# 5G NR Numerology

One OFDM symbol duration

- Scalable subcarrier spacing $= 2^{\mu} \cdot 15$ KHz

| | $\mu$ | Subcarrier Spacing $\Delta f$ (KHz) | Useful Samples duration $T_u$ ($\mu s$) | CP samples duration $T_{cp}$ ($\mu s$) | $T_u + T_{cp}$ ($\mu s$) |
|---|---|---|---|---|---|
| FR1 | 0 | 15 | 66.7 | 4.7 (NCP) | 71.4 |
| FR1 | 1 | 30 | 33.3 | 2.3 (NCP) | 35.7 |
| | 2 | 60 | 16.7 | 1.2 (NCP, ECP) | 17.9 |
| FR2 mm wave | 3 | 120 | 8.33 | 0.59 (NCP) | 8.9 |
| FR2 mm wave | 4 | 240 | 4.17 | 0.29 (NCP) | 4.5 |

$\Delta f = 2^{\mu} \cdot 15$ KHz

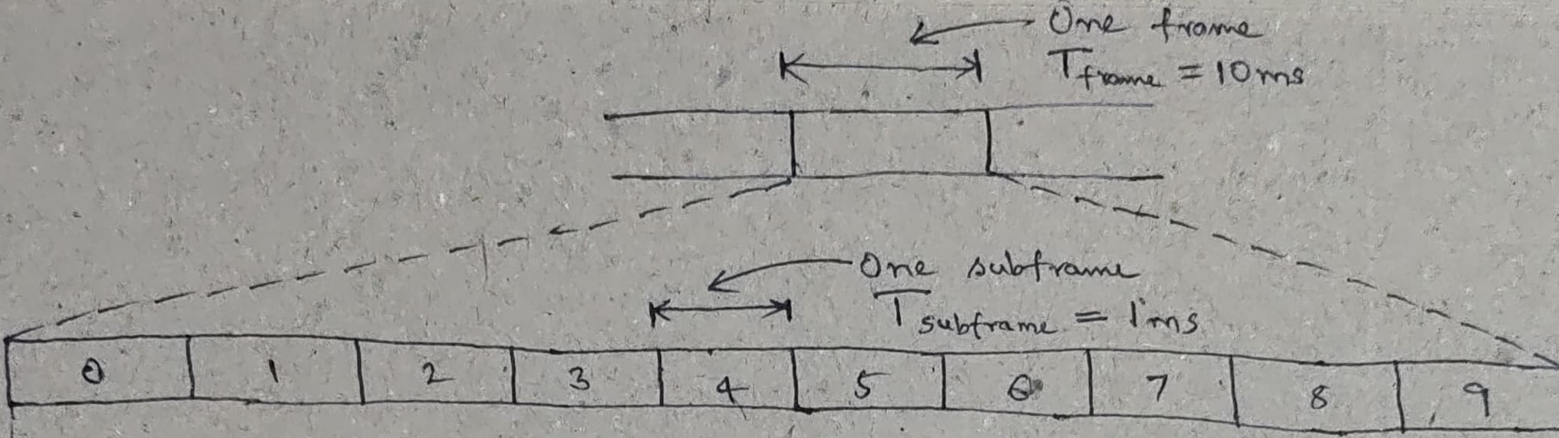
$T_u = \frac{1}{\Delta f}$

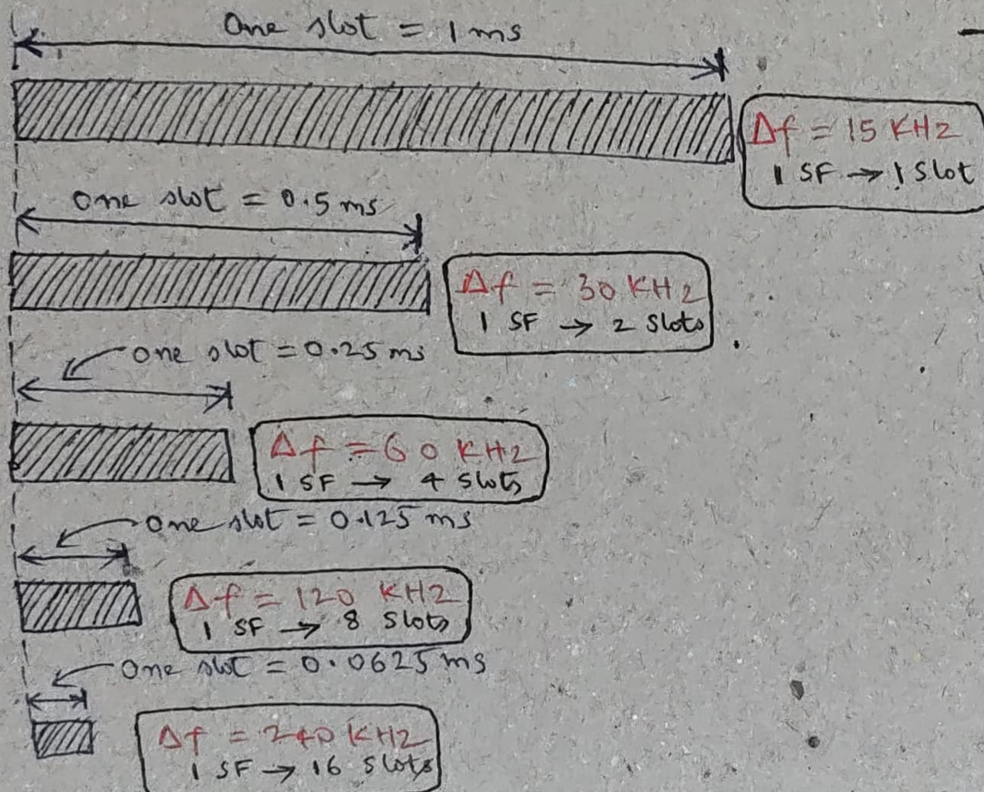
One OFDM symbol duration

PTO

- NR supports a wide range of deployment scenarios, from large cells with sub-1 GHz carrier frequency upto mm-wave deployments with wide bandwidths.
- A single numerology for all these scenarios is NOT EFFICIENT or even possible.
- <u>Frequency Range 1</u> (FR1)
  - → Cell sizes can be relatively large and a couple of μs of CP is necessary to handle delay spread expected in these type of deployments
  - → Subcarrier spacing of 15 – 30 KHz is needed
- <u>Frequency Range 2</u> (FR2)
  - → Due to higher phase noise, higher subcarrier spacing is required.
  - → Cell sizes will be smaller due to hostile channel, consequently requires higher subcarrier spacing and shorter CP.

# Time domain structure




- One slot contains <u>14</u> OFDM symbols, irrespective of the subcarrier spacing $\Delta f$.
- When $\Delta f = 15$ KHz,
  14 OFDM Sym. duration = 1 ms
  1 OFDM Sym. durn. $= \frac{1ms}{14} = 71.4\mu s$
- When $\Delta f = 30$ KHz,
  14 OFDM sym. duration = 0.5ms
  1 OFDM sym. durn. $= \frac{0.5ms}{14} = 35.7\mu s$

| $\Delta f$ | 1 OFDM Sym. durn. | | Slot duration |
|---|---|---|---|
| 15 KHz | 71.4 μs | X14 ≈ | 1 ms |
| 30 KHz | 35.7 μs | | 0.5 ms |
| 60 KHz | 17.9 μs | | 0.25 ms |
| 120 KHz | 8.9 μs | | 0.125 ms |
| 240 KHz | 4.5 μs | | 0.0625 ms |

→ NR transmissions are organized into frames of length 10 ms.

→ Each Frame is divided into 10 equal-sized subframes of length 1ms.

→ A subframe is divided into slots consisting of 14 OFDM symbols each.

- Duration of a slot in ms depends on the Numerology
- Slot is the typical dynamic scheduling unit

→ Subframe in NR serves as a numerology-independent time reference.

→ A slot = 14 OFDM symbols

- A higher subcarrier spacing leads to a shorter slot duration.

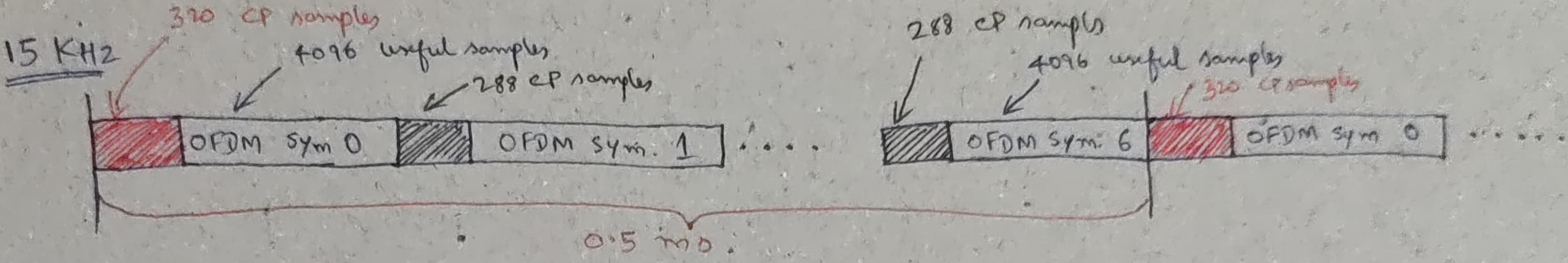
→ A higher subcarrier spacing can be used to support lower-latency transmission. But it is not a feasible approach in all deployments, as the CP shrinks with increase in subcarrier spacing.

Alternatively, the CP can be increased, but it will increase the overhead.

Therefore, reducing slot duration is a less efficient way of providing low latency.

→ Subcarrier spacing is primarily selected according to the deployment scenario. Eg: Carrier frequency (FR1, FR2)

## Time domain structure (in detail)




For $\Delta f = 15 KHz$,

* FFT/useful samples duration, $T_u = 66.7\ \mu s$
* CP samples duration, $T_{cp} = 4.7\ \mu s$
* $T_u + T_{cp} = 71.4\ \mu s$.

$\because$ 4096 point FFT/IFFT is being used,

In 66.7 μs $\rightarrow$ 4096 FFT/useful samples generated.

In 4.7 μs $\rightarrow \frac{4096}{66.7} \times 4.7 = 288.623$

$\approx$ 288 CP samples generated.

So, in 0.5 ms, there are 7 OFDM symbols.

$\Rightarrow 7 \times (4096 + 288) = 30,688$

samples generated every 0.5 ms

WKT

OFDM Symbol duration, $T_u = \frac{1}{\Delta f}$

Sampling time, $T_s = \frac{T_u}{4096}$

Sampling rate, $F_s = \frac{1}{T_s} = \frac{4096}{T_u}$

$= 4096 \times \Delta f$

$= 4096 \times 15 KHz$

$= 61.44 MHz$

which means that, in 1 second $61.44 \times 10^6$ samples are generated.

$\Rightarrow$ 1 sec $\rightarrow 61.44 \times 10^6$ samples

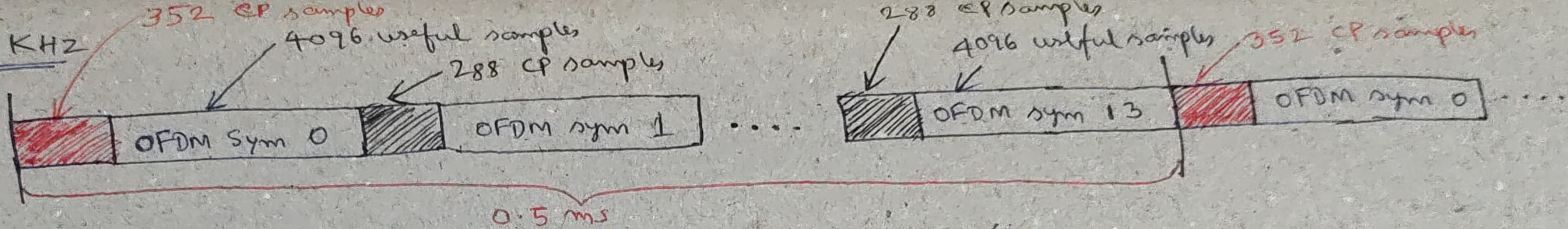
1 ms $\rightarrow 61.44 \times 10^3$ samples

$\rightarrow$ 61440 samples

0.5 ms $\rightarrow$ 30720 samples

$\therefore$ The difference $30720 - 30688 = 32$ samples are compensated at the beginning of every 0.5 ms.

30 KHZ




For $\Delta f = 30$ KHz,

* FFT / useful samples duration, $T_u = 33.3\ \mu s$
* CP samples duration, $T_{cp} = 2.3\ \mu s$
* $T_u + T_{cp} = 35.7\ \mu s$

∴ 4096 point FFT / IFFT is being used,

In 33.3 μs → 4096 FFT / useful samples generated.

In 2.3 μs → $\frac{4096}{33.3} \times 2.3 = 282.907$

≈ 288 CP samples generated.

So, in 0.5 ms, there are 14 OFDM symbols

$\Rightarrow 14 \times (4096 + 288) = 61,376$ samples generated every 0.5 ms.

WKT

OFDM symbol duration, $T_u = \frac{1}{\Delta f}$

Sampling time, $T_s = \frac{T_u}{4096}$

Sampling rate, $F_s = \frac{1}{T_s} = \frac{4096}{T_u}$

$= 4096 \times \Delta f$

$= 4096 \times 30$ KHZ

$= 122.88$ MHZ.

which means that, in 1 second $122.88 \times 10^6$ samples are generated.

$\Rightarrow$ 1 sec → $122.88 \times 10^6$ samples

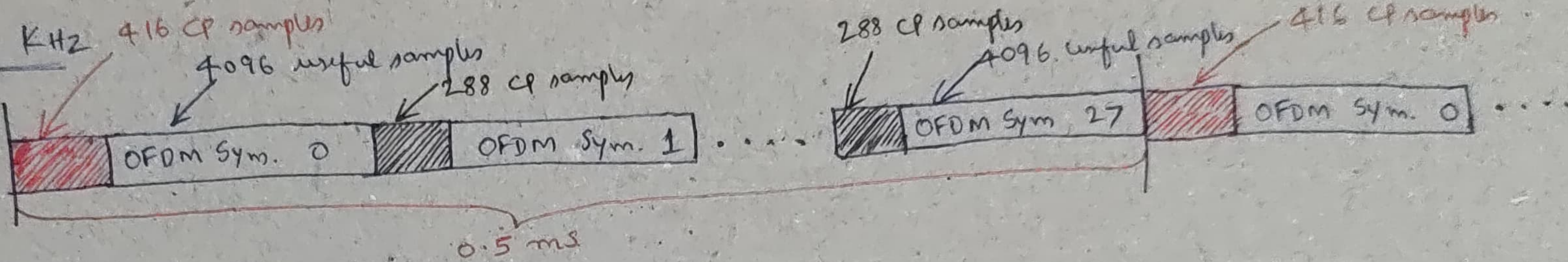
1 ms → $122.88 \times 10^3$ samples

→ 122880 samples

0.5 ms → 61440 samples

∴ The difference $61440 - 61376 = 64$ samples are compensated at the beginning of every 0.5 ms.

## 60 KHz




For $\Delta f = 60$ KHz,

* FFT/useful samples duration, $T_u = 16.7\ \mu s$
* CP samples duration, $T_{cp} = 1.2\ \mu s$.
* $T_u + T_{cp} = 17.9\ \mu s$

$\because$ 4096 point FFT/IFFT is being used,

In 16.7 μs $\rightarrow$ 4096 FFT/useful samples generated.

In 1.2 μs $\rightarrow \frac{4096}{16.7} \times 1.2 = 294.323$

$\approx 288$ CP samples generated..

So, in 0.5 ms, there are 28 OFDM symbols.

$\Rightarrow 28 \times (4096 + 288) = 122752$ samples generated every 0.5 ms.

WKT

OFDM symbol duration, $T_u = \frac{1}{\Delta f}$

Sampling Time, $T_s = \frac{T_u}{4096}$

Sampling rate, $F_s = \frac{1}{T_s} = \frac{4096}{T_u}$.

$= 4096 \times \Delta f$

$= 4096 \times 60$ KHz

$= 245.76$ MHz

which means that, in 1 second $245.76 \times 10^6$ samples are generated.

$\Rightarrow$ 1 sec $\rightarrow 245.76 \times 10^6$ samples

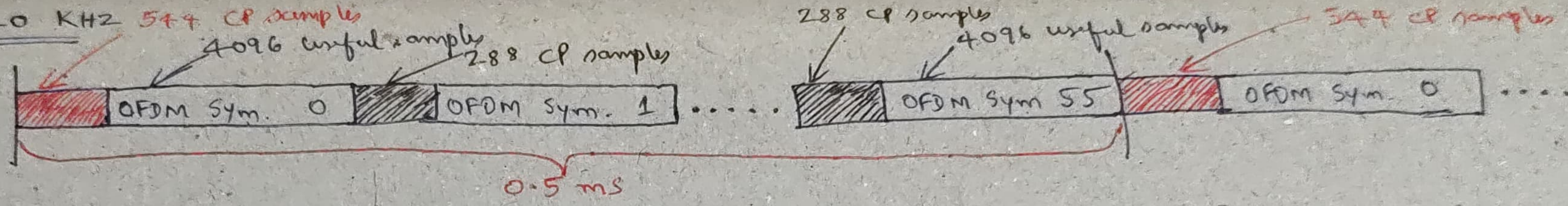
1 ms $\rightarrow 245.76 \times 10^3$ samples

$\rightarrow$ 245760 samples

0.5 ms $\rightarrow$ 122880 samples

$\therefore$ The difference $122880 - 122752 = 128$ samples are compensated at the beginning of every 0.5 ms.

## 120 KHz




For $\Delta f = 120$ KHz,

* FFT/useful samples duration, $T_u = 8.33\ \mu s$
* CP samples duration, $T_{cp} = 0.59\ \mu s$.
* $T_u + T_{cp} = 8.9\ \mu s$

$\because$ 4096 point FFT/IFFT is being used,

In $8.33\ \mu s \rightarrow$ 4096 FFT/useful samples generated.

In $0.59\ \mu s \rightarrow \frac{4096}{8.33} \times 0.59 = 290.113$
$\approx 288$ CP samples generated

So, in 0.5 ms, there are 56 OFDM symbols

$\Rightarrow 56 \times (4096 + 288) = 245504$ samples generated every 0.5 ms

WKT

OFDM symbol duration, $T_u = \frac{1}{\Delta f}$

Sampling Time, $T_s = \frac{T_u}{4096}$

Sampling rate, $F_s = \frac{1}{T_s} = \frac{4096}{T_u}$

$= 4096 \times \Delta f$

$= 4096 \times 120$ KHz

$= 491.52$ MHz

Which means that, in 1 second $491.52 \times 10^6$ samples are generated.

$\Rightarrow$ 1 sec $\rightarrow 491.52 \times 10^6$ samples

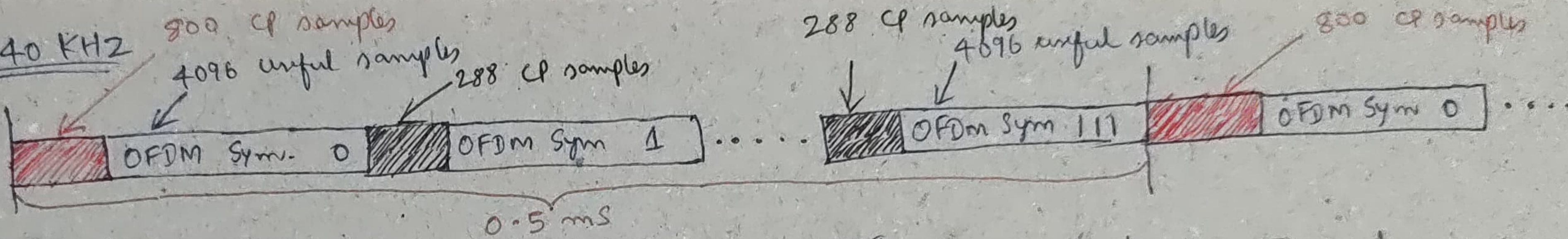
1 ms $\rightarrow 491.52 \times 10^3$ samples

$\rightarrow$ 491520 samples

0.5 ms $\rightarrow$ 245760 samples

$\therefore$ The difference $245760 - 245504 = 256$ samples are compensated at the beginning of every 0.5 ms.

**240 KHz**




For $\Delta f = 240\,\text{KHz}$,

* FFT/ useful samples duration, $T_u = 4.17\,\mu s$
* CP samples duration, $T_{cp} = 0.29\,\mu s$
* $T_u + T_{cp} = 4.5\,\mu s$

$\because$ 4096 point FFT/ IFFT is being used,

In $4.17\,\mu s \longrightarrow$ 4096 FFT/useful samples generated.

In $0.29\,\mu s \longrightarrow \frac{4096}{4.17} \times 0.29 = 284.854$
$\approx 288$ CP samples generated

So, in 0.5 ms, there are 112 OFDM symbols.

$\Rightarrow 112 \times (4096 + 288) = \underline{491008}$ samples generated every 0.5 ms.

WKT OFDM symbol duration, $T_u = \frac{1}{\Delta f}$

Sampling Time, $T_s = \frac{T_u}{4096}$

Sampling rate, $F_s = \frac{1}{T_s} = \frac{4096}{T_u}$

$= 4096 \times \Delta f$

$= 4096 \times 240\,\text{KHz}$

$= 983.04\,\text{MHz}$.

which means that, in 1 second $983.04 \times 10^6$ samples are generated.

$\Rightarrow$ 1 sec $\longrightarrow 983.04 \times 10^6$ samples

1 ms $\longrightarrow 983.04 \times 10^3$ samples

$\longrightarrow$ 983040 samples

0.5 ms $\longrightarrow \underline{491520}$ samples

$\therefore$ The difference $491520 - 491008 = \underline{\underline{512}}$ samples are compensated at the beginning of every 0.5 ms.