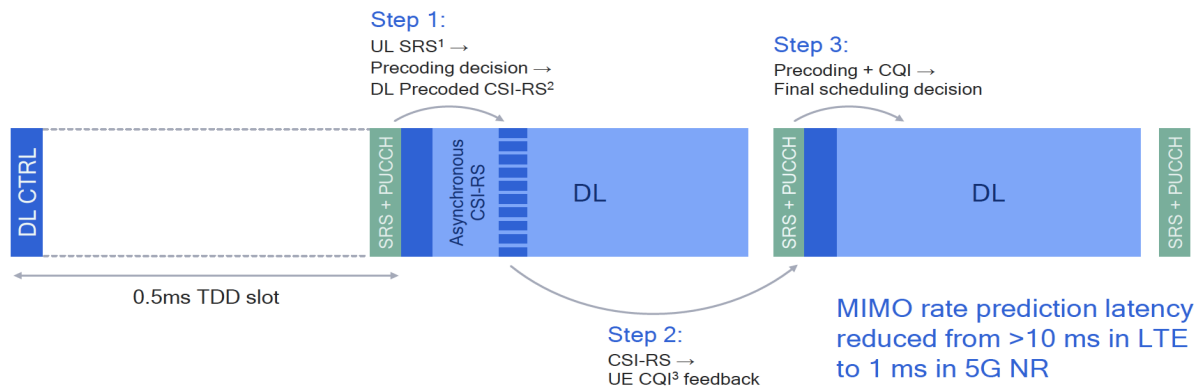


Figure 10: 5G-NR optimized design for massive MIMO.

5G NR slot structure and enhanced Ref Signals enable fast/accurate feedback



*Sub-6 GHz, macro cell numerology, 30 kHz tone spacing. Channel sounding opportunity increases from <= 200 Hz with LTE to 2 kHz with 5G NR.
1. Sounding Reference Signal. 2. Channel State Information Reference Signal. 3. Channel Quality Indicator

Figure 11: 5G-NR optimized design for TDD reciprocity procedures.

What is the difference between 4G and 5G?

Ans.: There are several differences between 4G and 5G:

- 5G is a unified platform that is more capable than 4G
- 5G uses spectrum better than 4G
- 5G is faster than 4G
- 5G has more capacity than 4G
- 5G has lower latency than 4G

Reference:

1. <https://www.qualcomm.com/invention/5g/what-is-5g>