5G INTERFERENCE TDD

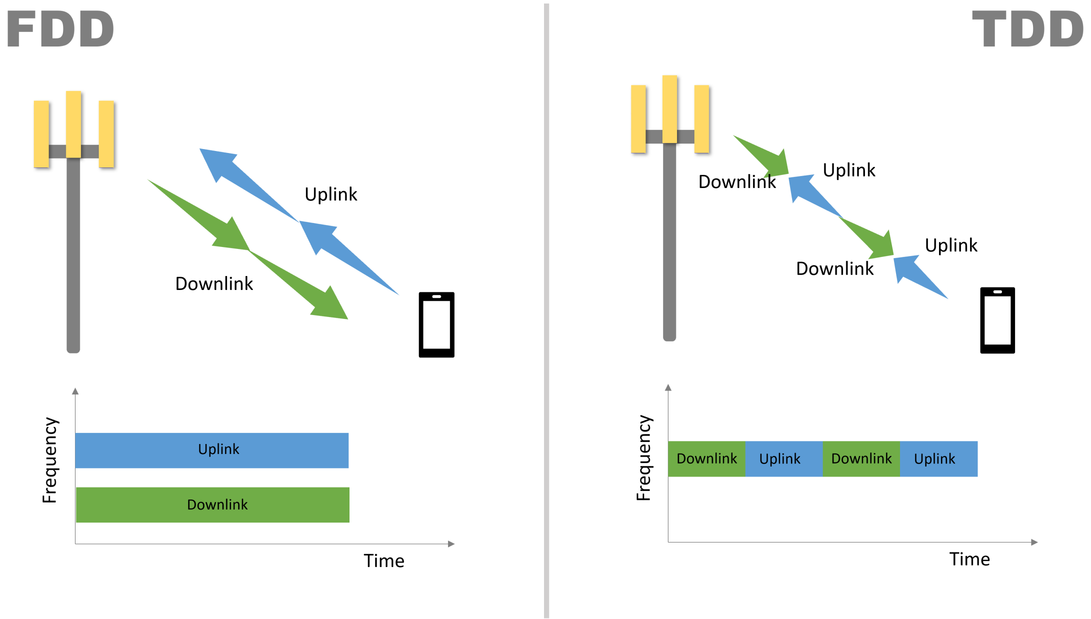
5G TDD Slot Formats & Interference

As explained previously in Battle of the Bands, most commercial 4G networks today have occupied all available FDD bands. This means 5G networks will primarily be launched at Time Division Duplexing (TDD) bands. It will be the first time that Time Division Duplexing (TDD) bands will have a major network footprint. **For RF engineers, the challenge starts with understanding the implications of managing the TDD networks, especially since TDD bands are prone to various types of interference, which in turn, decreases network performance.** In this article, we will try to cover the below points.

1. What is TDD?

As explained previously in Battle of the Bands, TDD architecture uses a single frequency band to transmit and receive. In simple words, it is a system that shares the same band and assigns alternative time slots for transmitting (downlink) and receiving (uplink), whereas FDD needs two different frequency bands, one for transmitting (downlink) and one for receiving (uplink), with sufficient frequency gap allocated between them, which is called a duplex distance.

The disadvantage of FDD is the separate frequency band allocation for downlink and uplink, as it requires sufficient duplex distance between downlink and uplink part of the band. This can be very difficult due to the available spectrum band allocation. Moreover, the required duplex distance increases when carrier frequency increases. Because of these challenges, once we move above the 3GHz spectrum, TDD starts to be more attractive, and at the FR2 (mmWave) spectrum, TDD is the one and only option.



Well, It looks very simple that during the time of the downlink slot, gNb transmits the data, and the user will receive the data from the gNb. During the time of the uplink slot, the user transmits the data, and gNb will be receiving during that time. Well, this is not the case in real life; neither User or gNB experience the same timing; this is due to the factor called "Propagation Delay" & "Switching Time.", as explained in the infographic below.

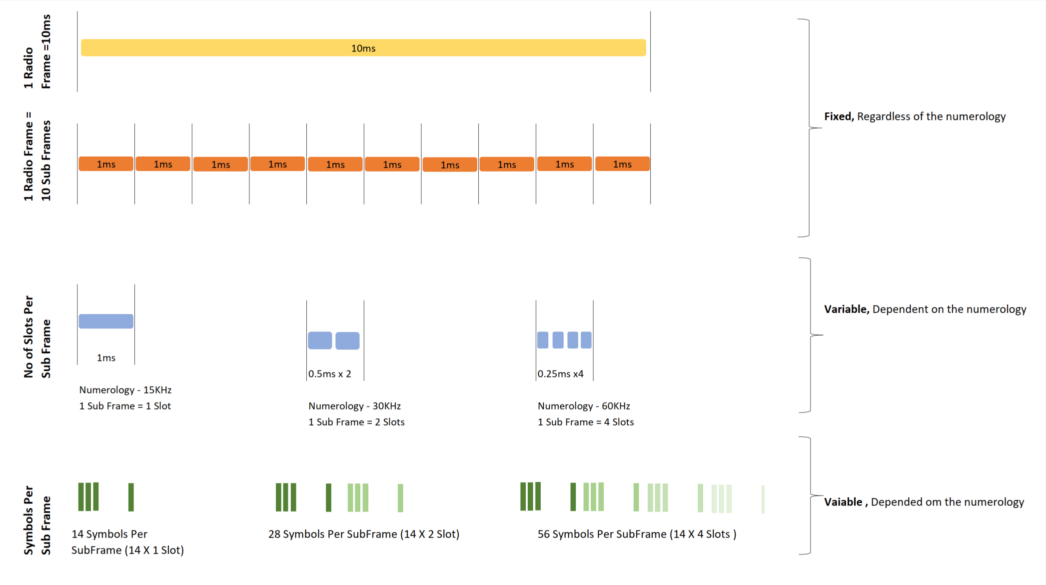
This means that during DL/UL transmissions, the guard period must be long enough to accommodate the propagation delay and switching time. The infographic below explains that during the downlink slot, gNB transmits the data, and the user will receive data with some delay, i.e. propagation delay. The purpose of the below explanation will be more clear when we will come to point 5: Intra System TDD Interference.

During switching, UE takes some time to switch its transceiver from receive to transmit mode. UE starts its transmission according to the Timing Advance (TA) value from the gNB. gNB uses Timing Advance (TA) mechanism to make sure that all the uplink transmissions are received with equal timings.

Note: Timing Advance (TA) is actually a negative offset, between the start of a received downlink subframe and a transmitted uplink subframe. This offset is a must to ensure that the downlink and uplink are synchronized at the gNB end.

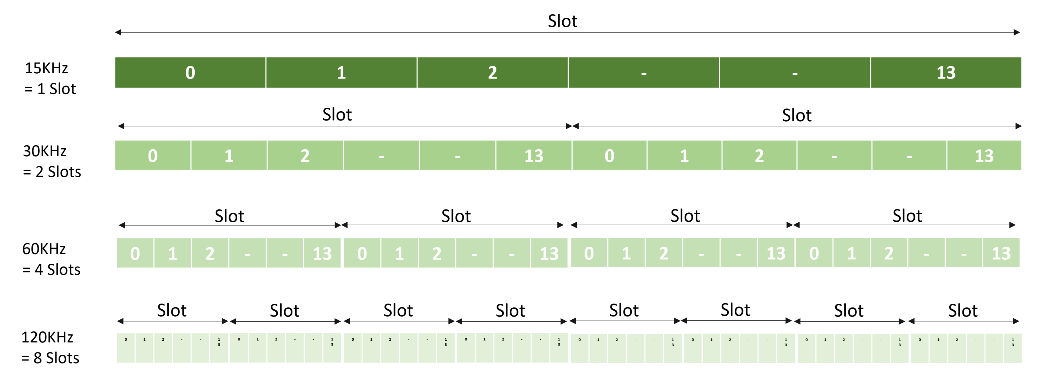
2. What is TDD Slot Format?

To understand the 5G TDD slot format, let's recall the 5G Radio Frame: 5G radio frame has a fixed duration of 10ms, and subframes have a fixed duration of 1ms. So there are always 10 subframes within 1 radio frame. 5G slot & symbol duration depend on the numerology, as explained in the picture below.



5G Frame Structure

The below figure explains the configuration of the slot/symbols based on the numerology. 15KHz subcarrier spacing is the same as 4G, 1 subframe has 1 slot of same 1ms length, and with 30KHz subcarrier spacing, 1 subframe is equal to 2 slots of 0.5ms duration each.



Slots & Symbols Per Subframe

In 5G FDD, symbols that belong to the DL carrier are used for gNB transmission, and symbols belong to the UL carrier are used for UE transmission. In TDD, we have a single carrier, 1 subset of which is used for DL (gNB transmission), while 1 subset is used for UL (UE transmissions), and the third subset is used for DL/UL switching and guarding against the impact of air-interface propagation delay. This distribution is defined by Slot format, i.e. which symbols are used for which purpose.

3GPP has allowed only 61 predefined combinations within a slot as in the following table, but an unlimited combination can be formed.

Slot

Format	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F
5	D	D	D	D	D	D	D	D	D	D	D	F	F	F
6	D	D	D	D	D	D	D	D	D	D	F	F	F	F
7	D	D	D	D	D	D	D	D	D	F	F	F	F	F
8	F	F	F	F	F	F	F	F	F	F	F	F	F	U
9	F	F	F	F	F	F	F	F	F	F	F	F	U	U
10	F	U	U	U	U	U	U	U	U	U	U	U	U	U
11	F	F	U	U	U	U	U	U	U	U	U	U	U	U
12	F	F	F	U	U	U	U	U	U	U	U	U	U	U
13	F	F	F	F	U	U	U	U	U	U	U	U	U	U
14	F	F	F	F	F	U	U	U	U	U	U	U	U	U
15	F	F	F	F	F	F	U	U	U	U	U	U	U	U
16	D	F	F	F	F	F	F	F	F	F	F	F	F	F
17	D	D	F	F	F	F	F	F	F	F	F	F	F	F
18	D	D	D	F	F	F	F	F	F	F	F	F	F	F
19	D	F	F	F	F	F	F	F	F	F	F	F	F	U
20	D	D	F	F	F	F	F	F	F	F	F	F	F	U
21	D	D	D	F	F	F	F	F	F	F	F	F	F	U
22	D	F	F	F	F	F	F	F	F	F	F	F	U	U
23	D	D	F	F	F	F	F	F	F	F	F	F	U	U
24	D	D	D	F	F	F	F	F	F	F	F	F	U	U
25	D	F	F	F	F	F	F	F	F	F	F	U	U	U
26	D	D	F	F	F	F	F	F	F	F	F	U	U	U
27	D	D	D	F	F	F	F	F	F	F	F	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	F	U
29	D	D	D	D	D	D	D	D	D	D	D	F	F	U
30	D	D	D	D	D	D	D	D	D	D	F	F	F	U
31	D	D	D	D	D	D	D	D	D	D	D	F	U	U
32	D	D	D	D	D	D	D	D	D	D	F	F	U	U
33	D	D	D	D	D	D	D	D	D	F	F	F	U	U
34	D	F	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	F	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	F	U	U	U	U	U	U	U	U	U	U
37	D	F	F	U	U	U	U	U	U	U	U	U	U	U
38	D	D	F	F	U	U	U	U	U	U	U	U	U	U
39	D	D	D	F	F	U	U	U	U	U	U	U	U	U
40	D	F	F	F	U	U	U	U	U	U	U	U	U	U
41	D	D	F	F	F	U	U	U	U	U	U	U	U	U
42	D	D	D	F	F	F	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	F	F	F	F	U
44	D	D	D	D	D	D	F	F	F	F	F	F	U	U
45	D	D	D	D	D	D	F	F	U	U	U	U	U	U
46	D	D	D	D	D	D	F	D	D	D	D	D	D	F
47	D	D	D	D	D	F	F	D	D	D	D	D	F	F
48	D	D	F	F	F	F	F	D	D	F	F	F	F	F
49	D	F	F	F	F	F	F	D	F	F	F	F	F	F
50	F	U	U	U	U	U	U		U	U	U	U	U	U
51	F	F	U	U	U	U	U	F	F	U	U	U	U	U
52	F	F	F	U	U	U	U	F	F	F	U	U	U	U
53	F	F	F	F	U	U	U	F	F	F	F	U	U	U
54	D	D	D	D	D	F	U	D	D	D	D	D	F	U
55	D	D	F	U	U	U	U	U	U	F	U	U	U	U
56	D	F	U	U	U	U	U	D	F	U	U	U	U	U
57	D	D	D	D	F	F	U	D	D	D	D	F	F	U
58	D	D	F	F	U	U	U	D	D	F	F	U	U	U
59	D	F	U	U	U	U	U	D	F	U	U	U	U	U
60	D	F	F	F	F	F	U	D	F	F	F	F	F	U
61	D	D	F	F	F	F	U	D	D	F	F	F	F	U

5G Slot Formats

Let’s take an example of slot format 29. This slot format has 11 symbols for DL transmission, 1 symbol for UL reception, and two are free. This means that user being served with this slot format will receive approx 78.5% DL Transmission, and only have 7.14% for UL, and remaining is free.

3. TDD Types (Static / Dynamic)

5G TDD has two TDD types: Static & Dynamic. Both have their own

advantages and disadvantages.
Static: It is the type in which the UL/DL ratio (slot format type) is decided only once, i.e. while designing the network, by the statistical analysis of the network's downlink and uplink volume.

- High Uplink Requirements (e.g., slot format 1): Events like sports matches, music concerts will require more uplink traffic, as videos & pictures upload to social media (YouTube, Facebook, etc.)
- High Downlink Requirements (e.g., slot format 0): Activities like streaming of the high definition video contents like 4K (e.g., Netflix, etc.)

Dynamic: 5G supports multiple applications; dynamic slot configurations has become a vital technology of 5G. In dynamic TDD, dynamic resource allocation between DL and UL will provide significant performance improvements, as resources can be allocated dynamically based on the traffic needs.
In Dynamic TDD operations, UE does not know the DL/UL format of the frame, rather, it operates based on the scheduling information available in the PDCCH (Physical Downlink Control Channel)
However, dynamic TDD also brings out additional cross-link interference that may degrade system performance.

4. Cross Link/Slot Interference

Dynamic TDD allows adaptive configuration and reconfiguration of symbols between UL and DL. This enables the gNB 1 to configure the DL/UL, based on traffic requirements, similarly, neighboring gNB 2 can also configure the DL/UL based on its own traffic requirements, without coordinating with gNB 1.

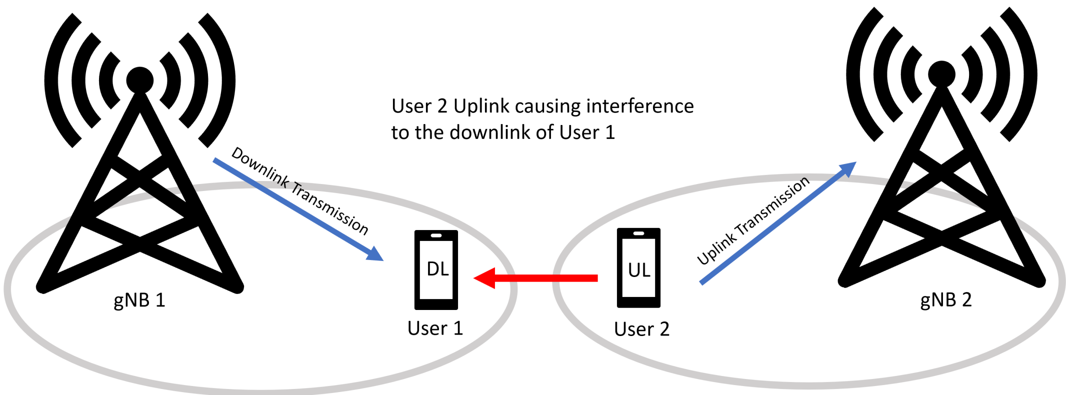
This means gNB 1, transmitting in the downlink, meanwhile neighboring gNB is receiving in the uplink, this kind of situations leads to cross-link interference.

There are two types of cross-link interference in dynamic TDD mode of 5G.

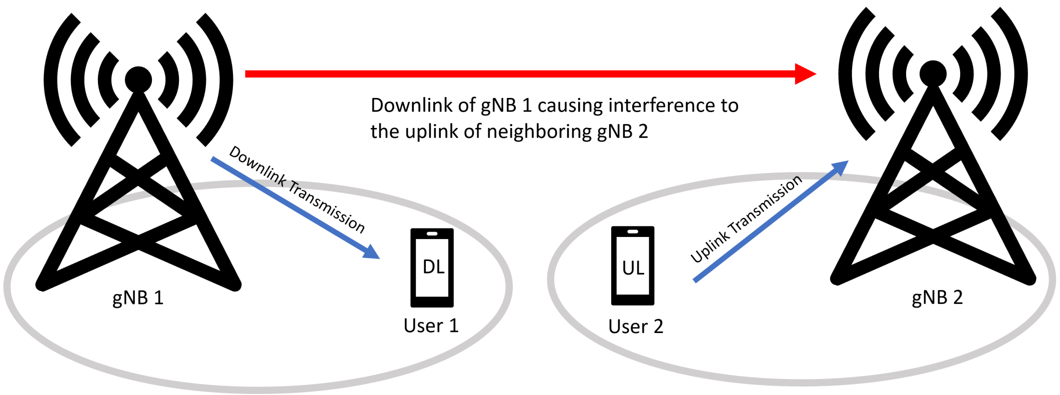
- UE to UE Interference
- gNB to gNB Interference

Let's discuss UE to UE interference first, since the user density of 5G devices will be high, compared to 4G (up to 1 Million connections per square kilometer), UE-UE cross-link interference becomes more critical.

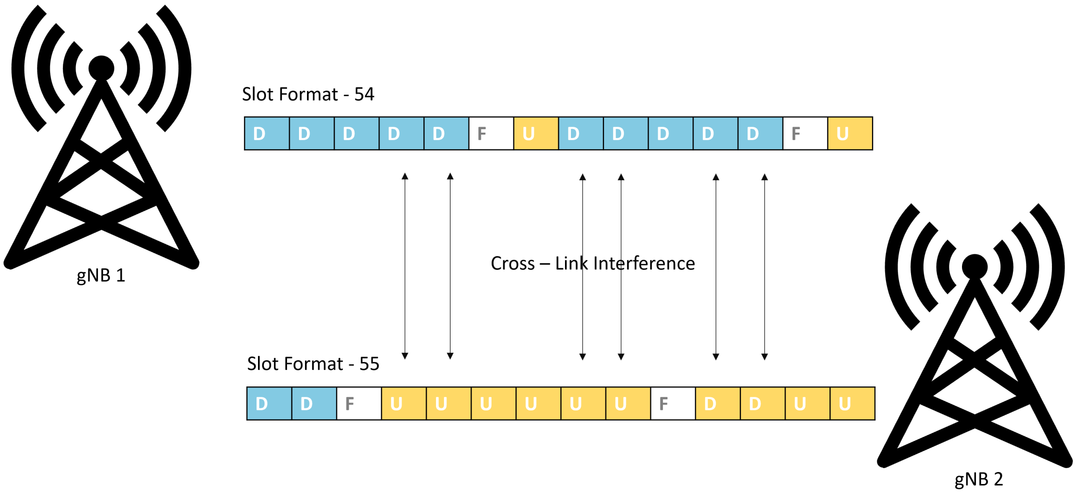
UE to UE Interference:



eNB to eNB Interference:



This means there is a possibility that at any given instant, gNB 1 may be transmitting, and neighboring gNB 2 will be receiving at the same time. This scenario will cause cross-link interference, and cross-link interference is also called cross-slot interference.



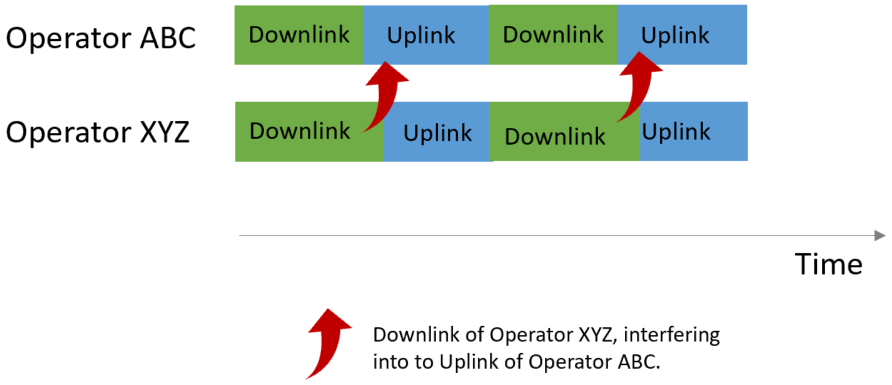
Optimization: Cross-link interference mitigation is not specified in 3GPP Release 15. However, vendors are open to implementing their specific SON techniques based on network requirements. Detailed specification is planned to be introduced in 3GPP Release 16.

One question that can arise is why cross-link interference was not observed in 4G TDD.

Answer: In 4G, all eNBs in the network share the same slot configurations. Initial 5G deployments will most likely use static format due to the challenges associated with the dynamic format. 3GPP has also identified the solution to this problem, by controlling the timings of uplink and downlink control regions, this will be covered in another article soon.

5. TDD Intra System Interference

The absence of synchronization, is the main source of interference in TDD based systems, belonging to the same carrier or different carrier. The figure below provides a quick overview of the asynchronous situation between different carriers. In simple words, we call it Inter-carrier Interference.



However, interference can also come within the same synchronized carrier, due to the propagation delay called Intra-carrier Interference. Propagation delay can create an overlapping of the DL/UL slots, which will result in interference.

TDD interference can cause network performance degradation, mainly due to downlink transmission interfering with uplink reception since downlink has high transmitted power than uplink. To protect the uplink from downlink interference, the guard period is extended. However, it is a possibility that due to certain atmospheric conditions and clutter types, downlink transmission can travel very large distances and interfere uplink part despite the guard band.

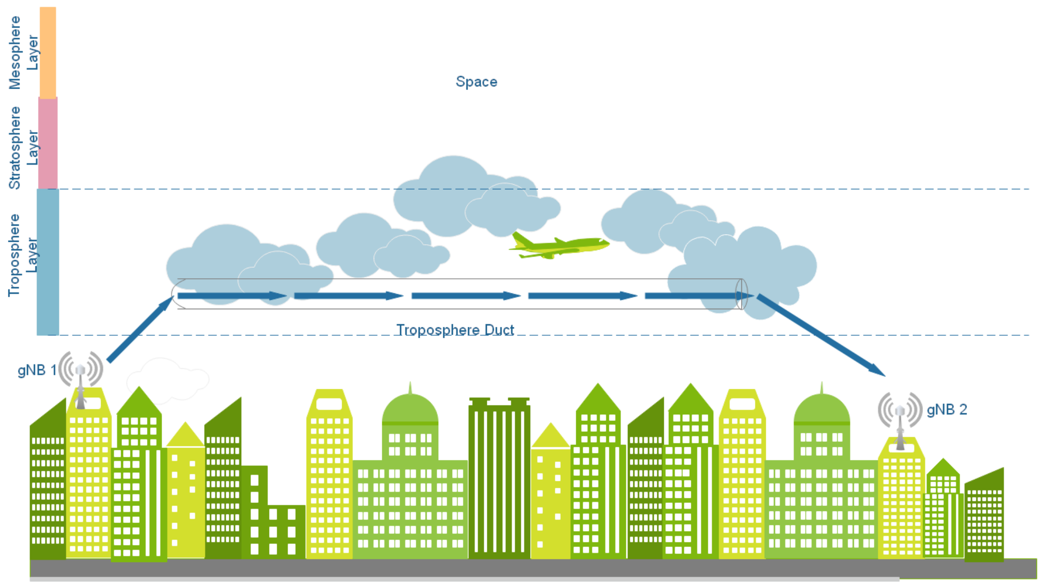
For example, the following two scenarios can cause downlink transmission to travel a large distance.

1) Tropospheric Ducting

2) Coastal Areas

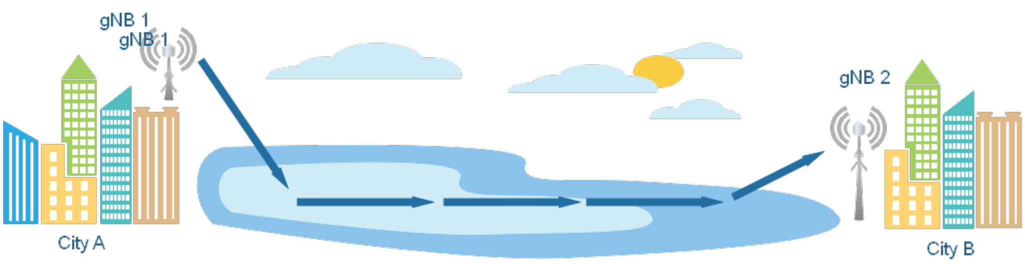
Let's start with a tropospheric ducting first. The **troposphere** is the lowest layer of Earth's atmosphere and is also where nearly all weather conditions take place.

In the lowest part of the tropospheric layer, friction with the Earth's surfaces influences airflow. During certain atmospheric conditions, layering of the air in the troposphere layer may form a waveguide. This phenomenon is called ducting. Radio signals that enter into the duct can travel several kilometers.



As shown in the above example, downlink signals from gNB 1, travel very far due to troposphere duct and interfere with the uplink of gNB 2. This ducting phenomenon can last for anything between a few minutes to several hours or days.

Coastal Areas: Footprint of the radio waves propagation through water is very large compared to a footprint on the land. This phenomenon can also cause radio signals to travel several kilometers. Downlink transmission can travel very large distances and interfere uplink part despite the guard band.



> **This is a large scale phenomenon, and multiple gNB can interfere due to this, and impact network performance**

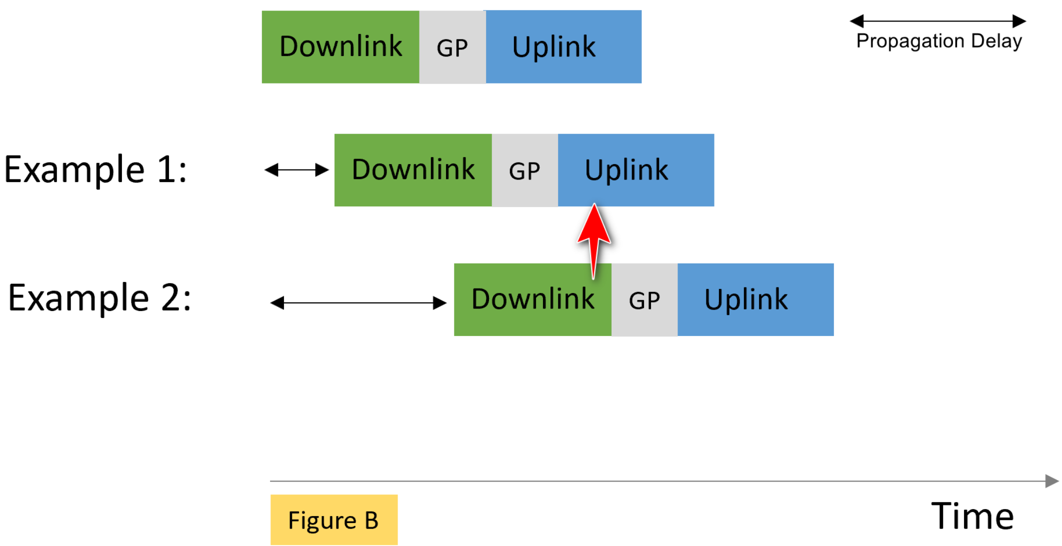
In the below example, we will try to explain the above phenomenon in terms of UL/DL slot architecture.

Figure A: Slot format without any guard period.

Figure B: Sot format with a guard period.

For example, 1: Propagation delay is accommodated within the guard period, so the downlink slot does not interfere with uplink.

For example, 2: Propagation delay is very large due to, e.g., “Troposphere Duct Phenomenon”, downlink passes the guard period and interferes with the uplink.



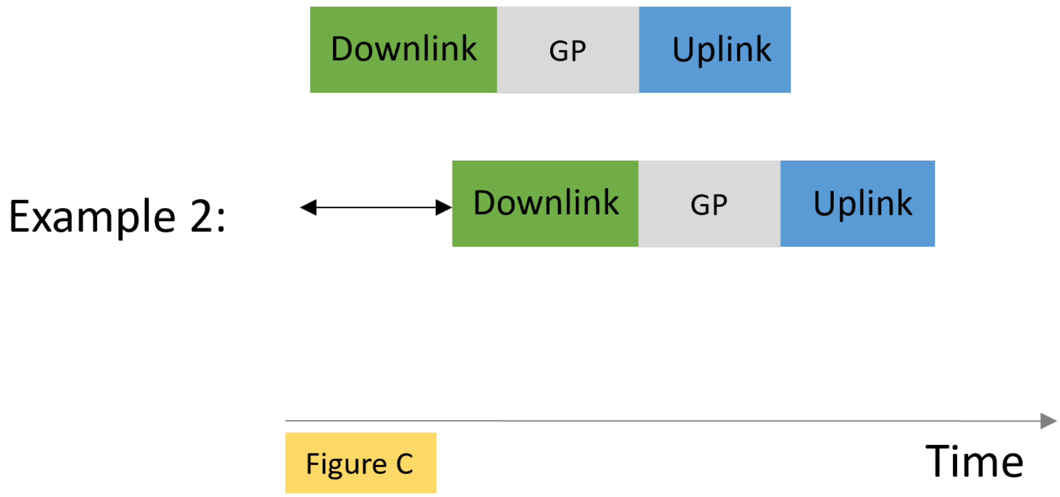
Optimization: Multiple steps can be performed to overcome TDD interference:

1. Physical Optimization, like down tilting to minimize the antenna radiation entering into troposphere duct.

2. Parameter Optimization like reducing the downlink power, which will decrease the footprint, and chances of interference will be less.

3. Or by increasing the guard period.

Figure C: Sot format with a large guard period to accommodate the large path delay, but a large guard period reduce the network capacity.



Why GP is only needed while switching from DL to UL and not the other way around: UE always transmit in UL after receiving a grant from the Base Station (BS). BS can advance or retard the UL timing command as needed. Once the DL signal is received completely, then UE can send command in return with respective timing (UE is not allowed to transmit on its own before receiving a complete response on the DL). So we need a guard period between DL to UL switching, to avoid interference. Whereas in the case of UL to DL switching, there is no need for Guard period, as base station has Timing Advance feature.

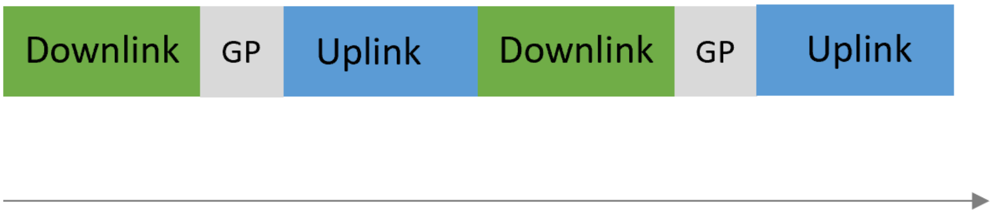
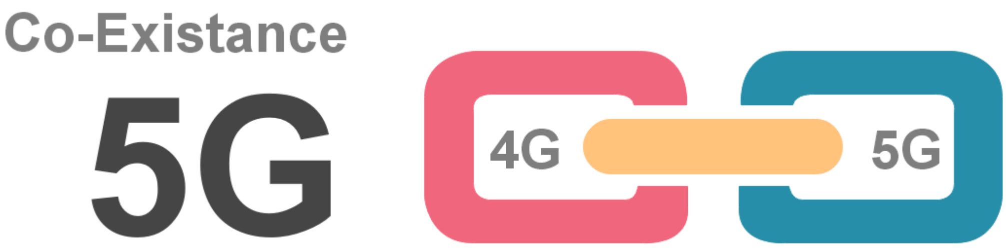


Figure D

For the next article, we are working on EN-DC Interference and avoidance; stay tuned.



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