5G : What and why ?

- Who decides the rules for 5G ?
- Who decides the minimum requirements for 5G ?
- Who put up the technical specifications that are followed by different countries, different operators, different RAN providers ?
- There has to be a body that says, "This is called 5G".

International Telecommunication Union (ITU)

It is a body that says, "These are the requirements. If you call a technology 5G, it should satisfy atleast these".
It is a body that regulates communication across countries.
(ii) It's a United Nations Agency.

For example, let's say, as a country, you want to put a satellite in orbit. You can't go ahead, put it and transmit or receive at whatever frequency you want. You cannot have your set of rules, because it is something that impacts across the borders, across different countries. So, there has to be a body that controls everything. This body is known as ITU.

What is ITU ? What is it made of ?

* 193 + countries
* 160 + Universities
* Different Sectors (pubic/private companies),
  Eg. Airtel, Jio, NTT, Dokomo, Apple, AT & T, etc.;

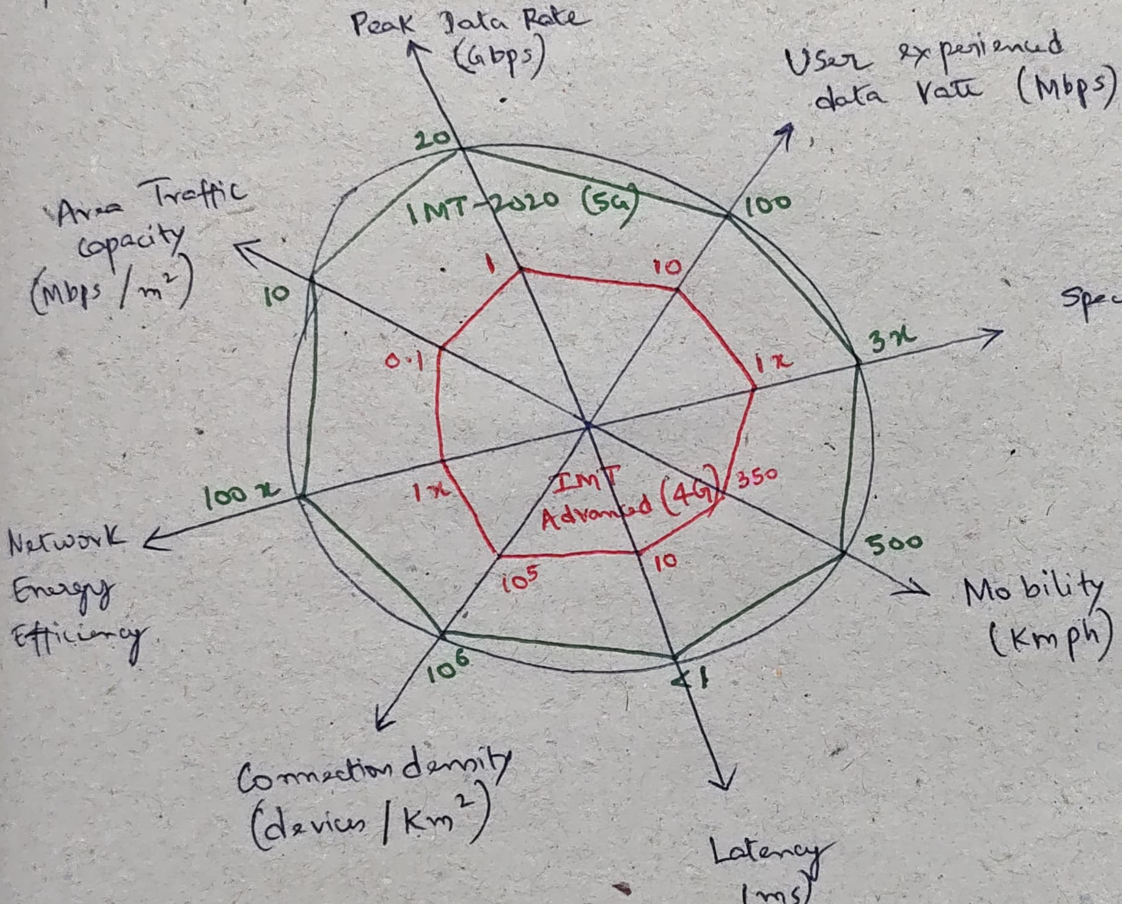
There are different members of ITU who decides the Rules.

ITU has 3 main sectors.

- Radio communication (ITU-R)
- Telecommunication Standardization (ITU-T)
- Telecommunication Development. (ITU-D)

ITU-R is the one that decides the minimum requirements for 5G. It has a project named "IMT-2020", (aka) 5G & beyond, which describes minimum rules to be satisfied, If satisfied, then it qualifies to be called 5G.

The Rules / Requirements is shown in figure below.



These are the minimum requirements that ITU has put forward. So, we build a technology, Set of Rules, Specifications, that satisfies atleast these.

So, who is building this set of rules / technology that satisfy these requirements ? That body is known as 3GPP.

The 3rd Generation Partnership project (3GPP)

As the name says, 3GPP started building the technical specifications from 3G, 4G, Nb-iot, 5G and all.

What is 3GPP ?

3GPP is a consortium of different companies and academic institutes, which comes together, builds a set of rules, which satisfies the minimum requirements set by ITU. And ITU says, "Okay. These specifications satisfies the minimum requirements. And this can be called 5G".

This is how the 5G specifications and rules comes out.

3GPP, RAN Meetings and Technical Specifications

ITU-R is the one that decides the minimum requirement and 3GPP is the one that builds the technical specifications that satisfy those minimum requirements.

3GPP is a consortium of different companies (public/private) and different Universities, who come together, meet, propose, and finalize the specifications. All these specifications are used across the world by all 5G devices.

3GPP website : 3gpp.org.

3GPP groups (organization partners)

- ARIB (Japan)
- ATIS (North America)
- CCSA (China)
- ETSI (Europe)
- TTA (South Korea)
- TTC (Japan)
- TSDSI (India)

TSDSI - Telecommunications Standards Development Society, India

Any individual who wants to be part of 3GPP, first they have to be a part of one of these organization, and then they can become part of 3GPP.

Few organizations that are part of TSDSI is follows.

- Qualcomm, Reliance Jio, Samsung R&D, TCS, Tech Mahindra, Tejas, Wipro, WiSig, ZTE, etc.,

These different organizations, they come together, meet at a pre-scheduled time, and discuss. They comeup with different proposals, discuss those proposals and finalize the specifications.

There are different Technical Specification Groups (TSG) in 3GPP.

TSG RAN Groups

- RAN 1 (Radio Layer 1) (Physical Layer) ✓
- RAN 2 (Radio Layer 2 and Radio Layer 3) (Radio Resource Control)
- RAN 3 (UTRAN / E-UTRAN / NG-RAN Architecture and Related Network Interfaces)
- RAN 4 (Radio performance and Protocol aspects)
- RAN 5 (Mobile Terminal Conformance Testing)
- RAN AH1 (TSG RAN ITU-R Ad Hoc)

In the 3gpp.org website, under each TSG RAN groups, the relevant documents and Meetings can be accessed.

Specifications (important)

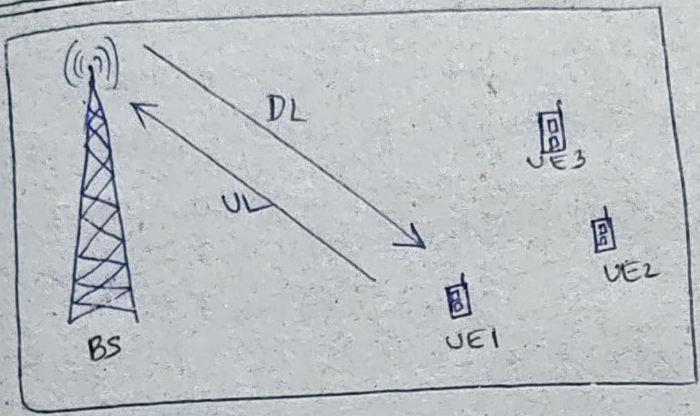
- 38.211 (NR: Physical channels and Modulation)
- 38.212 (NR: Multiplexing and Channel coding)
- 38.213 (NR: Physical Layer procedures for control)
- 38.214 (NR: Physical Layer procedures for Data)
- 38.215 (NR: Physical Layer measurements)

Throughout this Course, we'll be using Release 15.3.0.

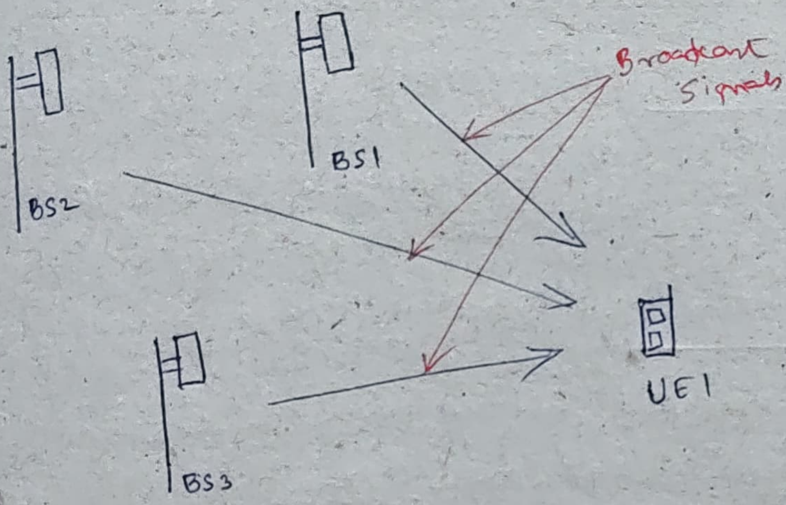
PDF version of Specifications can be accessed from ETSI Website.

ETSI -
European
Telecommunication
Standards
Institute

5G Physical Layer Design



Assume UE1 wants to send a text message.



In order to send the text message, first it needs to find out which BS to connect. Before that, it even needs to find out if the UE wants to send data through 5G, which of them supports 5G. For that, there has to be some signals to be transmitted periodically, using which UE needs to be synchronized with BS. (ie) Both the BS and UE should work at the same frequency. And also they should be synchronized in time, to decode the data.

Now, to facilitate that, Base Stations should transmit some signals even if there is no UE out there. These signals are called Broadcast signals. So, there has to be some broadcast signals continuously transmitted by Base Stations (even if there is no UE around) to help UEs to synchronize in time and frequency, and get more details of that BS.

The Broadcast signals are PSS / SSS / PBCH / SIB1.

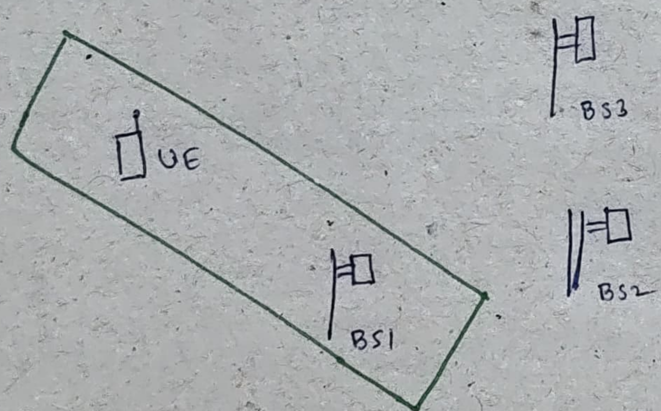
* PSS / SSS → For time and frequency synchronization
  → Also help to decode the cell ID of the BS.
  → continuously transmitted, without having much detail.

* PBCH → Physical Broadcast Channel
  → contains some bare minimum information, which will help the UE to decode the major chunk of data. (location of SIB1).

* SIB1 → This message contains major details about the BS

Our goal was to send a text message. But the UE can't send a text message if it dont even know how to transmit it. So, the first step is, decode the broadcast signals from BS to UE.

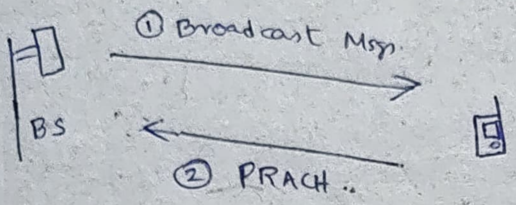
There may be multiple BS in the environment. The UE may connect with the cell which has higher signal energy.



Now, UE knows about the BS. But the BS doesn't know that there is a UE out there, that wants to connect.

UE got synchronized in time and frequency with BS. But, the BS doesn't know how far that UE is. Even the UE does not know how far it is from the BS.

So, to facilitate that, UE has to send a signal to the BS. This signal should be designed in a way that it help the BS to find out, how far that particular UE is, from the BS.



Now, the UE after decoding the broadcast information, it should send its first message known as PRACH. to the gNB. This will help the BS to identify that, "There is a UE out there, that wants to connect. Lets facilitate that".

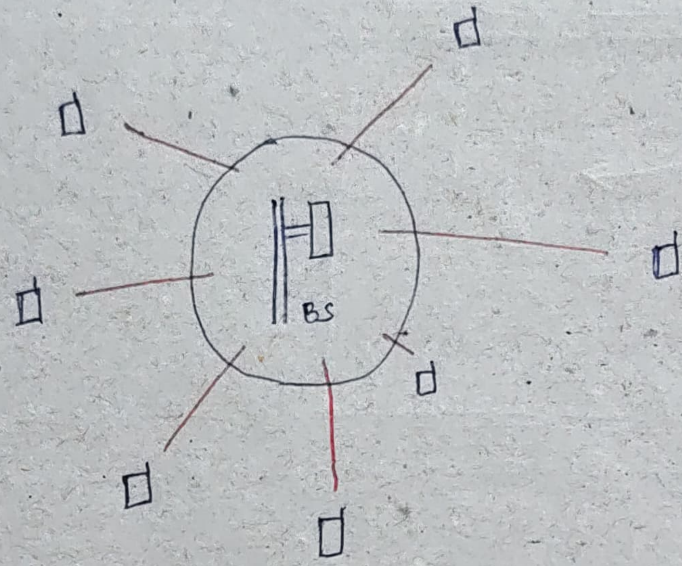
So, there will be a group of message exchange after this PRACH transmission, which is called Initial Access.

And this PRACH signal should be designed in a way that, it accommodates randomness (BS is able to handle all different following variations), coz the BS doesn't even know that there is a UE out there.

- What if at the same time, multiple UEs send PRACH?
- What if one UE is very close, and one UE very far?

So, the signal should be designed in a way that the BS is able to handle all these variations, since it is the first signal from UE. And PRACH should also help in finding the distance between the UE and BS.

And, the BS can signal UE that, "You are 1/2 km (or) 1500 meters (or) 5 km away. Hence from next time, when you send the signals, you can prepone them, so that they are aligned with my boundaries".



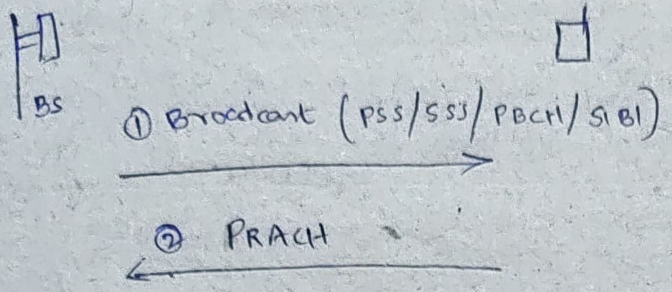
The BS should be the master (ie) the BS can have many UEs connected to it. Since we have fixed resources (time, frequency, and Space), in these resources, there has to be a connection between the BS and multiple UEs, and the data transfer should happen. This can only be achieved if there is a Single Master controlling it.

The BS should be the one that decides, "when it should transmit data to a UE, and when a UE should transmit data back to the BS.

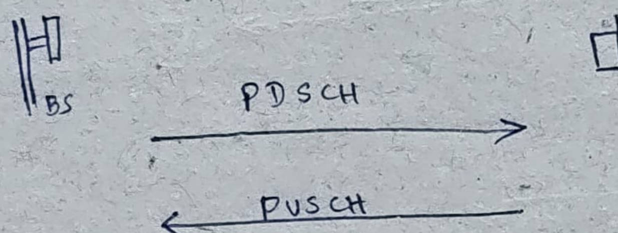
The BS should tell UE that, "okay. You transmit the signal at this particular time, using this particular frequency or space resources".

And, the BS should also control all the configurations of data being transmitted in the DL, and the data being transmitted in the UL. It should have control over everything coz it has to manage multiple UEs connected to it, and allocate the resources wisely.

WKT



Now, our goal was to send a Text message. For this data, to go from BS to UE, (or) from UE to BS, there ~~exists~~ exists channels namely PDSCH (for DL) and PUSCH (for UL) respectively. These particular channels carry the actual data that has to be exchanged between the BS and UE.



Now, in order to optimize this whole transmission, say for example, the BS wants to send a particular data to UE over the PDSCH channel, there can be many different configurations exists, means lets say

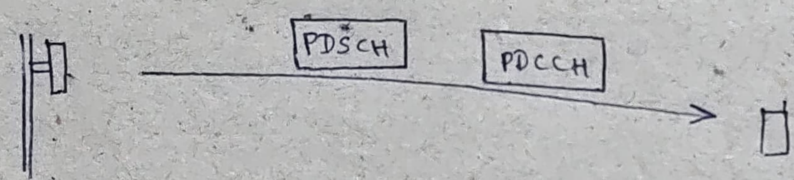
- At one instance, I want to send only 24 bits.
- In another instance, I want to send 1 Lakh bits.
- In one case, UE is very close, and I have to use 256 QAM
- In another case, UE is very far, and I have to use QPSK.
- In one case, I want to use 1 Layer
- In another case, I want to use 4 layers

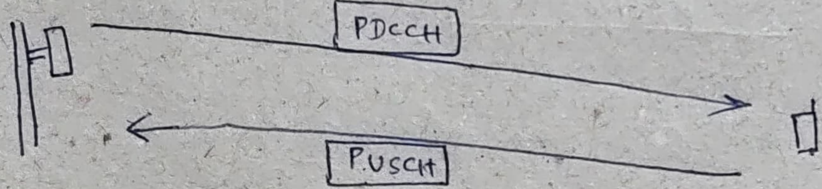
} using different Resources in space.

- In one case, I want to use different frequency / time resources.

So, there are lot many variations to transmit data in the shared channels (PDSCH or PUSCH). And if we use a Fixed pattern to transmit the data, that is not an optimized way. So, we should account for all the scenarios, and then transmit PDSCH / PUSCH accordingly.

The Receiver should know about all the different variations in the configuration, so that it can decode. So, the configuration has to be communicated to the receiver before the data is transmitted.

(i)


(ii)


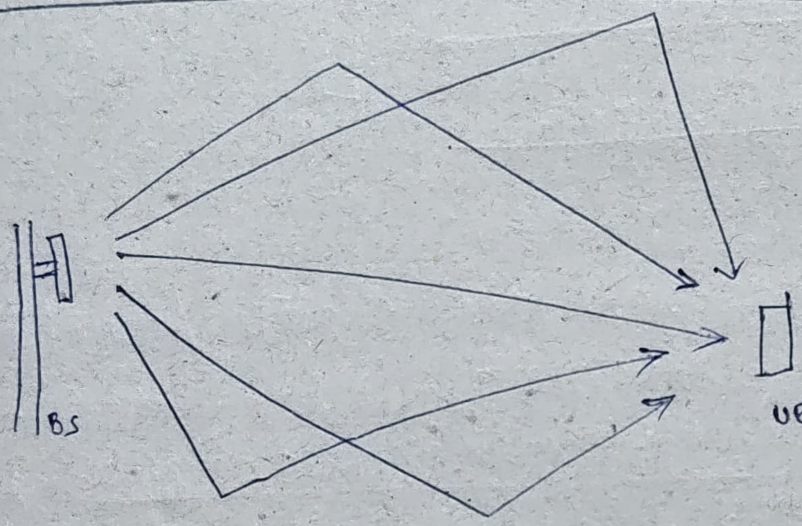
(i) When a BS sends a data packet, it should also send the configuration before PDSCH, which goes through a different channel called PDCCH. (ie) PDCCH carries the configuration, whereas the PDSCH carries data.

So, the receiver will first decode PDCCH to find out what configuration to apply, then it will decode PDSCH using that configuration.

(ii) The Same is applied to the UL also.
When the UE sends a data packet via PUSCH, since BS is the Master and UE is a Slave, the BS should communicate the configuration to the UE via PDCCH. UE uses this configuration and send the UL data via PUSCH. Here, as the

BS already knows the configuration (coz BS is the one that gave the configuration to the UE), it uses that configuration and decode PUSCH data.

So, this is how, the PDCCH, PDSCH and PUSCH are doing the data transfer.



Now, the signal that is transmitted (DL/UL), need not travel in a simple straight path. It may take multiple paths to reach the receiver. In this process, the phase and amplitude may change.

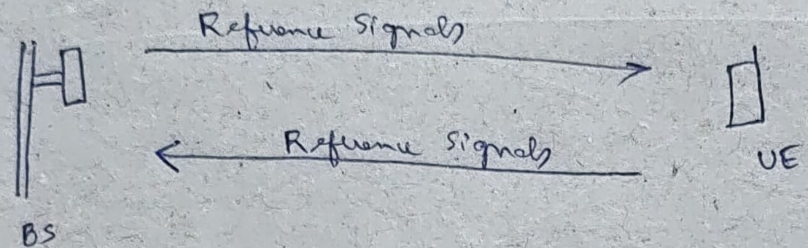
Also, the UE may move (Bike / Car / Train), when the data transfer is happening. UE may move closer to the BS, or away from the BS, at varying speed.

This means, the signal that is reaching the receiver and the path it takes is changing.

Now, when the receiver is decoding the data (PBCH / PDSCH / PUSCH / ...), the decoding is possible only when we know some information about the channel. The channel will vary continuously due to

- UE moving at a faster / slower speed
- UE inside a Lift / Basement / Room
- Even if UE doesn't move, something in the environment continuously changes.

So, the receiver should know some information about the channel (ie) how the channel is changing the signal. In order to facilitate this, so, that the receiver is able to decode the data, the transmitter should send some reference signals along with the data.

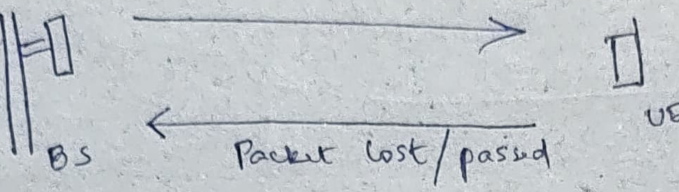


So, when transmitter sends data via PBCH / PDSCH / PUSCH, along with the data, there has to be reference signals. The way we design the RS, or the way we assign it may change, based on different scenarios.

The RS will help the receiver to find out the details about, "how the channel has changed the signal, whether it has changed the amplitude or phase, or how fast it is changing, and all". Then the receiver will be able to apply the impact of the respective change, correct / de rotate the signal, and then try to decode it.

These signals are known as DMRS, which goes along with the data.

Consider - the BS sent a signal to UE. Now, there should be a way, the receiver (UE) sends a signal back to the transmitter (BS), conveys Packet loss (or) Packet pass, based on which, the Transmitter (BS) may send the data packet again (if the packet is lost), or go ahead and send a new packet (if the packet is passed).

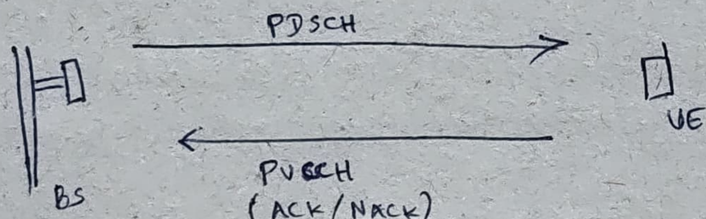


This decision should be taken based on the information provided by the receiver.

This is facilitated by CRC, which tells whether the packet passed or lost.

For broadcast information, we don't need this Packet Pass/Lost, coz the BS is continuously transmitting the same information. If UE fails to decode one, it tries the next.

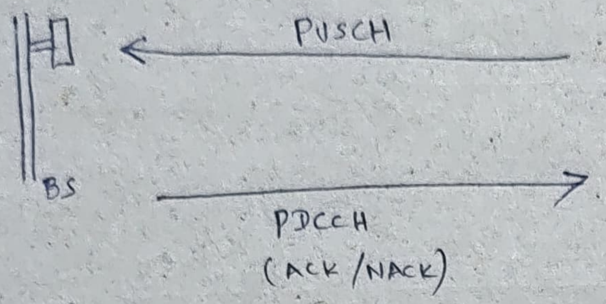
But for the actual data that is transmitted (PDSCH/PUSCH), lets discuss one by one.

(i) 

For PDSCH, that goes from BS to UE, there has to be a message from ~~BS~~ UE to BS, which conveys the information of the packet (PASS/FAIL), which is PUCCH.

Recall: PDCCH carries configuration for PDSCH and PUSCH both. Whereas the PUCCH here is carrying the ACK/NACK of PDSCH. Of course, the PUCCH carries other information as well (not discussed now). But it carries ACK/NACK for PDSCH, that helps BS to find out what happened to the last packet and what should I do next.

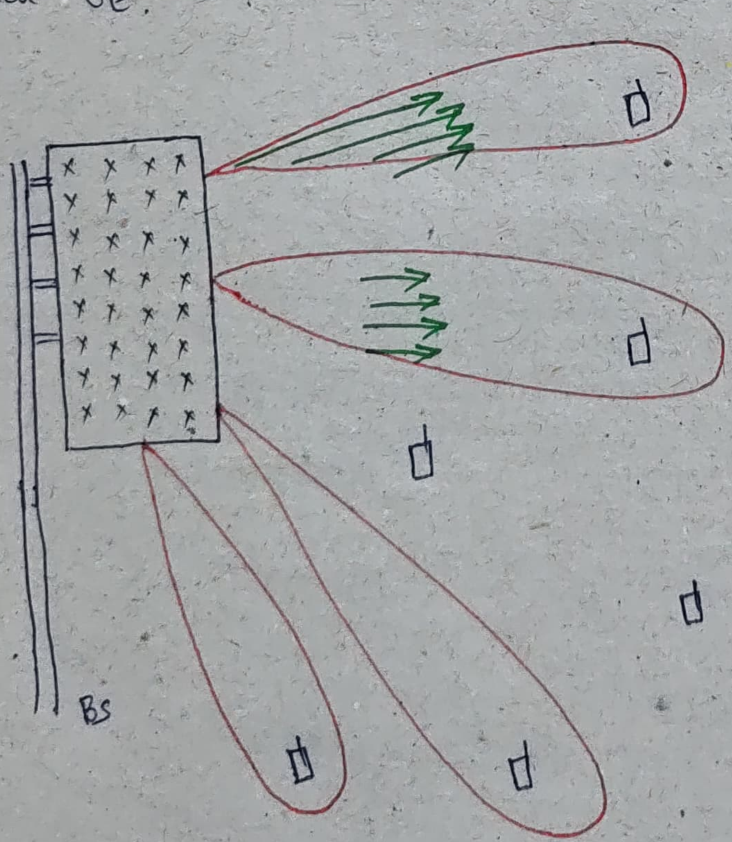
(ii)



When the UE is sending PUSCH, for this also, there has to be a way for the BS to tell UE whether the packet Passed / Lost. This is facilitated in the PDCCH itself. In PDCCH, already Control data (configurations) are present, this ACK / NACK (i.e.) CRC is transmitted in PDCCH itself.

In 5G, we can optimize the above whole process further, by using many, many antennas, both at the BS and UE.

By using multiple antennas, we can also direct the signal towards a particular UE, when we want to send data to that particular UE.



In this way, we can optimize the signal transmission further. In UE also, we can use multiple antennas. Use of multiple antennas in BS and UE, helps in many ways.

① We can transmit data parallely to multiple UEs, at the same time

② We can transmit multiple streams of data to a single UE, at the same time. Say, 4 parallel streams (4 layers of data) transmitted to a single UE.

③ We can also transmit multiple streams of data to multiple UEs, at the same time.

To facilitate this, the transmitter (BS) should know

- In which direction, the UE is ?
- What is the capability of that particular UE & channel? Whether this particular channel at this moment can support 4 parallel streams ? or it supports only 2 ? or it supports only 1 ? What's the condition out there ?

The transmitter (BS) has to know these information in advance, to facilitate this.

For this, there has to be another type of RS that help UE to find out the conditions. (ie) The UE will find out, "Right now, at this moment, the current channel (ie) b/w me and the BS can support 2 parallel streams; in this direction". or "This particular combination of Antennas work best for me".

This information is derived, by decoding the CSI-RS, which is DL reference signals, transmitted from BS to UE.

Similarly, there is a RS for the same purpose, transmitted in UL direction (UE to BS), named as SRS, which helps BS to find out, the channel b/w UE and BS, for UL transmission. It finds out, "How many parallel streams that particular UE can send in UL, and what resources works best for that particular UE", by decoding SRS.

So, the CSI-RS and SRS are two different RS in DL and UL respectively, that helps further optimize the data transfer. (ie) for high throughput / Beam Steering / parallel streams

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In 5G, there are two different set of frequencies.

* FR1 (aka) Sub-6 GHz Frequencies
  (410 MHz to 7.125 GHz)
* FR2 (aka) mm Wave
  (24.25 GHz to 52.6 GHz) or higher

In mmWave, very high frequencies are being used. There is a possibility that the Hardware may not perfectly generate the signals, in case of FR2. And hence, there is a possibility of having Phase Noise in the generated signals, because of Hardware impairments. The Phase Noise can be in both BS side and UE side.

Due to the phase noise, the Receiver may not be able to decode the data properly.

If the Receiver, can somehow finds this phase noise in the signal, it can correct it, so that it can decode the data correctly. Here, the data implies PDSCH / PUSCH.

In order to facilitate this, there has to be another reference signal, which should be designed in a way that, can help the receiver to decode the phase noise, and then it can be corrected. These signals are known as PTRS.
(ie) we need to track the phase of the signals, Apply it on the data and correct it.

This particular RS is used in mmWave Communication.

PSS
SSS
PBCH
PDSCH
PUSCH
PDCCH
PRACH
DMRS
PUCCH
CSI-RS
SRS
PTRS

- The goal was to send data via PDSCH and PUSCH.
- Everything else is overhead (ie) in order to facilitate the goal, there has to be many signals around.
- Apart from carrying the actual data, the PDSCH / PUSCH can also carry other information about the BS or UE (Heavy messages)

- In this course, we'll understand each signal and channel in detail.
- We'll understand, how these signals and channels are designed to facilitate what they are supposed to do.
- How the receiver will decode these signals.

Course Overview

* Essential Modules

- CRC
- Channel coding in 5G
- Rate matching for Polar & LDPC. [& LBRM]
- ZC and PN sequence
- Scrambling
- Modulation
- CP and OFDM
- Numerology, Frame, Slot, Subframe, Point A.
- Bandwidth Part and Resource Blocks
- Antennas and Beamforming
- Concept of DMRS, channel Estimation and Equalization.

* SSBurst

- Design of SSBurst signal
- PSS, SSS, PBCH and PBCH DMRS
- Time and Frequency Locations
- Receiver design

* PDCCH

- Transmitter Design and DMRS
- Receiver processing and blind decoding
- DCIs
- Coreset and Search space.

* PDSCH and PUSCH

- DMRS design and signal generation
- Transmitter design and time frequency allocations
- MCS tables and TB size calculations
- MIMO and Precoding
- UE multiplexing and resource allocation
- SU-MIMO and MU-MIMO.
- Transform precoding in PUSCH
- Codebook and non-codebook based MIMO in UL

* PRACH

- PRACH signal design and Transmitter processing
- Restricted sets, cyclic shift and timing offset
- Short and Long formats
- Understanding on Resource allocation
- Receiver design

* PUCCH

- F0 : Signal generation, Resource Allocation, Receiver design and UE multiplexing.
- F1 : DMRS design, Signal generation, Resource Allocation, Receiver design and UE multiplexing.
- F2 : Bit processing, CSI part 1 & 2, DMRS design, Signal generation and Receiver design.
- F3 : DMRS design, Signal generation and Receiver design and allocation
- F4 : DMRS design, signal generation, Resource allocation, Receiver design and UE multiplexing.

* CSI - RS

  - What is CSI-RS and why do we need it ?
  - Concept of CDM
  - Sequence generation and Mapping
  - CQI , RI and PMI
  - CSI - IM

* SRS

  - What is SRS and why do we need it ?
  - Sequence generation and Resource Mapping
  - Receiver design
  - TDD reciprocity and antenna switching

* PTRS for DL and UL

  - What is phase noise ?
  - Signal generation and Mapping
  - PTRS for PUSCH with Transmit precoding
  - Receiver design.

* HARQ
  - What is HARQ ?
  - CBG based transmission
  - HARQ Codebooks for PDSCH

* Additional Topics
  - 5G operating bands , SUL and SDL
  - RSRP and RSRQ
  - Sampling rates
  - ARFCN and GSCN
  - TDD Slot structure
  - Throughput Calculation
  - PAPR issue in OFDM