A Concise Introduction to Practical LTE Systems

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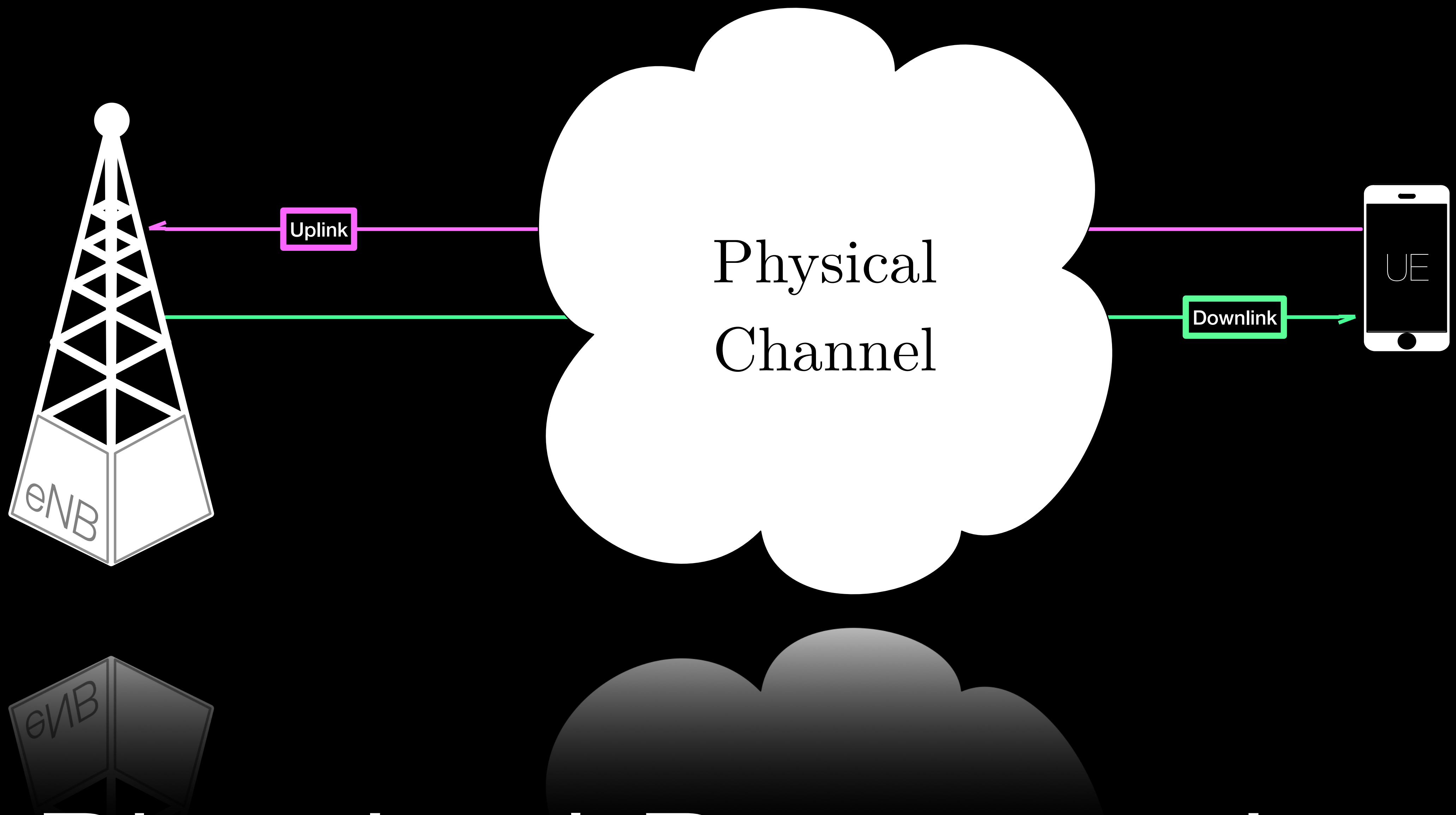
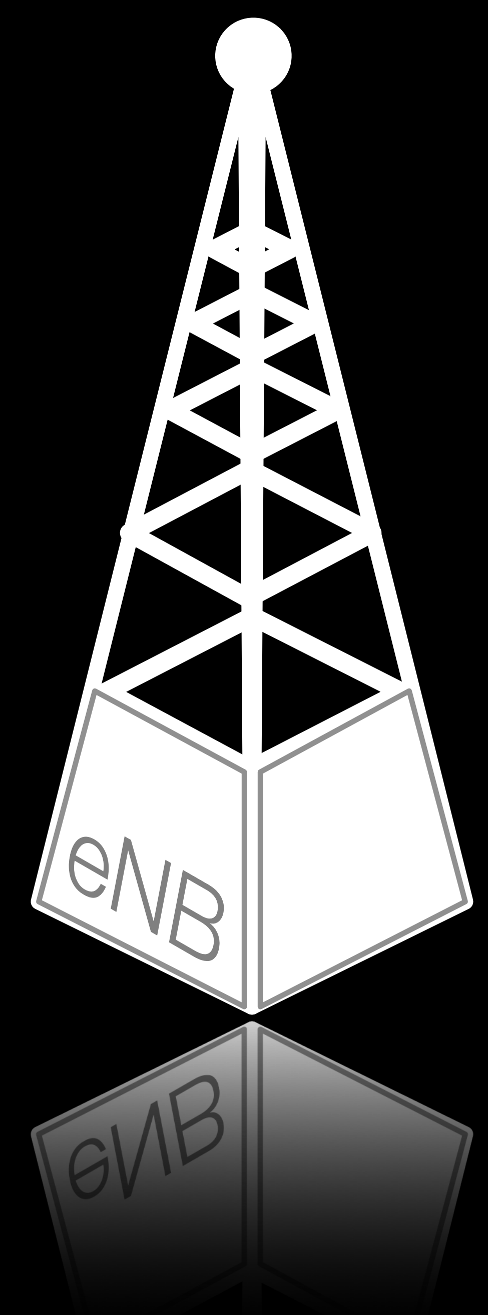


Physical Perspective

An **eNodeB** communicates through a **physical channel** with a specific **UE**.

eNodeB

- To establish a connection to an LTE network, a UE must first determine the following from the eNB base station:
    - Complete **time and frequency synchronization** information
    - Unique **Cell Identity**
    - Cyclic Prefix (**CP**) Length
    - Access Mode (**FDD/TDD**)
- Synchronization requirements in LTE
    - Symbol Timing Acquisition
    - Carrier Frequency Synchronization
    - Sampling Clock Synchronization



- Accomplished by broadcasting two special signals:

    1. Primary Synchronization Service (**PSS**): Used for **initial synchronization**.

    2. Secondary Synchronization Service (**SSS**): Used for **handoff synchronization.**

- These synchronization signals are transmitted twice per 10ms radio frame.

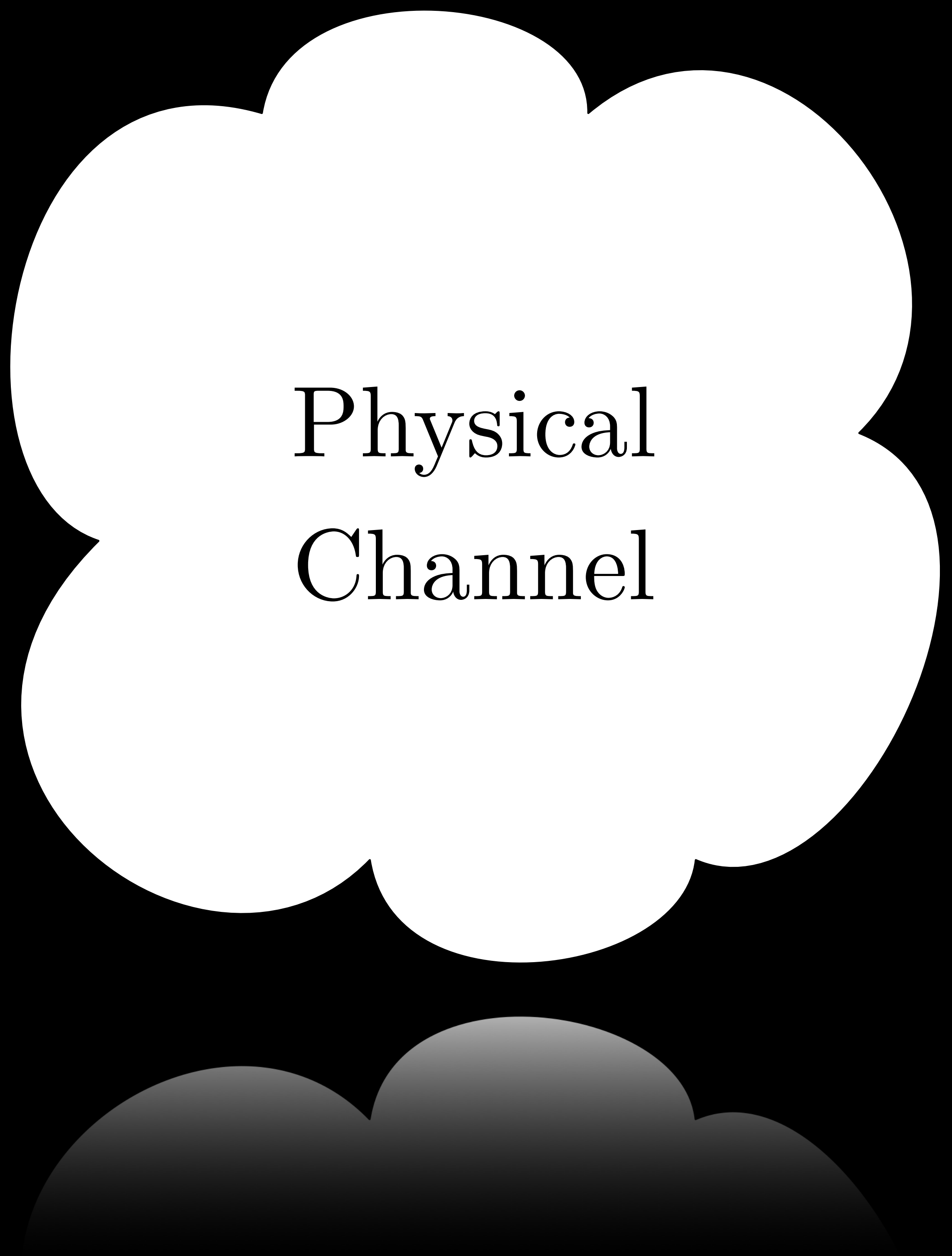
- For the sake of simplicity, we will assume from this point that:

    - all parameters necessary for communication between the UE and the radio-access network are known to both entities (*RRC_CONNECTED*)

    - our UE has successfully established a synchronized connection to our eNB (*IN_SYNC*).

Physical Channel

- Simply the region between the UE and the eNB.
- If the physical channel did not alter the signal (i.e. a vacuum) the waveform transmitted would be identical to the waveform received.
- If the physical channel altered the signal in a predictable and deterministic fashion (i.e. attenuation) the waveform transmitted could be determined exactly by applying an operation on the waveform received.



- Unfortunately, the physical channel modifies the transmitted signal in a random fashion.
- The presence of obstacles and reflectors in the communications environment create multiple paths a transmitted signal can traverse.
- Each copy of a transmitted signal experiences differences in attenuation, delay, and phase shift.
- This results in either constructive or destructive interference when observed at the receiver.
- Known as **multipath fading**

- The multiple copies of a transmitted signal generated by *multipath fading* arrive at the receiver at different times, inducing and effect known as **time dispersion**.
- In the frequency domain, *time dispersion* corresponds to a *non-constant channel frequency response*.
- **Flat Fading**:
  - All frequency components experience the same magnitude of fading.
- **Frequency-Selective Fading**:
  - Different frequency components experience uncorrelated fading.
- In LTE, the **downlink** (eNB -> UE) uses **OFDM** to ameliorate performance detriments due to frequency-selective fading.

OFDM

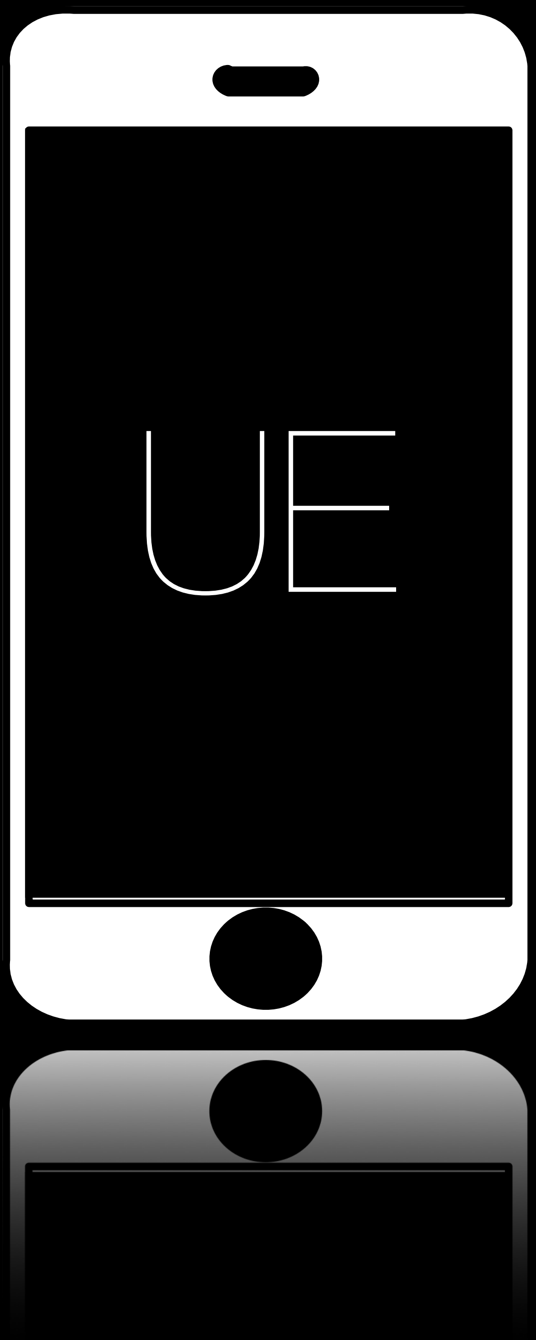
- OFDM divides a wideband signal into tightly packed narrowband **subcarriers**.
- *Each subcarrier* is now exposed to flat fading, rather than frequency-selective fading.
- Two modulated OFDM subcarriers are mutually orthogonal over a given time interval, known as a symbol length, and denoted T_{u}.
- Unfortunately the delay introduced by multipath fading can shift one subcarrier out of the interval of inter-subcarrier orthogonality, resulting in interference between subcarriers.

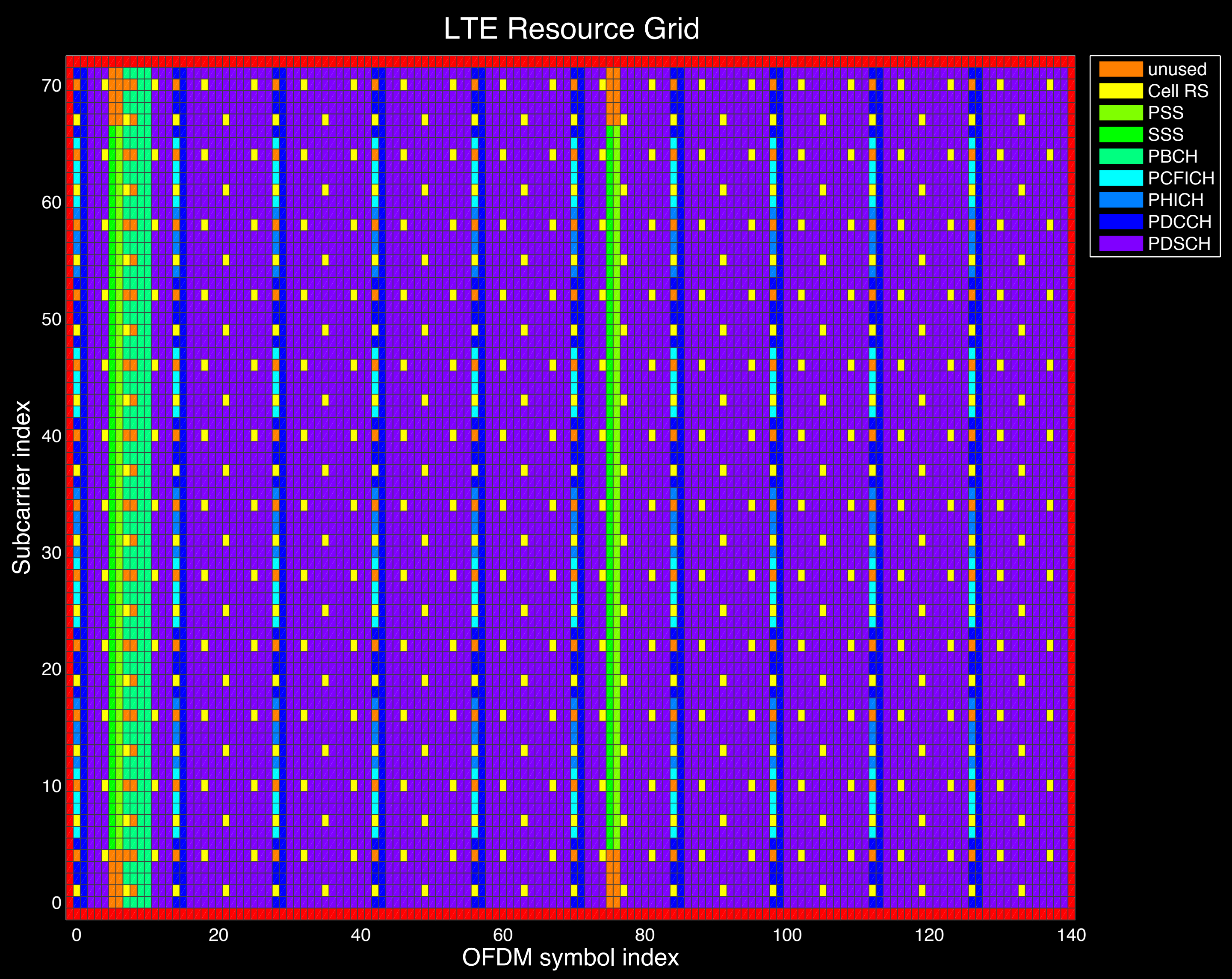
- To solve this interference problem, the duration of each symbol interval is extended by duplicating the last portion of a symbol and adding it as a prefix to the symbol.
- This is termed **cyclic-prefix insertion**, and it extends the symbol time from T_{u} to $T_{u} + T_{cp}$.
- As long as the span of the time dispersion is shorter than T_{cp}, the problem is solved.
- One last issue: a frequency-selective channel still has the ability to strongly attenuate a given subcarrier.

- **Channel Coding** spreads out each bit of information over multiple *code bits*.
- These code bits may be distributed in the frequency domain over the entire transmission bandwidth, a process known as **frequency interleaving**.
- This provides **frequency diversity** to each data bit, ensuring resilience to the failure of any specific subcarrier.

User Equipment

- Concerned with power consumption.
- Assigned one or more **Resource Block (RB)**





Logical Perspective

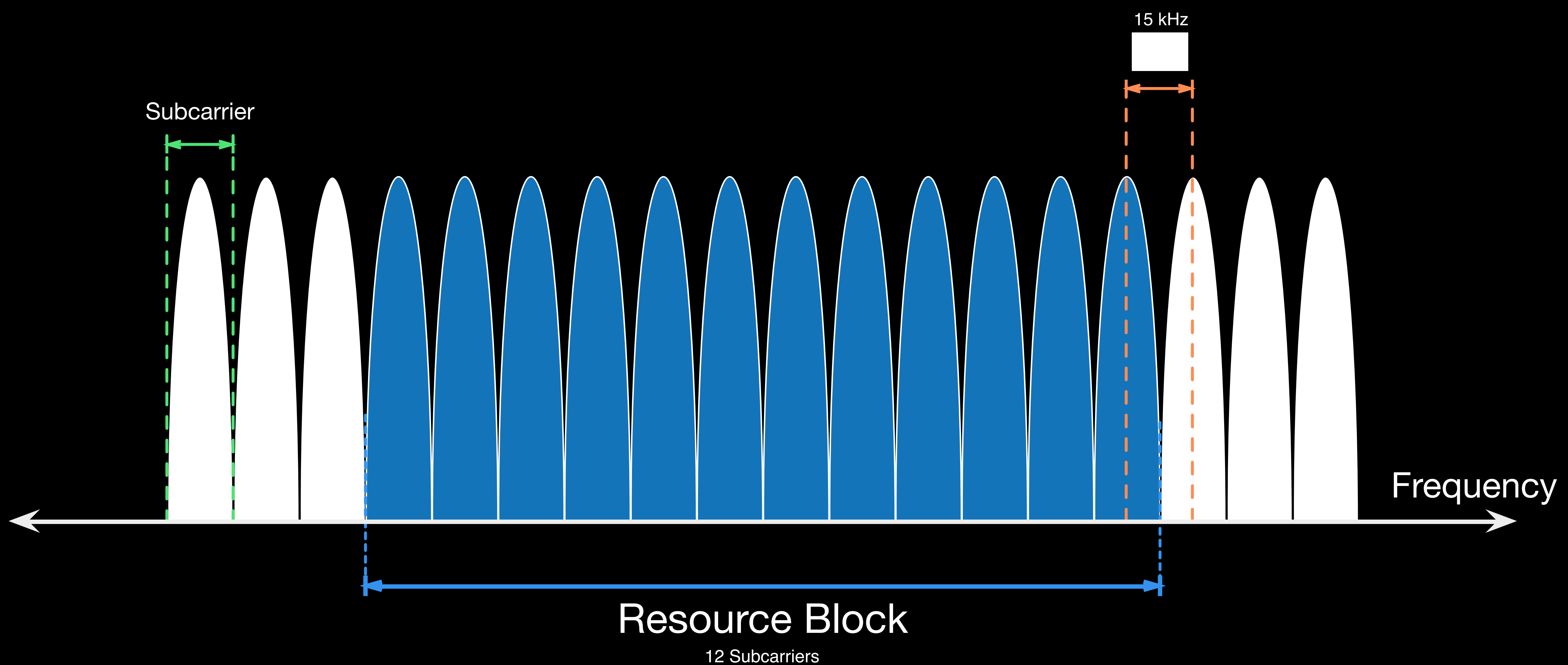
A **Resource Grid** represents a 2D data structure over both the time and frequency domain.

Time-Domain Resources

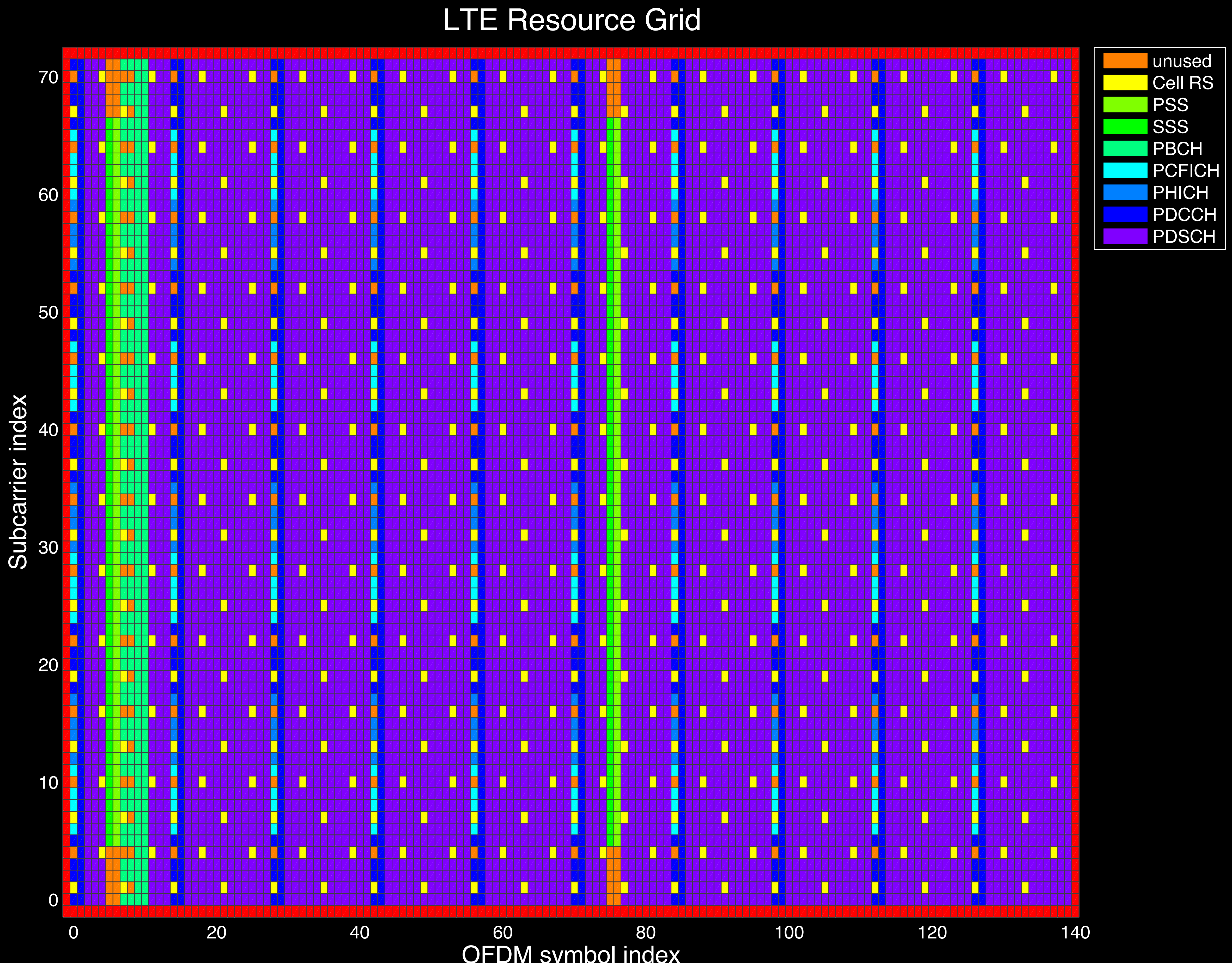
- Variable Symbol Duration
- Time quantum: $T_s = \frac{1}{2048(15000)}$

	Duration (ms)	Number of Quanta (T_s)
Radio Frame	10	307200
Subframe	1	30720
Slot	0.5	15360
Symbol	0.5/7	2048

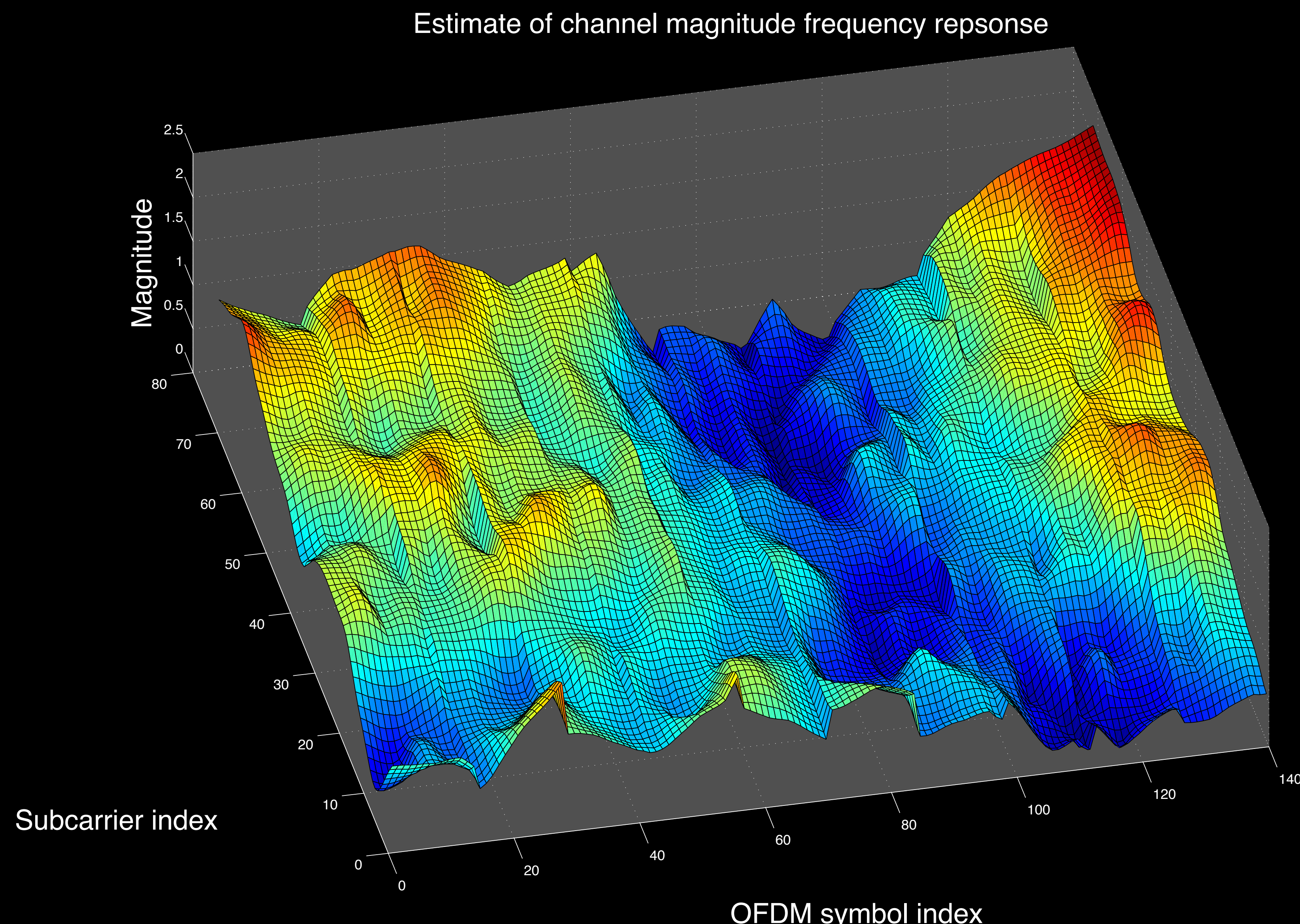
Frequency Domain Resources



- Subcarrier spacing of 15 kHz
- LTE bandwidth is highly flexible
  - 1 MHz to 20 MHz is standard, even more with *carrier aggregation*.



LTE Resource Grid
Subcarrier index
OFDM symbol index
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
unused
Cell RS
PSS
SSS
PBCH
PCFICH
PHICH
PDCCH
PDSCH



Algorithmic Perspective

Both the receiver and the transmitter implement methods to reduce the detrimental effect of the channel.

Adaptive Processing

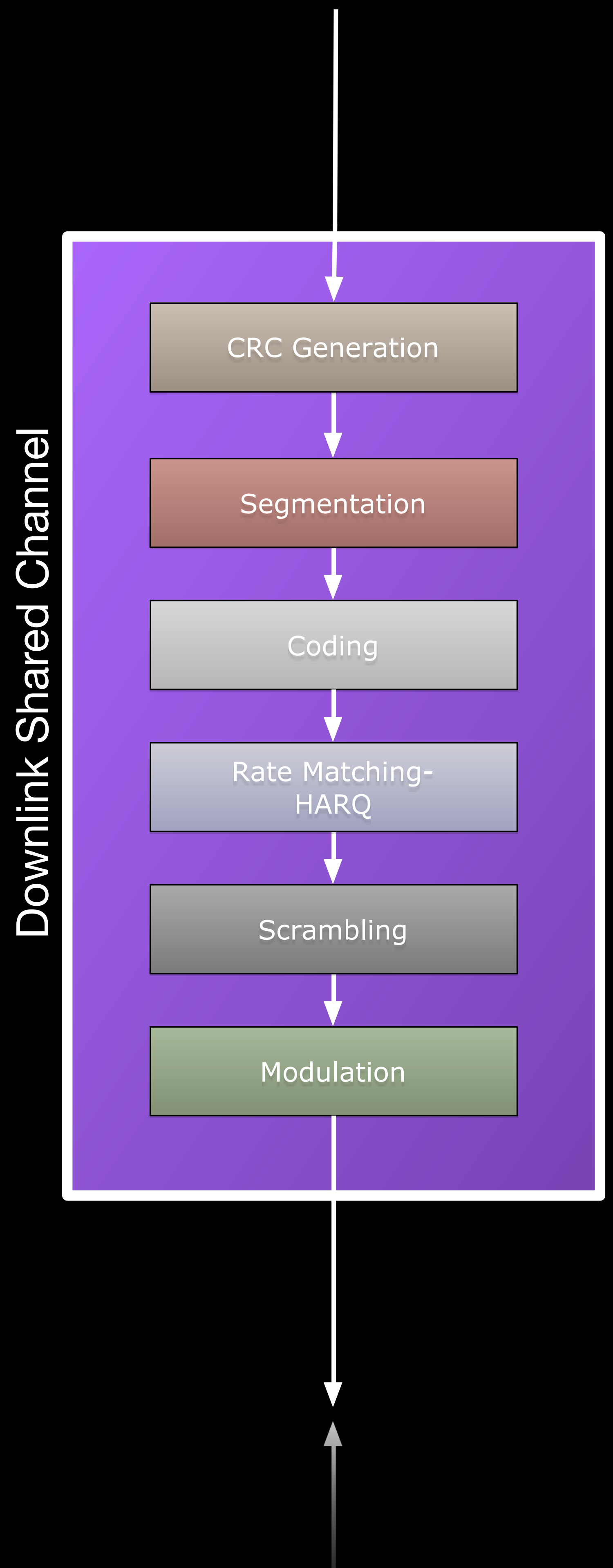
- In **dynamic rate control**, a transmitter dynamically adjusts the data rate in response to varying channel conditions.
  - The data rate is increased by increasing the channel coding rate and/or modulation scheme when the channel is clear, and decreasing them under disadvantageous conditions.
  - Transmission power is kept constant
- Also known as **Adaptive Modulation and Coding (AMC)**
- Channel conditions can be determined by the receiver by analyzing a transmitted **pilot** or **reference signal**.
- These results are then reported to the transmitter.

Error Correction and Retransmission

- **Forward Error Correction (FEC)**
  - *Goal:* Introduce redundancy to a transmitted signal to allow bit errors to be *corrected* by the receiver.
  - These redundant bits, known as **parity bits**, are computed by applying a coding scheme to the information to be transmitted.
- **Automatic Repeat reQuest (ARQ)**
  - Goal: Introduce redundancy to a transmitted signal to allow bit errors to be *detected* by the receiver.
  - The receiver validates all received packets:
    - *if valid:* receiver notifies transmitter with an **ACK**, data is used
    - *if invalid:* receiver notifies transmitter with a **NAK**, data is discarded
- **Hybrid ARQ (HARQ)**
  - Uses FEC to correct a subset of all errors, falling back to ARQ for uncorrectable errors.
  - May optionally use **soft combining**
    - Packets deemed uncorrectable are stored in a buffer for later use instead of being discarded.

DL-SCH

- CRC Generation
    - 24-bit CRC appended to each transport block (**TB**)
- Segmentation
    - **TB** is split into smaller **code blocks**, each with their own 24-bit CRC.
- Coding
    - **Turbo Coding** is used to encode each code block in parallel.
- Rate Matching - HARQ
    - each code block is interleaved with a circular buffer
    - the appropriate number of code bits is selected based on cell parameters to be transmitted within a given subframe.
- Scrambling
    - the block of code bits is XOR'ed with a cell-specific scrambling sequence.
    - ensures any potentially interfering signals are randomized, appearing as gaussian white noise to a receiver.
- Modulation
    - transforms the block of scrambled bits to a corresponding block of complex modulation symbols.



Sources

- The information for the slides was compiled from the notes I took while reading the following three texts:
  - **Dahlman, Erik, Stefan Parkvall, Johan Skold, and Per Beming. 3G Evolution: HSPA and LTE for Mobile Broadband. Amsterdam: Academic, 2008. Print.**
  - **Dahlman, Erik, Stefan Parkvall, and Johan Sköld. 4G LTE/LTE-Advanced for Mobile Broadband. 2nd ed. Amsterdam: Elsevier/Academic, 2011. Print.**
  - **Zarrinkoub, Houman. Understanding LTE with MATLAB: From Mathematical Modeling to Simulation and Prototyping. N.p.: Wiley, n.d. Print.**