NR Physical Layer Design: Physical layer structure, numerology and frame structure

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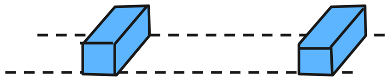
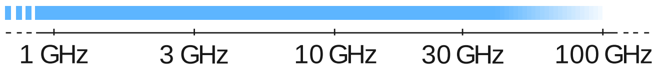
NR – Key benefits

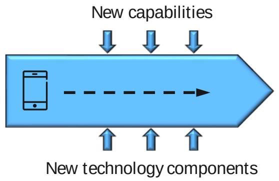
Ultra-lean



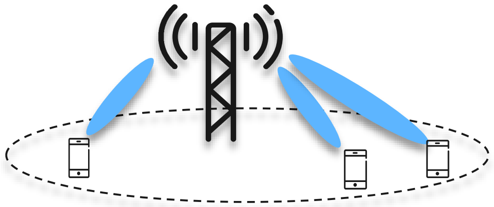
Wide spectrum range



Forward compatibility

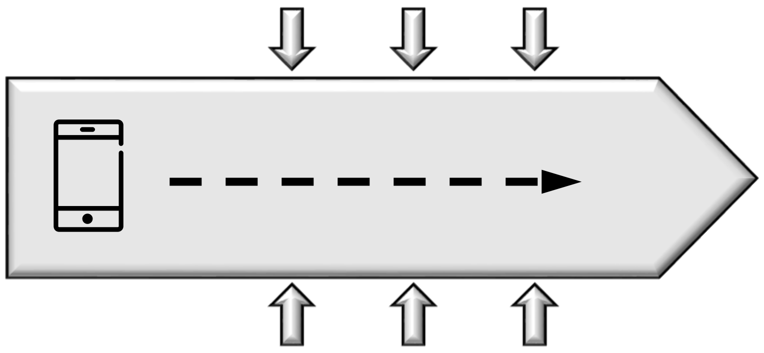


Multi-antenna



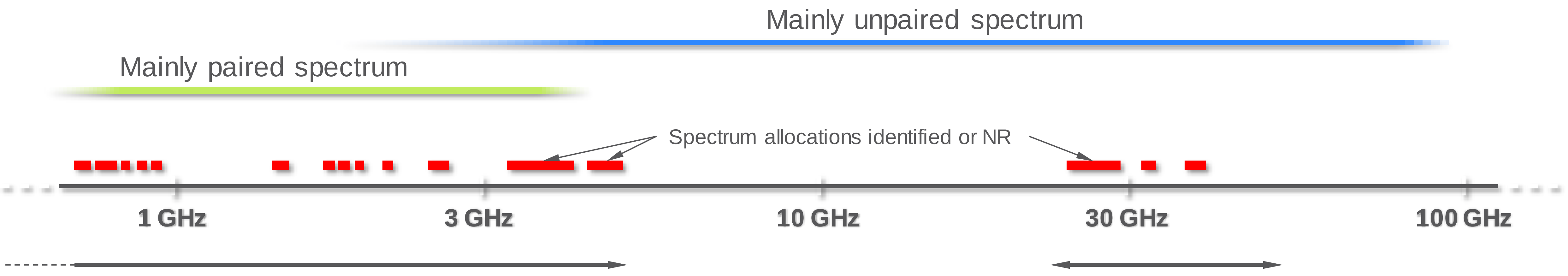
Low latency

Forward compatibility



- Minimize "always-on" transmissions (ultra-lean)
  - Bad example: Always-on CRS
- Keep transmissions together in frequency
  - Bad example: LTE PDCCH/PCFICH/PHICH
- Avoid static/strict timing relations
  - Bad example: LTE uplink HARQ
- Reserved resources
  - Downlink transmissions rate matched around

Frequency bands



Frequency Range 1

Subcarrier spacing	15/30/60 kHz
Max carrier bandwidth	50/100/200 MHz

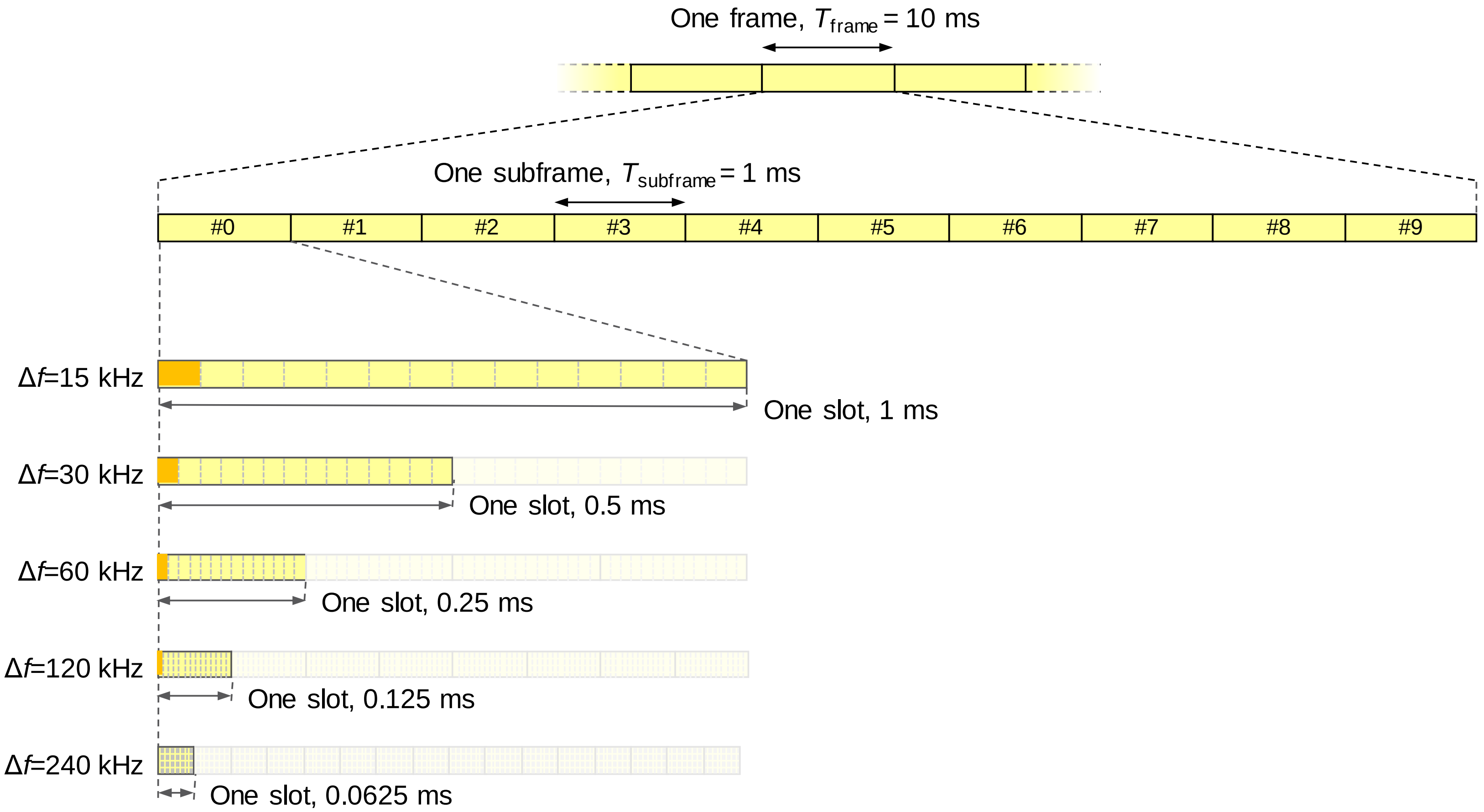
Frequency Range 2

Subcarrier spacing	60/120 kHz
Max carrier bandwidth	200/400 MHz

Time-frequency structure

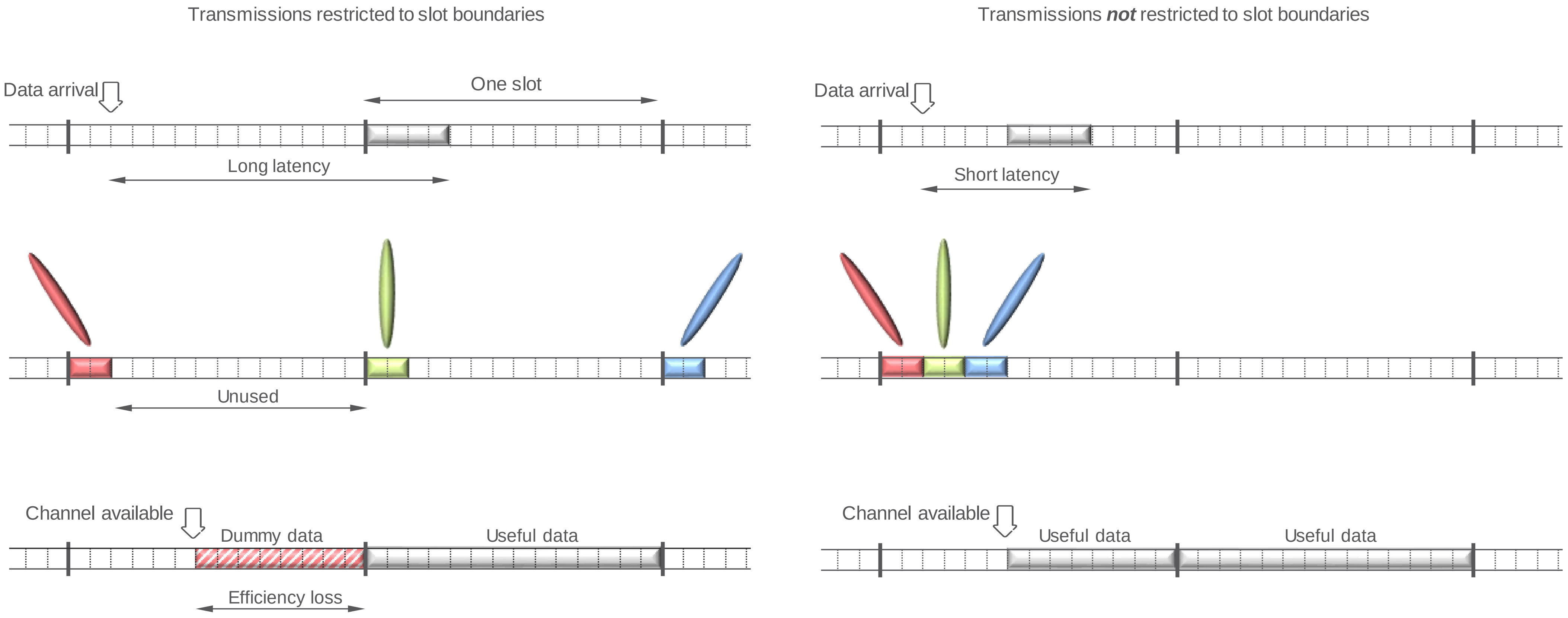
Frame structure

- Single frame structure
  - Applicable to FDD and TDD
- Dynamic TDD baseline
  - Possible to semi-statically configure UL/DL split
- 15 kHz slot identical to LTE subframe
  - Including extra samples in every 7th symbol



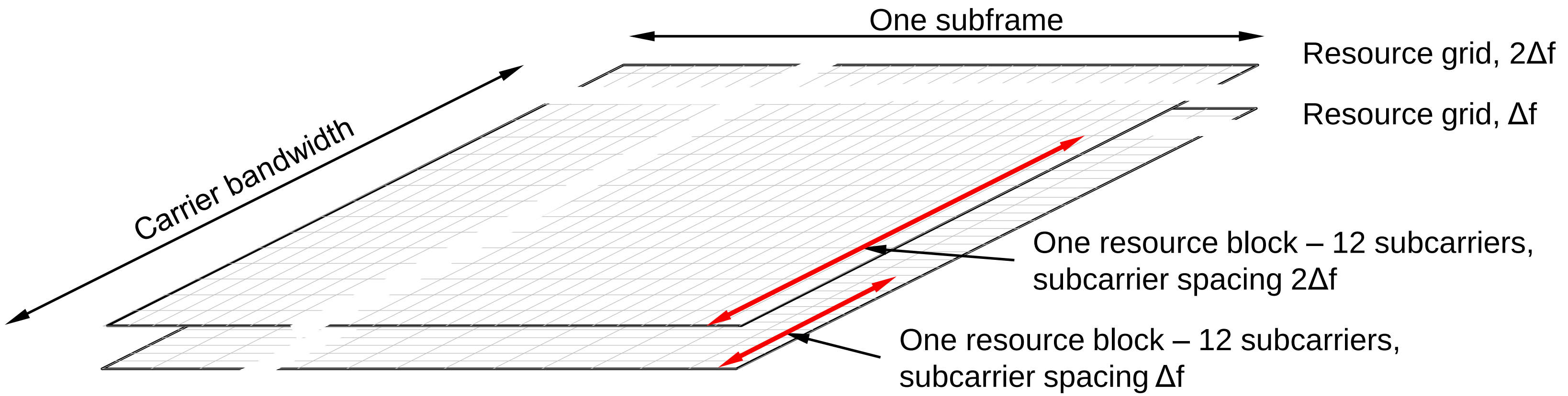
Frame structure

- Transmissions not restricted to slot boundaries

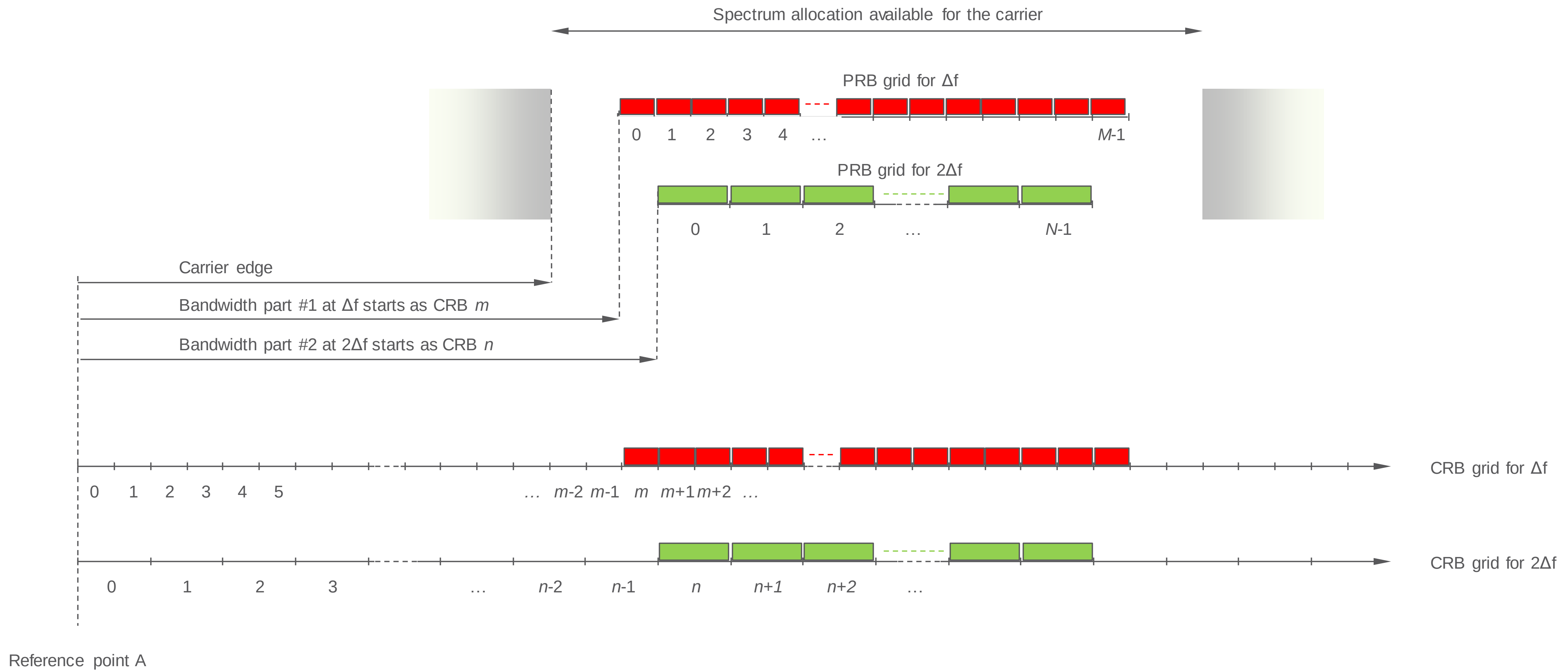


Resource grid

- One resource grid per numerology and antenna port
- Resource block = 12 subcarriers
  - One dimensional unit (unlike LTE)
- Resource element = 1 subcarrier in one OFDM symbol

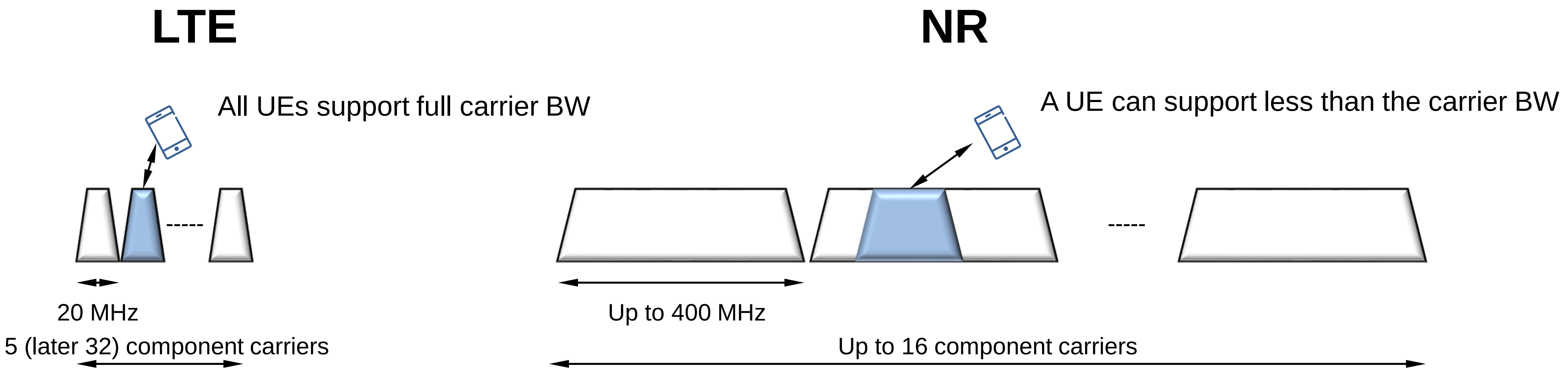


Resource-block grid



Bandwidths

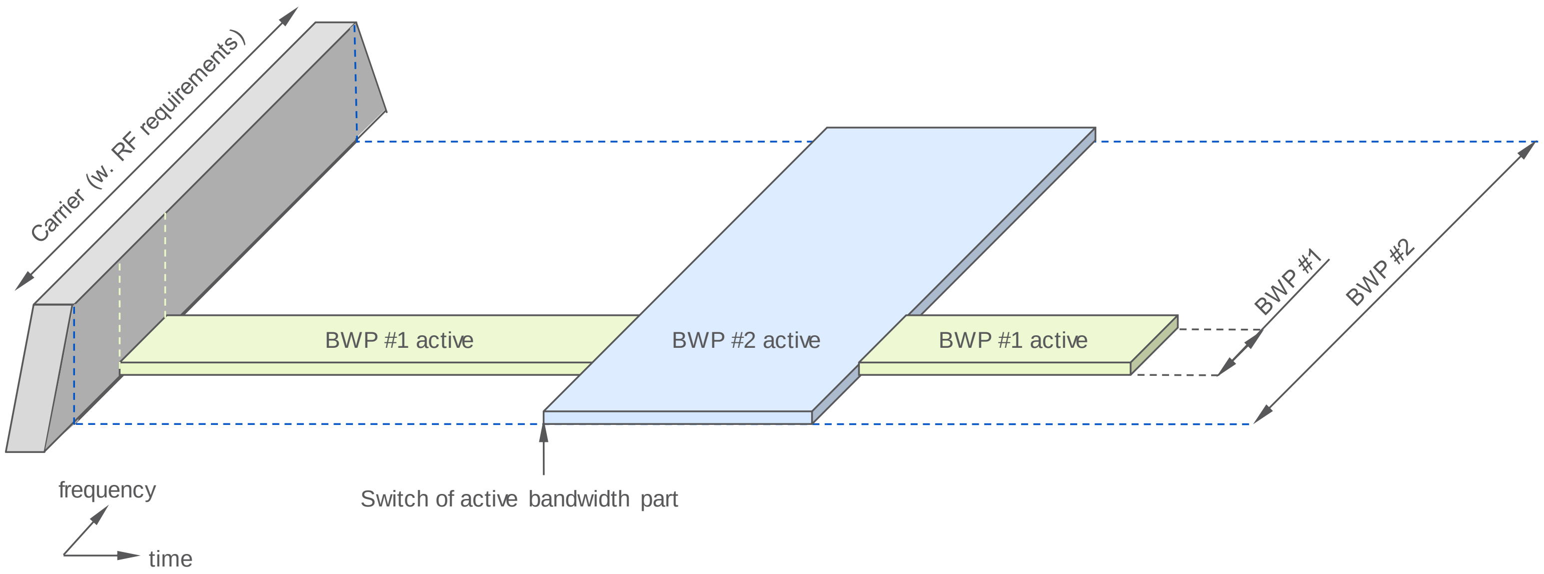
- Up to 400 MHz component-carrier bandwidth (20 MHz for LTE)
- Up to 16 component carriers
  - Overall bandwidth depends on frequency band
- Not all devices must support the full network carrier bandwidth



Bandwidth parts

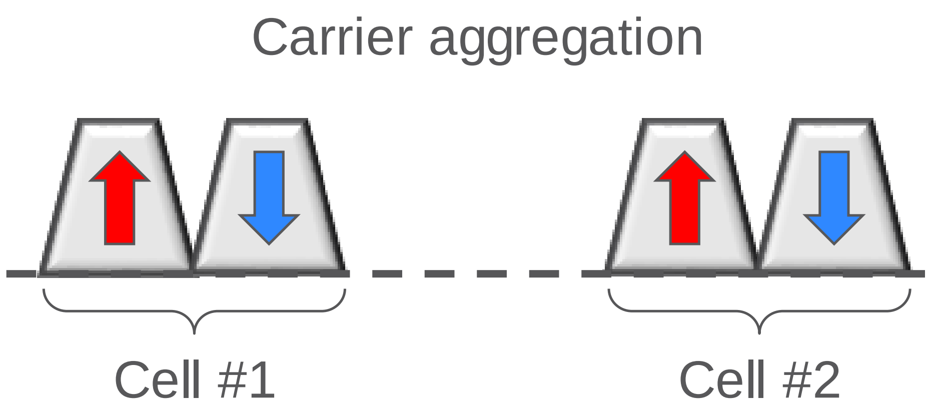
- To support UEs not capable of full carrier bandwidth
- To support bandwidth adaptation (reduced UE power consumption)

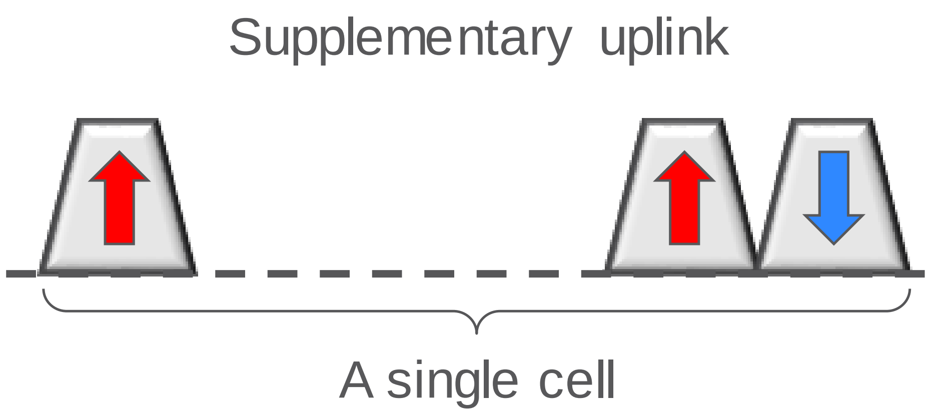
- Up to 4 bandwidth parts per carrier, one of which is active
- A UE is not supposed to receive/transmit outside the active bandwidth part
- Many parameters are configured per bandwidth part



Carrier aggregation and supplementary uplink

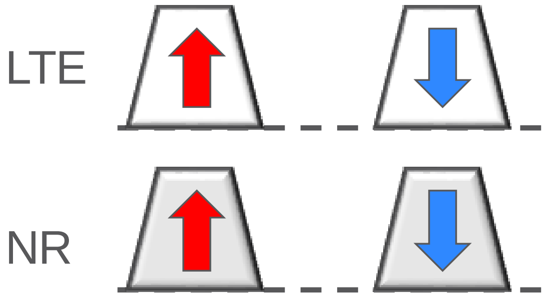
- Carrier aggregation (up to 16 carriers)
  - Main use case: bandwidth extension
- Supplementary uplink
  - Main use case: uplink coverage



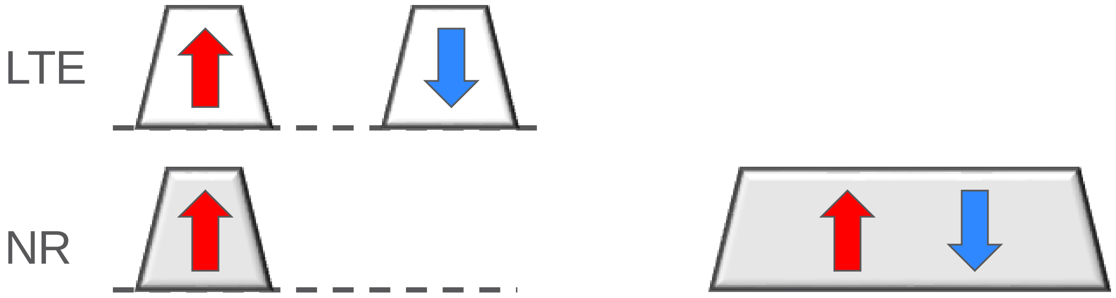


NR-LTE Coexistence

- NR can coexist with LTE on the same carrier
  - Example: NB-IoT or eMTC for MTC on same carrier as NR



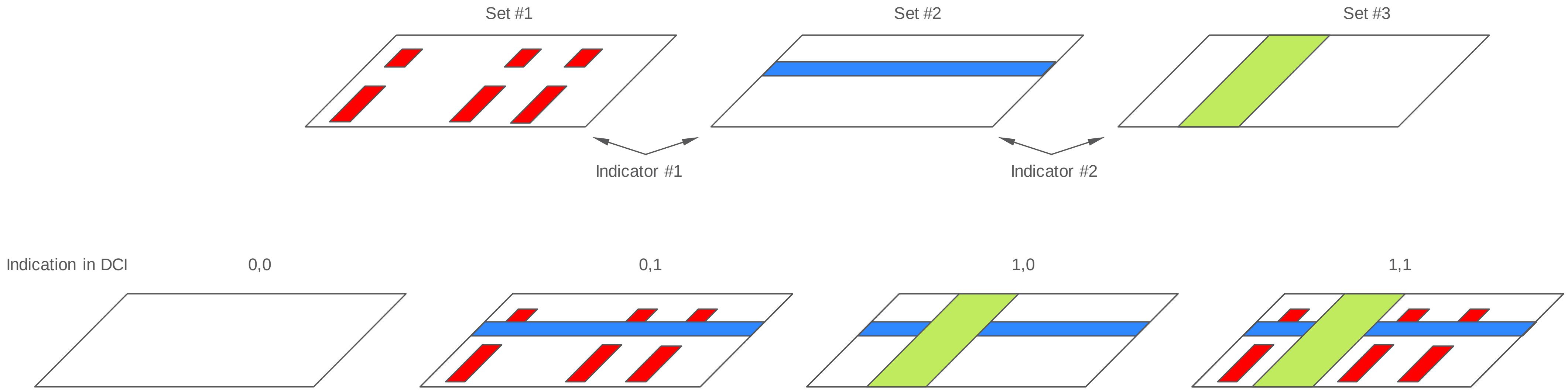
Downlink and uplink co-existence



Uplink-only co-existence

Reserved resources

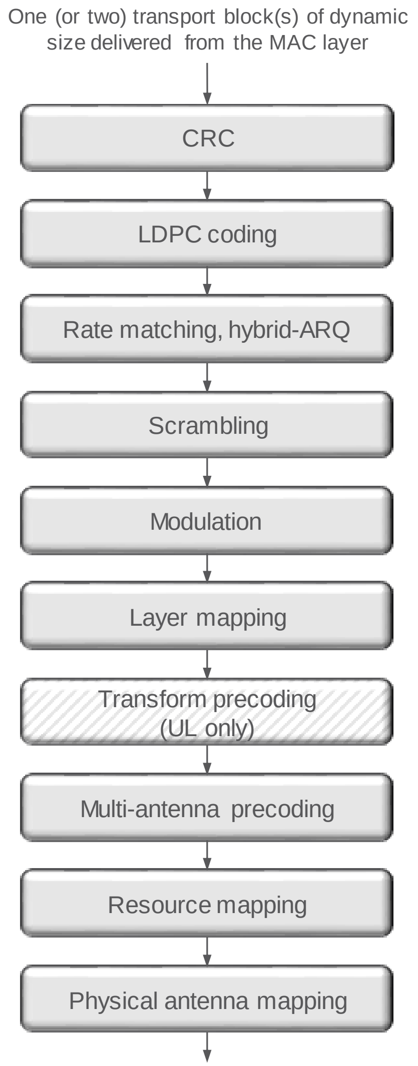
- To enable coexistence with LTE/NB-IoT on the downlink
  - Treat LTE CRS as reserved resources
- To facilitate forward compatibility in downlink
  - Three sets can be configured using a set of bitmaps
  - Dynamic indication of whether resources are reserved or not



Transport channel processing

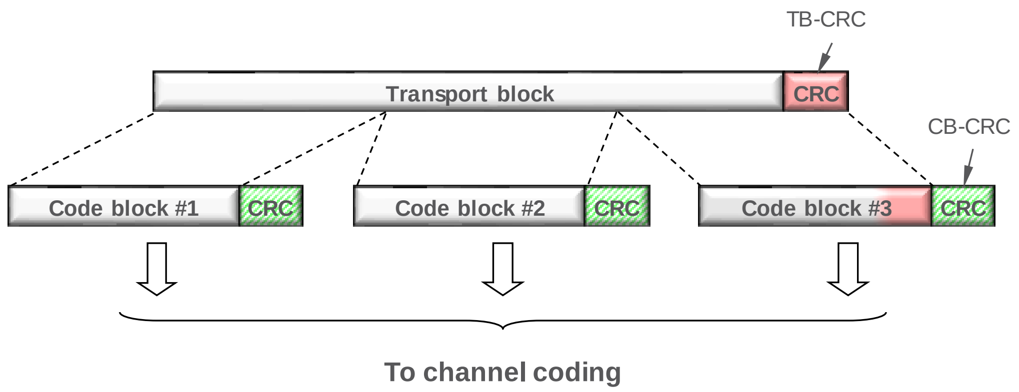
Transport-Channel Processing

- Overall transport-channel processing resembles LTE
- Main differences:
  - LDPC coding
  - Multi-antenna handling
  - OFDM and DFTS-OFDM in UL

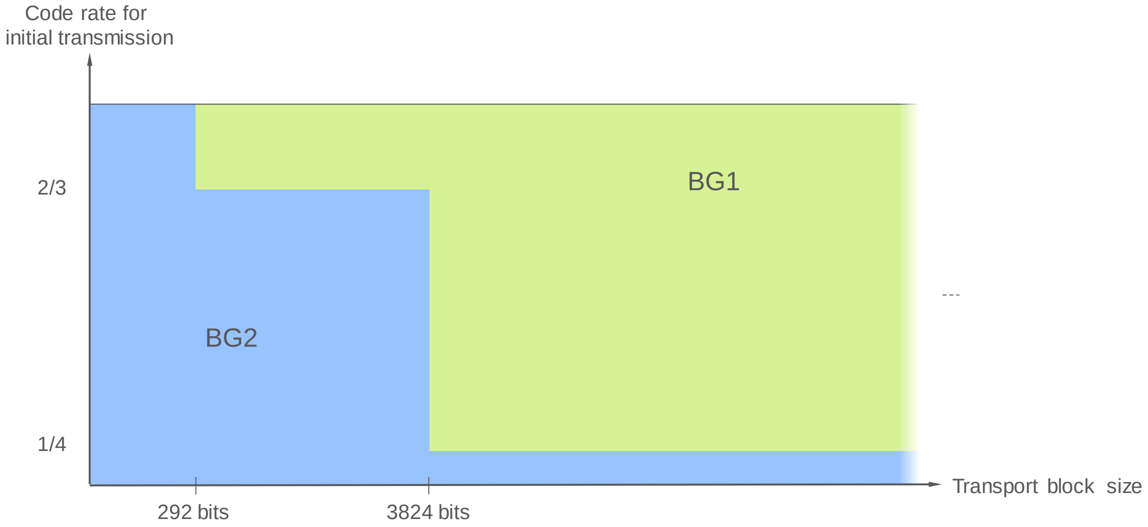


Coding

- Code-block segmentation
  - CRC per TB *and* CB (as in LTE)

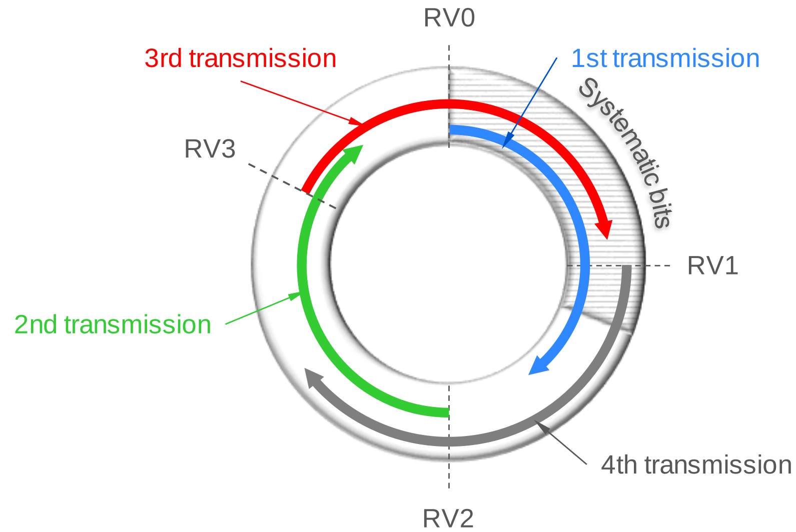


- LDPC coding
  - Two base graphs

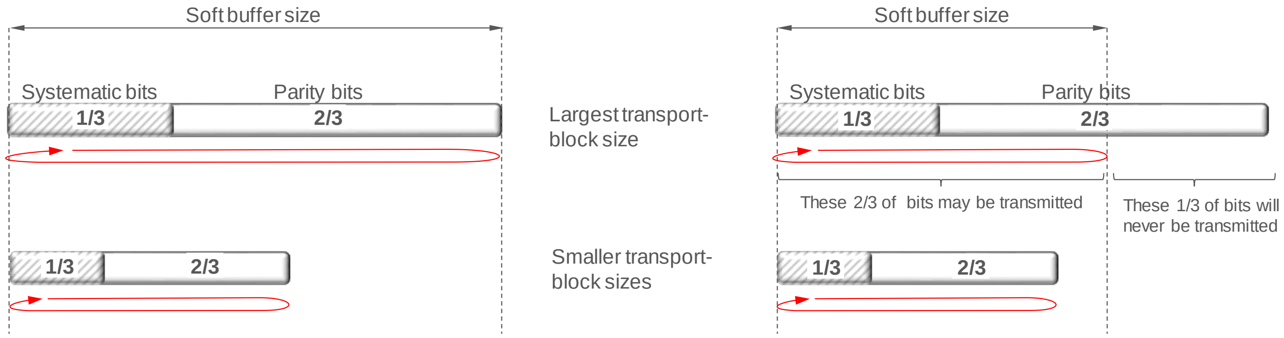


Rate Matching

- Circular buffer rate matching
  - Some systematic bits removed prior to circular buffer insertion
  - 4 different redundancy versions

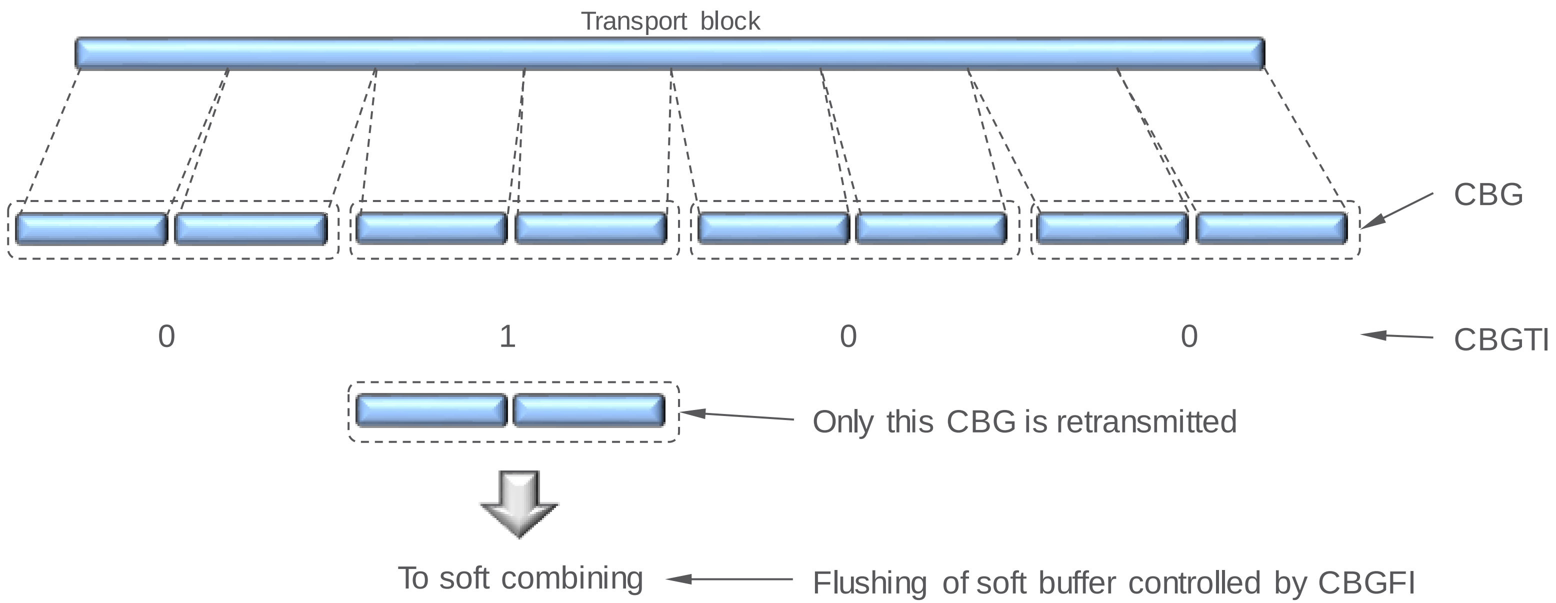


- Limited-buffer rate matching
  - To handle limited UE soft-buffer size
  - Determines amount of bits put into the circular buffer
  - Can also be used in UL



Hybrid ARQ

- Similar to LTE but with some differences
  - Possibility for per-CBG retransmission
  - Asynchronous in DL and UL (up to 16 processes)



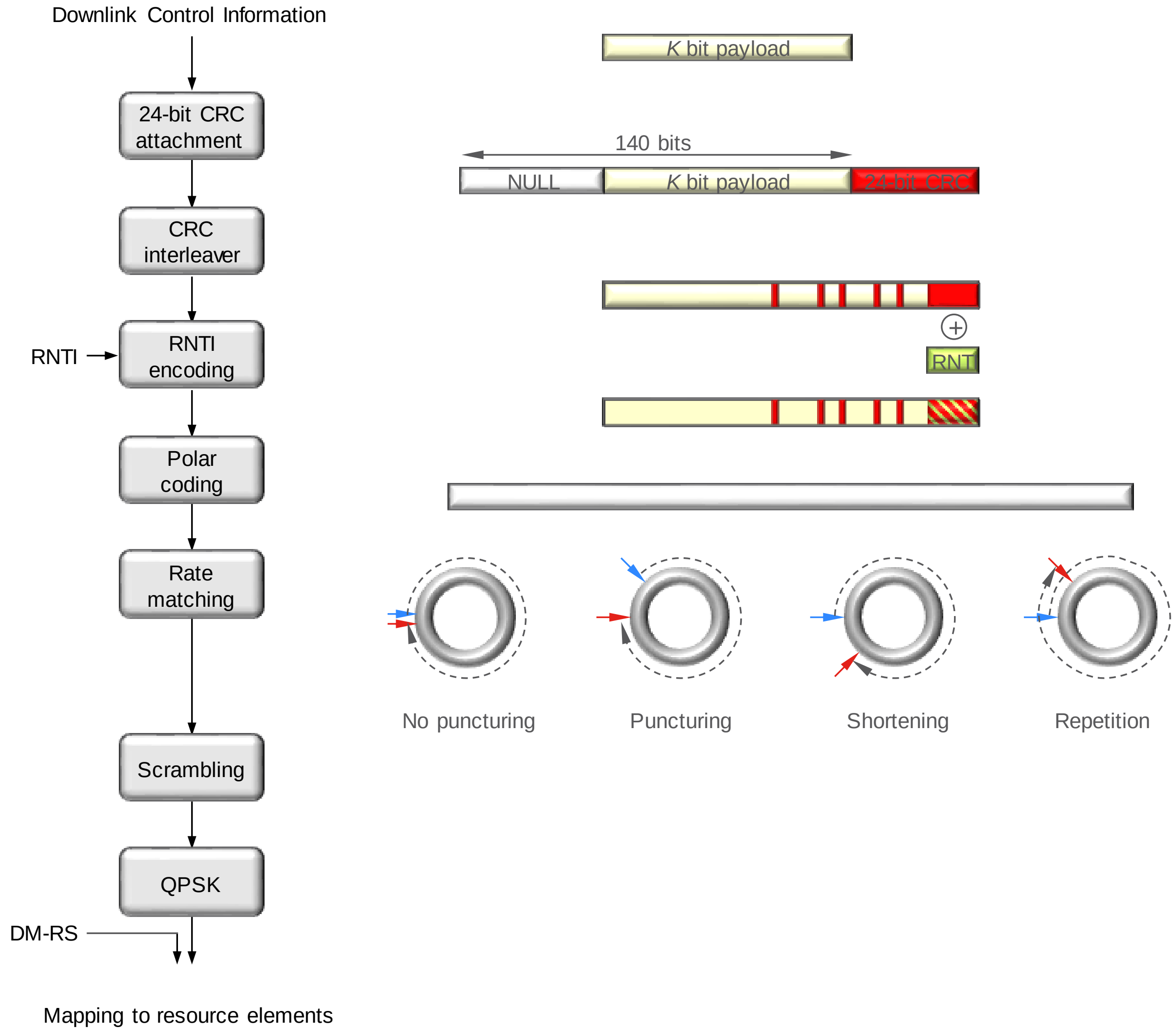
Control channels

Downlink L1/L2 control signaling

- Downlink Control information (DCI), transmitted on PDCCH
  - Similar usage as in LTE (scheduling, …)
- PDCCH
  - The only type of L1/L2 control channel in NR
  - No PCFICH or PHICH (not needed in NR)
- Main difference compared to LTE
  - Possibility for beamforming
  - Not necessarily spanning full carrier bandwidth

PDCCH Processing

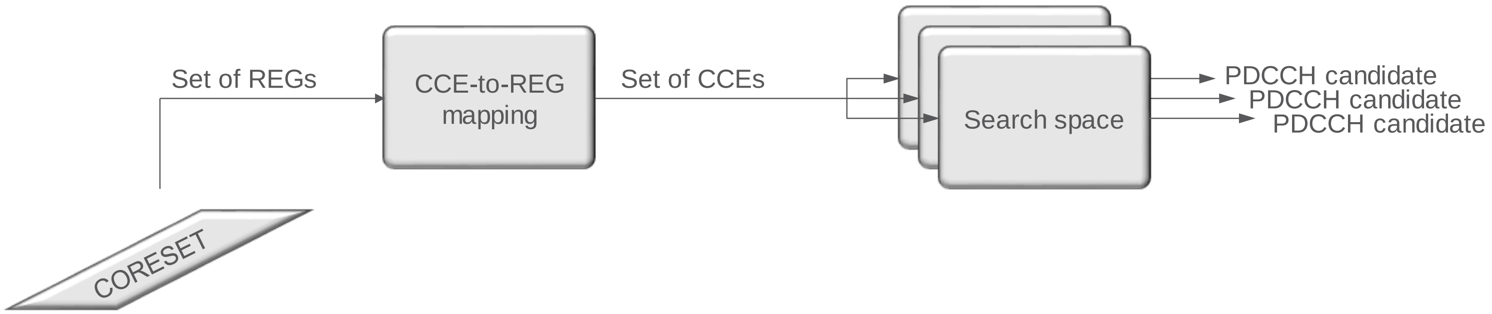
- Similar processing chain as for LTE
  - Polar coding
  - Larger CRC
- Each PDCCH
  - Independently processed
  - Has its own DM-RS



PDCCH Monitoring

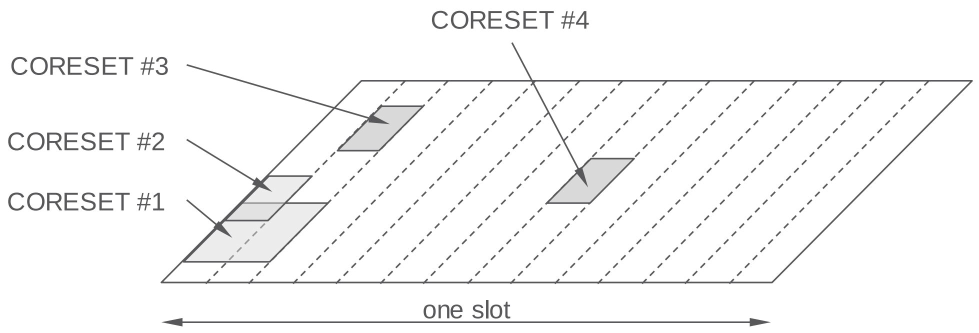
- CORESET (Control Resource Set)
  - Time-frequency region where the UE monitors for PDCCH transmission
  - Multiple CORESETs can be configured in a UE using RRC signaling
  - CORESET0 obtained from MIB

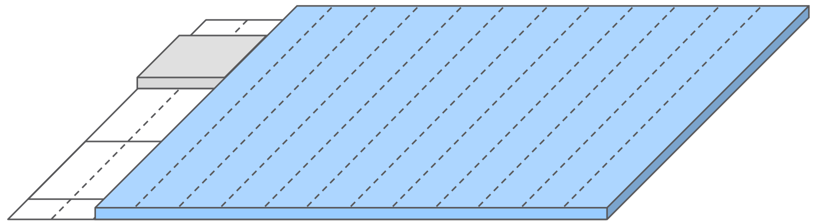
- Search spaces
  - Set of CCEs upon which the UE tries to blindly detect PDCCH transmissions
  - One PDCCH transmitted using aggregation level 1, 2, 4, 8, or 16 CCEs



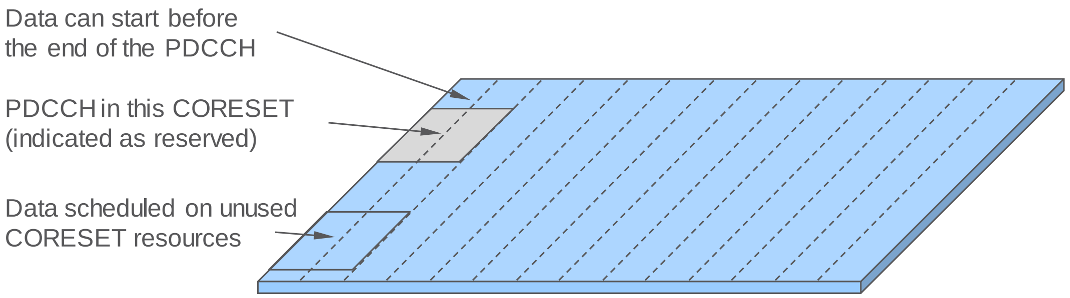
CORESET

- Multiple CORESETs can be configured in one UE
  - Not necessarily located at the beginning of the slot
  - Frequency span in multiples of 6 RB
  - Time span of 1, 2, or 3 OFDM symbols



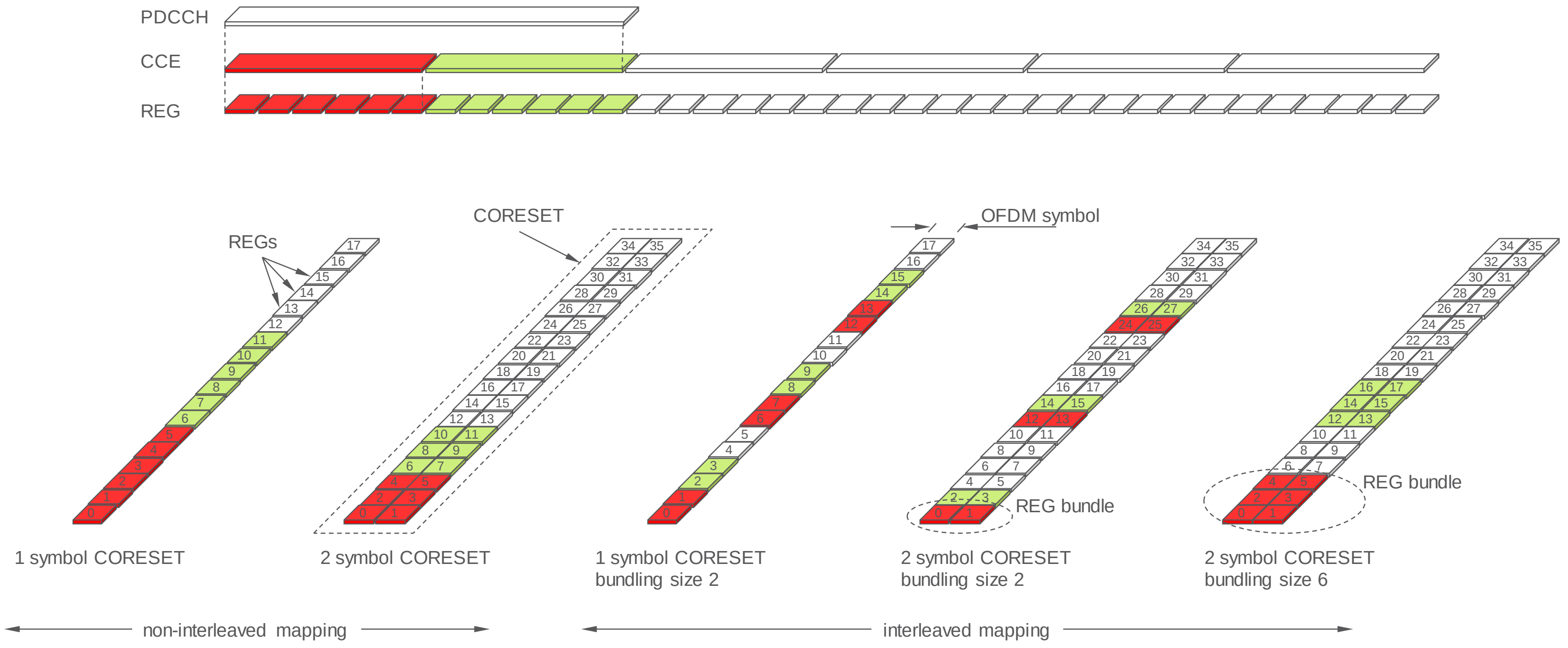


- CORESET resources can be reused for data
  - Use reserved resources mechanism



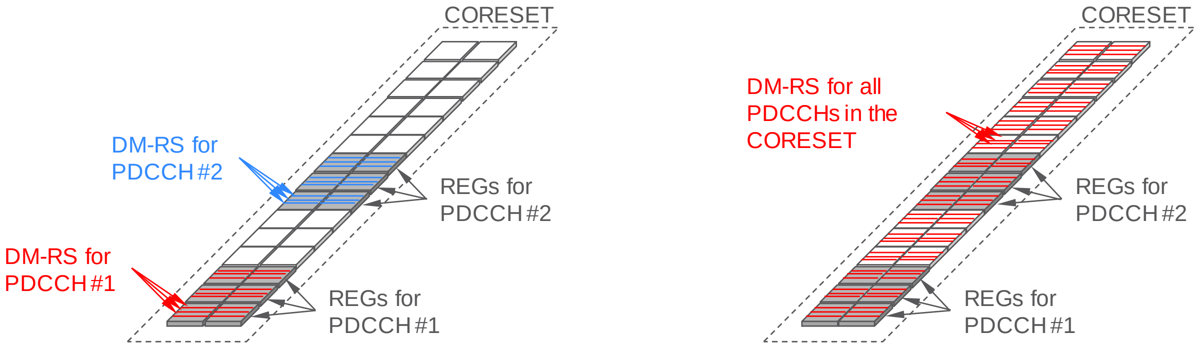
CCE-to-REG mapping

- Each CORESET has an associated CCE-to-REG mapping
  - Interleaved mapping
  - Non-interleaved mapping



DM-RS and QCL

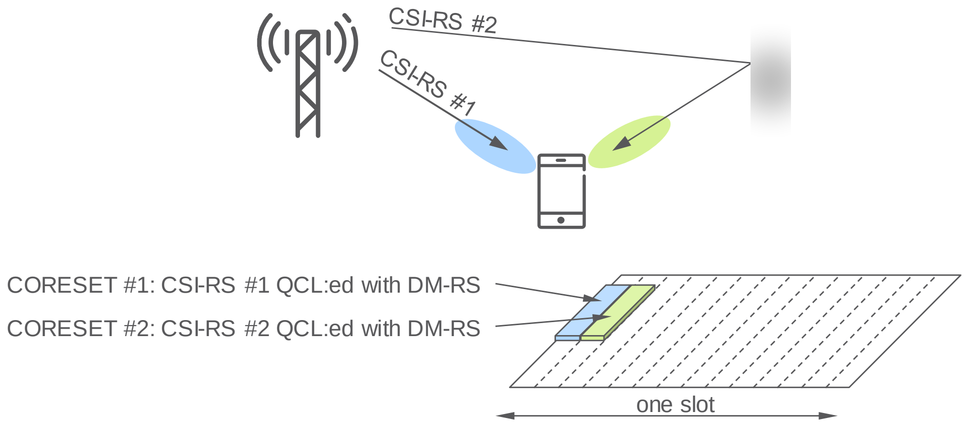
- Each PDCCH has its own DM-RS…
  …but possible to configure 'wideband RS'
  - DM-RS on every 4th subcarrier



Normal case – DM-RS per PDCCH

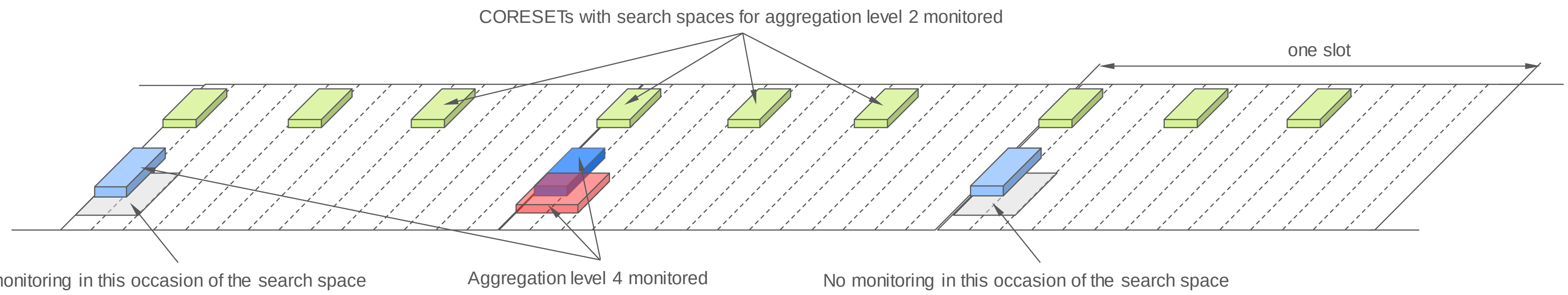
Wideband RS

- Can configure TCI states (QCL relations) per CORESET
  - If none configured – assume QCL with SS block



Blind Decoding

- Blind decoding of PDCCH using search spaces and DCI formats
  - Similar concept as in LTE
  - Aggregation level 1, 2, 4, 8, or 16
- Flexible configuration of when, what formats, and what aggregation levels to monitor



DCI formats

- Format 0-0 – uplink scheduling (fallback format)
- Format 0-1 – uplink scheduling
- Format 1-0 – downlink scheduling (fallback format)
- Format 1-1 – downlink scheduling
- Format 2-0 – slot-format indicator
- Format 2-1 – preemption indictor
- Format 2-2 – PUSCH/PUCCH power control
- Format 2-3 – SRS power control

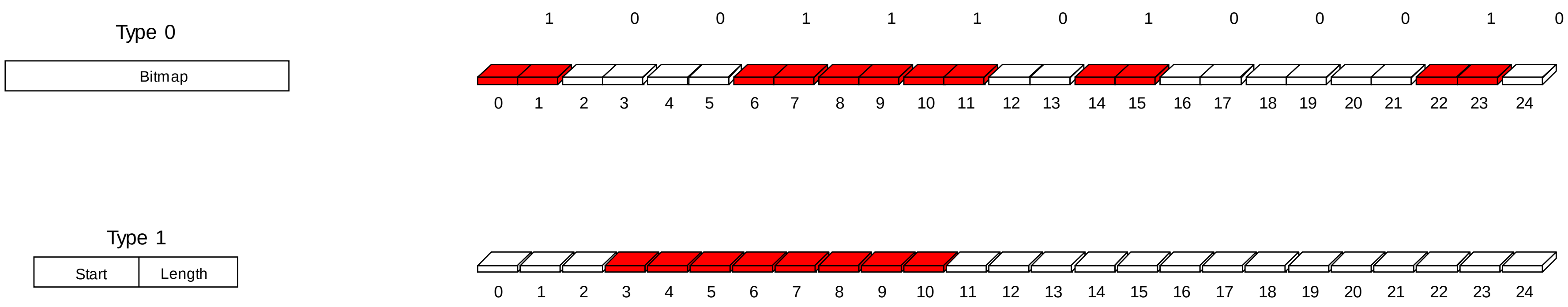
Field		Format 1-0	Format 1-1
Format identifier		•	•
Resource information	CFI		•
	BWP indicator		•
	Frequency domain allocation	•	•
	Time-domain allocation	•	•
	VRB-to-PRB mapping	•	•
	PRB bundling size indicator		•
	Reserved resources		•
	Zero-power CSI-RS trigger		•
Transport-block related	MCS	•	•
	NDI	•	•
	RV	•	•
	MCS, 2nd TB		•
	NDI, 2nd TB		•
	RV, 2nd TB		•
Hybrid-ARQ related	Process number	•	•
	DAI	•	•
	PDSCH-to-HARQ feedback timing	•	•
	CBGTI		•
	CBGFI		•
Multi-antenna related	Antenna ports		•
	TCI		•
	SRS request		•
	DM-RS sequence initialization		•
PUCCH-related information	PUCCH power control	•	•
	PUCCH resource indicator		•

See 38.212 for an up-to-date detailed list

Frequency-domain resource allocation

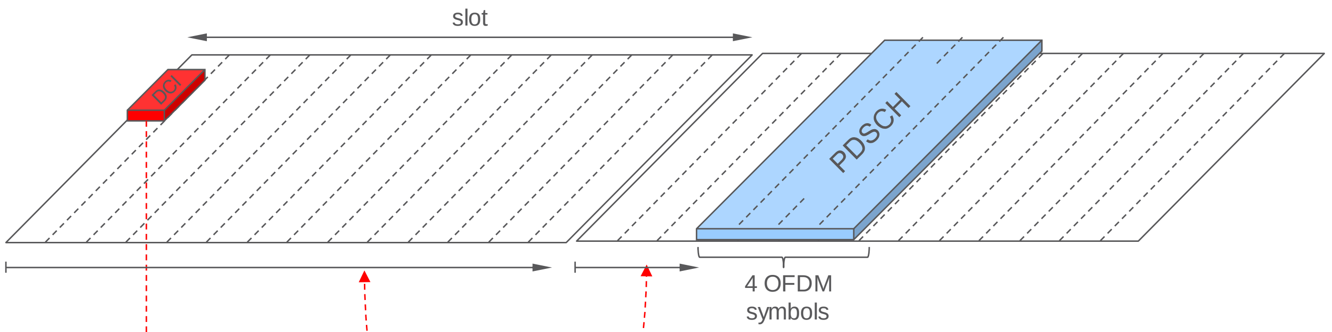
- Resource allocation type 0 – bitmap, each bit corresponds to a group of RBs
- Resource allocation type 1 – start and length of RB allocation

- The type to use is RRC configured (always 0, always 1, dynamic selection of 0/1)
  - Uplink transmissions limited to contiguous allocations in Rel-15



Time-domain resource allocation

- Index into RRC-configured table
  - Default values specified (needed before configuration)



Index	Slot offset	Start symbol	Length	PDSCH mapping type
0	0	2	12	A
1	0	2	10	A
2	1	3	4	B
…	…	…	…	…

RRC configured

Jointly encoded

Time-domain allocation

- Specification structure supports ‘any’ combination of start, length, and mapping type

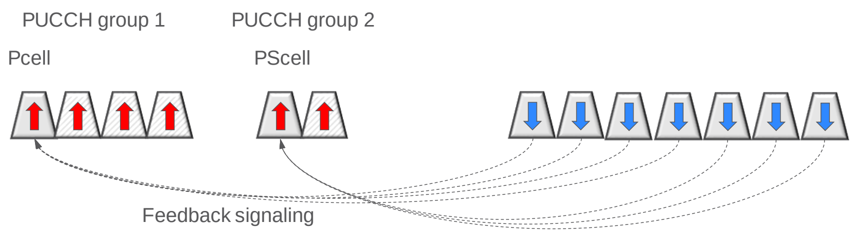
- Restrictions made on what UEs need to support
  - Allocations may not span the slot boundary

- PDSCH mapping type A
  - Start symbol: 0, 1, 2, 3 in a slot.
  - Length: 3 – 14 symbols
- PDSCH mapping type B
  - Start symbol: any
  - Length: 2, 4, 7 symbols

- PUSCH mapping type A
  - Start symbol: 0 in a slot
  - Length: 4 – 14 symbols
- PUSCH mapping type B
  - Start symbol: any
  - Length: 2 – 14 symbols

Uplink L1/L2 control signaling

- UCI on PUCCH (no simultaneous data) or PUSCH (simultaneous data, ‘UCI on PUCCH’)
  - Hybrid-ARQ acknowledgements, channel-state information, scheduling request
- PUCCH not necessarily at carrier edges (as in LTE)
  - DCI can indicate the resource to use for UCI
- Beamforming support: spatial relations between PUCCH and downlink signals can be configured
  - MAC-CE used to switch between different configurations
- PUCCH on Pcell (or PScell) in case of CA, similar to LTE



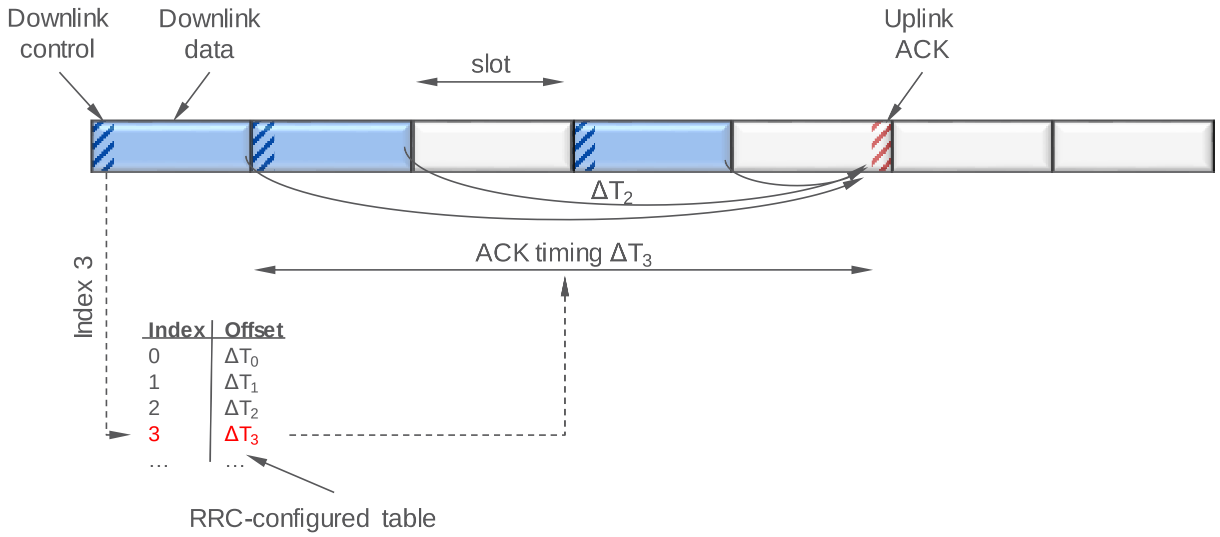
PUCCH formats

- Five different PUCCH formats
- All designed with low PAPR in mind, can be used irrespective of PUSCH waveform

Payload	Short (1-2 OFDM symbol)	Long (4 – 14 OFDM symbols)
≤2 bits	PUCCH format 0	PUCCH format 1
>2 bits	PUCCH format 2	PUCCH formats 3 and 4

PUCCH Timing

- PUCCH timing and resources indicated in the DCI
  - In essence ‘scheduling’ of PUCCH



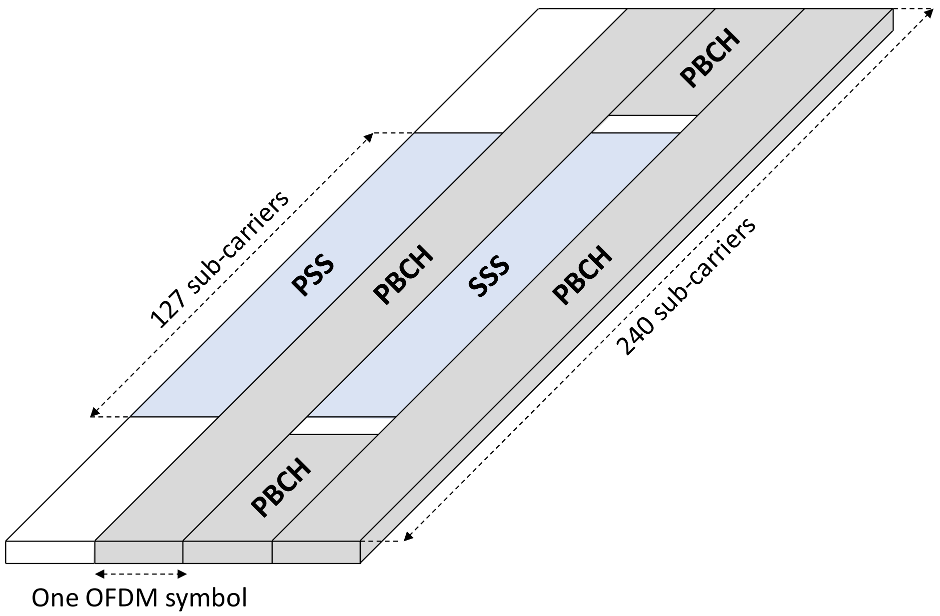
- Much faster processing time than in LTE

DM-RS configuration	Device capability	Subcarrier spacing 15 kHz	30 kHz	60 kHz	120 kHz	LT rel
Front-loaded	Baseline	0.57 ms	0.36 ms	0.30 ms	0.18 ms	2.3
	Aggressive	0.18 – 0.29 ms	0.08 – 0.17 ms			
Additional	Baseline	0.92 ms	0.46 ms	0.36 ms	0.21 ms	
	Aggressive	0.85 ms	0.4 ms			

Cell search and Random access

Cell Search and System Information Acquisition

- SS Block (SSB)
  - PSS and SSS to obtain synchronization
  - PBCH for (parts of) system information



- Main difference compared to LTE
  - Less frequent PSS/SSS/PBCH transmission (20 ms periodicity)
  - Support for beamforming
  - Minimize “always on” broadcasting of system information (possibility for “on demand” delivery)

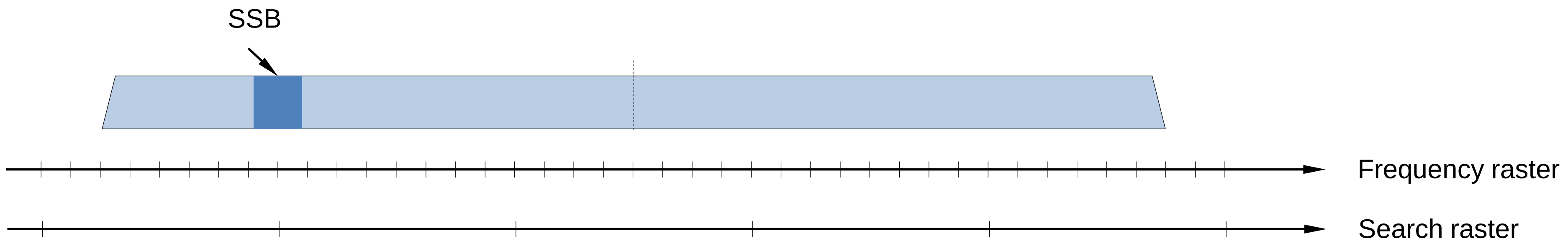
SS Block

- Subcarrier spacing for SS Block depends on frequency band

Numerology	SSB bandwidth	SSB duration	Frequency range
15 kHz	3.6 MHz	≈285 µs	FR1 < 3GHz
30 kHz	7.2 MHz	≈143 µs	FR1
120 kHz	28.8 MHz	≈36 µs	FR2
240 kHz	57.6 MHz	≈18 µs	FR2

SS Block

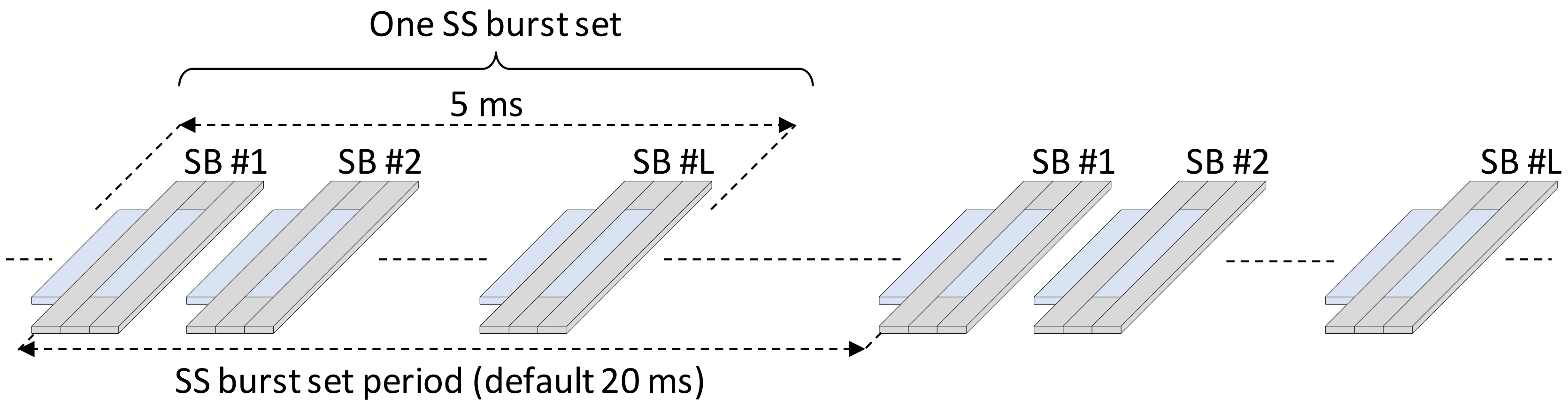
- SS Block not necessarily at the center of the carrier (as in LTE)
  - Reason: allow for a search raster sparser than the frequency raster
  - Note: SS block not necessarily aligned with the resource block grid

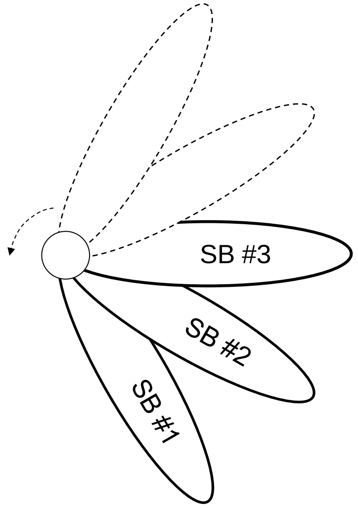


SS block and Beam Sweeping

- SS burst set
  - Multiple SS blocks in different beams

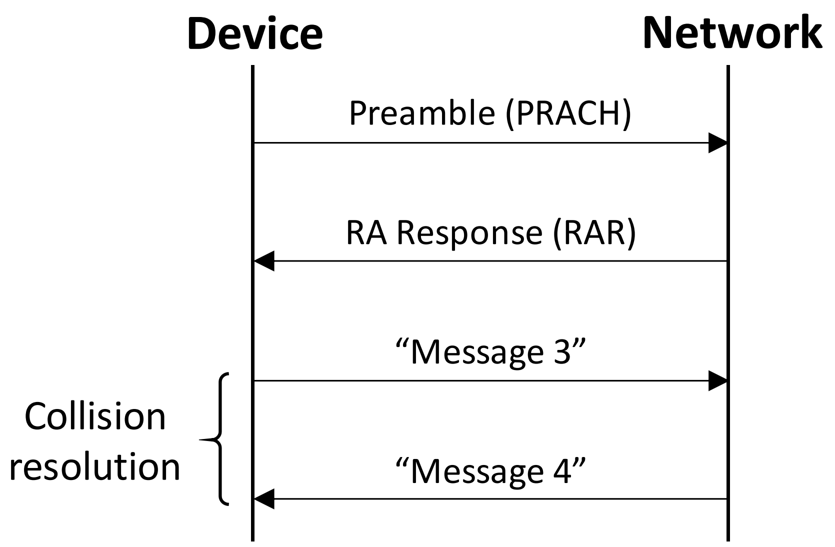
Frequency range	SS blocks per SS burst set
– 3 GHz	4
3 – 6 GHz	8
mm-wave	64





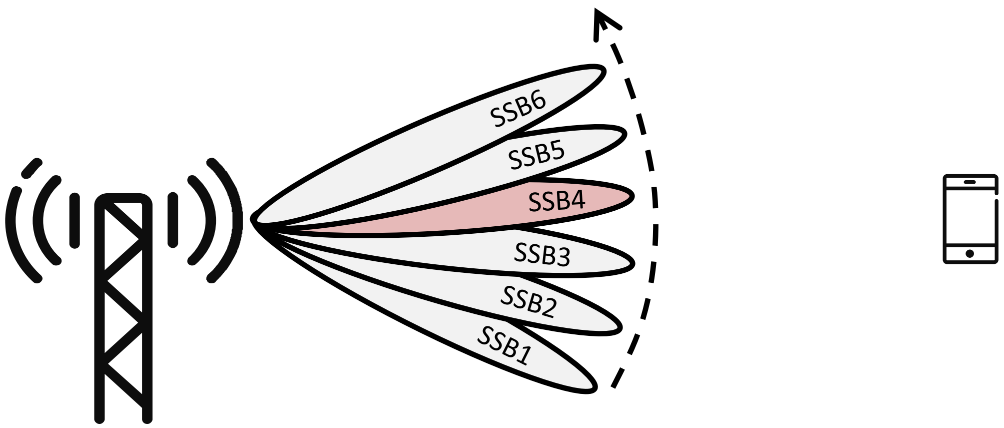
Random Access

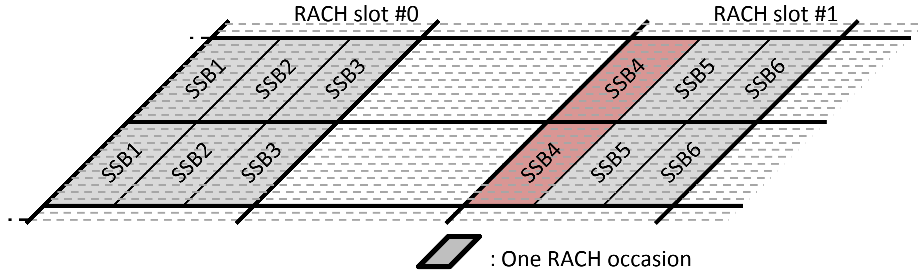
- Four-step random access procedure
  - 1 Preamble transmission
  - 2 Random-access response
  - 3, 4 Contention resolution



Beam Establishment

- Different SS block time indices are associated with different RACH time/frequency occasions
  - SIB1 provides "number of SS-block time indices per RACH time/frequency occasion"
  - SSB time indices associated with RACH occasions,
    first in frequency, then in time within a slot, and last in time between slots





Supplementary Uplink

- System information provides
  - separate RACH configurations for ‘normal’ and ‘supplementary’ uplinks
  - threshold for carrier selection

- Measure downlink RSRP and select uplink carrier for random access
  - RSRP above threshold ➡ random-access on non-SUL carrier
  - RSRP below threshold ➡ random-access on SUL carrier

Conclusions

- NR addresses a broad range of use cases with a flexible physical layer structure
- Key enablers include
  - Ultra-lean design
  - Operability in a wide spectrum range
  - Low latency
  - Forward compatible design
  - Advanced multi-antenna techniques

For more Information:

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