Multi-channel Communications Fall 2022

Lecture 23
MIMO - OFDM

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Introduction

- MIMO takes advantage of multipath induced spatial fading to boost capacity by opening parallel channels using multiple antennas or enhance reliability by exploiting spatial diversity
- OFDM takes advantage of multipath induced frequency-selective fading by creating parallel channels in frequency using the DFT
- Combining the two ideas makes sense since they are complementary and both take advantage of multipath
- Also temporal equalization with MIMO is very complex – combining MIMO with OFDM is needed in channels with high delay spread

MIMO-OFDM Channel Model

- The time-varying M_r x 1 received signal vector

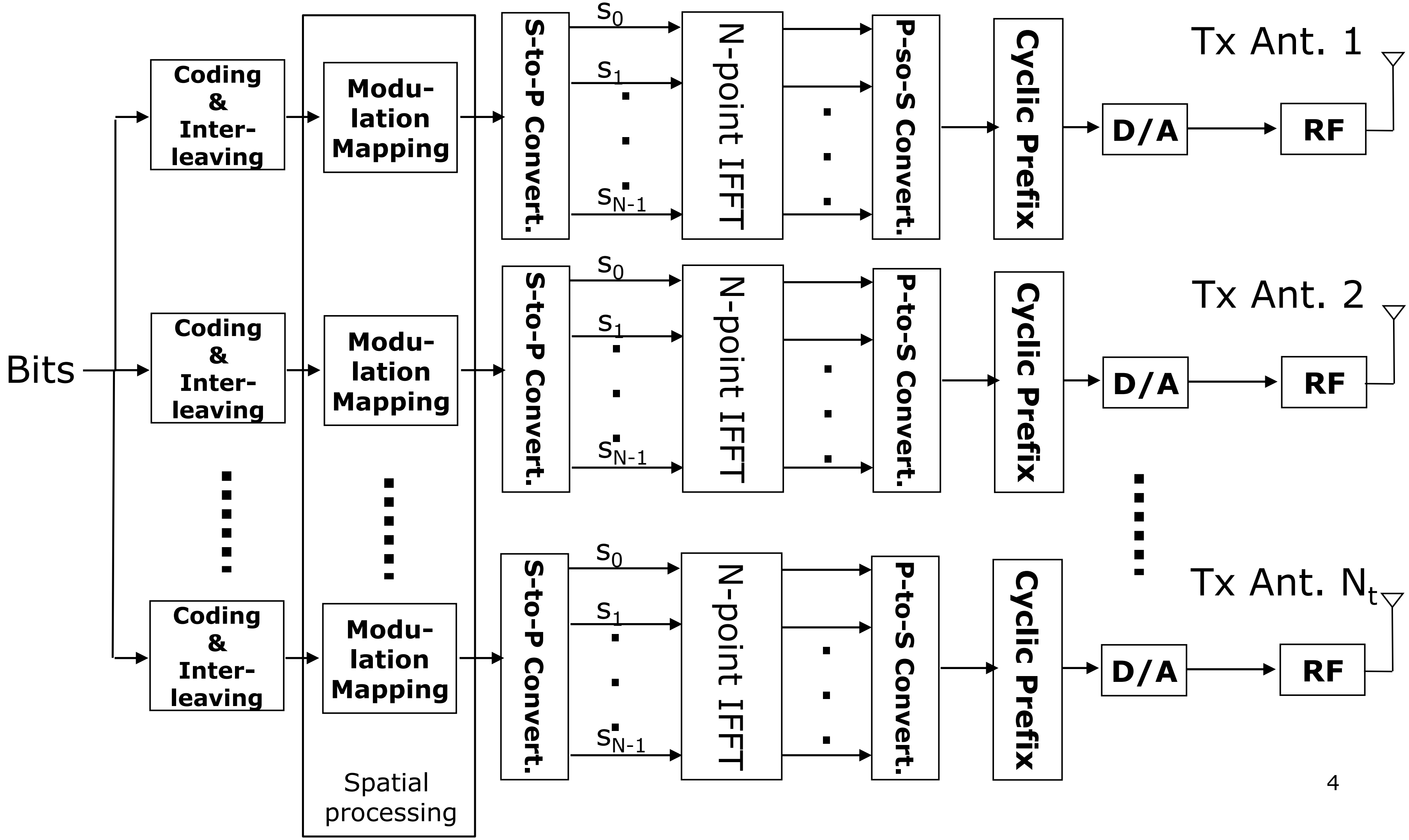
$$\mathbf{r}(t) = \sum_{k=0}^{L-1} \mathbf{H}^k(t)\mathbf{x}(t - k\Delta t) + \mathbf{n}(t)$$

- The M_r x N_t channel matrix for the *k*th resolvable multipath

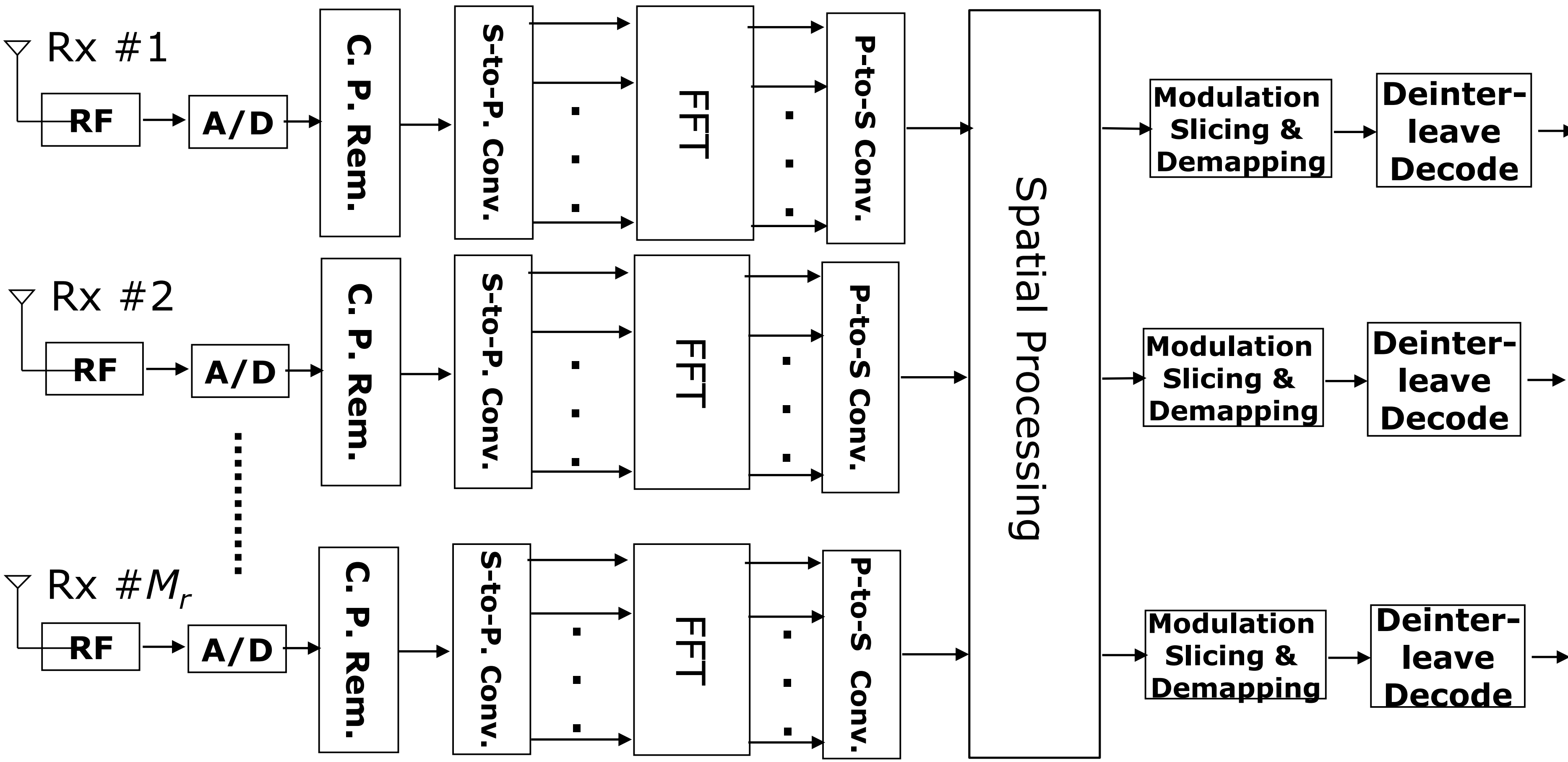
$$\mathbf{H}^k(t) = \sqrt{\frac{\sigma_k^2}{N}} \sum_{i=1}^{N} \underbrace{e^{j(2\pi f_{i,k} t + \phi_{i,k})}}_{scalar} \underbrace{e^{-j\left(\frac{2\pi}{\lambda}\mathbf{d}\sin\theta_{i,k}\right)}}_{M_r \times 1} \underbrace{e^{-j\left(\frac{2\pi}{\lambda}\overline{\Delta}^T \sin\Phi_{i,k}\right)}}_{1 \times N_t}$$

$$\sigma_k^2 = P_T \gamma e^{-\gamma k / f_s} \qquad \gamma = \frac{1}{\tau_{rms}}$$

Transmitter (Horizontal Coding)



Receiver block diagram



Spatial Processing

- In the absence of Doppler, each sub-carrier is orthogonal to all other sub-carriers and standard spatial processing can be used
- Horizontal Encoding Detector structures
  - Maximum Likelihood
  - Zero-forcing
  - MMSE
  - SIC
  - SIC w/MMSE/ZF
  - Sphere decoding

Spatial Processing - With Doppler

- In the presence of Doppler spread (or frequency offset) each sub-carrier experiences ICI as well as inter-stream interference due to spatial multiplexing
- In this case we must use more sophisticated processing to detect each symbol

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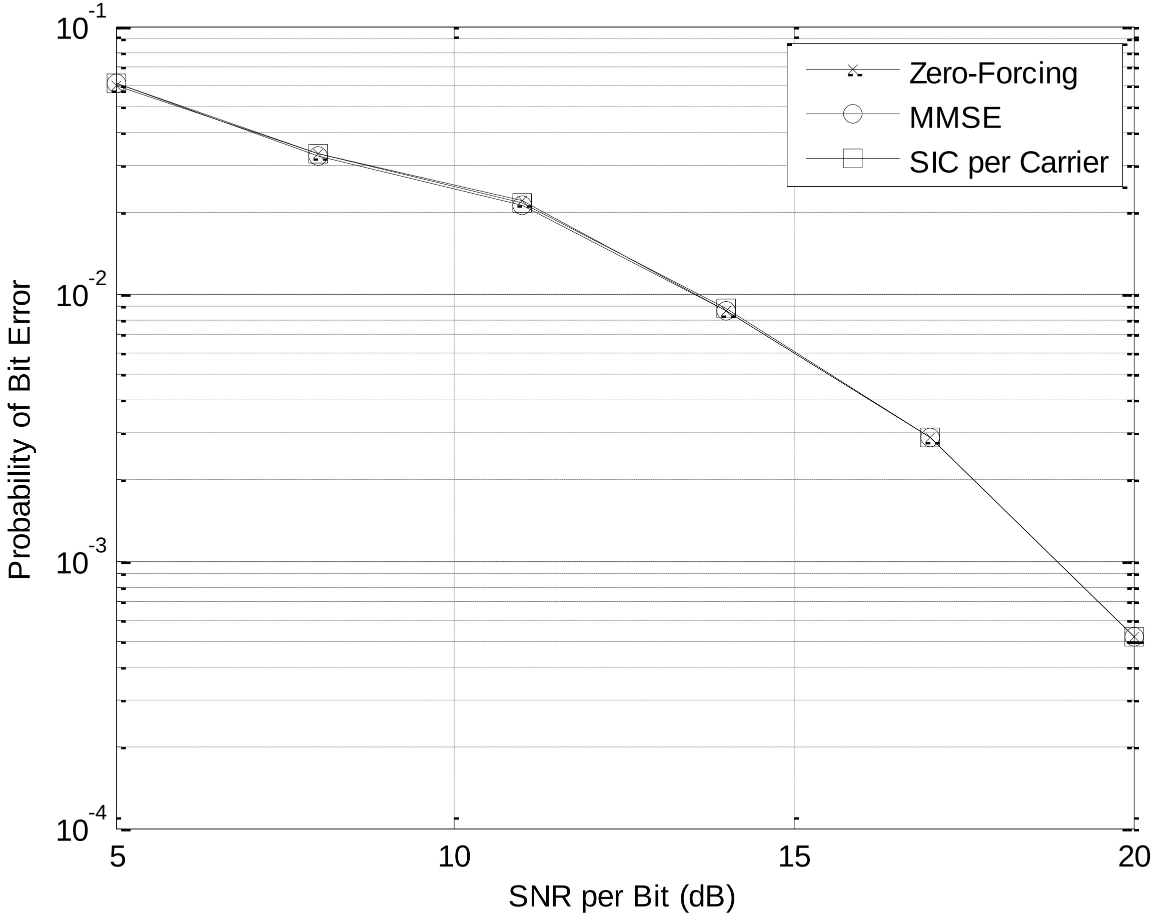
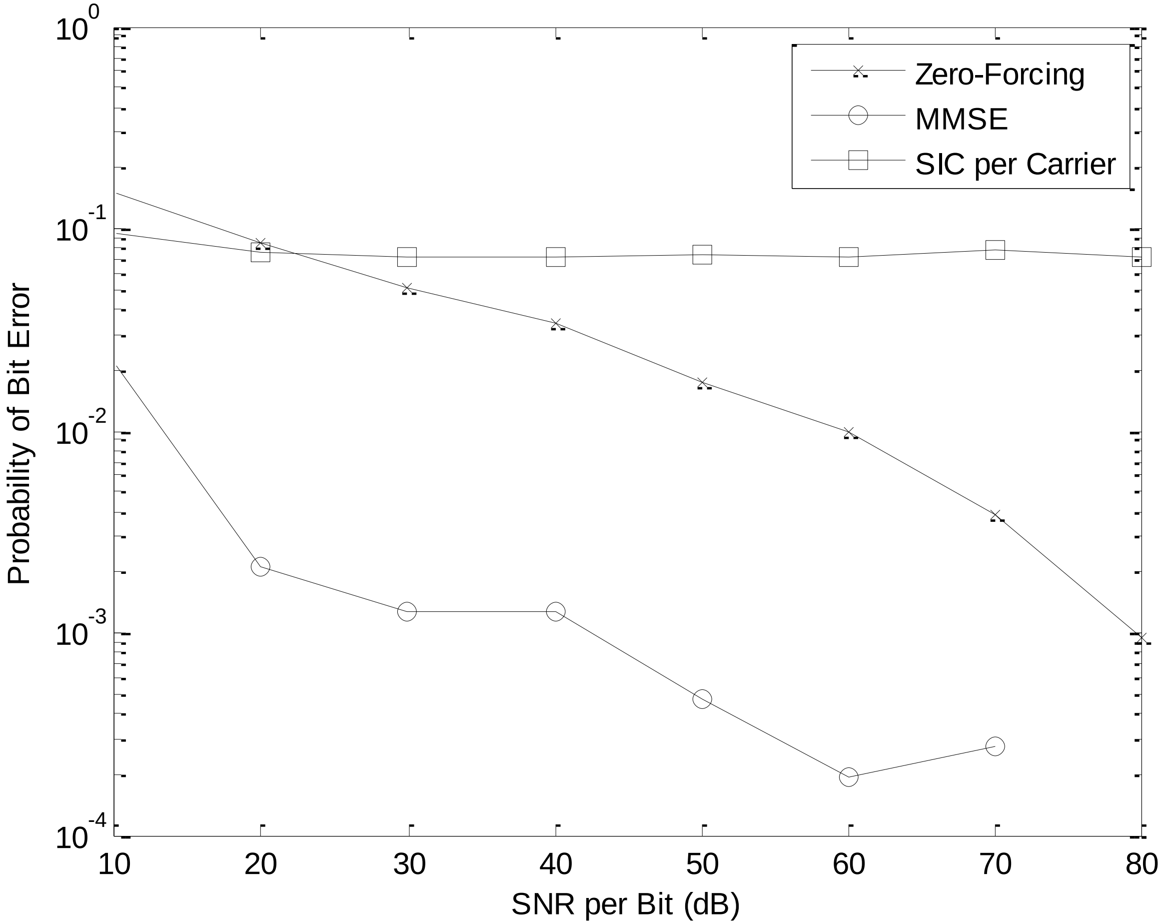
Example



- Max Doppler =50Hz
- T_{ofdm} = 1ms
- N = 64
- N_t=M_r=1
- QPSK
- Delay spectrum - [1 0.9 0.7 0.5 0.25 0.15 0.1 0.05]
- No ICI or spatial interference

Example



- Max Doppler =500Hz
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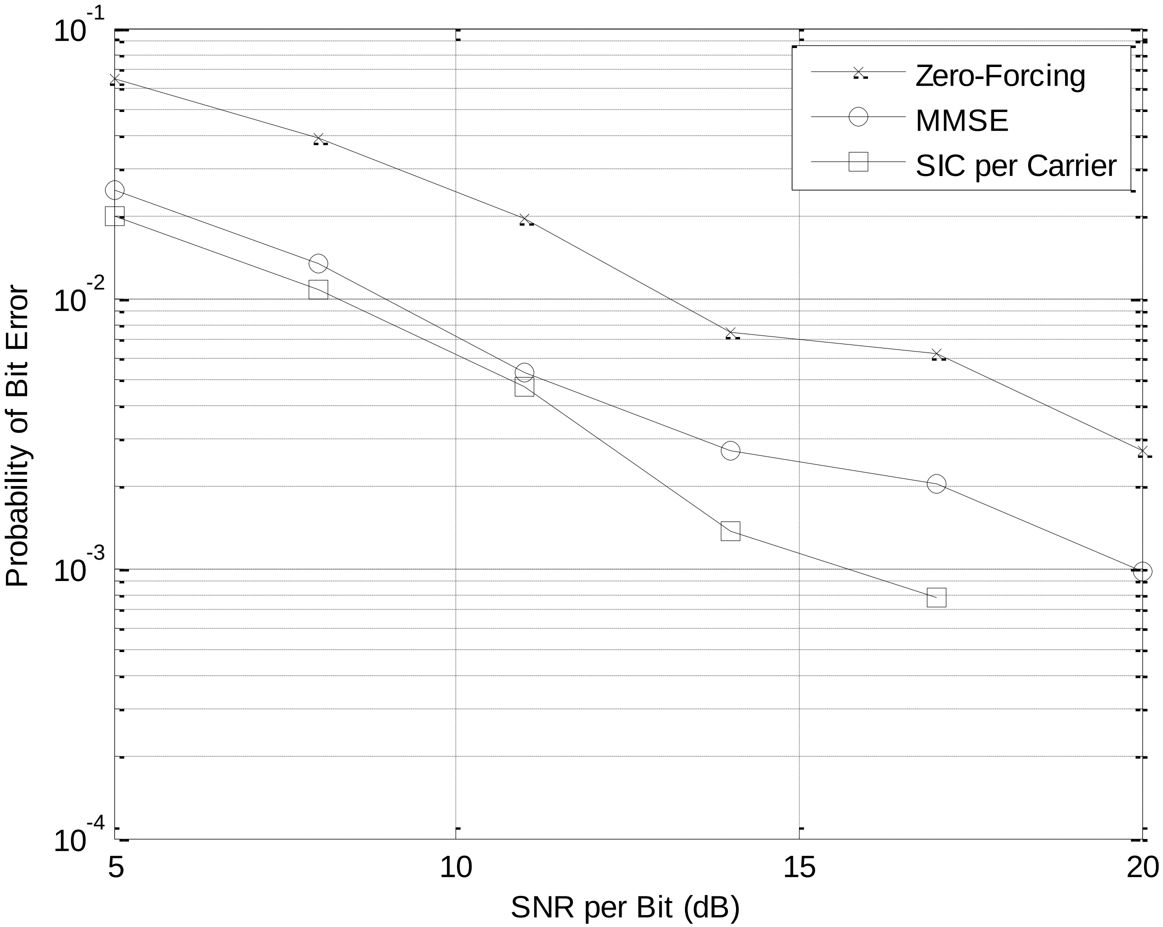
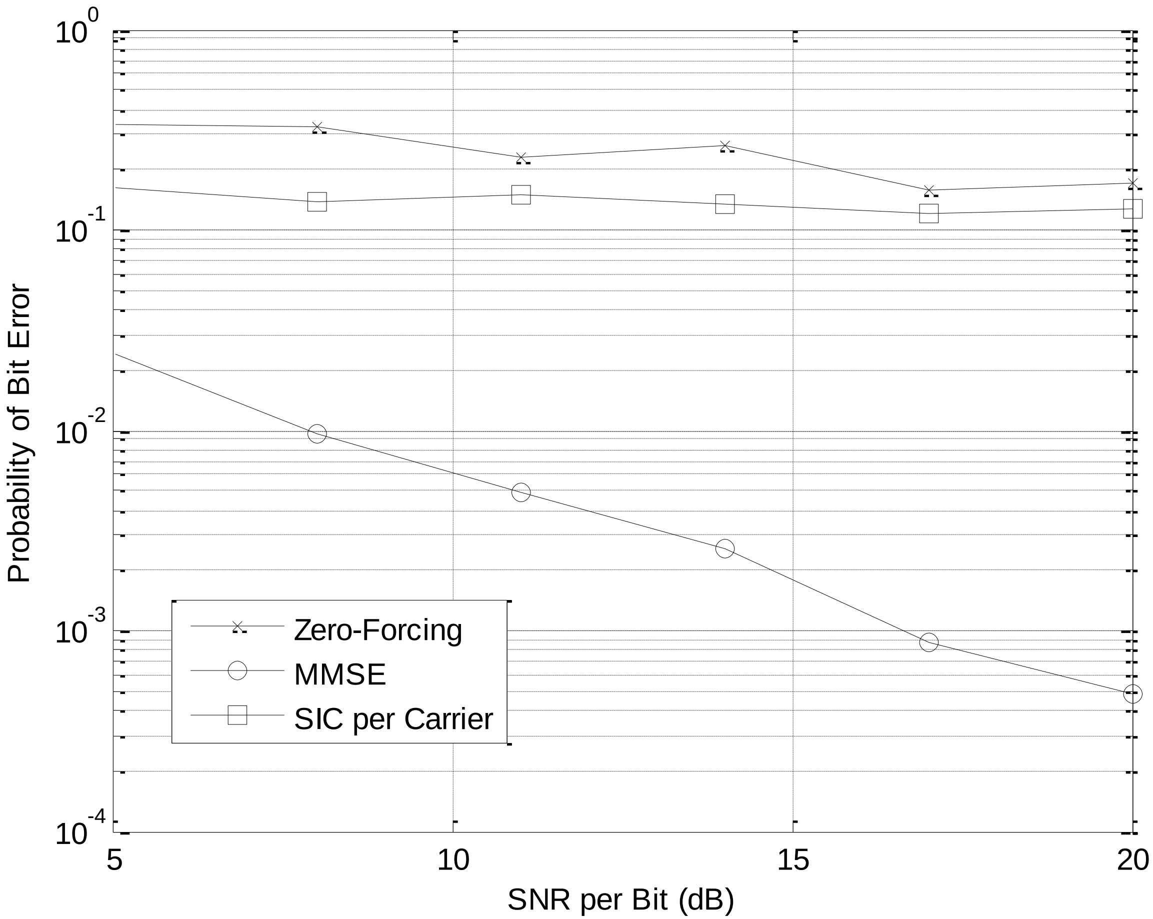
- N = 64
- N_t=M_r=1
- QPSK
- Delay spectrum - [1 0.9 0.7 0.5 0.25 0.15 0.1 0.05]
- ICI but no spatial interference
- SIC applied to spatial interference

Performance



- Max Doppler =50Hz
- T_{ofdm} = 1ms
- N = 64
- $N_t=M_r=4$
- QPSK
- Delay spectrum - [1 0.9 0.7 0.5 0.25 0.15 0.1 0.05]
- Spatial interference but no ICI

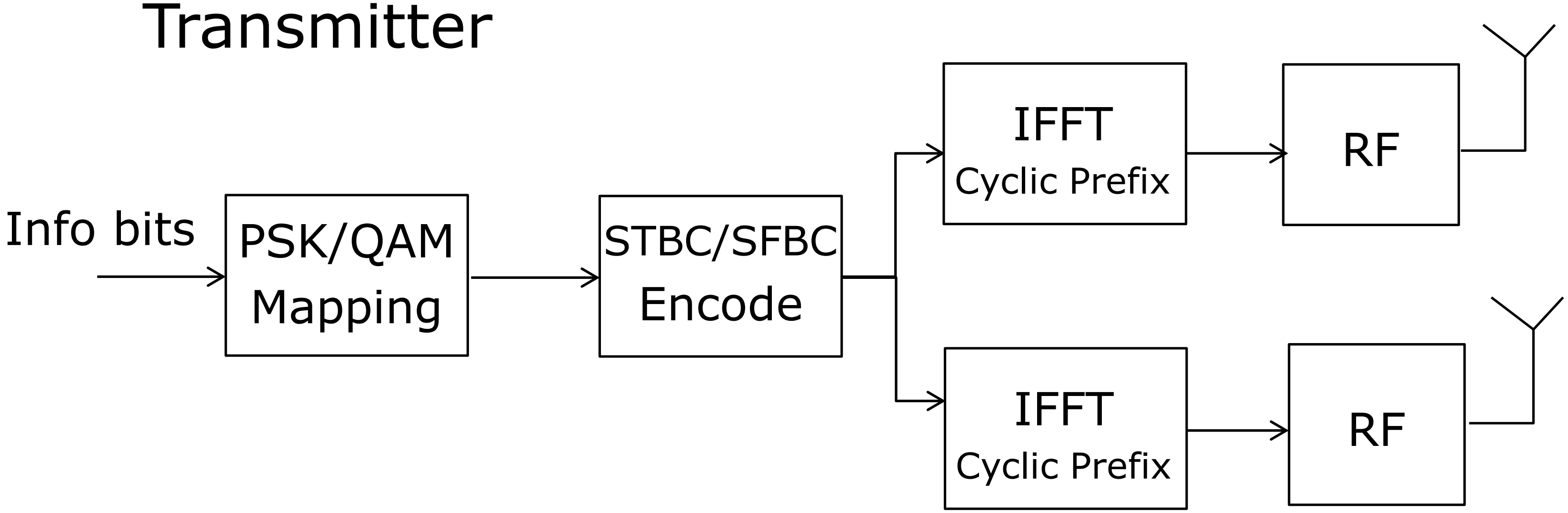
Example



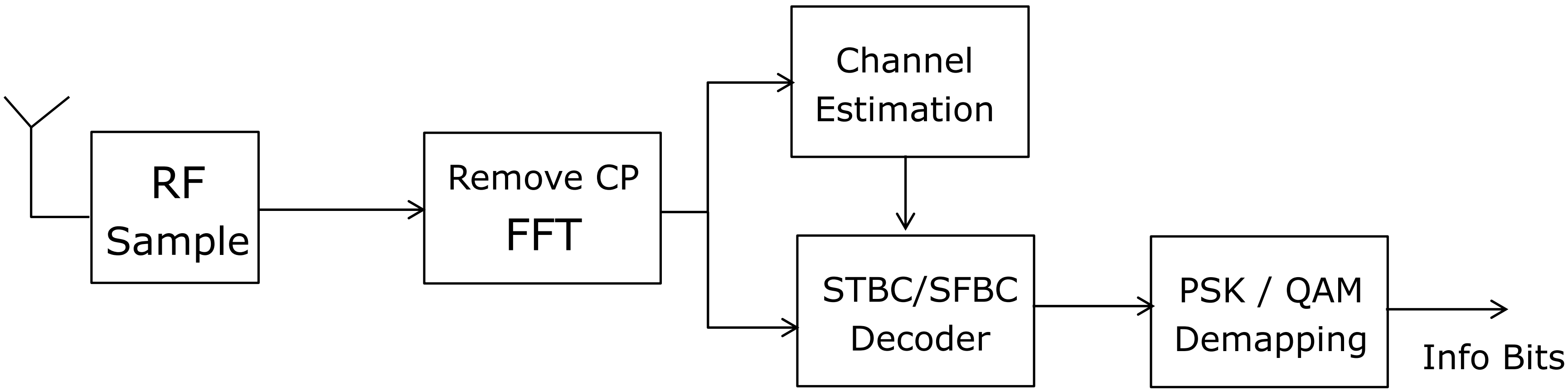
- Max Doppler =500Hz
- T_{ofdm} = 1ms
- N = 64
- N_t=M_r=4
- QPSK
- Delay spectrum - [1 0.9 0.7 0.5 0.25 0.15 0.1 0.05]
- ICI & spatial interference

2x1 STBC or SFBC

Transmitter



OFDM STBC Receiver



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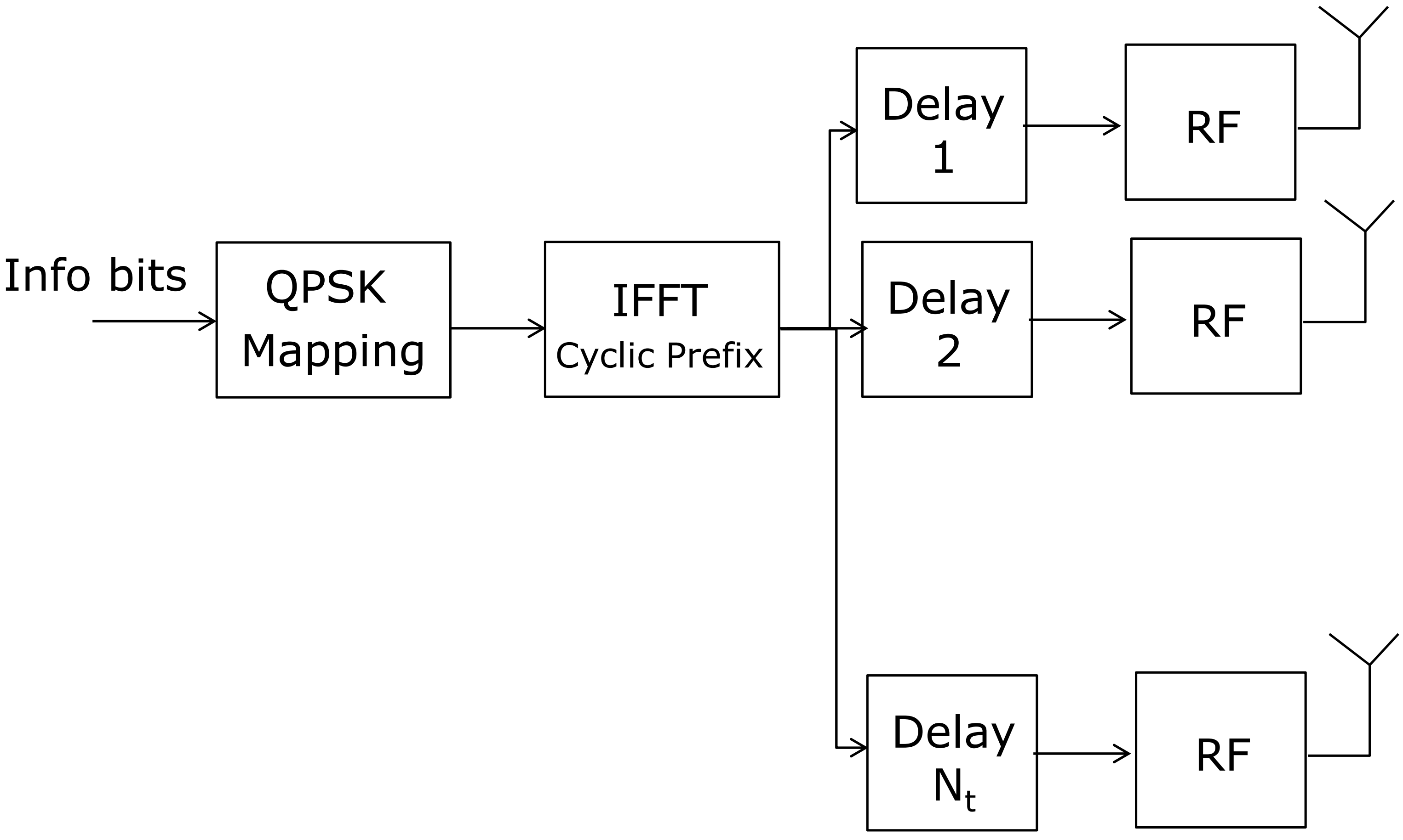
Issues with STBC

- Due to the elongated symbol period of OFDM, the chance of channel variation between consecutive symbols is higher
- When the channel varies from one OFDM symbol to another due to Doppler
  - STBC suffers from interference when decoding
  - Inter-carrier interference is introduced
- The receiver structure must take into account both types of interference

Other Transmit Diversity Techniques

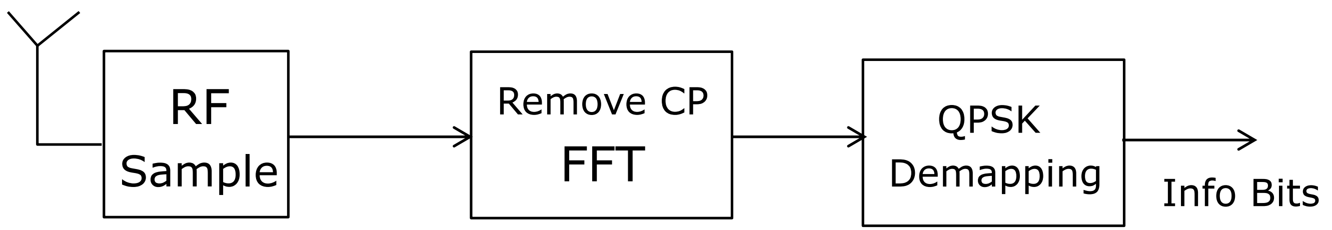
- One method to introduce diversity in OFDM at the transmit side is transmit diversity
- This can be accomplished multiple ways
  - Delay diversity – transmit the same signal with different delays from different antennas
    - Causes intentional multipath and frequency selective fading
  - Subcarrier diversity – transmit groups of subcarriers from different antennas
    - Causes frequency selective fading
- Both require coding to be used across carriers to capture the diversity

Transmit Diversity



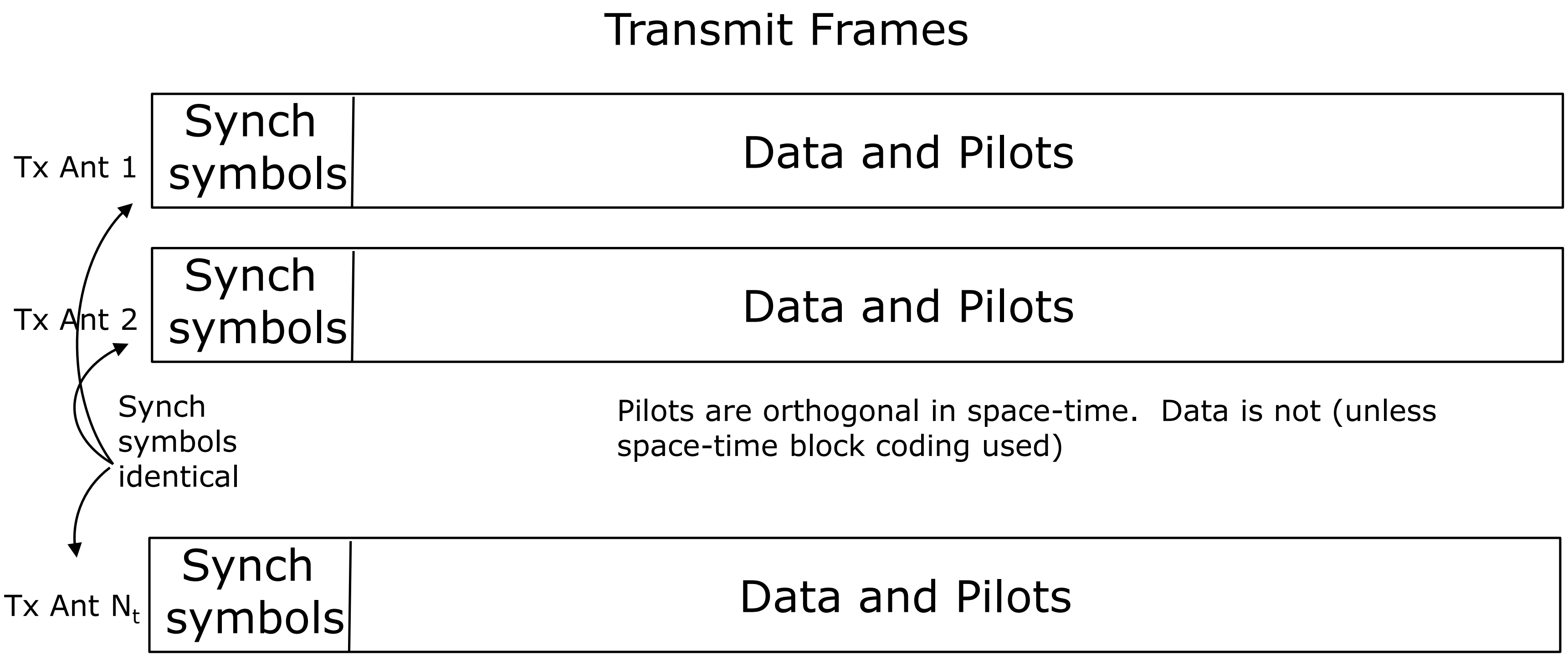
Transmit Diversity Receiver

- Identical to standard OFDM receiver



Synchronization

- Synchronization can be accomplished as described for OFDM
- Given that the time and frequency offsets should be similar from one antenna to another (due to the use of a common oscillator), synchronization (unlike channel estimation) need not be done over all antennas separately.

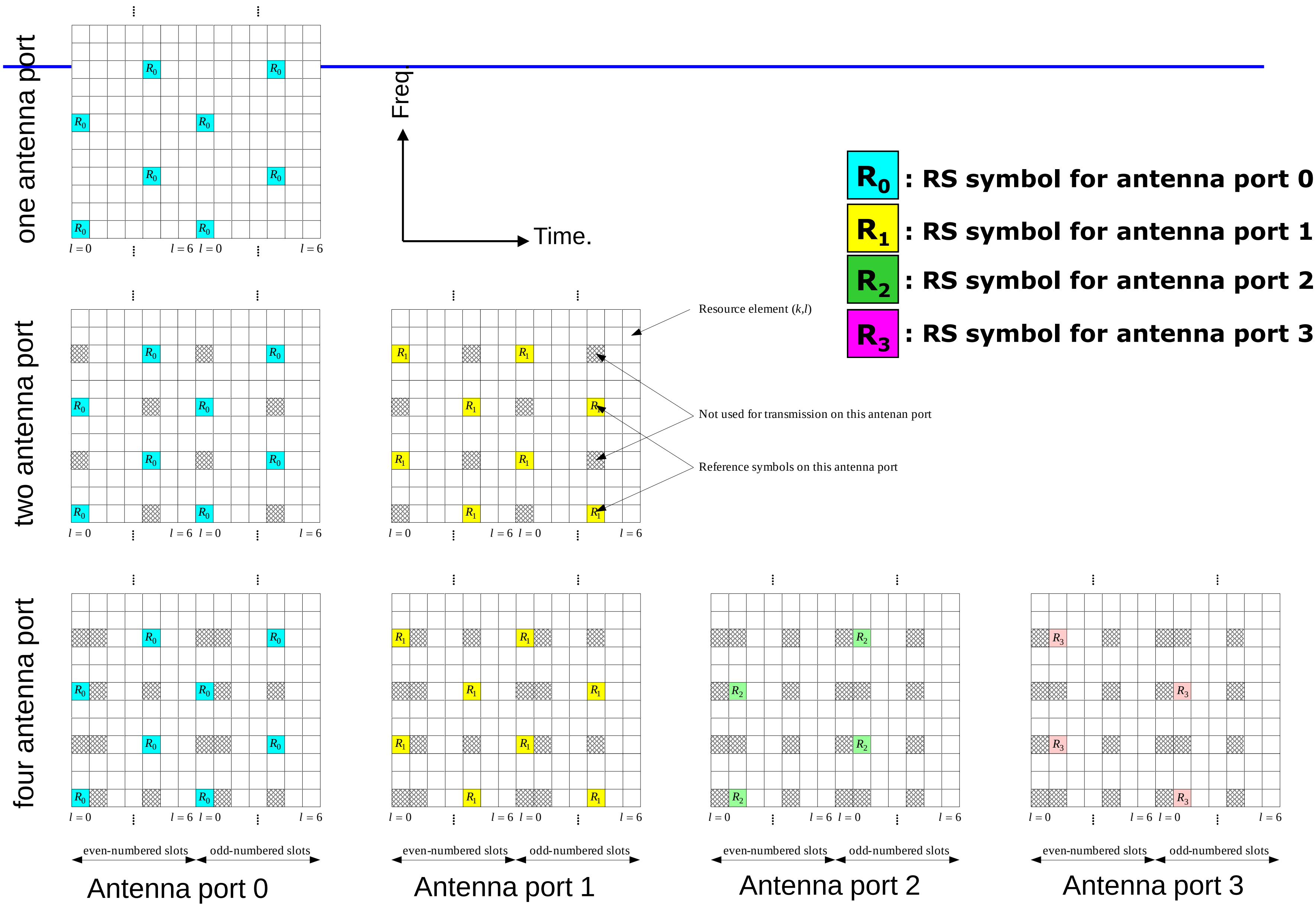


Channel Estimation

- Channel estimation is performed in exactly the same way that it is in typical OFDM.
- Differences:
  - Since we must estimate $M_r N_t$ frequency domain channels, we must send pilots from each transmit antenna.
  - We must orthogonalize the pilots from each antenna. To typical ways of doing this:
    - orthogonalize in frequency
    - orthogonalize in time, i.e., we require that

$$\mathcal{P}^{(i)} \subseteq \mathcal{N}^{(j)} \quad \forall i \neq j \quad 1 \leq i, j \leq N_t$$

Mapping of Cell-specific Reference Signal



Conclusions

- In this lecture we have examined a few methods of combining OFDM and MIMO
- Due to the complexity of equalization in MIMO, OFDM is the typical approach to dealing with frequency selective channels when MIMO is employed
- We specifically examined spatial multiplexing, space-time coding and transmit diversity
- There are other MIMO techniques that can be employed with OFDM
  - If the channel is static the receiver processing is identical to the single carrier case, but on a carrier by carrier basis
  - If the channel is not static, the receiver processing is more complicated