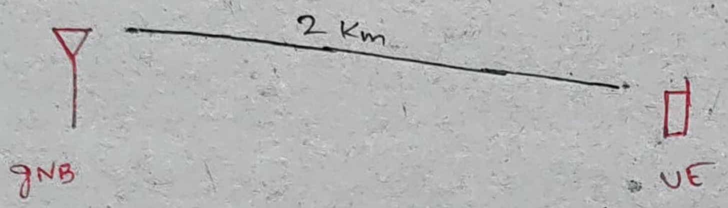
# Timing Advance : What is it and Why it matters ?

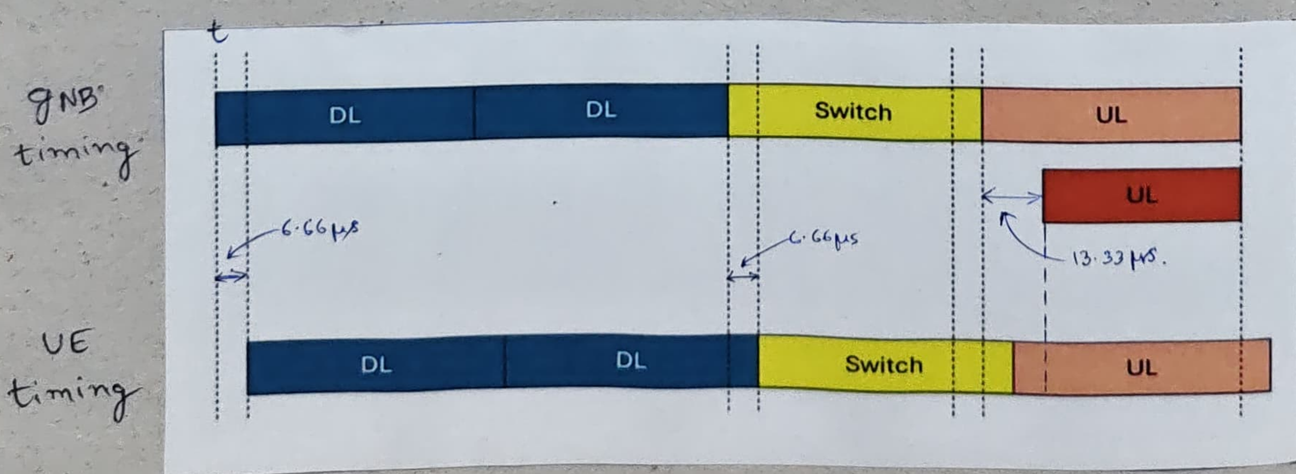
Lets understand what is Timing Advance and why do we need timing advance in the system ? In order to understand the TA, lets understand the timing diagram.




Consider the gNB and UE are 2Km away from each other. The signal that gNB transmits in DL travels 2 Kms to reach the UE. Similarly, the signal that UE transmits in UL travels 2 Kms to reach the gNB. So, the time taken for the signal to travel 2 Kms is

$$t = \frac{\text{distance}}{\text{speed}} = \frac{2 \times 10^3 \text{ m}}{3 \times 10^8 \text{ m/s}} = 6.66 \, \mu s$$

So, the signal will reach after 6.66 μs whenever the gNB transmits, to UE. And the same time is taken will be taken whenever UE transmits to gNB.



The gNB starts transmitting signal at time t. This signal travels 2 Kms and takes 6.66 µs to reach the UE.

Now, when the UE transmits UL signal, it will again takes 6.6 µs to reach the gNB. So, in total, the UL signal delays by 13.33 µs to reach the gNB.

What is Timing Advance (TA) ?

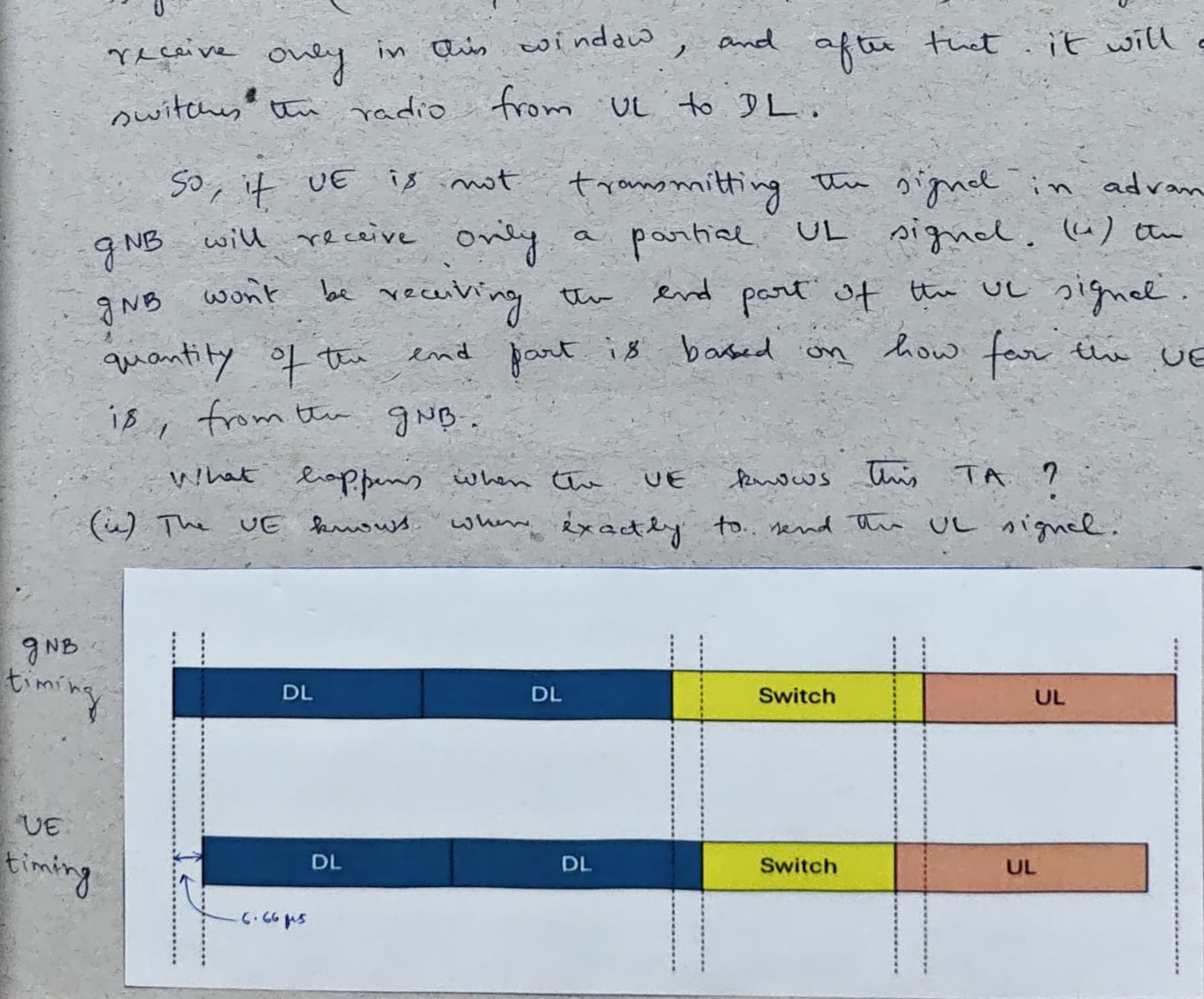
Here, gNB need to communicate to the UE that, "UE is supposed to transmit UL signal, in advance", so that the UL signal reaches the gNB at perfect time.

Here, the gNB switches the radio from DL to UL, and it opens the reception window for a particular time. This time is fixed, where the gNB will be receiving UL data from all the UEs whoever wants to transmit whatever signal is. (PRACH / PUSCH / PUCCH / SRS / ...). The gNB will receive only in this window, and after that it will again switches the radio from UL to DL.

So, if UE is not transmitting the signal in advance, gNB will receive only a partial UL signal. (ie) the gNB won't be receiving the end part of the UL signal. This quantity of the end part is based on how far the UE is, from the gNB.

What happens when the UE knows this TA ?

(ie) The UE knows when exactly to send the UL signal.



Here, the UE receives the DL signals after 6.66 μs. And the UE sends the UL signals 6.66 μs in advance w.r.t the gNB reception window. From UE's perspective, it is transmitting the UL signals 13.33 μs in advance.

So, the TA communicated to the UE helps to send the UL signal right at time, so that it goes to the gNB reception window perfectly, hence the gNB decodes the UL signal.

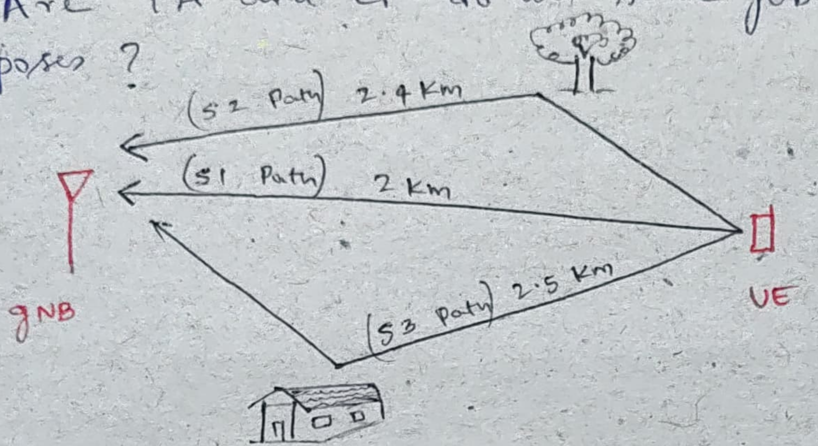
If the timing window is incorrect / not applied, then the gNB will miss the UL signal and decoding will fail whatever the signal is. (PUSCH/PUCCH/PRACH/SRS/...).

$$\text{Speed} = \frac{\text{distance}}{\text{time}}$$

$$\Rightarrow \text{time} = \frac{\text{distance}}{\text{Speed}}$$

# Timing Advance VS Cyclic Prefix (ISI VS Propagation delay)

Are TA and CP do the same job (or) for different purposes?



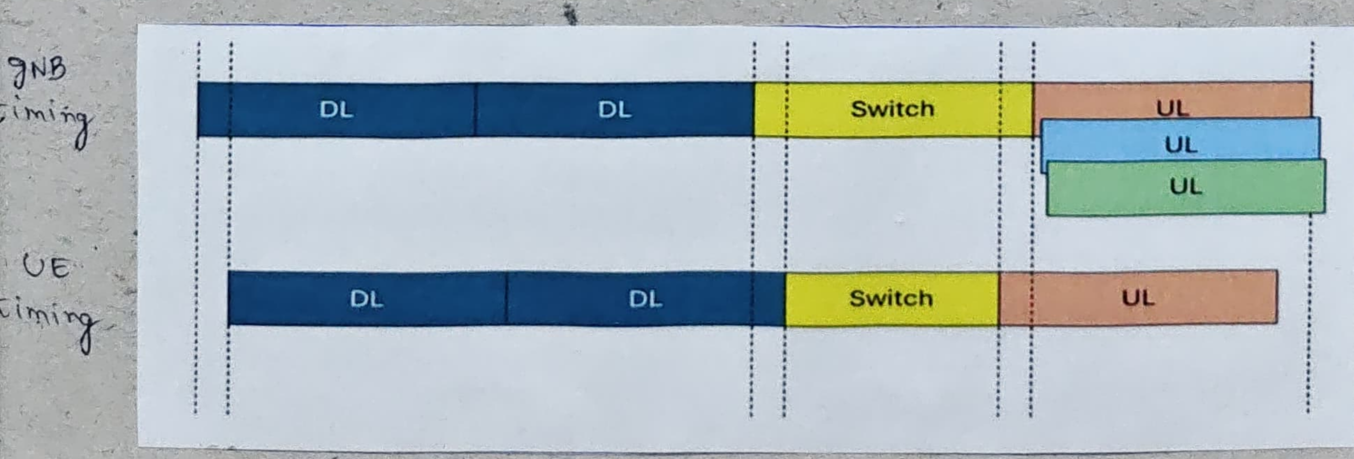

Assume, UE is 2 Km away from gNB. When UE sends UL signal, it travels 2 Km to reach the gNB. WKT, there are multiple copies received by the gNB after the reflections. Lets consider 3 such paths (S1, S2 and S3) as below.

S1 path → 2 Kms → takes $t = \dfrac{2 \times 10^3 \, m}{3 \times 10^8 \, m/s} = 6.66 \, \mu s$.

S2 path → 2.4 Kms → takes $t = \dfrac{2.4 \times 10^3 \, m}{3 \times 10^8 \, m/s} = 8 \, \mu s$

S3 path → 2.5 Kms → takes $t = \dfrac{2.5 \times 10^3 \, m}{3 \times 10^8 \, m/s} = 8.33 \, \mu s$

So, as we see, the same signal which is transmitted from UE, reaches the gNB at different times. (ie) gNB receives multiple copies of the same signal with some delay



If the UE transmits the UL signal in advance (say 6.66 μs), the first copy (via S1 path) reaches the gNB right at time; the second copy (via S2 path) reaches the gNB after 1.33 μs (8 μs - 6.66 μs), the third copy (via S3 path) reaches the gNB after 1.66 μs (8.33 μs - 6.66 μs).

- So, the Timing Advance (TA) takes care of, how much in advance UE is supposed to send the signal to gNB so that it reaches the gNB UL window right at time.

And, since the UE transmitted signals, travelled through multiple paths and reached the gNB at multiple instances. This multipath delays are taken care by Cyclic prefix (CP).

So, the <u>6.66 μs delay</u> that the UE is transmitted in advance, is taken care by TA.

And, the <u>1.66 μs delay</u> due to the multipath propagation is taken care by CP. (ie) Every symbol will have CP in advance, to make sure that there is no Inter-symbol Interference (ISI).

<u>Summary</u>:

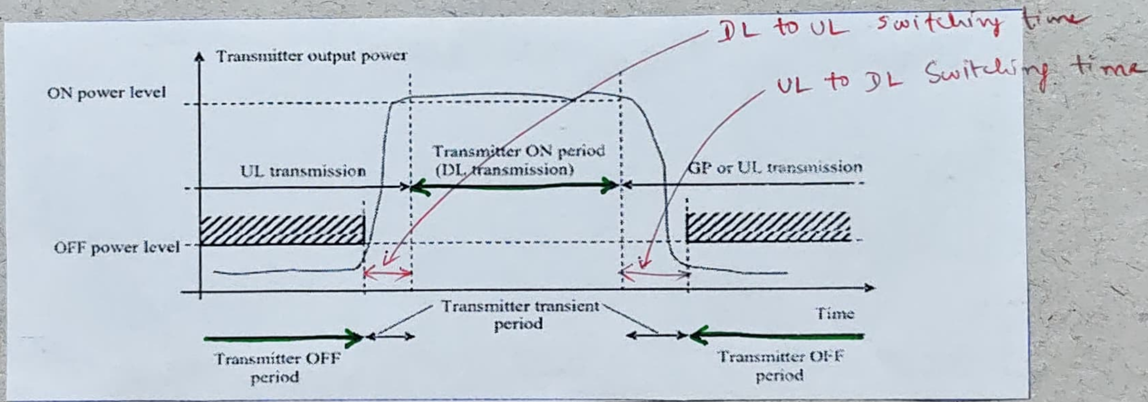
- CP is used to reduce ISI
- TA is used to make sure the signal reaches at the right time in the right boundary.

# Timing Advance in TDD vs FDD : (Differences in Timing adjustments)

So far we've seen the TA, because of the propagation delay, where the signal goes from BS to UE (or) from UE to BS takes some time, and the transmitter has to send the UL signal in advance, to make sure that the signal reaches the receiver right on time.

But, are there any other parameters which might impact this? Yes!

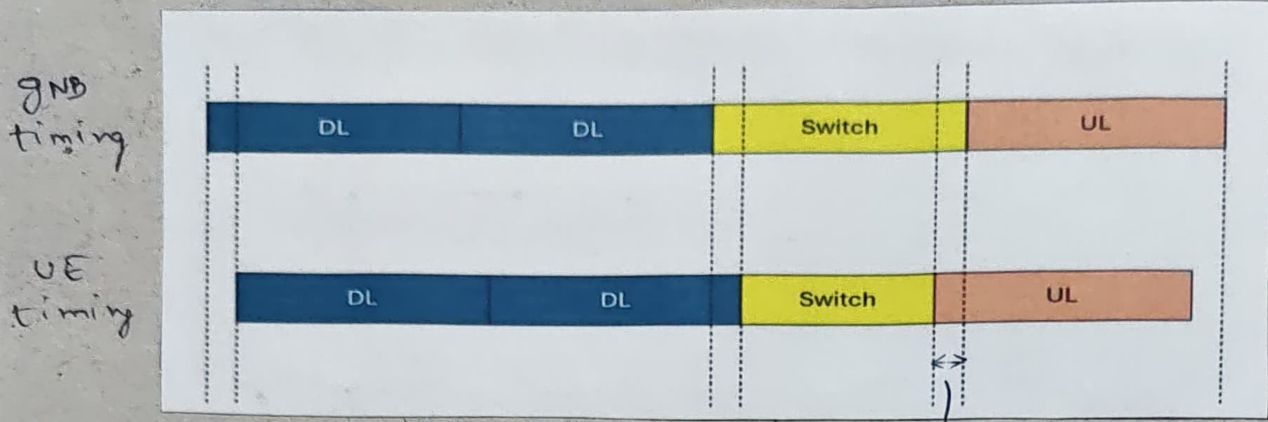
The UL to DL switching (or) DL to UL switching takes some time. (Transition period).



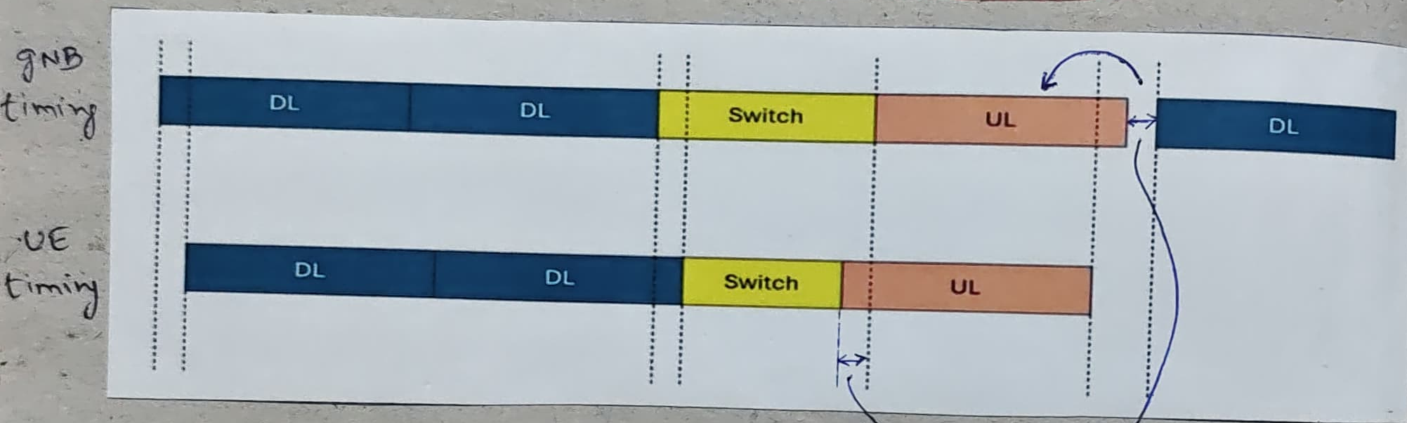

Refer 38.104

From UL transmission to DL transmission (whether the transmitter is ON / OFF), it takes some time to switch. This switching time is significant. (ie) when gNB is transmitting, before that, it needs some time to switch off UL and start transmission in DL.

Lets understand this from the Timing diagram.




WKT, UEs are supposed to send UL in this much advance, due to the propagation delay.




Now, because of the switching, UEs have to further advance its UL transmission. How much? Defined in specification.

Above figure illustrates, UL to DL switching in gNB does not happen in no time. It takes some time to switch. Because of this, the UL is further moved at the gNB ahead in time. This time is compensated in the switching symbols. And because of this, eventually, UE has to send the UL signal further in advance.

**Table 9.5.3.2-1: Minimum requirement for the OTA transmitter transient period for *BS type 1-O***

| Transition | Transient period length (µs) |
|---|---|
| OFF to ON | 10 |
| ON to OFF | 10 |

FR 1

**Table 9.5.3.3-1: Minimum requirement for the OTA transmitter transient period for *BS type 2-O***

| Transition | Transient period length (µs) |
|---|---|
| OFF to ON | 3 |
| ON to OFF | 3 |

FR 2

Refer 38.104

(ii) For FR1, the transient period is 10 µs and
For FR2, the transient period is 3 µs.

Table 7.6.4-1: Maximum receive timing difference requirement for intra-band non-contiguous NR carrier aggregation

| Frequency Range | Maximum receive timing difference (µs) |
|---|---|
| FR1 | 3 |
| FR2 | 3 |

Apart from the transient period, two Base stations may not be perfectly synchronized. They may have a maximum error of 3µs, which is allowed. So, this BTS-to-BTS synchronization error is also considered and compensated along with the switching delay.

So, the total transient period becomes

For FR1, 10 µs + 3 µs = 13 µs

For FR2, 3 µs + 3 µs = 6 µs

So, UE has to send the signal in advance, due to

- Propagation delay
- Switching period
- BTS-BTS sync. error

Since we account for DL and UL both, the UL TA is

(2 × Propagation delay) + (Switching period) + (BTS-to-BTS sync. Error).

Note:

The switching period is not applicable for FDD case.

Now, let us see how 3GPP has defined these delays.

Table 7.1.2-2: The Value of $N_{TA\ offset}$

| | Frequency range and band of cell used for uplink transmission | $N_{TA\ offset}$ (Unit: Tc) |
|---|---|---|
| 1 | FR1 FDD band without LTE-NR coexistence case or FR1 TDD band without LTE-NR coexistence case | 25600 (Note 1) |
| 2 | FR1 FDD band with LTE-NR coexistence case | 0 (Note 1) |
| 3 | FR1 TDD band with LTE-NR coexistence case | 39936 or 25600 (Note 1) |
| 4 | FR2 | 13792 |

When FR1 goes with LTE-NR coexistance in the Dynamic Spectrum Sharing, then we'll have to consider LTE Switching time as well.

When FR1 goes without LTE, then we'll consider NR switching time alone.

① FR1 FDD/TDD without LTE-NR coexistence, the total transient period is 13 μs.

(ie) $13 \times \underbrace{480 \times 10^3 \times 4096} = 25559.040\ T_c$

$\approx 25600\ T_c$

② FR1 FDD with LTE-NR coexistence, the total transient period is $0\ T_c$

③ FR1 TDD with LTE-NR coexistance, the total transient period is $624\ T_s = 39936\ T_c$

(or)

$25600\ T_c$

④ FR2 (Not defined with coexistence), the total transient period is 6 μs (with 1 μs overhead).

So, 7 μs.

(ie) $7 \times \underbrace{480 \times 10^3 \times 4096} \approx 13792\ T_c$

In summary, the UE has to send the UL signal in advance, and it is supposed to account $N_{TA\ offset}$ and Propagation delay.

# Timing Advance Calculation & Formula

(Understanding the TA equation)

From the previous section, WKT the UE has to send the UL signal in advance. The advance duration depends on Propagation delay, UL/DL switch delay and BTS-BTS synchronization error. This duration is particularly defined and fixed, based on the deployment scenarios.

The propagation delay is always calculated and communicated to the UE. (Not just one side, but round trip propagation)

So, UE has to send the signal in advance by

$$(2 \times \text{Propagation delay}) + \underbrace{\begin{pmatrix}\text{UL/DL Switch} \\ \text{Delay}\end{pmatrix} + \begin{pmatrix}\text{BTS to BTS} \\ \text{Sync. Error}\end{pmatrix}}$$

$$\Rightarrow (2 \times \text{Propagation delay}) + N_{TA\ offset} * T_C \text{ (unit)}$$

$$\Rightarrow \left(\frac{2 \times \text{Propagation delay}}{T_c} + N_{TA\ offset}\right) * T_c$$

$$\Rightarrow \left(N_{TA} + N_{TA\ offset}\right) * T_c$$

---

So, the gNB will calculate this propagation delay based on the PRACH signal sent by the UE. And the gNB has to send this delay back to the UE.

But, gNB does not send this $N_{TA}$ directly to the UE. Instead, it quantizes $N_{TA}$ and sends to UE. This quantization depends on the subcarrier spacing.

So, what gNB sends to UE is not $N_{TA}$, but something called $T_A$.

$$T_A = \frac{N_{TA}}{16 \times \frac{64}{2^{\mu}}}$$

Rewriting this,

$$\boxed{N_{TA} = \frac{T_A \times 64 \times 16}{2^{\mu}}}$$

Refer 38.213

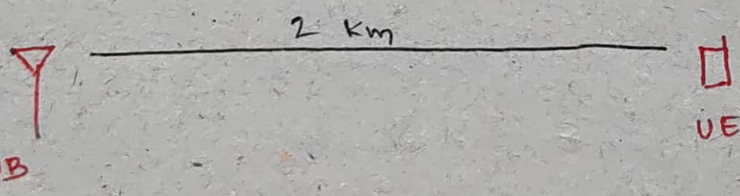
Note :

This quantization depends on the SCS, Coz for different SCS, the symbol time is different, CP is also different. So, this quantization should also be different for different SCS.

So, basically, when we use higher SCS, then the symbol time will be less. So, the quantization should be better.

---

Now, from our previous example, lets calculate this number.




One way propagation delay = 6.66 μs

Two way propagation delay = 13.33 μs

$$N_{TA} = \frac{13.33}{480 \times 10^3 \times 4096} \approx 26214$$

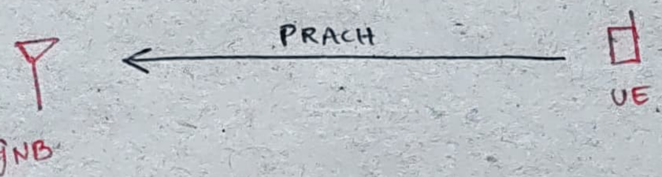
Now, instead of sending this $N_{TA}$ directly to the UE, gNB will quantize it and convert it to $T_A$

$$T_A = \frac{26214}{16 \times \frac{64}{2^{\mu}}} = \frac{26214}{16 \times \frac{64}{2^{1}}}$$ (considering 30KHz SCS, $\mu = 1$)

$$\approx 51$$

(ie) gNB sends this $T_A = 51$ for the propagation delay of 13.33 μs.

---




PRACH signal is designed in a way that, gNB can calculate propagation delay, and different PRACH formats are designed, to cater different cell size and different deployment scenarios.

- When UE sends the PRACH, gNB calculates the propagation delay, from which $N_{TA}$ is calculated, and from which $T_A$ is calculated. This $T_A$ is sent to the UE in the next message. UE will apply this Timing Advance for every UL signals from that time onwards. (ie) UE will calculate back the $N_{TA}$. (ie) Once UE receives $T_A = 51$, it calculates $N_{TA}$ as follows.

$$N_{TA} = \frac{51 \times 16 \times 64}{2^{\mu}} \approx 26214$$

And then, UE calculates Timing Advance ($T_{TA}$)

$$T_{TA} = (N_{TA} + N_{TA\ offset}) * T_c$$

And, UE advances its UL by this much time.

---

Timing Advance : A quick and easy check

The $T_A$ value that the gNB sends to the UE, to inform UE about the timing advance, this parameter value ranges from 0 to 3846.

Lets calculate the distance (or) cell range for $T_A = 1$, considering SCS = 30 kHz

$$N_{TA} = \frac{T_A \times 16 \times 64}{2^{\mu}} = \frac{16 \times 64}{2} \text{ (in terms of } T_c\text{)}$$

Now, $T_{TA}$ (without $N_{TA\,offset}$) is

$$T_{TA} = \frac{16 \times 64}{2} * T_c$$

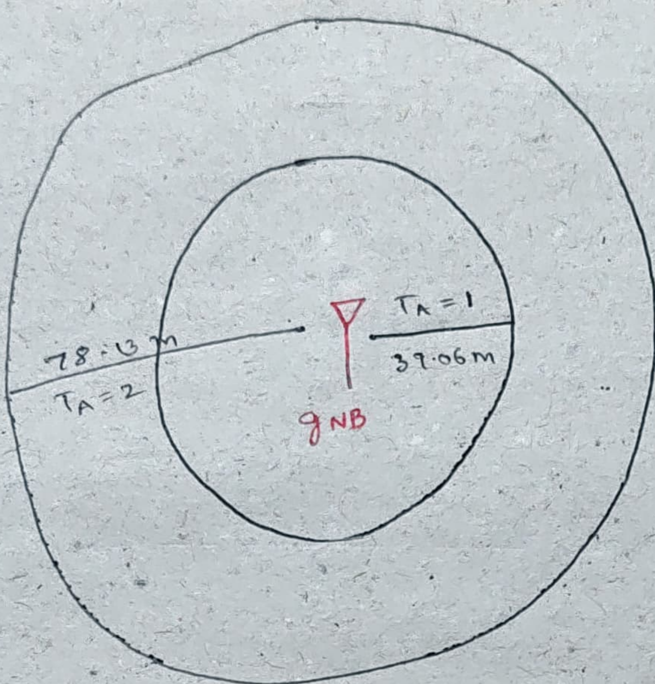
$$= \frac{16 \times 64}{2} * \left(\frac{1}{480 \times 10^3 \times 4096}\right)$$

$$= 260.42 \text{ ns}$$

This is the round trip propagation delay. Now, the distance b/w cell tower and UE would be

$$\text{distance} = \text{speed} \times \text{time}$$
$$= 3 \times 10^8 \times 260.42 \text{ ns}$$
$$= 78.13 \text{ m. (Round trip distance)}$$

One way distance = 39.06 m




$T_A = 1$, SCS = 30KHZ

dist = $T_A * 40$ m

$\approx 40$ m

---

$T_A = 2$, SCS = 30 KHZ

dist = $T_A * 40$ m

$= 2 * 40$ m

$\approx 80$ m

---

So, this is a quick way to check, how far the UE is from the BS, based on $T_A$ value. Following approximate values may be kept in mind.

| | | |
|---|---|---|
| 15 KHZ | → | 80 m |
| 30 KHZ | → | 40 m |
| 60 KHZ | → | 20 m |
| 120 KHZ | → | 10 m |

One way distance

Example: If $T_A = 50$, SCS = 30 kHz

dist = $T_A * 40$m

$= 50 \times 40$ m

$\approx 2$ km

This is what we've computed in previous example. (ii) for 2km, $T_A = 51$.

This is the quick way to check and remember.

---

Considering $T_A = 3846$ (max value), 30 KHZ SCS,

One way dist = $T_A * 40$m = $3846 * 40$ m $\approx 150$ Km

One way time = $\frac{\text{dist}}{\text{speed}} = \frac{150 \times 10^3 \text{ m}}{3 \times 10^8 \text{ m/s}} = 0.5$ ms.

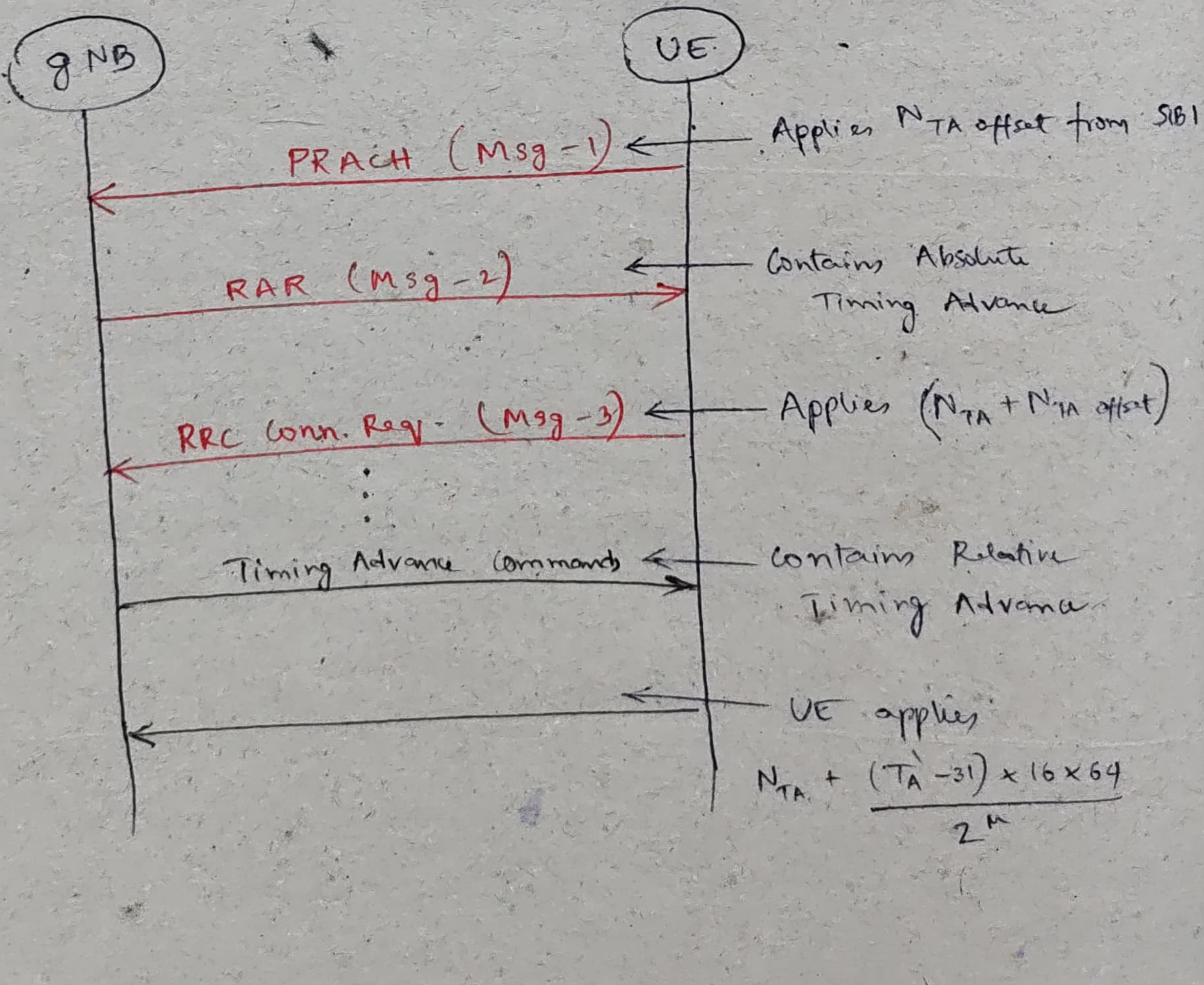
Round trip delay = 0.5 ms × 2 = 1 ms.

# TA Procedures and Reporting in 5G

Lets understand the TA procedures in gNB and UE. One thing that we should remember is that, without TA, no UL messages can be decoded at the gNB side. If the UL message transmitted by UE does not receive the gNB at right time, gNB will fail to decode it.

- If the delay is less than the CP, then it is manageable (ie) gNB will decode it.
- If the delay is more than the CP, and the TA is not correct, gNB will fail to decode it.

So, the TA is applied by the UE, from the first UL message onwards. Lets understand with the message flow.



UE sends the first message (Message-1 PRACH). When UE sends the first message, it has no idea, how far it is from the gNB. So, it does not apply any TA, but it applies $N_{TA}$ offset. $N_{TA}$ offset is conveyed in SIB 1. And $N_{TA}$ offset depends on the deployment like Dynamic Spectrum Sharing / FDD / TDD / FR1 / FR2, which is known. So, UE applies $N_{TA}$ offset in the PRACH and sends the PRACH signal. This PRACH signal is designed in a way that gNB can use it to calculate the TA.

gNB calculates this TA, and sends it back to UE, in the immediate next message RAR. (Msg-2) since this is Absolute Timing Advance.

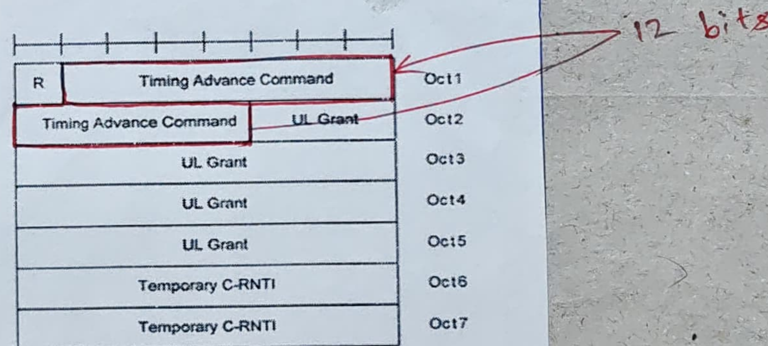



Figure 6.2.3-1: MAC RAR

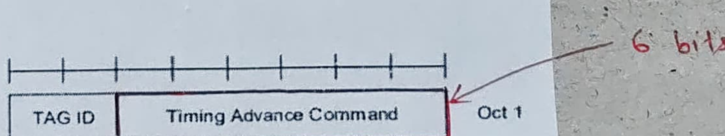


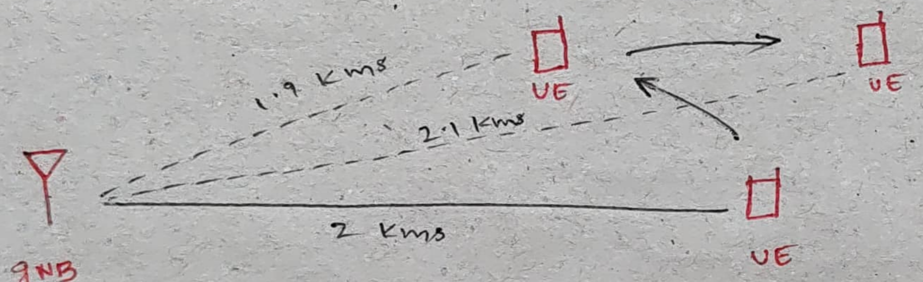

Figure 6.1.3.4-1: Timing Advance Command MAC CE

Figure shows the (Message-2 MAC RAR CE), where the Timing Advance Command contains 12 bits. These 12 bits carries TA (from 0 to 3846).

Now, from Msg-3 onwards, for every UL message, UE has to apply this Timing Advance ($N_{TA}$ + $N_{TA}$ offset).

Now, after the Msg-3 onwards, gNB can use any UL message to calculate the TA. (i) gNB can use PUSCH/PUCCH/SRS/... after Msg-3 onwards. Even though the gNB is doing only DL data transmission, and UE sends the ACK/NACK through PUCCH, gNB can even use those UL messages to calculate the TA.

Now, the UE moves here and there. So, the gNB can further send ~~TAC~~ Timing Advance Commands, but this time gNB wont send the Absolute Timing Advance, it will only send the relative Timing Advance.




Say, UE and gNB are 2 Kms away. And after some time, UE moves a little towards gNB. (say now UE and gNB are 1.9 Kms away). Now since the distance have changed, the TA should be different.

Now the UE can also move 2.1 Kms far from gNB. In this case as well, the TA applied by the UE should be different.

So, w.r.t the change in distance b/w UE and gNB, the corresponding TA is calculated by gNB and signal back to the UE. This TA is only 6 bits (small) which takes values from 0 to 63. This new TA is applied by the UE. Since this TA is a relative timing advance, UE apply this TA on top of the previous TA.

That means, UE will update the $N_{TA}$ with this new TA.

(i.e) $N_{TA} + \frac{(T_A - 31) \times 16 \times 64}{2^{\mu}}$

where, $(T_A - 31)$ takes care of whether the UE moves towards the BS (or) far from the BS.

0 - 31 → when UE moves towards BS. So, the value will be negative.

32 - 63 → when UE moves far from BS. So, the TA value will increase.

---

So, if $T_A = 31$, SCS = 15 KHz

dist = $T_A$ * 80 m

= 31 * 80 m

≈ 2.5 Kms

So, upto 2.5 Km, UE can be moved.

---

And, if $T_A = 31$, SCS = 30 KHz

dist = $T_A$ * 40 m

= 31 * 40 m

≈ 1.24 Kms.

So, upto 1.24 Km, UE can be moved.

---

Remember:

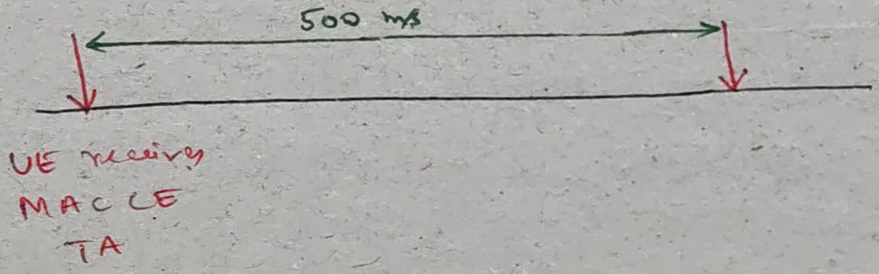
When the UE receives this TA, it does not apply it immediately for its UL signals. If the UE receives TA on $n^{th}$ slot, it applies the same on $(n+6)^{th}$ slot.

## Time Alignment Timer :

This timer starts at the UE side, as and when the UE receives the TA in MAC CE. (ie) This timer will start when the MAC receives the Timing Advance Command.

This timer takes values such as 500 ms / 750 ms / 1280 ms / .... / 10.24 s / ∞.

Consider this timer value is set to 500 ms.




If UE doesn't receive any new Timing advance commands, and this timer expires, then UE will assume that the UL synchronization have lost. In this case, UE will halt all the UL transmissions, clear all the DL buffers and re-initiate PRACH. And UE will get the new absolute Timing advance.

- So, the gNB has to send the Timing Advance Commands within the Time Alignment Timer. Or, the gNB should configure a large enough Time Alignment Timer.

This is all about the Timing Advance procedures in the gNB and UE side.