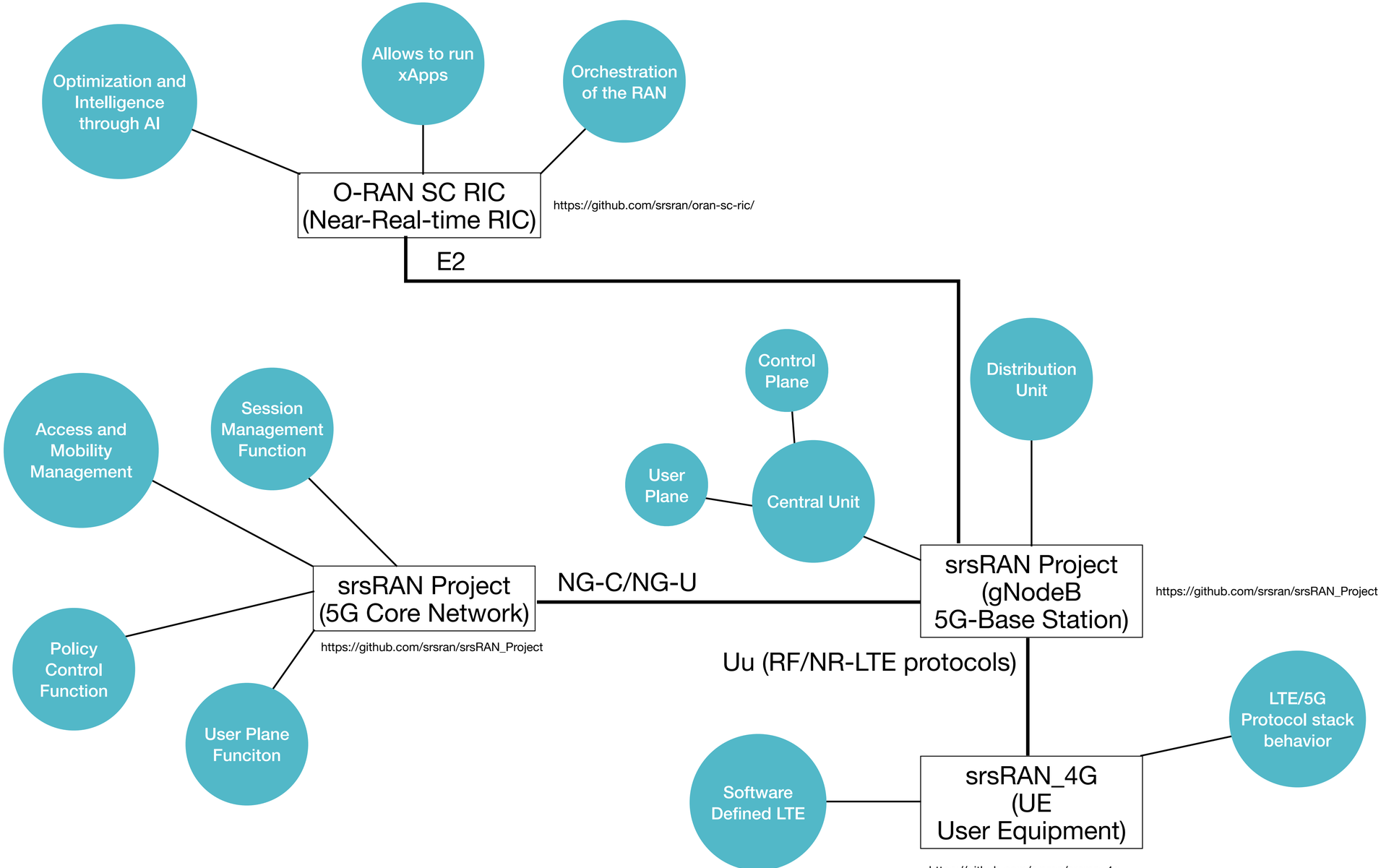
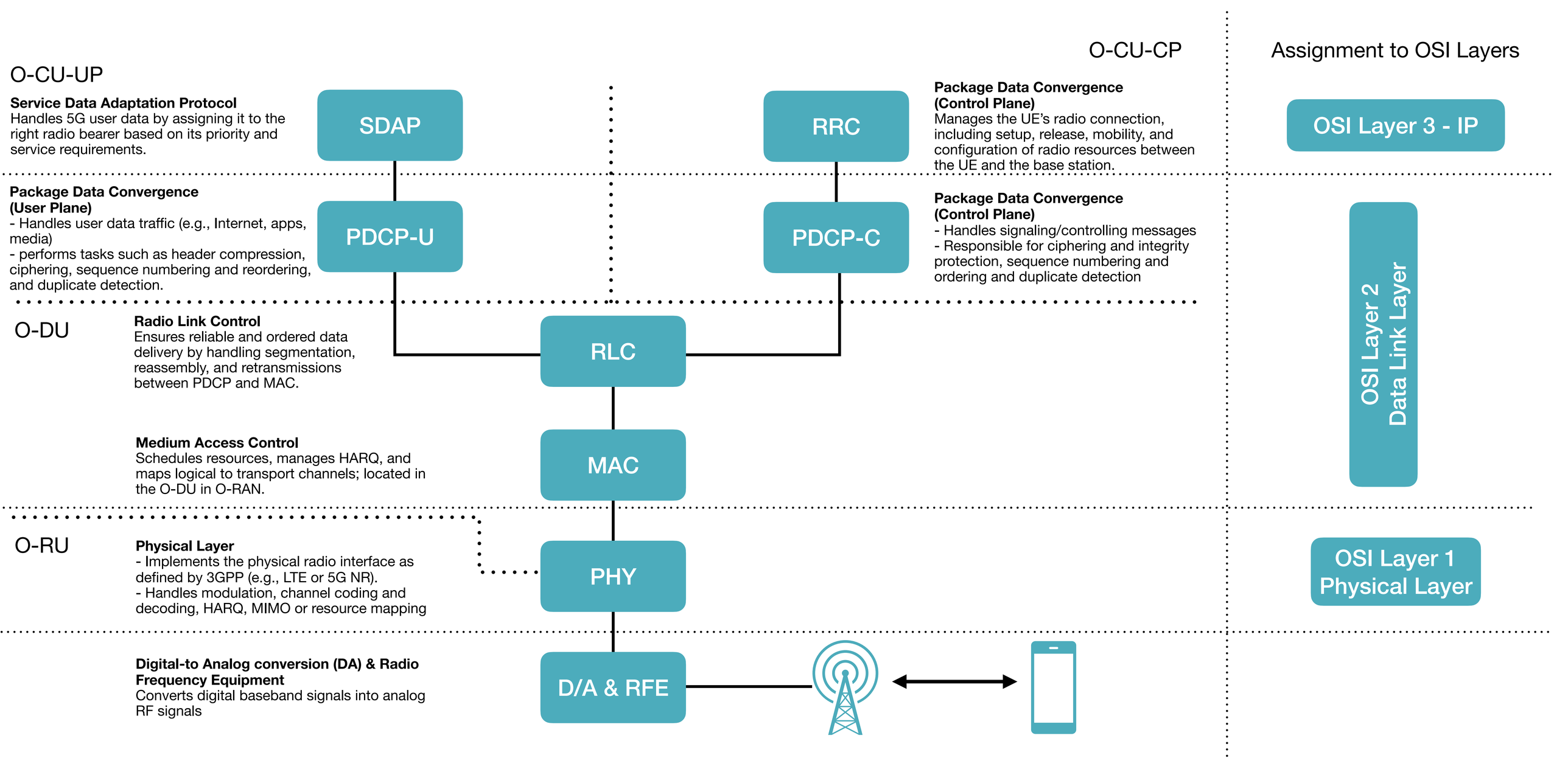

Optimization and Intelligence through AI
Allows to run xApps
Orchestration of the RAN
O-RAN SC RIC (Near-Real-time RIC)
https://github.com/srsran/oran-sc-ric/
E2
Control Plane
Distribution Unit
Access and Mobility Management
Session Management Function
User Plane
Central Unit
srsRAN Project (5G Core Network)
NG-C/NG-U
srsRAN Project (gNodeB 5G-Base Station)
https://github.com/srsran/srsRAN_Project
https://github.com/srsran/srsRAN_Project
Policy Control Function
User Plane Funciton
Uu (RF/NR-LTE protocols)
LTE/5G Protocol stack behavior
Software Defined LTE
srsRAN_4G (UE User Equipment)
https://github.com/srsran/srsran_4g


O-CU-UP
Service Data Adaptation Protocol
Handles 5G user data by assigning it to the right radio bearer based on its priority and service requirements.
SDAP
Package Data Convergence (User Plane)
- Handles user data traffic (e.g., Internet, apps, media)
- performs tasks such as header compression, ciphering, sequence numbering and reordering, and duplicate detection.
PDCP-U
O-CU-CP
RRC
Package Data Convergence (Control Plane)
Manages the UE's radio connection, including setup, release, mobility, and configuration of radio resources between the UE and the base station.
PDCP-C
Package Data Convergence (Control Plane)
- Handles signaling/controlling messages
- Responsible for ciphering and integrity protection, sequence numbering and ordering and duplicate detection
O-DU
Radio Link Control
Ensures reliable and ordered data delivery by handling segmentation, reassembly, and retransmissions between PDCP and MAC.
RLC
Medium Access Control
Schedules resources, manages HARQ, and maps logical to transport channels; located in the O-DU in O-RAN.
MAC
O-RU
Physical Layer
- Implements the physical radio interface as defined by 3GPP (e.g., LTE or 5G NR).
- Handles modulation, channel coding and decoding, HARQ, MIMO or resource mapping
PHY
Digital-to Analog conversion (DA) & Radio Frequency Equipment
Converts digital baseband signals into analog RF signals
D/A & RFE
Assignment to OSI Layers
OSI Layer 3 - IP
OSI Layer 2 Data Link Layer
OSI Layer 1 Physical Layer

Scope: Standardized Radio Access technologies across generations (2G, 3G, 4G, 5G)

Responsibilities: Defines protocol stacks (PHY, MAC, RLC, PDCP, RRC, NAS, SDAP), interfaces (N2, N3, E1, F1), UE categories, QoS, signaling, and base station behavior (gNB/eNB) with the core network.

3GPP (3rd Generation Partnership Project)

O-RAN Alliance

- **Scope:** Specifies open, disaggregated RAN architectures and interfaces for multi-vendor interoperability.

Responsibilities:

- Defines functional splits (O-CU-CP, O-CU-UP, O-DU, O-RU).
- Specifies E2, A1, and open fronthaul interfaces.
- Defines Near-RT RIC and control loops.

Scope: Focuses on software-defined RAN controllers and orchestration.

Responsibilities:

- Provides software platforms to control and manage disaggregated RAN elements.
- Implements policy-driven automation, network slicing, and optimization.
- Interfaces with O-RAN components via standard interfaces.

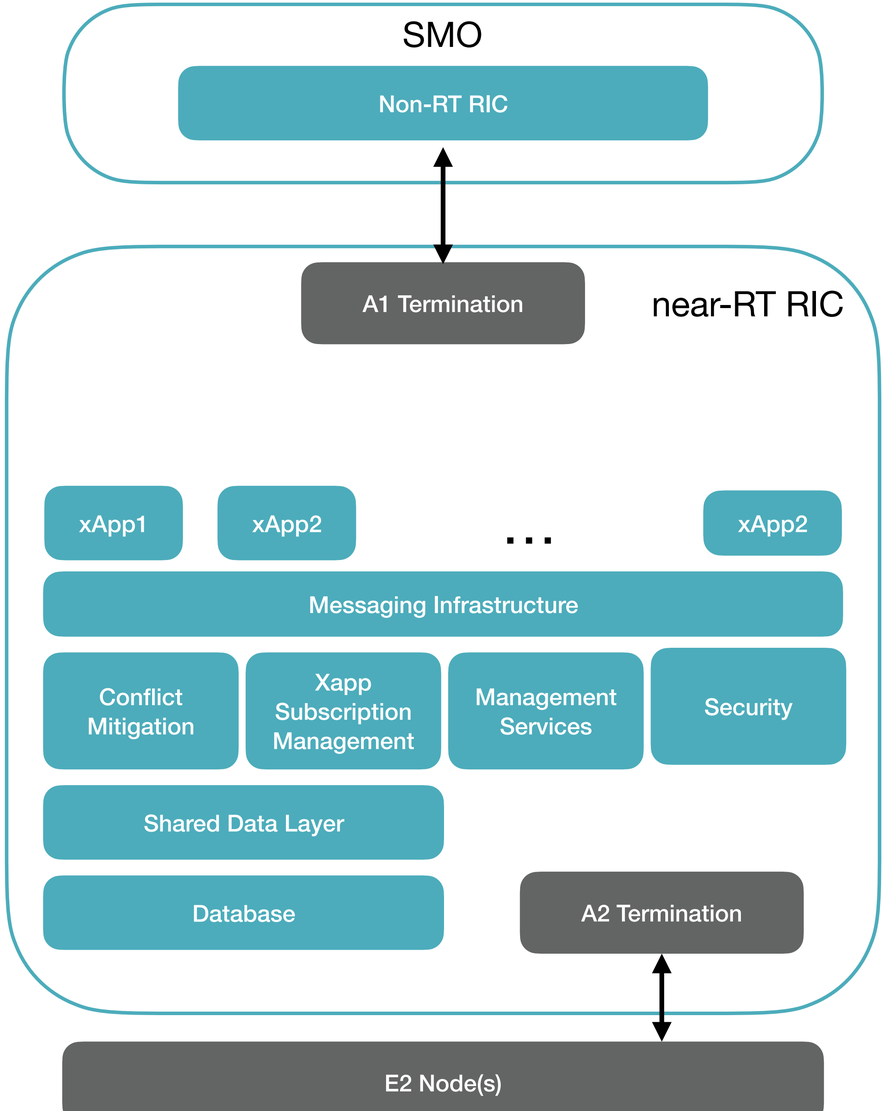
ONF SD-RAN

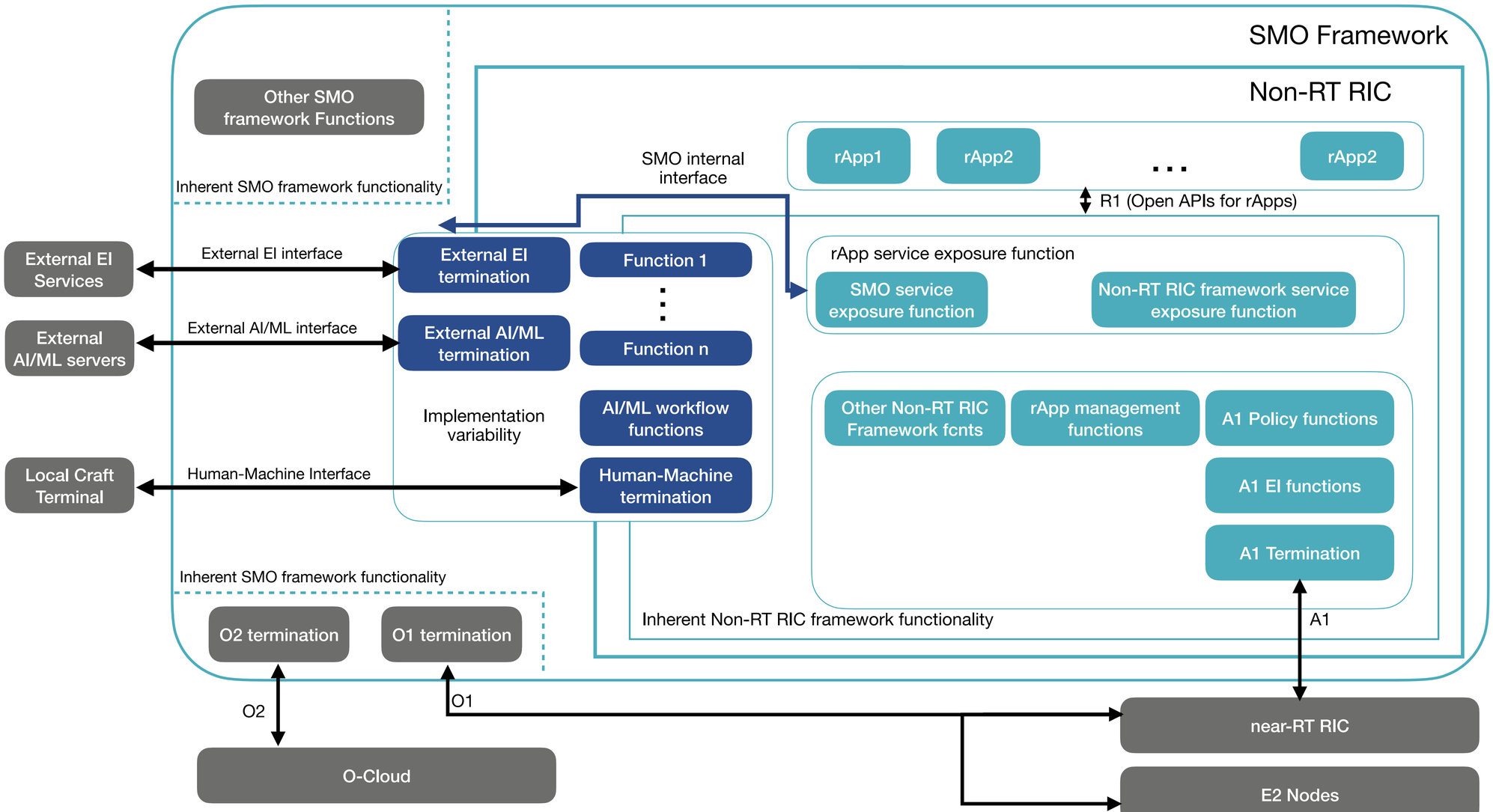
Telecom Infra

Scope: Physical deployment of RAN components and networking infrastructure.

Responsibilities:

- Supply radio units (O-RU), antennas, fiber fronthaul/backhaul, and data centers.
- Ensure site installation, power, cooling, and maintenance.
- integrate O-RAN and 3GPP components into a working network.

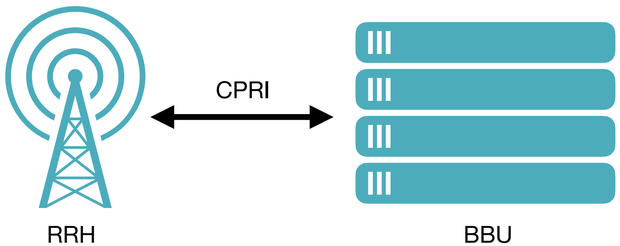

SMO
Non-RT RIC
A1 Termination
near-RT RIC
xApp1
xApp2
...
xApp2
Messaging Infrastructure
Conflict Mitigation
Xapp Subscription Management
Management Services
Security
Shared Data Layer
Database
A2 Termination
E2 Node(s)


SMO Framework
Non-RT RIC
Other SMO framework Functions
Inherent SMO framework functionality
SMO internal interface
rApp1
rApp2
...
rApp2
R1 (Open APIs for rApps)
External EI Services
External EI interface
External EI termination
Function 1
Function n
rApp service exposure function
SMO service exposure function
Non-RT RIC framework service exposure function
External AI/ML servers
External AI/ML interface
External AI/ML termination
Implementation variability
AI/ML workflow functions
Other Non-RT RIC Framework fcnts
rApp management functions
A1 Policy functions
A1 EI functions
A1 Termination
Local Craft Terminal
Human-Machine Interface
Human-Machine termination
Inherent SMO framework functionality
Inherent Non-RT RIC framework functionality
A1
O2 termination
O1 termination
O2
O1
O-Cloud
near-RT RIC
E2 Nodes

1.

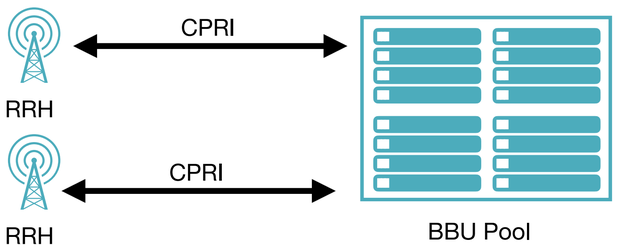
Conventional Base Station
Combined RF + BB

2.



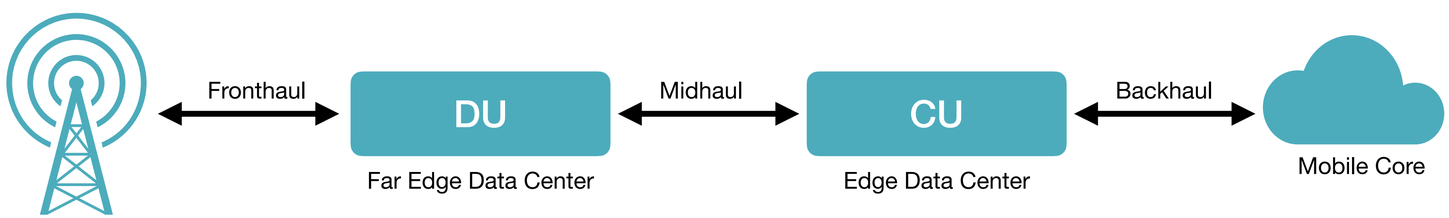
Mobile Front-haul Network
Separated RRH and BBU

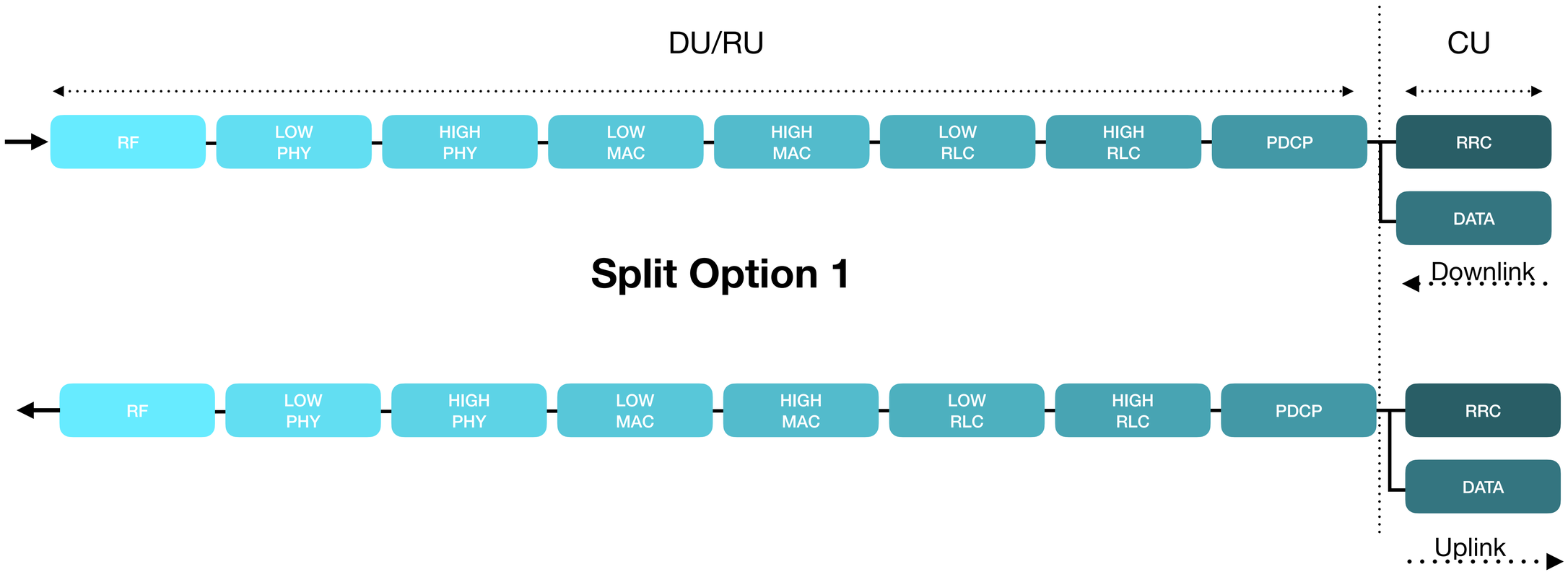
3.

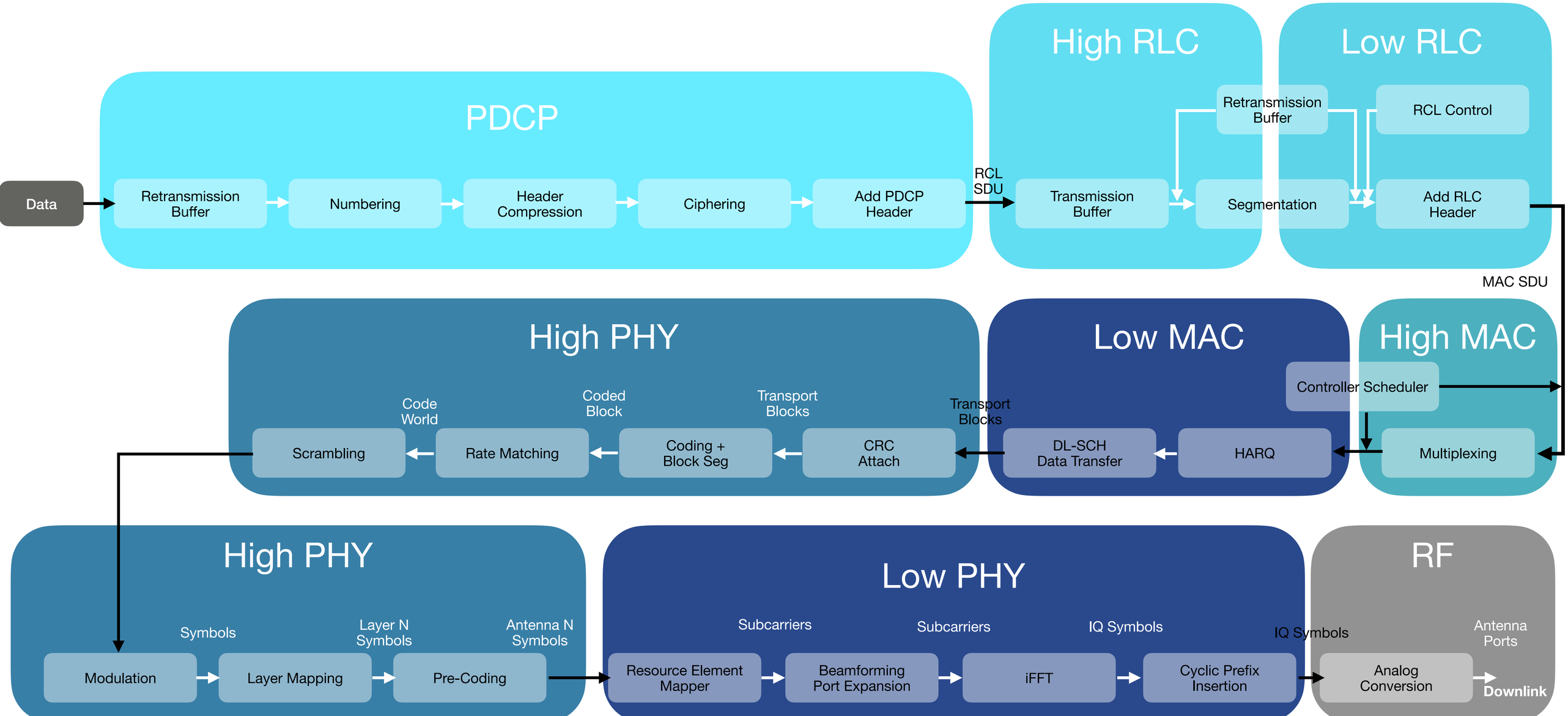


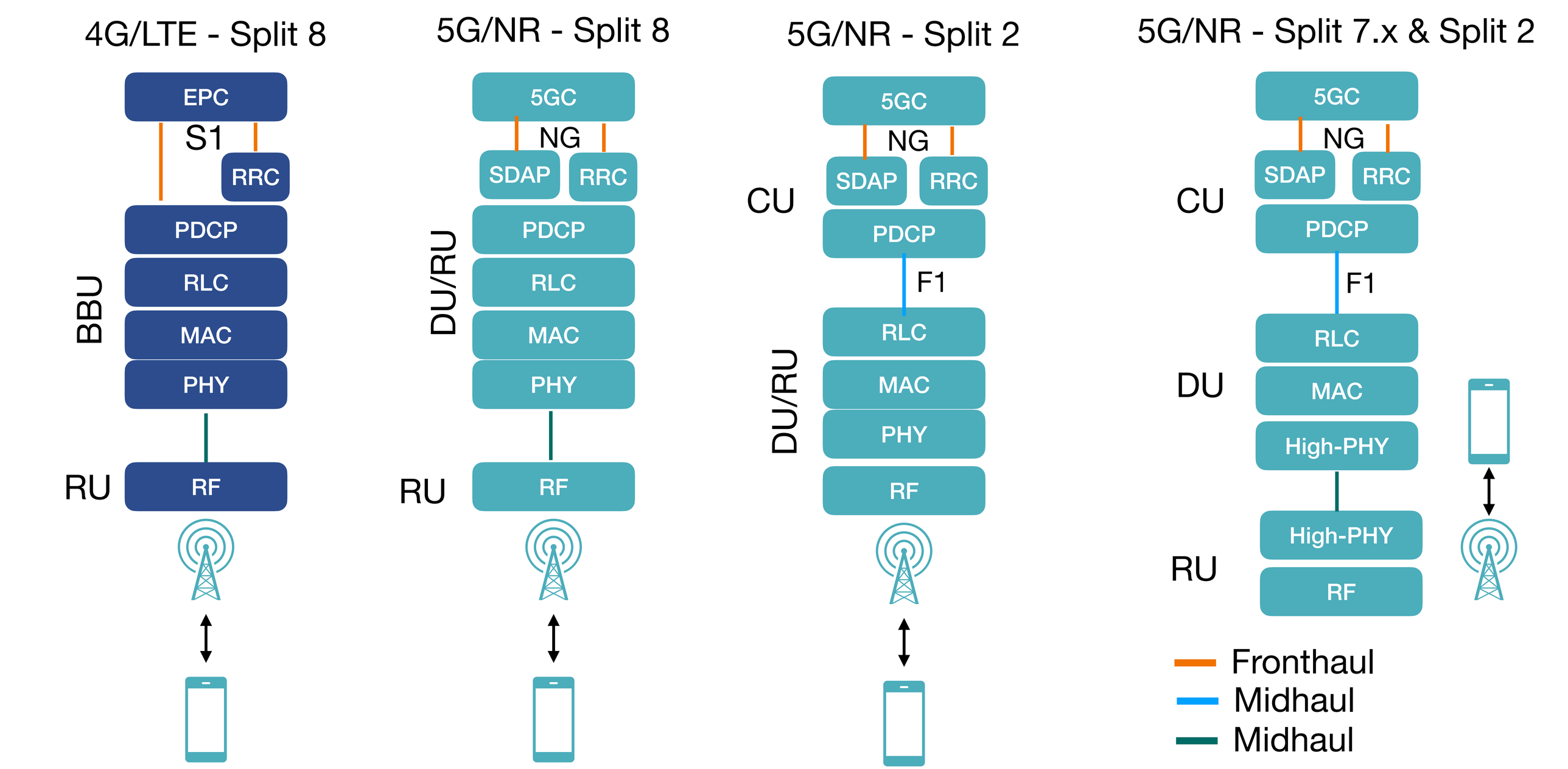
Centralized RAN
Multiple BBUS Combined to Pools (often virtualized)

4.

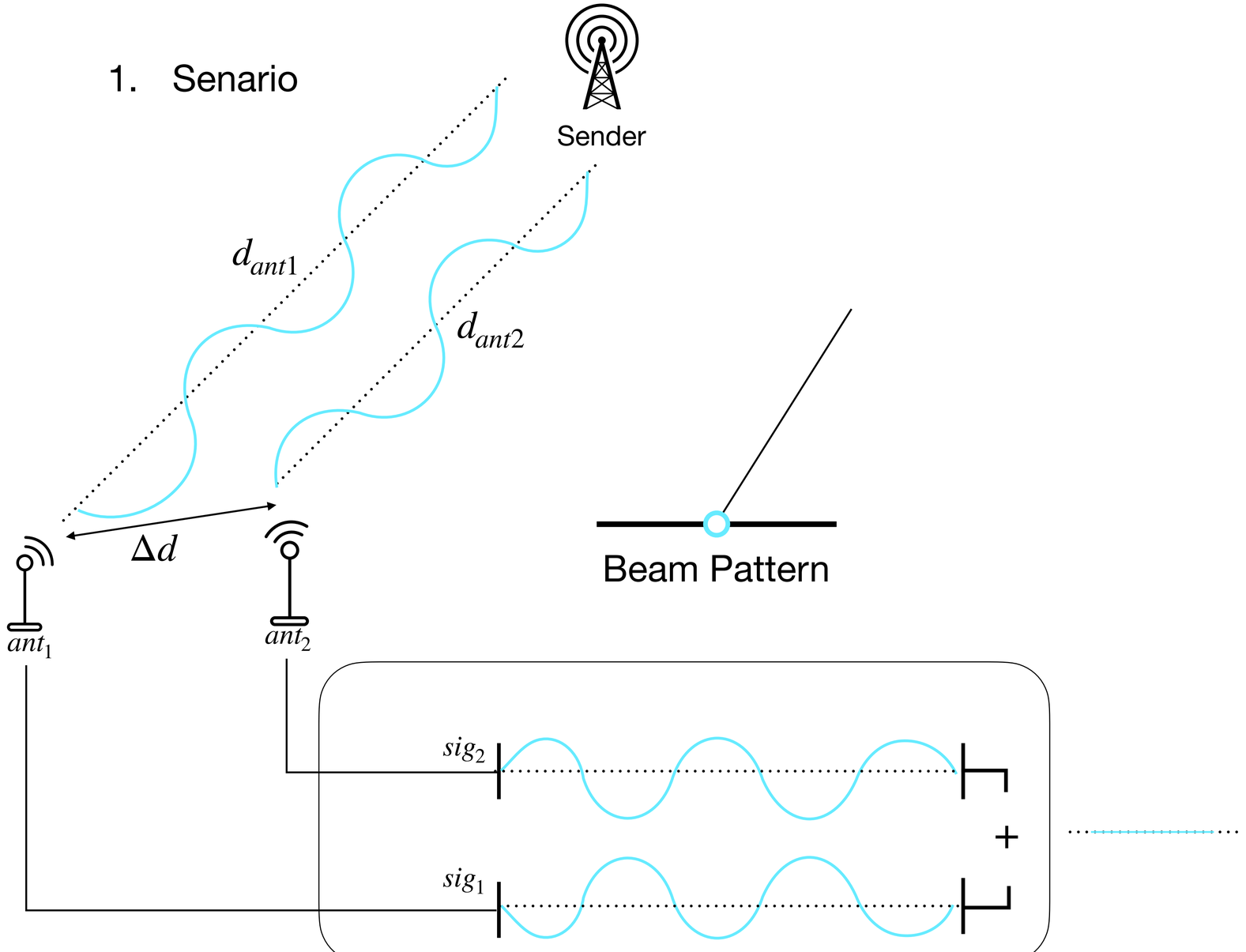


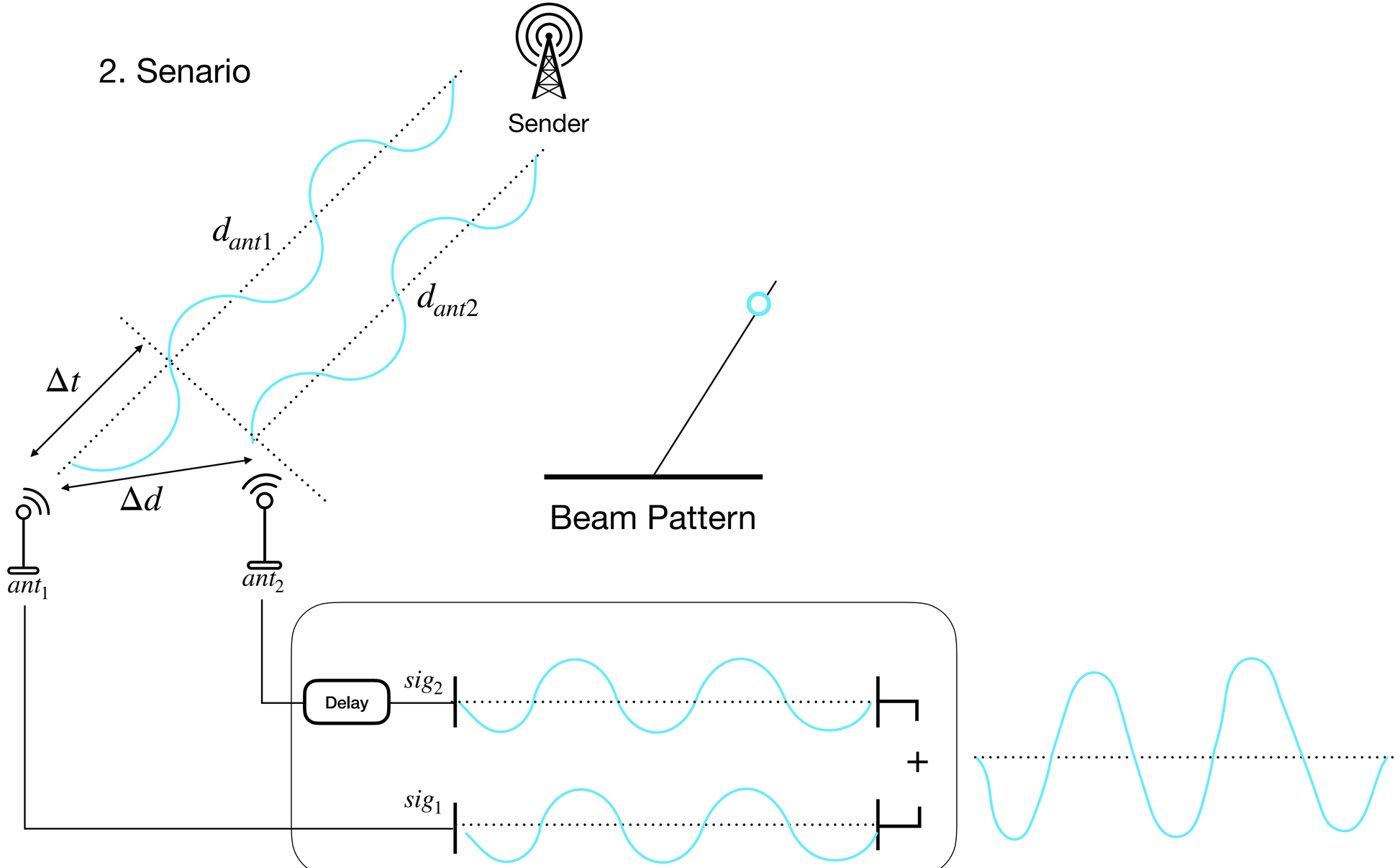

DU/RU
CU
RF
LOW PHY
HIGH PHY
LOW MAC
HIGH MAC
LOW RLC
HIGH RLC
PDCP
RRC
DATA
Downlink
Split Option 1
RF
LOW PHY
HIGH PHY
LOW MAC
HIGH MAC
LOW RLC
HIGH RLC
PDCP
RRC
DATA
Uplink

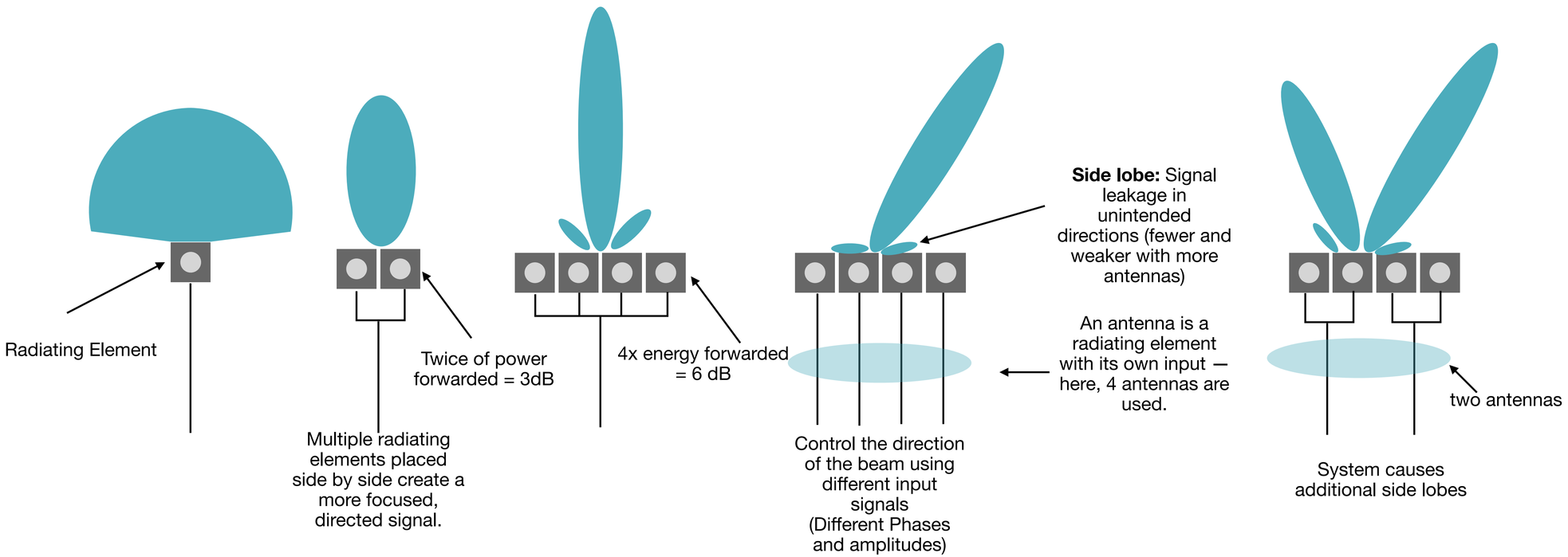

Data
PDCP
Retransmission Buffer
Numbering
Header Compression
Ciphering
Add PDCP Header
RCL SDU
High RLC
Transmission Buffer
Segmentation
Retransmission Buffer
Low RLC
RCL Control
Add RLC Header
MAC SDU
High PHY
Scrambling
Code World
Rate Matching
Coded Block
Coding + Block Seg
Transport Blocks
CRC Attach
Transport Blocks
Low MAC
DL-SCH Data Transfer
HARQ
High MAC
Controller Scheduler
Multiplexing
High PHY
Modulation
Symbols
Layer Mapping
Layer N Symbols
Pre-Coding
Antenna N Symbols
Low PHY
Resource Element Mapper
Subcarriers
Beamforming Port Expansion
Subcarriers
iFFT
IQ Symbols
Cyclic Prefix Insertion
IQ Symbols
RF
Analog Conversion
Antenna Ports
Downlink

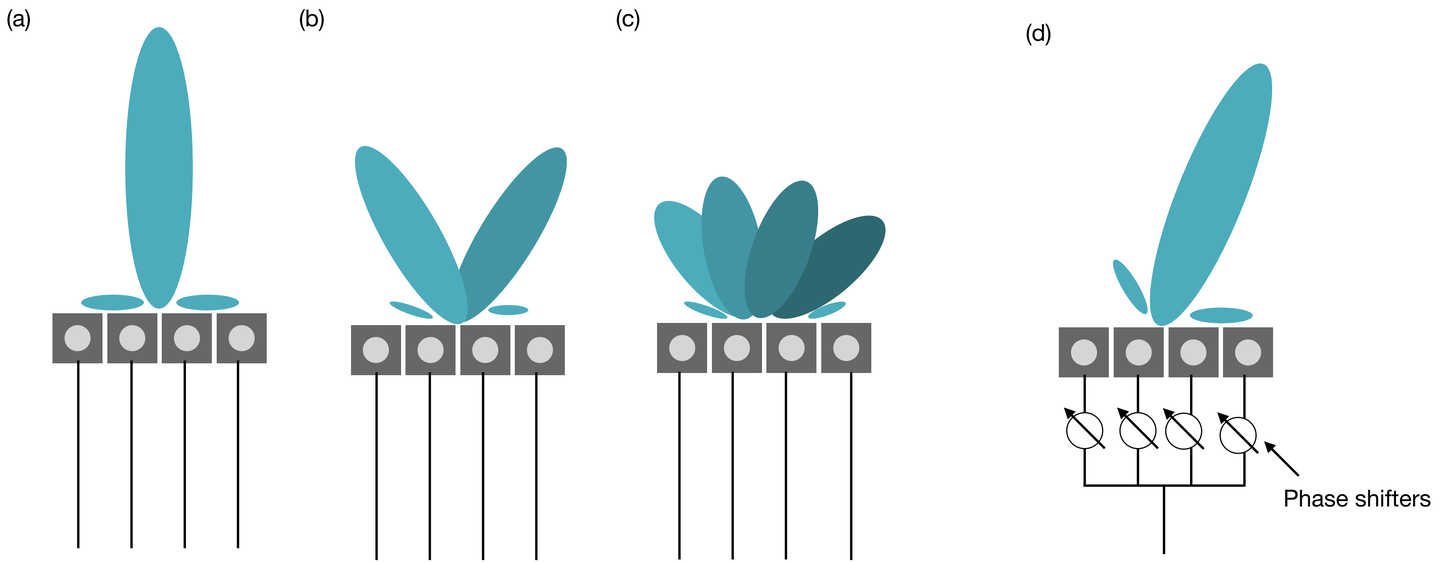

4G/LTE - Split 8
EPC
S1
RRC
PDCP
RLC
MAC
PHY
BBU
RU
RF
5G/NR - Split 8
5GC
NG
SDAP
RRC
PDCP
RLC
MAC
PHY
DU/RU
RU
RF
5G/NR - Split 2
5GC
NG
SDAP
RRC
CU
PDCP
F1
RLC
MAC
PHY
DU/RU
RF
5G/NR - Split 7.x & Split 2
5GC
NG
SDAP
RRC
CU
PDCP
F1
RLC
DU
MAC
High-PHY
High-PHY
RU
RF
Fronthaul
Midhaul
Midhaul

1. Senario

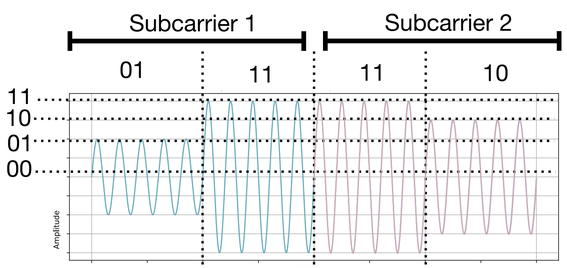



2. Senario
Sender
d_{ant1}
d_{ant2}
Δt
Δd
ant_1
ant_2
Beam Pattern
Delay
sig_2
sig_1
+


Radiating Element
Multiple radiating elements placed side by side create a more focused, directed signal.
Twice of power forwarded = 3dB
4x energy forwarded = 6 dB
Control the direction of the beam using different input signals (Different Phases and amplitudes)
Side lobe: Signal leakage in unintended directions (fewer and weaker with more antennas)
An antenna is a radiating element with its own input — here, 4 antennas are used.
two antennas
System causes additional side lobes

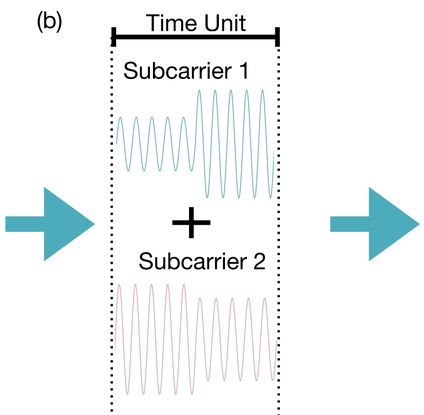

(a)
(b)
(c)
(d)
Phase shifters

(a)



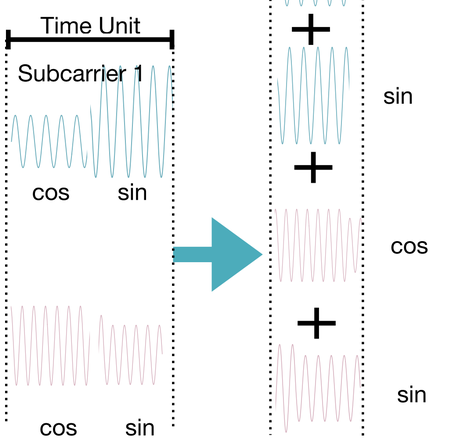
Using multiple subcarriers
Spread data over multiple subcarrier waves

(b)

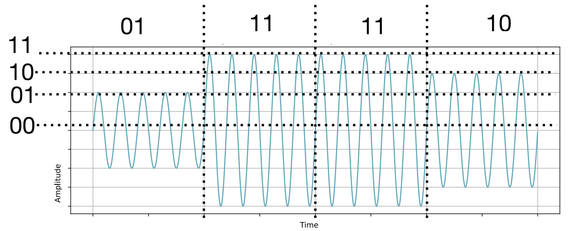


By combining these subcarriers double the information can be transmitted within a time unit

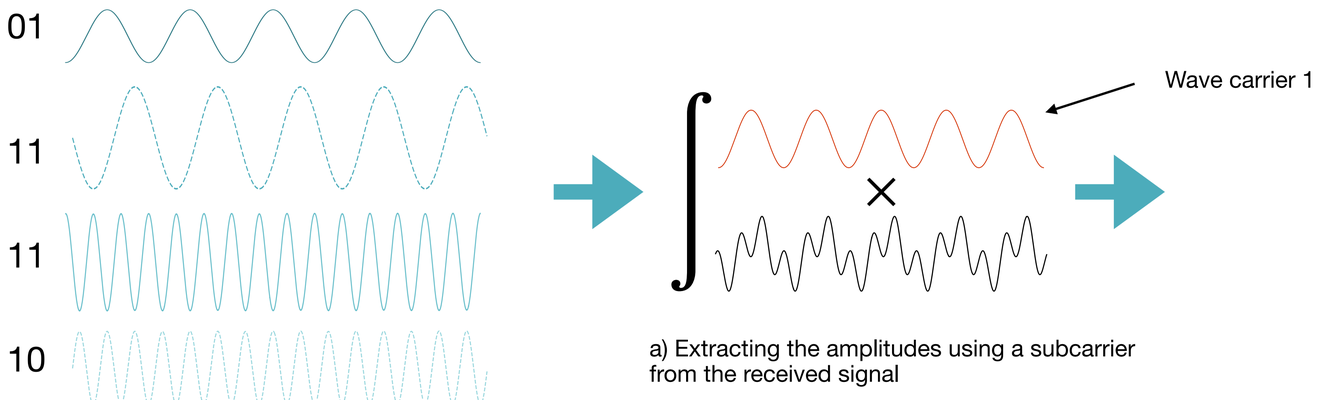
(c)



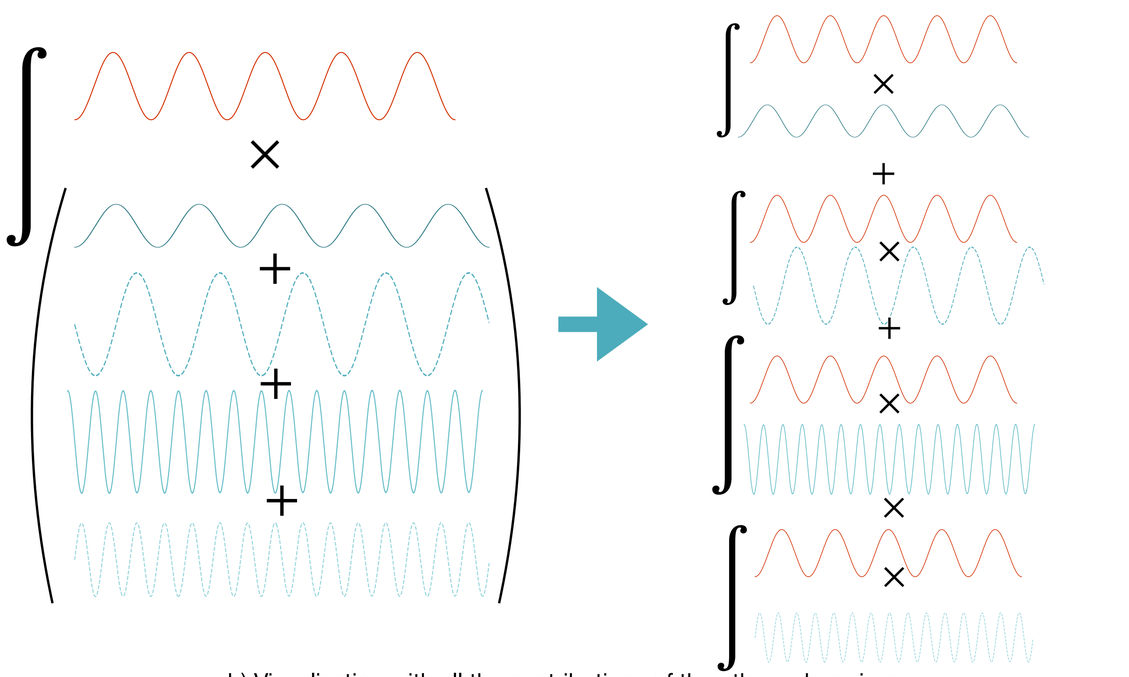
Each subcarrier uses a sinus signal and a cos signal allow to double the transmission per time unit. This technique is referred to as QAM modulation.



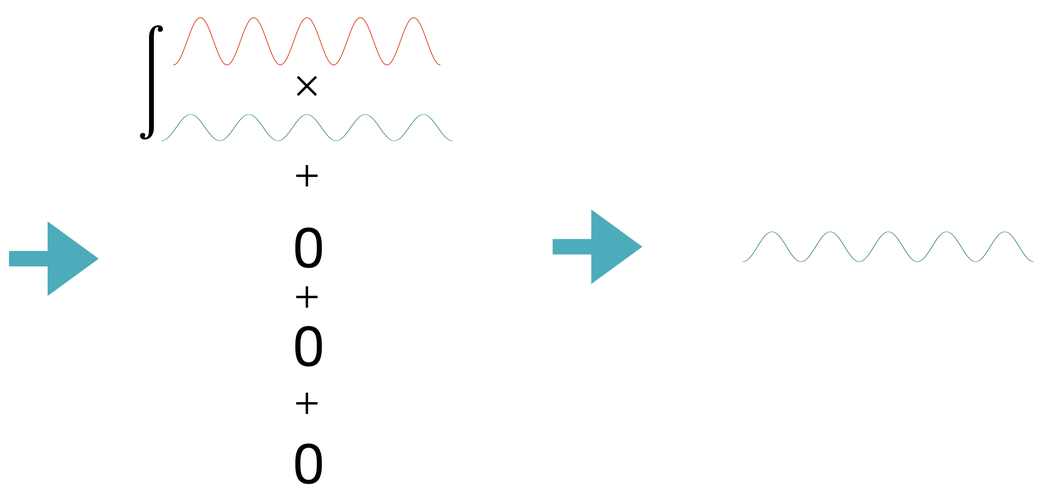
Naive transmission approach
Using a single carrier wave and use the amplitude to transmit data.



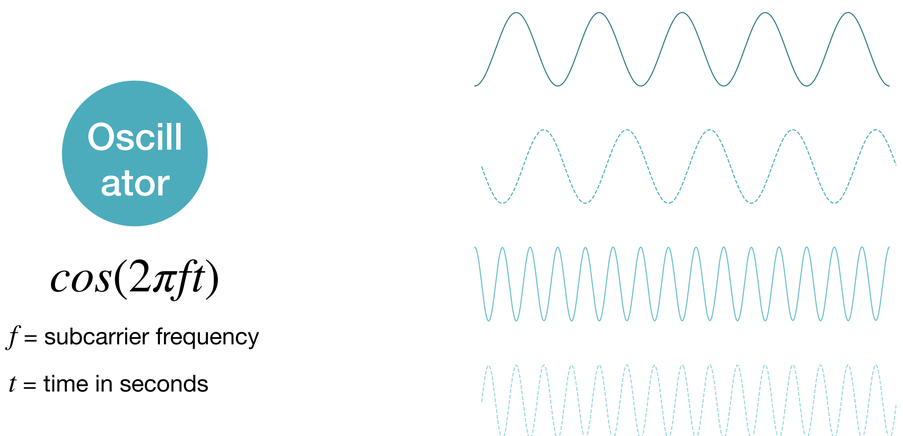
a) Extracting the amplitudes using a subcarrier from the received signal



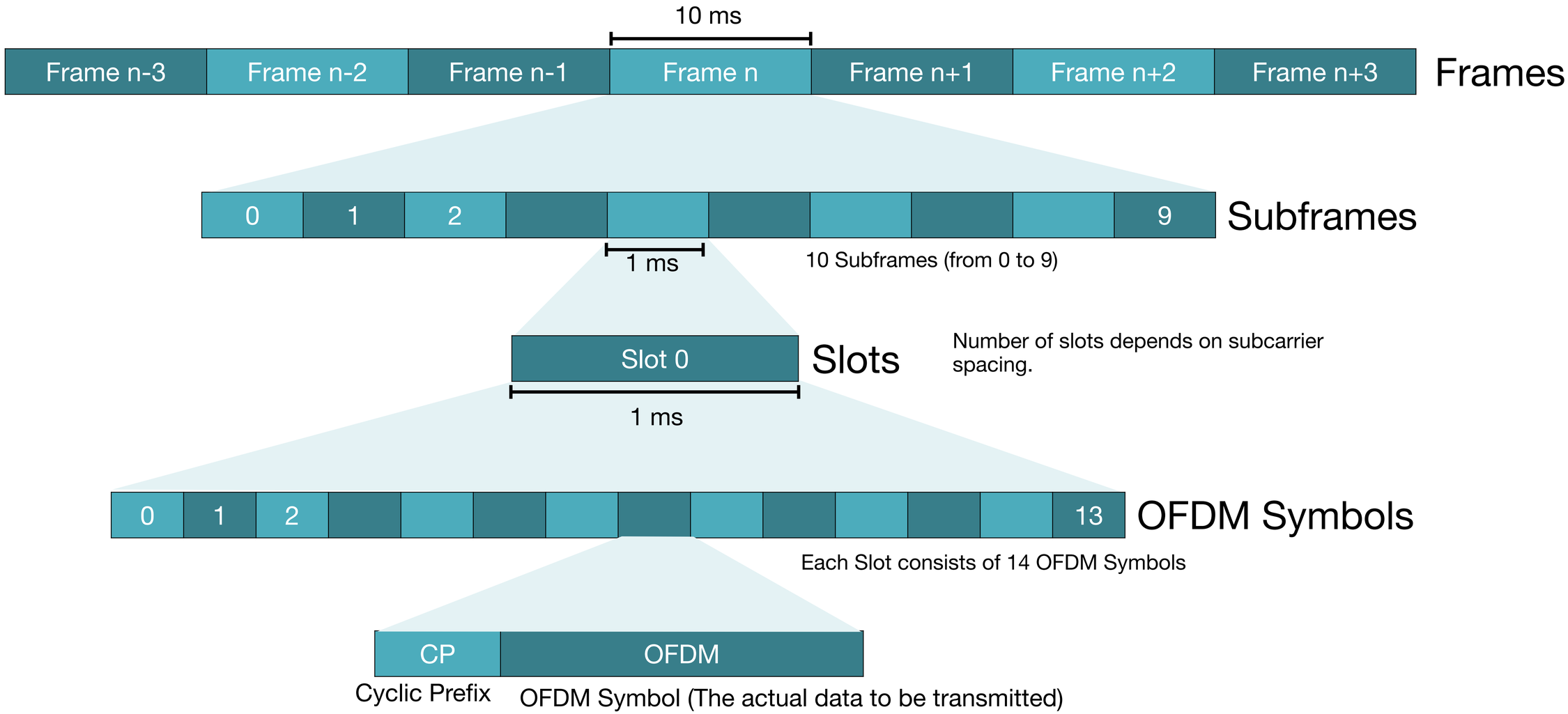
b) Visualization with all the contributions of the other subcarriers

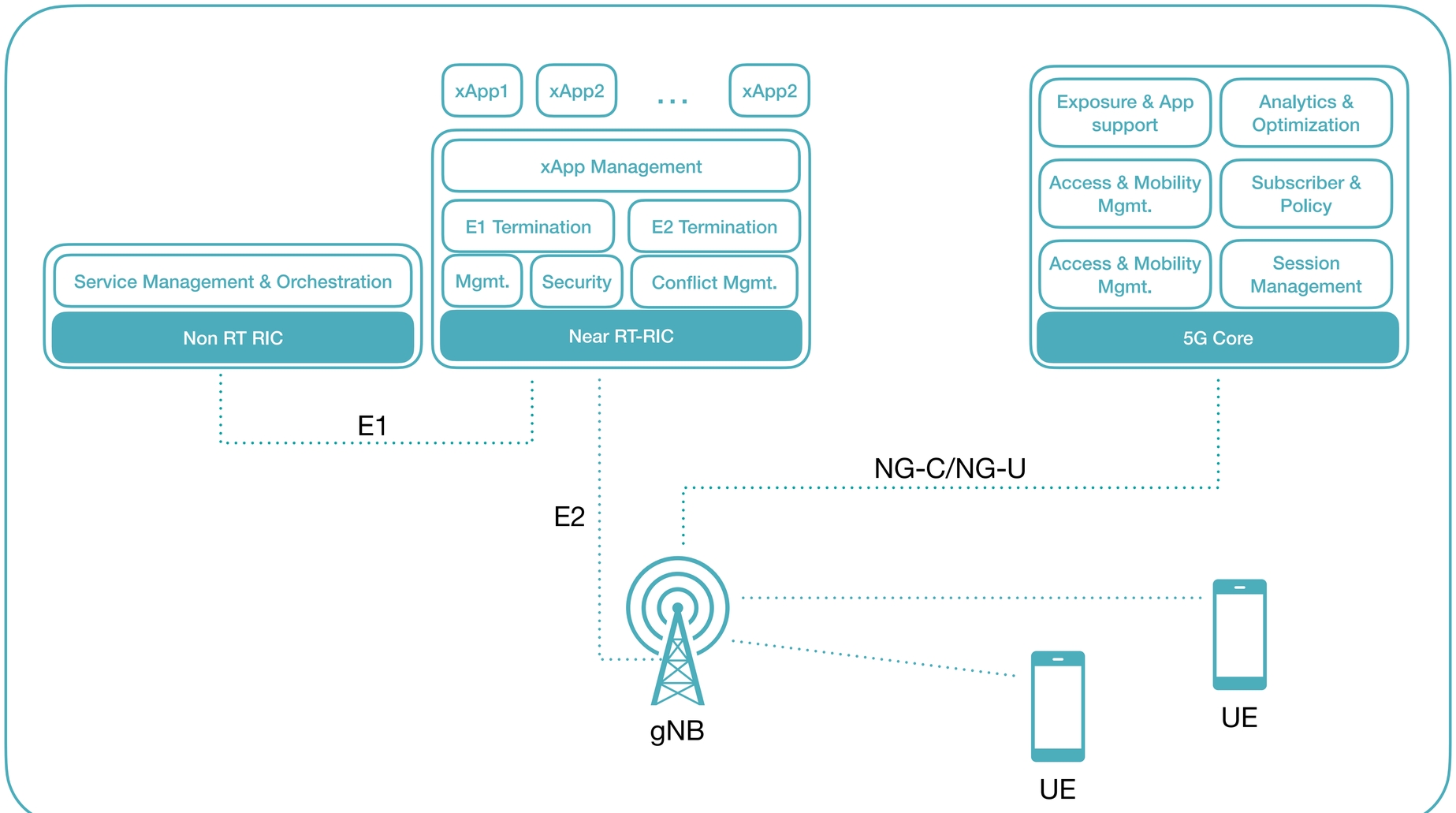


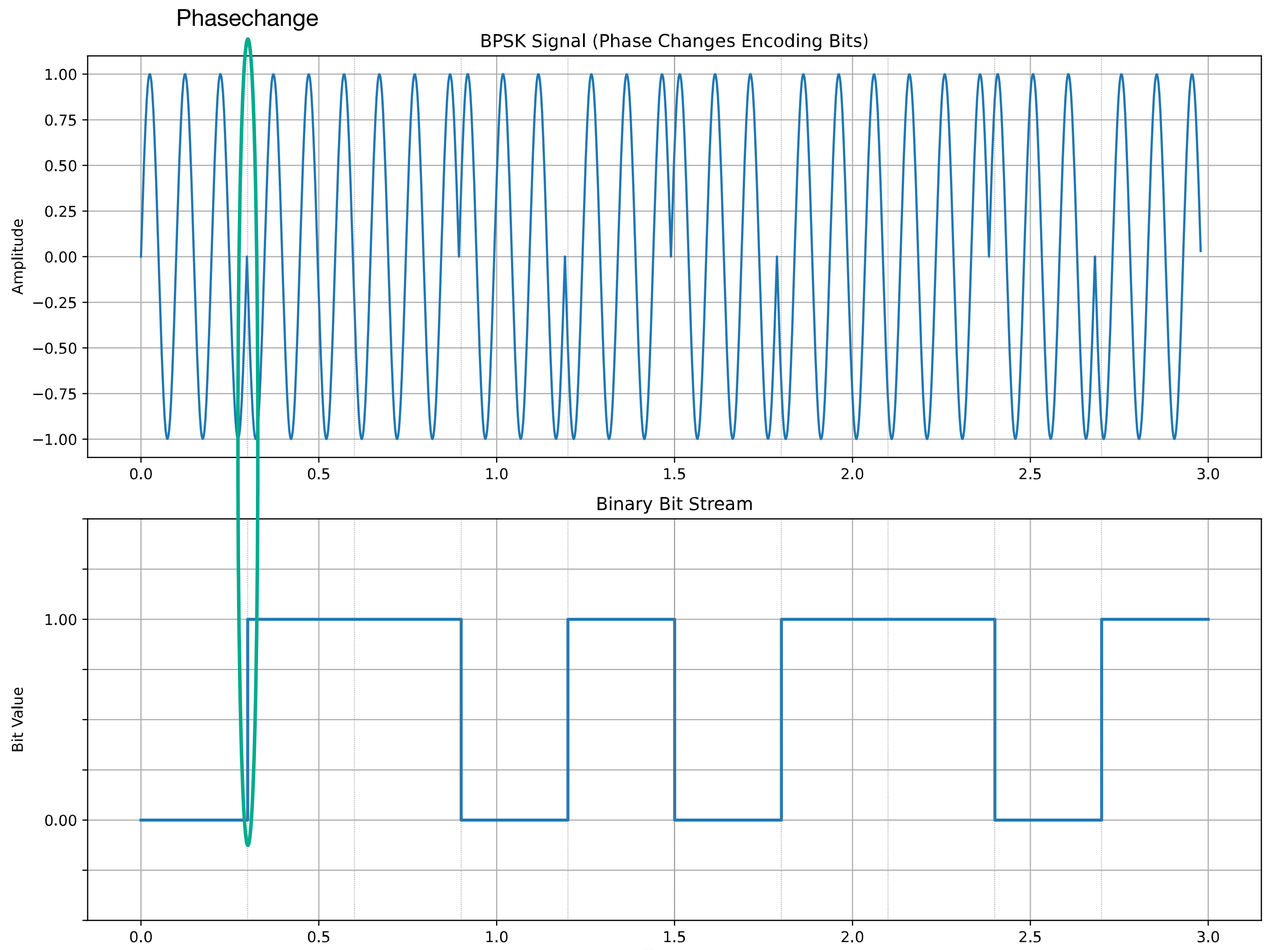
c) Contribution of other subcarriers vanish to zero resulting in the amplitude of the subcarrier from the received signal.

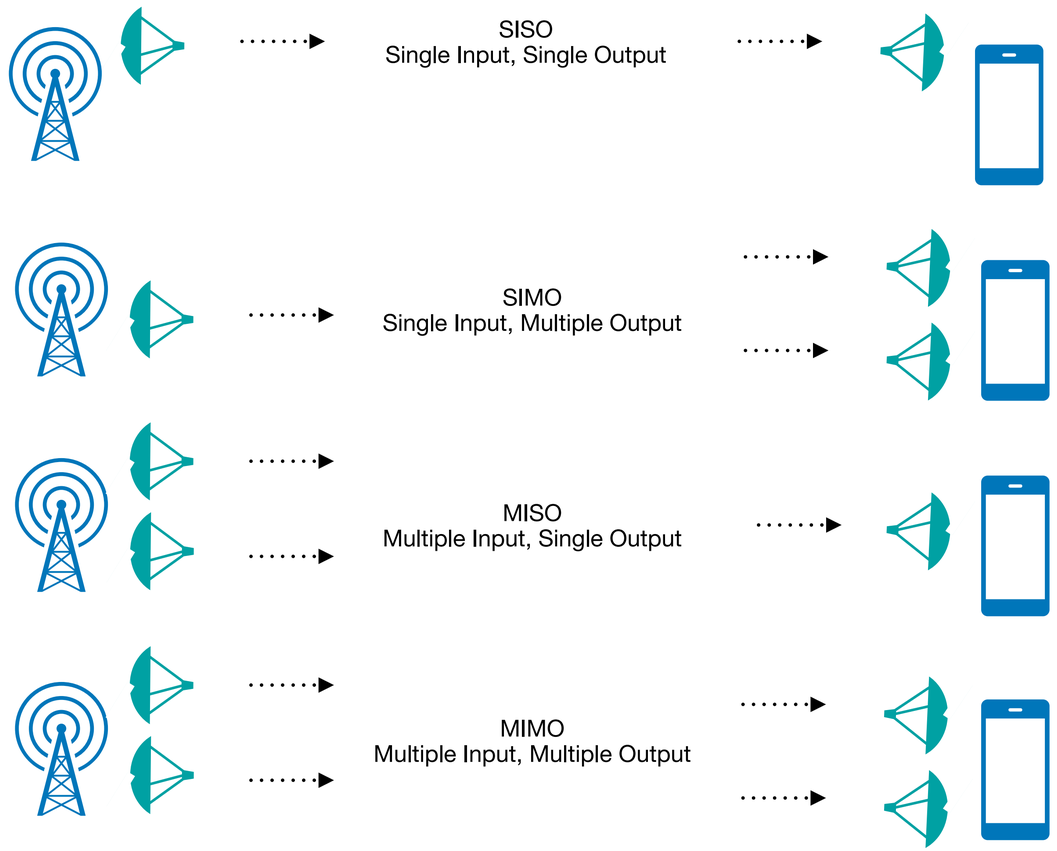


(a) Take amplitudes of cos and sin wave and represent them as complex numbers


10 ms
Frame n-3
Frame n-2
Frame n-1
Frame n
Frame n+1
Frame n+2
Frame n+3
Frames
0
1
2
9
Subframes
1 ms
10 Subframes (from 0 to 9)
Slot 0
Slots
Number of slots depends on subcarrier spacing.
1 ms
0
1
2
13
OFDM Symbols
Each Slot consists of 14 OFDM Symbols
CP
OFDM
Cyclic Prefix
OFDM Symbol (The actual data to be transmitted)


xApp1
xApp2
...
xApp2
xApp Management
E1 Termination
E2 Termination
Mgmt.
Security
Conflict Mgmt.
Service Management & Orchestration
Non RT RIC
Near RT-RIC
Exposure & App support
Analytics & Optimization
Access & Mobility Mgmt.
Subscriber & Policy
Access & Mobility Mgmt.
Session Management
5G Core
E1
E2
NG-C/NG-U
gNB
UE
UE


Phasechange
BPSK Signal (Phase Changes Encoding Bits)
Amplitude
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Binary Bit Stream
Bit Value
1.00
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Time [s]


SISO
Single Input, Single Output
SIMO
Single Input, Multiple Output
MISO
Multiple Input, Single Output
MIMO
Multiple Input, Multiple Output