OFDM and HARQ

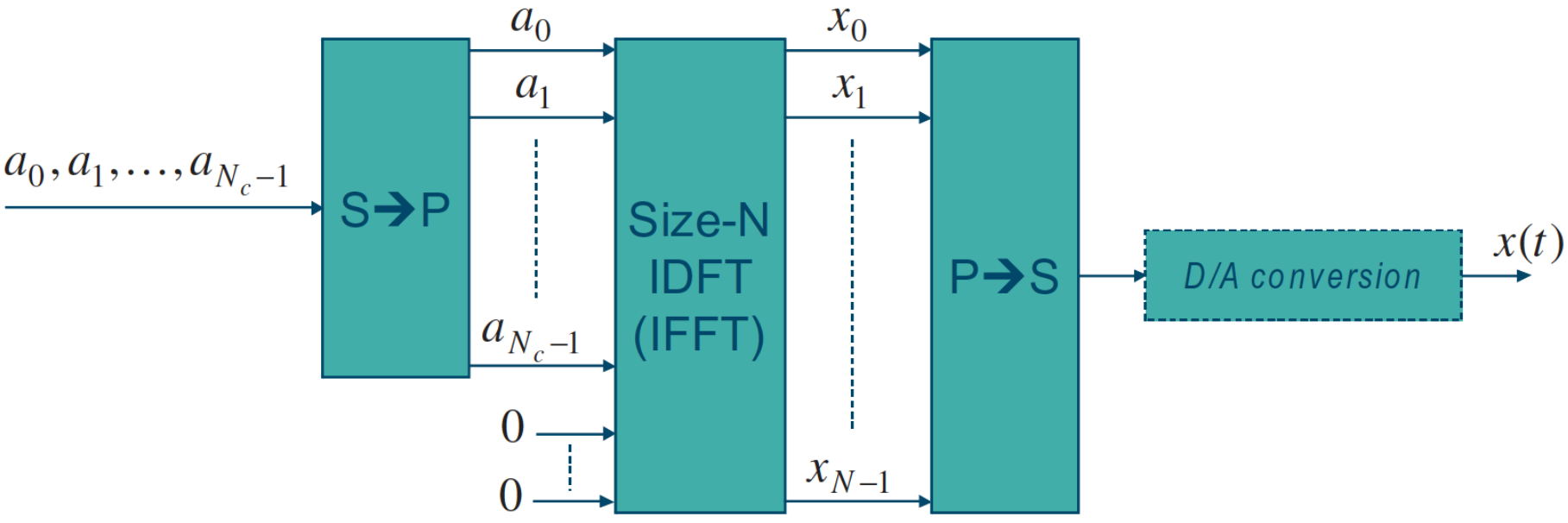
Rohit Budhiraja

Simulation-Based Design of 5G Wireless Standards (EE698H)

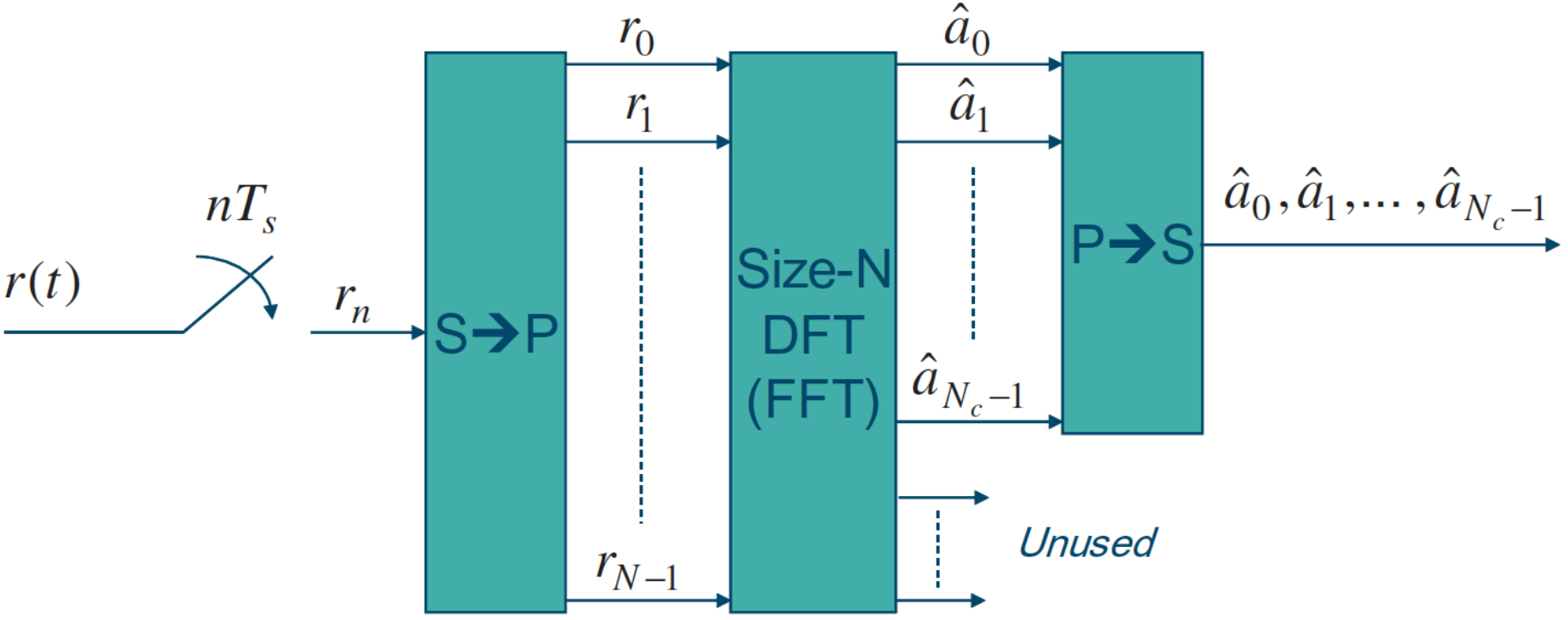
Agenda for today

- Finish discussing OFDM
- Discuss HARQ
  - Reference – Chap6 of the 4G LTE/LTE-A book

5G-NR baseband OFDM transmitter with IFFT



5G-NR baseband OFDM receiver with FFT



System dimensioning for 5G-NR

- NR baseband bandwidth = 100 MHz; Usable baseband bandwidth = 99 MHz
  - NR uses guard band of 1 MHz for 100 MHz bandwidth
- Subcarrier spacing $\Delta f = 30$ kHz
- Total subcarriers required $N_c = 3300$ $(30 * 3300 = 99$ MHz$)$
- (I)FFT size used $N = 4096$
- OFDM symbol duration $T_u = \frac{1}{\Delta f}$
  - OFDM symbol duration is fixed once subcarrier spacing is fixed
- Sampling time in the last slide $T_s = \frac{T_u}{4096}$
- Sampling rate

$$F_s = \frac{1}{T_s} = \frac{4096}{T_u} = 4096 \cdot \Delta F = 4096 \cdot 30 = 122.88 \text{ MHz}$$

- Sampling rate required according to Nyquist criteria = 99 MHz

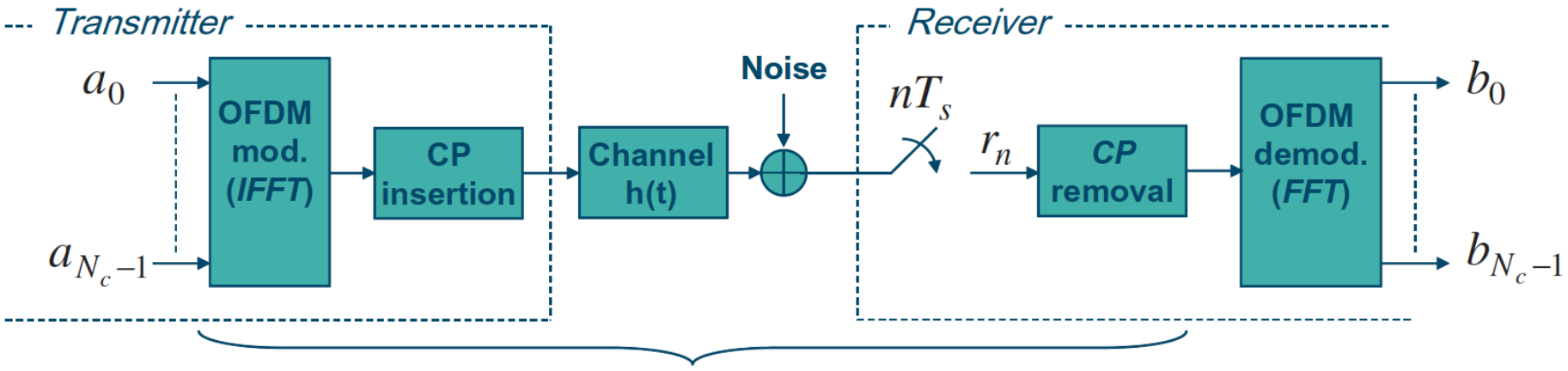
System dimensioning for 5G-NR (50 MHz)

- NR baseband bandwidth = 50 MHz; Usable baseband bandwidth = 49.5 MHz
  - NR uses guard band of 0.5 MHz for 50 MHz bandwidth
- Subcarrier spacing $\Delta f = 15$ kHz
- Total subcarriers required $N_c = 3300$ $(15 * 3300 = 49.5$ MHz$)$
- (I)FFT size used $N = 4096$
- OFDM symbol duration $T_u = \frac{1}{\Delta f}$
  - OFDM symbol duration is fixed once subcarrier spacing is fixed
- Sampling time in the last slide $T_s = \frac{T_u}{4096}$
- Sampling rate

$$F_s = \frac{1}{T_s} = \frac{4096}{T_u} = 4096 \cdot \Delta F = 4096 \cdot 15 = 61.44 \text{ MHz}$$

- Sampling rate required according to Nyquist criteria = 49.5 MHz

Equivalent OFDM system with channel



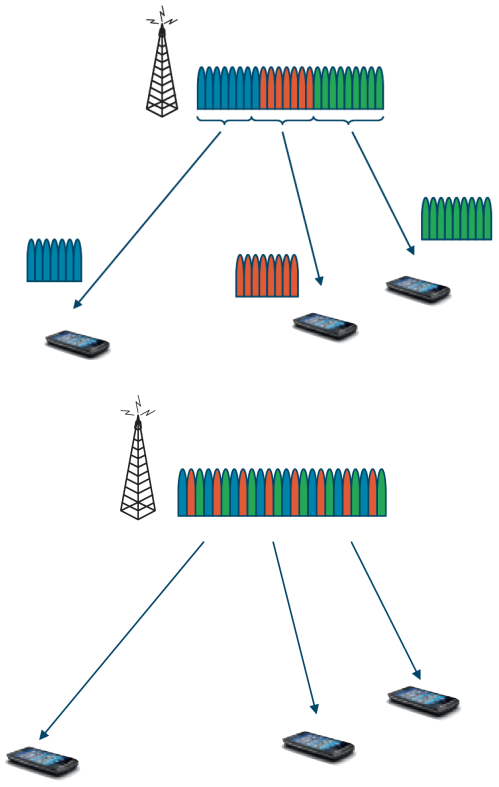
- System model for data on subcarriers

$$\begin{aligned} b_0 &= h_0 a_0 + n_0 \\ \vdots &= \vdots \\ b_{N_c-1} &= h_{N_c-1} a_{N_c-1} + n_{N_c-1} \end{aligned}$$

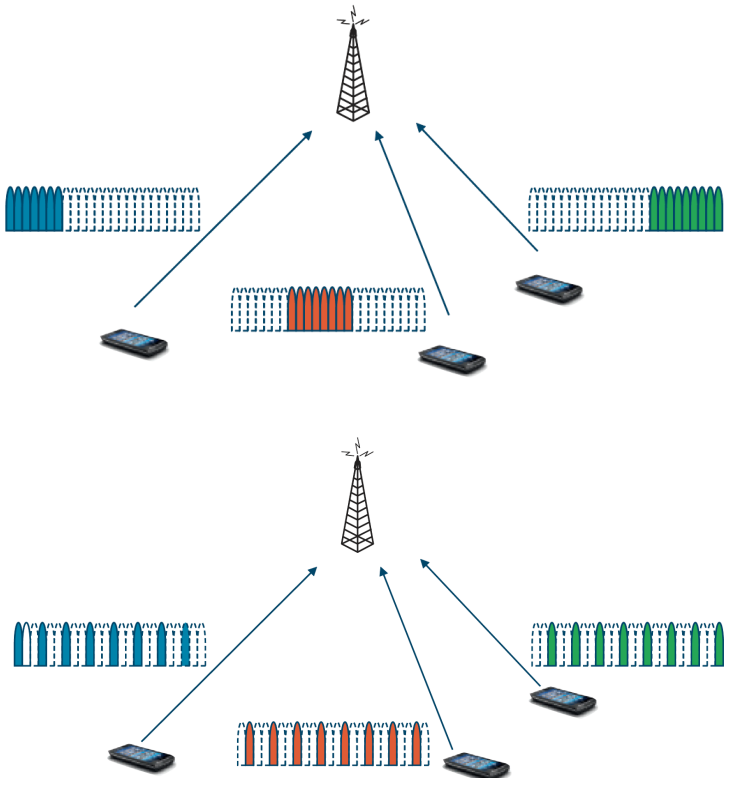
- Noise is independent across subcarriers

OFDM as multiple access scheme in 5G - downlink

- OFDMA - Orthogonal frequency division multiple access
- Two types of subcarrier allocation - localized and distributed



OFDM as multiple access scheme 5G - uplink



Automatic repeat request (ARQ) protocol (1)

- Receiver uses an error detection code to check whether a receive data block is in error
- Error detection code is typically Cyclic Redundancy Check (CRC)
- If no error is detected in the received data block
  - the received data is declared error-free and
  - the transmitter is notified by sending a positive acknowledgement (ACK)
- If an error is detected,
  - the receiver discards the received data
  - and notifies the transmitter via a return channel by sending a negative acknowledgement (NAK)
  - In response to an NAK, the transmitter retransmits the same information

Automatic repeat request (ARQ) protocol (2)

- All modern communication systems, including 5G NR, employ a combination of FEC and ARQ
  - Known as hybrid ARQ (ARQ)
- HARQ uses FEC codes to correct a subset of all errors and relies on error detection to detect uncorrectable errors
- Erroneously received blocks are retained and receiver requests retransmissions of corrupted packets