# Lec30

Saturday, March 28, 2020 4:43 PM

# Uplink control channels - 10min

Sunday, February 25, 2018 8:42 PM

- PUSCH : Physical uplink shared channel
  - used by UE to send data traffic
  - scheduled by DL PDCCH
  - can also do freq-hopping for diversity.

- PUCCH: Physical uplink control channel
  - report CQI (channel quality information)
  - UL scheduling request: to ask for PUSCH resources later
  - HARQ ACK/NACK corresponding to DL transmissions.

TABLE IX
SUPPORTED PUCCH FORMATS (* FROM REL. 10)

| Format | Modulation | # bits | Purpose |
|---|---|---|---|
| 1 | N/A | N/A | Positive Scheduling Request (SR) for PUSCH |
| 1a | BPSK | 1 | 1 bit HARQ-ACK |
| 1b | QPSK | 2 | 2 bits HARQ-ACK |
| 2 | QPSK | 20 | a CSI Report |
| 2a | QPSK+BPSK | 21 | a CSI and 1 bit HARQ-ACK (Normal CP) |
| 2b | QPSK | 22 | a CSI and 2 bit HARQ-ACK (Normal CP) |
| 3* | QPSK | 48 | Multiple CSI and HARQ-ACKs |

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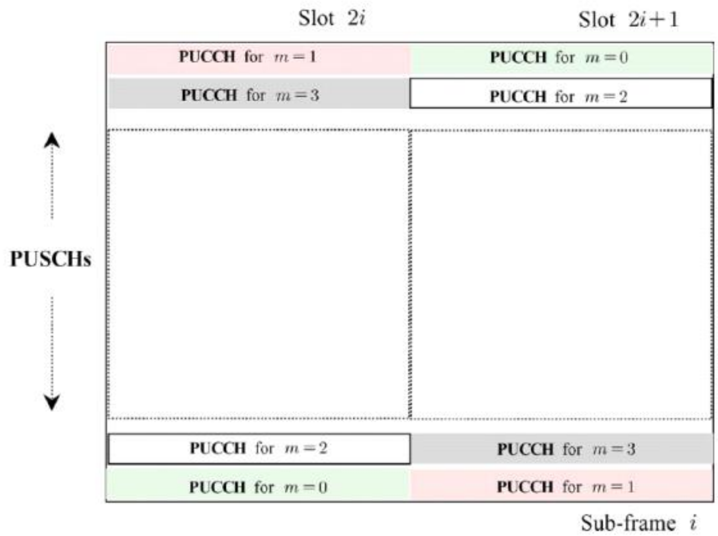
<u>Allocation in resource</u> grid

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- PUCCH is always at the edge of the bandwidth
  allows contiguous allocation of SC-FDMA data in PUSCH
- Divided into "PUCCH regions".
  - each region is hopped at both ends of the bandwidth for frequency diversity
  - UE is mapped to a region based on its id.
  - Control signalling from multiple UEs is multiplexed via orthogonal coding
    - time-shifts of a common code.
- Finally, UCI can also be carried along with uplink data, if the UE has been assigned resource for uplink transmission.

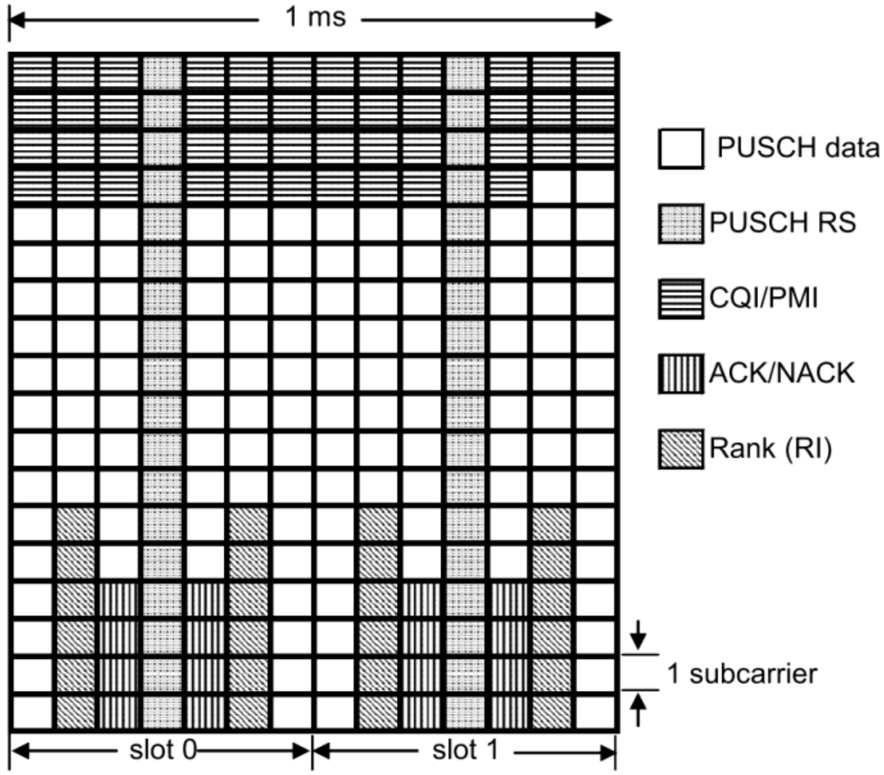


Figure 16.15: Multiplexing of control signalling with UL-SCH data.

PRACH

- given region of PUSCH is carved out for random access (72 subcarriers, given subframes)
- for initial network access (e.g. send new data)
  do not carry data.

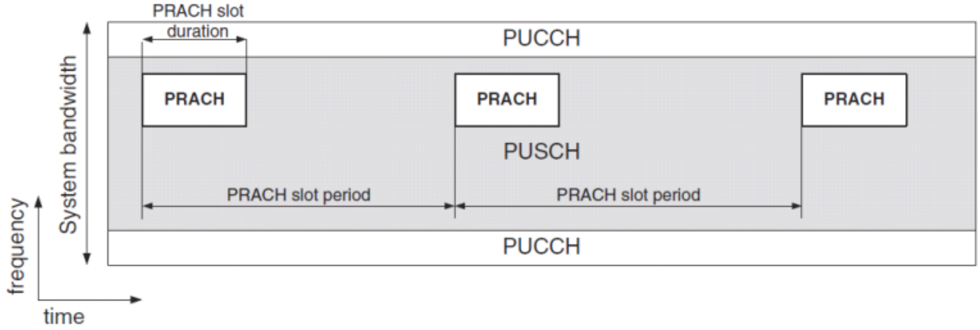


Figure 17.5: PRACH multiplexing with PUSCH and PUCCH.

The preamble uses subcarrier spacing of 1.25KHz instead of 15KHz. The random access preamble occupies 1,2 or 3 subframes in the time domain(1,2,3ms) and 839 subcarriers in frequency domain(1.05MHz) . There will be 15KHz guard band on both the sides and hence it uses total of 1.08MHz (equal to 6 RBs). The position of LTE random access preamble is defined by PRACH frequency offset parameter carried in SIB-2.

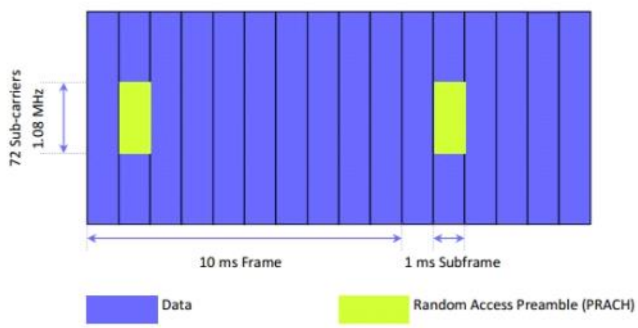


Fig.1 Position of PRACH in uplink frame

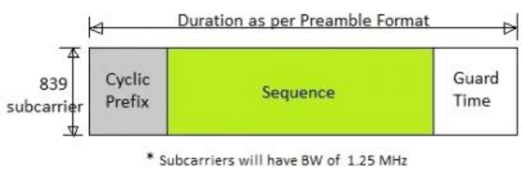


Fig.2 Structure of random access preamble

There is a max. of 1 random access preamble in a subframe but more than one UEs can use it. Multiple UEs using same preamble resource allocations are differentiated by their unique preamble sequences.

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- A UE randomly picks a time-freq. resource.
- In addition, it can choose one out of 64 preamble signatures
- A collision will only happen when both the

time-freq resource & preamble are the same.

## Random access procedure

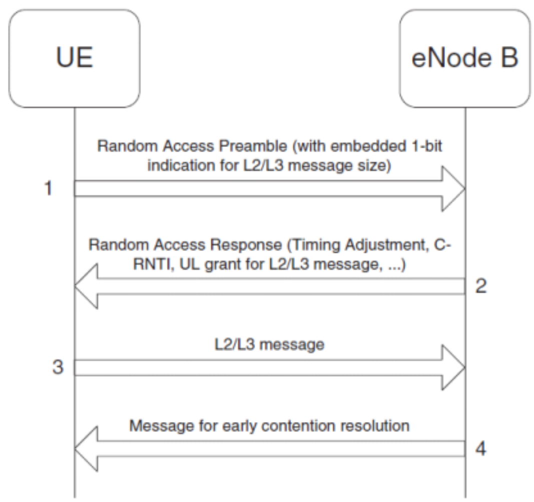


Figure 17.1: Contention-based random access procedure. Reproduced by permission of © 3GPP.

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- RAR sent in PDSCH, indicating the time-freq slot in which the preamble is detected
- If collision occurs, it will happen again in L2/L3 messages
- If no collision, the last message acks the id of the successful sender

Reference:


Section IV.B, G. Ku and J. M. Walsh, "Resource Allocation and Link Adaptation in LTE and LTE Advanced: A Tutorial," *IEEE Communication Surveys & Tutorials*, vol. 17, no. 3, 2015.

Chapter 16.3, 16.4, 17.3, 17.4.1, S. Sesia, I. Toufik, and M. Baker, "LTE-the UMTS long term evolution: from theory to practice," John Wiley & Sons, 2011. (available online from Purdue library.)

# Summary

Friday, March 2, 2018 8:13 AM

1. Significant overhead due to scheduling and channel measurement
   a. The benefit of OFDMA and MIMO do not come for free
2. Many round of control packet exchange before packets can be transmitted

Implications to 5G:

1. Massive MIMO
2. Ultra-low latency
3. Massive connectivity of devices sending short packets.

Are there other ways to manage resources without BS:

- Random access, which is used both in 2G/3G/4G and WLAN

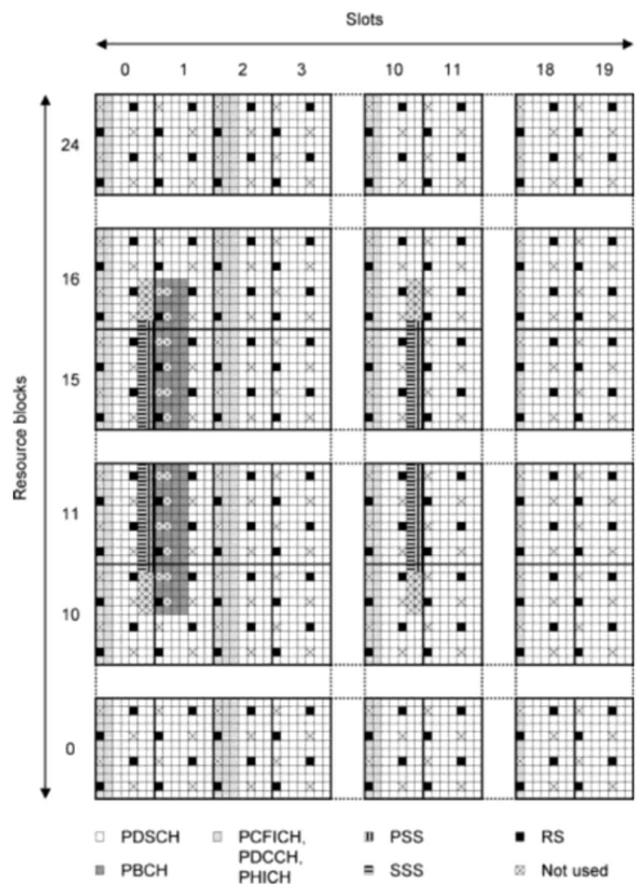



Figure 6.10 Example mapping of physical channels to resource elements in the downlink, using FDD mode, a normal cyclic prefix, a 5MHz bandwidth, the first antenna port of two and a physical cell ID of 1

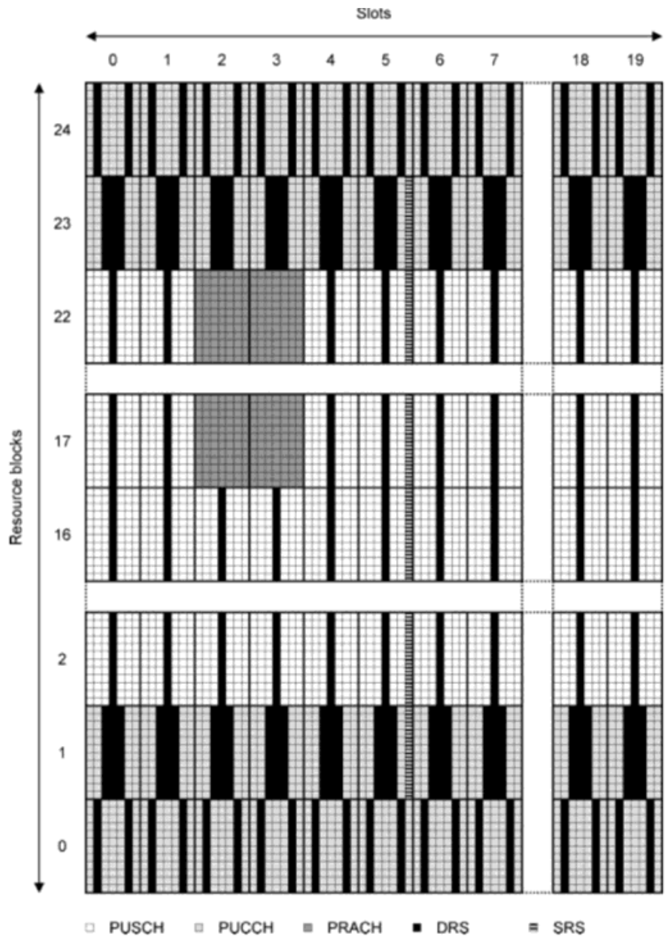


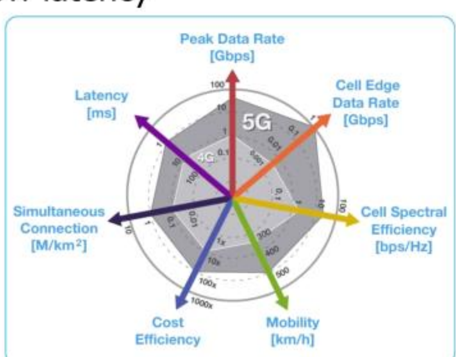

Figure 6.11 shows the corresponding situation on the uplink. The figure assumes the use of FDD mode, the normal cyclic prefix and a bandwidth of 5MHz.

## How about 5G?

- First specification (Phase 1) agreed on Dec. 2017

## Wish Lists (3 Use Cases) for 5G

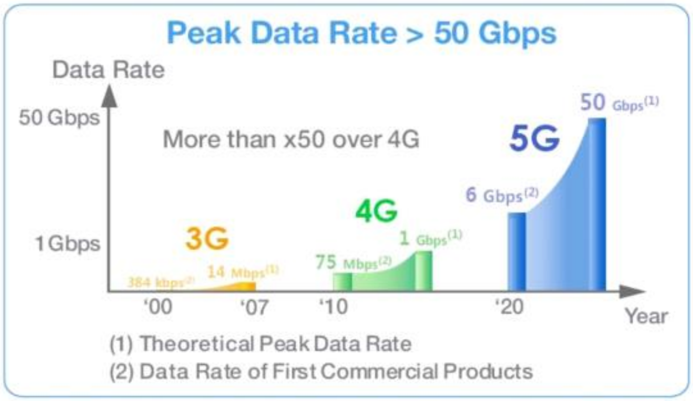
- High Data Rate: Enhanced mobile broadband (eMBB)
- Low Delay: Ultra-reliable low latency communications (URLLC)
- Massive # of devices: machine-type communications (mMTC)
- Possibly along different "slices" of the same core network (network virtualization)




Source: Samsung

3 service category in 5G

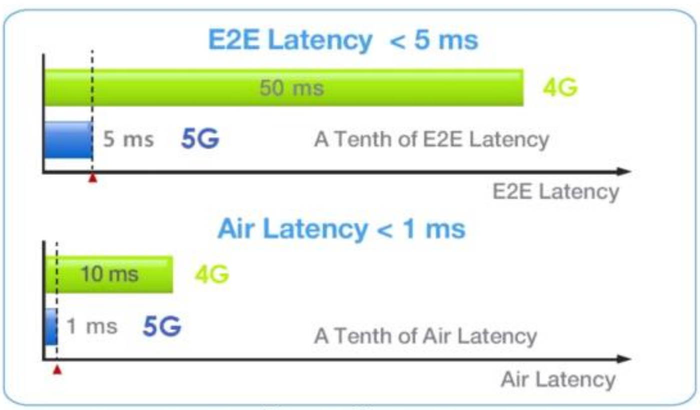
## High Data Rate




Source: Samsung

What driving applications?

## Ultra Low Latency

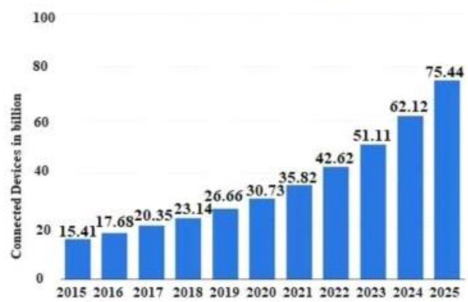



Source: Samsung

What driving applications?

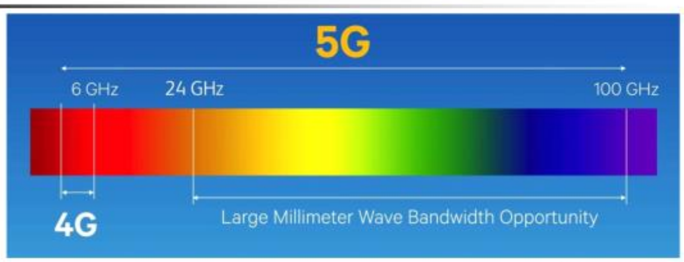
## Massive Connectivity

- Internet-of-Things
- But each device may be of low rate
- **Low overhead** is critical
- Low latency
- Low power


Source: statista.com

## Some Likely Technology for 5G




Source: rcrwireless.com

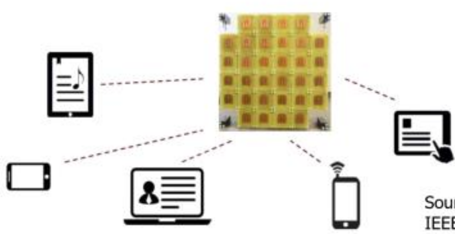
- mmWave
  - 30-300Ghz, sometimes including 24Ghz (about 10mm and below)
  - Much higher free-space loss
  - Absorption by atmosphere, rain, etc.
  - Line-of-sight propagation: low diffraction, does not penetrate walls/objects

## Some Likely Technology for 5G

Source: rcrwireless.com

- mmWave
  - Smaller coverage (100-200m), higher frequency reuse
  - Highly-directional beams may be needed to improve coverage
  - Beam alignment and beam tracking becomes a problem

## Some Likely Technology for 5G



Source: Massive MIMO for 5G, IEEE 5G Tech Focus: Volume 1, Number 1, March 2017

- Massive MIMO
  - Smaller wavelength of mmWave allows large antenna arrays to be packed at the transmitter/receiver
  - Potentially huge spectrum efficiency gain
  - High directionality
  - More resources needed for channel estimation/feedback. Pilot contamination

# Some Likely Technology for 5G

- Non-orthogonal access (NOMA)
  - In 3G/4G each user is assigned orthogonal resource (time/frequency) when transmitting
  - Signaling is needed for scheduling resources
  - For low-rate IoT applications, such signaling incurs high overhead
  - Potentially more advantageous to have multiple transmissions over the same set of the orthogonal resources

  - Sounds like CDMA?
  - How about spectrum efficiency, diversity gain, etc?

# 5G New Radio Release 15

Thursday, April 2, 2020 3:22 PM

- Completed around Dec. 2017 to June 2018
- Release 16 will be completed mid-2020.
- Release 15 focuses more on eMBB and URLLC
- Key architecture similar to 4G-LTE
  - OFDM in both uplink & downlink
  - similar set of data & control channels

## Design Considerations

① Larger bandwidth
- important for increased data rate
- mmWave band also has larger bandwidth

② Small cells
- important for improved spatial reuse.
- mmWave band also has small coverage
  → small cells

However, small cells will bring new challenges
- The energy consumption of a large # of small-cell BSs may be quite significant
- Neighboring small-cell BSs interfere with each other.
- The traffic load at a small cell can be

quite bursty.

→ small-cell BS does not need to operate all the time

(3) Massive # of Antenna Elements

- Important for both increased spectrum efficiency and improved mmWave coverage
- However, measuring the downlink SINR across many transmitting antennas will incur significant overhead for reference signals, etc.
- Further, each antenna needing separate A/D & D/A chain is also expensive and energy-hungry
- Need other ways of exploiting multiple antennas

e.g.

  - Analog beam-forming
  - Measuring uplink SINR and assume channel is the same in uplink & downlink (channel reciprocity)

- A one-size-fit-all solution is not feasible.

(4) Support low-latency applications.

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5G New Radio

- "Lean Carrier"
  - Cell-specific RS replaced by UE-data

associated DM-RS in the downlink

- PDCCH does not span all RBs

- BS does not needs to be always on, which saves both energy & inter-cell interference.

- Multiple subcarrier spacing to accommodate large-BW, small delay-spread settings

- Dynamic TDD

- Front-loading control signals & mini-slots

S. Parkvall, E. Dahlman, A. Furuskar, and M. Frenne, "NR: The new 5G radio access technology," IEEE Communications Standards Magazine, vol. 1, no. 4, pp. 24-30, December 2017.

# Resource Grid

Thursday, April 2, 2020 3:52 PM

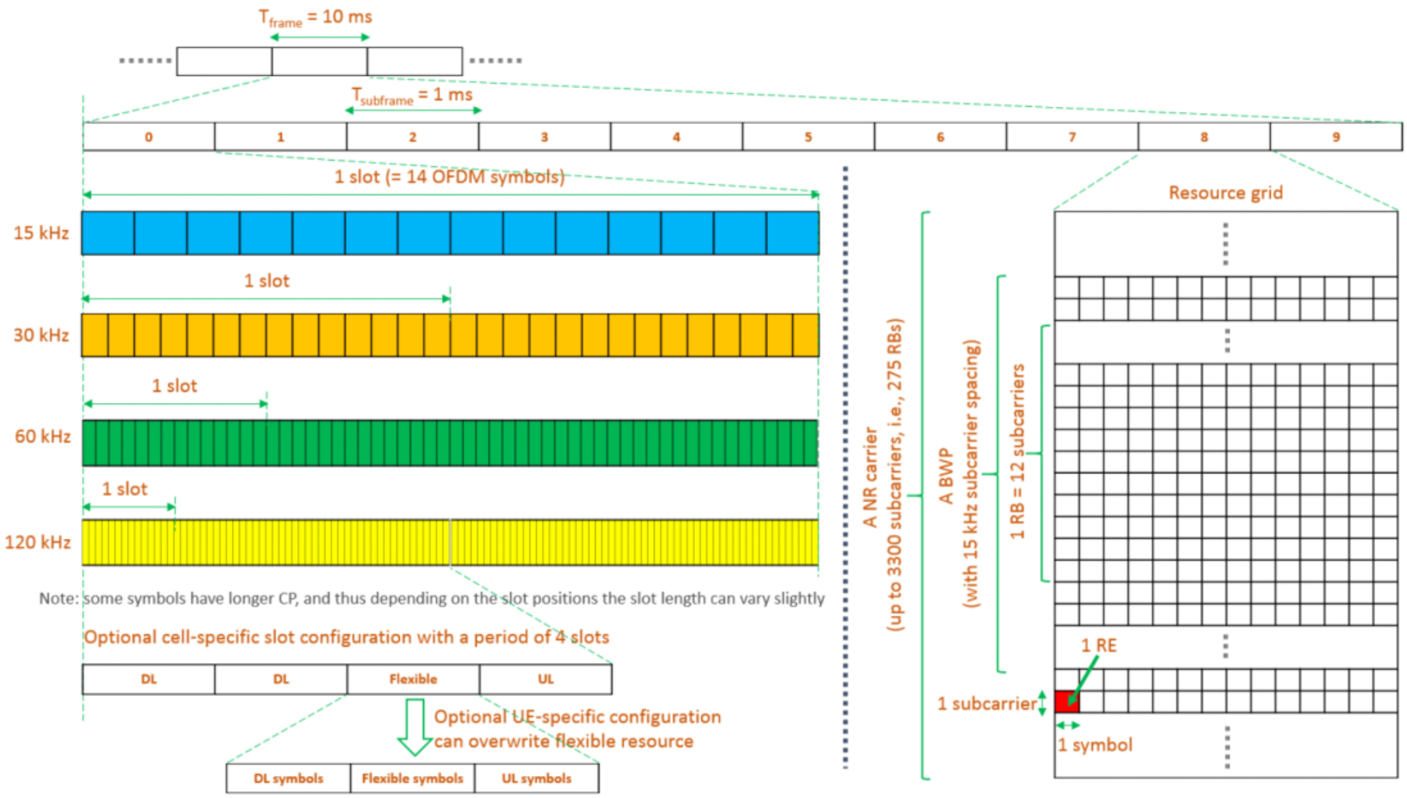


Figure 1: Illustration of 5G NR frame structure and basic terminologies

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- Release 15 define 2 frequency range (FR):
  - FR1: 450 MHz – 6 GHz
  - FR2: 24.25 GHz – 52.6 GHz (mm Wave)
  - Maximum BW is 100 MHz in FR1 and 400 MHz in FR2

## Scalable OFDM:

- In 4G LTE, the subcarrier spacing is 15 kHz

- In 5G NR, ~~the~~ the subcarrier spacing can be
  15, 30, 60, 120 KHz

- Recall frequency selectivity. The coherent bw is
  $\propto \frac{1}{T_{av}}$ ← delay spread

  - Larger subcarriers can only be used when the delay spread is small.
  - Likely small-cells & indoor environment.
  - The corresponding CP can also be shorter

- A frame is 10ms, divided into 1ms subframe

- The length of a slot, however, is defined by 14 symbols, and hence becomes shorter when the subcarrier is large.

- A RB is still 12 subcarriers and 1 slot.

## Latency

- Small slots reduces delay

- Further, UEs can transmit in the middle of a slot

- mini-slot
- further reduce delay
- the pre-empted transmission recovers by hybrid ARQ

Dynamic TDD:

- When traffic is bursty (e.g. for small cells), it is inefficient to dedicate frequency or time for UL & DL
- Instead, each slot can be switched between UL & DL

Bandwidth parts

- When the bandwidth is large, UE will spend a lot of energy monitoring all subcarriers
- Instead, the UE can be assigned to transmit and received on a subset of subcarriers (BWP).

Lin, Xingqin, et al. "5G new radio: Unveiling the essentials of the next generation wireless access technology." *IEEE Communications Standards Magazine* 3.3 (2019): 30-37.

# Lean Carrier

Thursday, April 2, 2020 4:12 PM

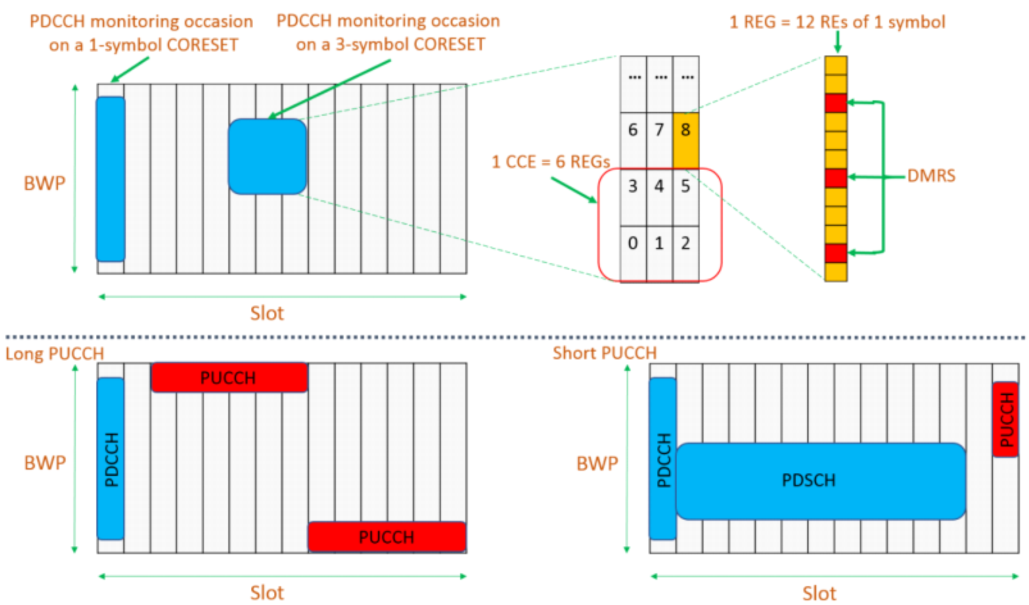


Figure 5: Illustration of 5G NR PDCCH and PUCCH

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- In LTE, the PDCCH and RS span the entire band all the time
  - This not only leads to high energy consumption at the (small-cell) BSs
  - But also create interference to neighboring cells
- Further, not all multi-antenna use cases rely on RS
  - e.g. Analog beam-forming can "sweep" the possible beam directions and ask for UE response

- or, can measure uplink SINR instead (by the SRS from the UE)

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- Thus, in 5G NR, cell-specific always-on RS is removed.

- Instead, UE-specific DM-RS is added along with UE data for channel estimation to assist demodulation

- If downlink SINR still needs to be measured, another UE-specific CSI-RS is defined
- This design allows flexibility for different use cases, and saves BS energy and inter-cell interference.

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- Further, PDCCH no longer spans the entire band.

- It is now defined on CORESETs (control resource set), which can be placed more flexibly in frequency & time.

- PDCCH is transmitted with its own DM-RS, enabling UE-specific beamforming on the control channel.

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- Similarly, PUCCH has more flexible placement in freq & time
  - LTE always places PUCCH at the edge
- Supports UE with smaller BWP

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In summary, lean-carrier design reduces overhead for control signals, reduces inter-cell interference, reduces BS energy consumption, and allows future flexibility.

# Low Latency

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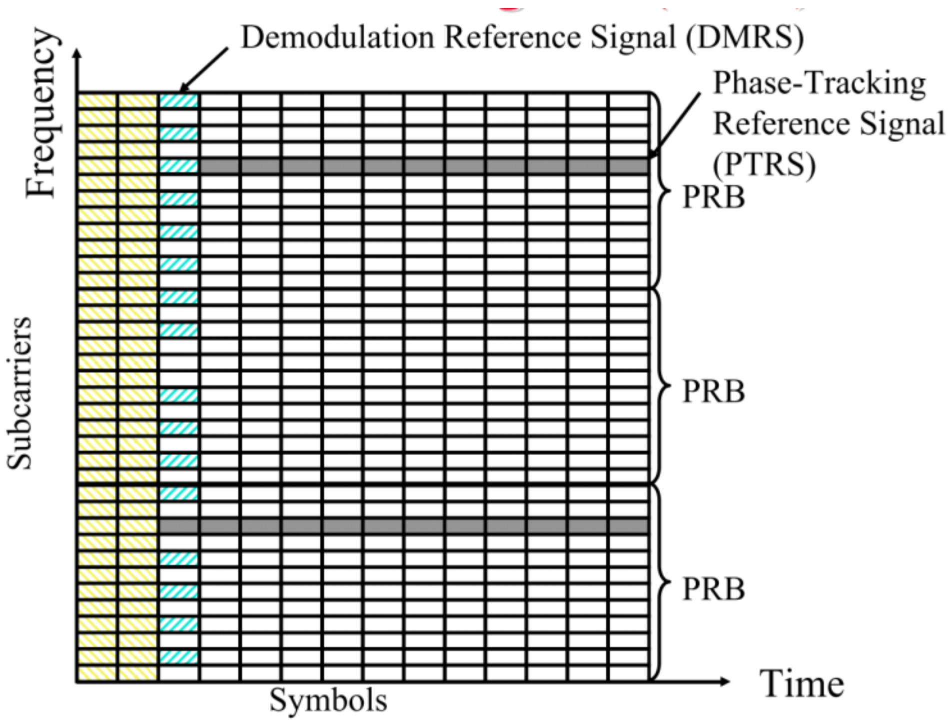
- Front-loading reference-signals & control channel

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- allows UE to process data immediately after control information (instead of interleaving in time)

- Mini-slot:
  - UE can upload data within one slot of grant
  - UE can respond with HARQ within one slot of

| | LTE-Advanced (Release 10) | NR (Release 15) |
|---|---|---|
| Peak data rate for downlink | Without CA: 600 Mb/s<br>With CA (5 CCs): 3 Gb/s | Without CA: 4.9 Gb/s for FR1, 10.7 Gb/s for FR2<br>With CA (16 CCs): 78.2 Gb/s for FR1, 171.2 Gb/s for FR2 |
| Peak data rate for uplink | Without CA: 300 Mb/s<br>With CA (5 CCs): 1.5 Gb/s | Without CA: 2.4 Gb/s for FR1, 4.0 Gb/s for FR2<br>With CA (16 CCs): 38.2 Gb/s for FR1, 64.6 Gb/s for FR2 |
| Average spectral efficiency | Downlink: 3.2 bps/Hz<br>Uplink: 2.5 bps/Hz | Downlink: 13.9 b/s/Hz<br>Uplink: 7.7 b/s/Hz |
| Achievable minimum air latency | 4.8 ms | 0.48 ms |
| Maximum mobility | 350 km/h | 500 km/h |

**TABLE 2**. Key performance comparison between Release 15 NR and Release 10 LTE-Advanced.

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# Release 16/17

Thursday, April 2, 2020 4:34 PM

- unlicensed spectrum
- above 52.6 GHz spectrum
- multicast / broadcast
- IoT
- Multi-hop mmWave backhaul
- Vehicle-based applications
  - sensing
  - platooning
  - automatic driving

Kim, Younsun, et al. "New Radio (NR) and its Evolution toward 5G-Advanced." *IEEE Wireless Communications* 26.3 (2019): 2-7.