
Cooperation: Brno University of Technology

5G Simulator: FBMC

Ronald Nissel

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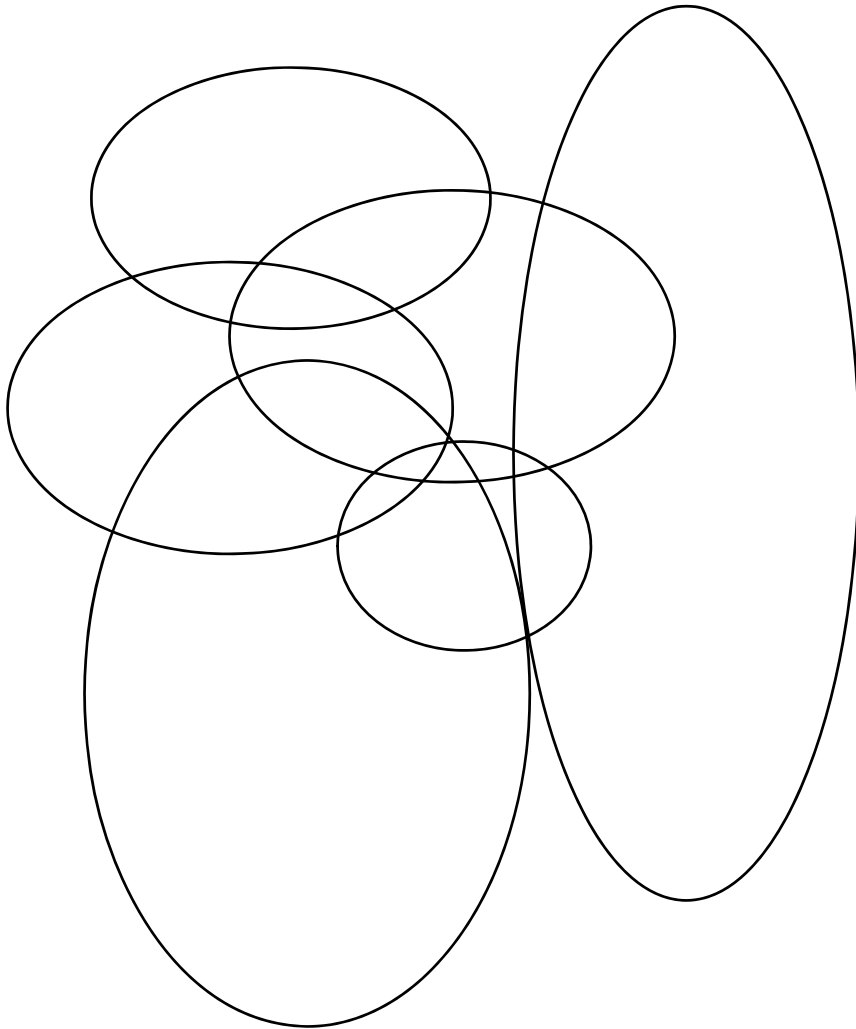
The 5G Simulator is under development, expected release date is 2017.

Our FBMC Matlab code, however, can be downloaded at:

<https://www.nt.tuwien.ac.at/downloads/> and corresponds to our published papers

LTE Simulator

Matlab functions and classes



Main Simulation Files

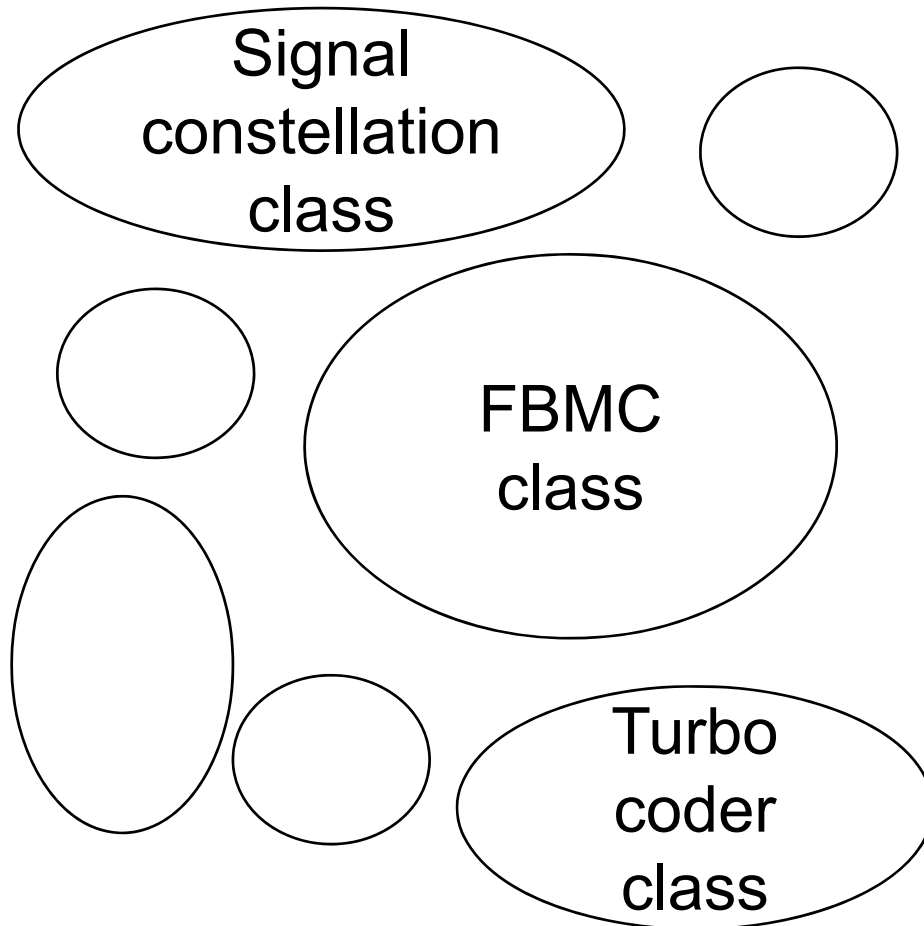
LTE_load_parameters

LTE_sim_main

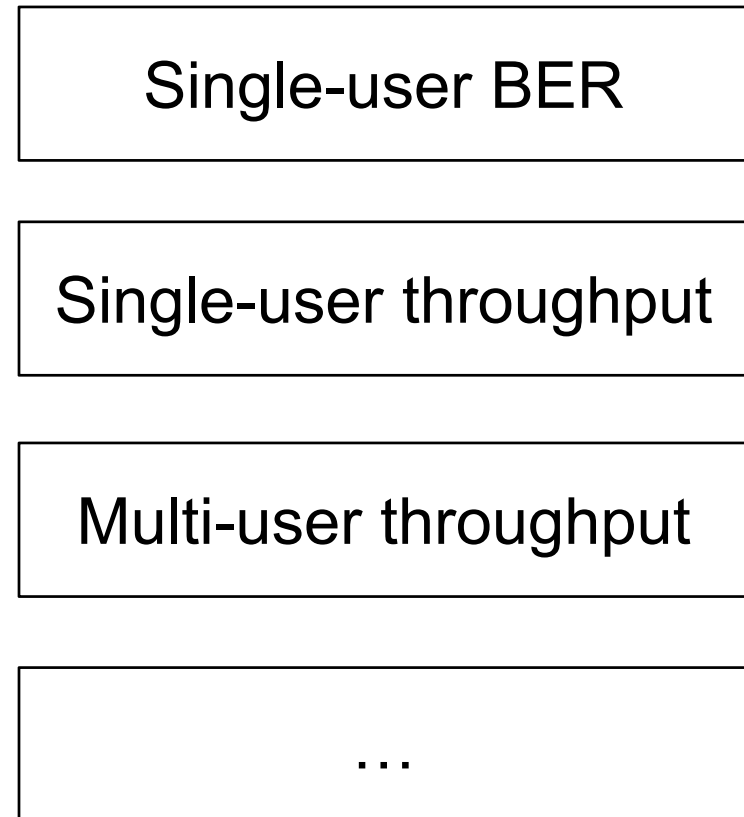
5G Simulator – Design Paradigm

Matlab functions and classes

...should have a simple input output relation



Main Simulation Files



Currently Implemented Classes

- Modulation:
 - FBMC
 - OFDM
 - Signal Constellation (QAM, PAM)
- Coding
 - TurboCoding
- Channel Estimation
 - ImaginaryInterferenceCancellationAtPilotPosition
 - PilotSymbolAidedChannelEstimation

Turbo Coding Class

```
TurboCoding = Coding.TurboCoding(...           % Class constructor
    2700,...                                   % Number of coded bits
    206 ...                                   % Number of data bits
);

CodedBits = TurboCoding.TurboEncoder(DataBits); % Code binary stream
EstimatedDataBits = TurboCoding.TurboDecoder(LLR); % Decode bits
```

- **To DO:** Rewrite class

Currently, the Communications System Toolbox is used for the turbo coder

- Slow
- Not included in all MATLAB versions

FBMC Class

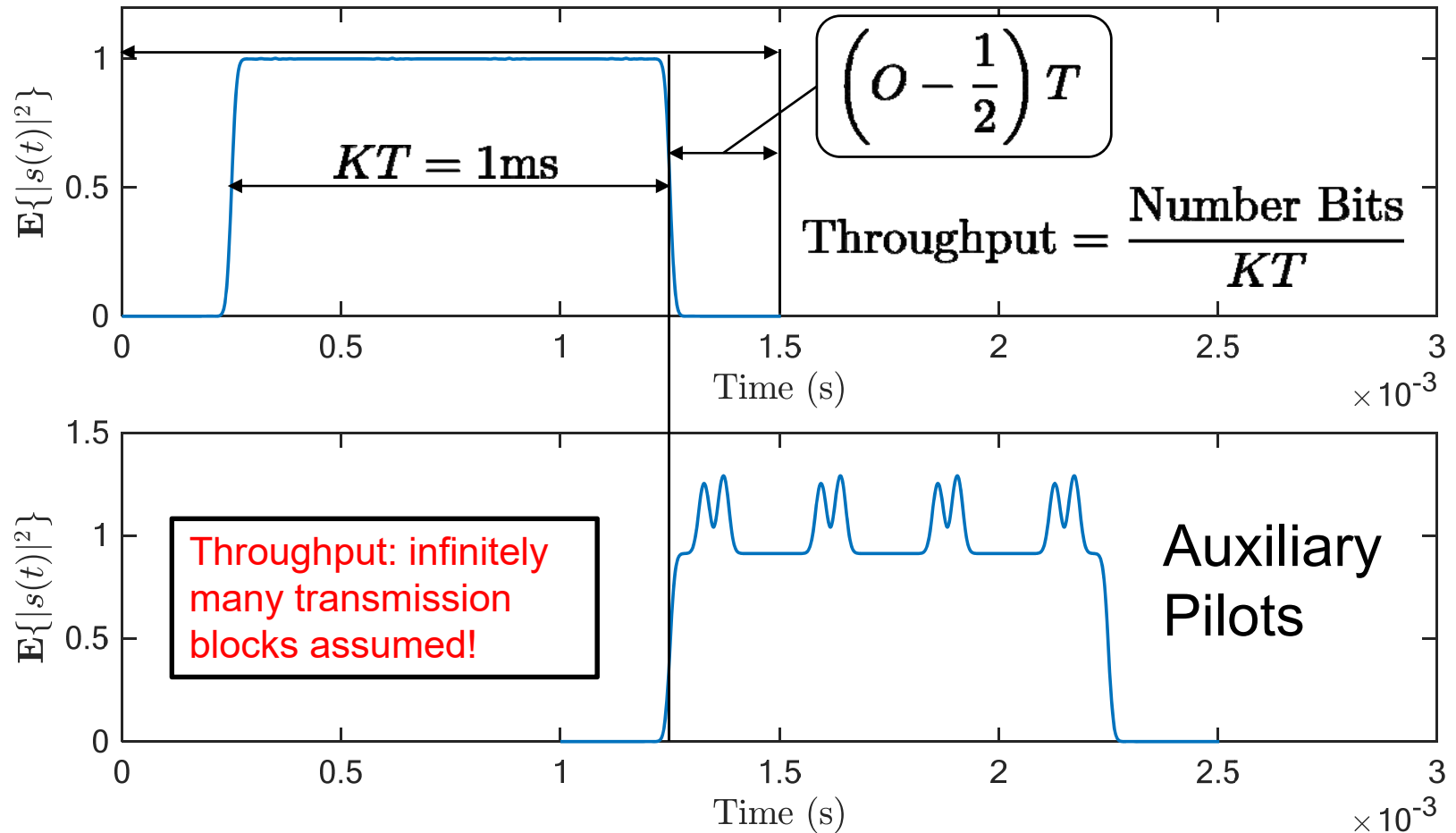
```
FBMC = Modulation.FBMC(...           % Class constructor
    90,...                             % Number of subcarriers
    30,...                             % Number of FBMC symbols
    15e3,...                            % Subcarrier spacing
    15e3*90,...                        % Sampling frequency
    0,...                               % Intermediate frequency
    false,...                          % Transmit real valued signal
    'Hermite-OQAM',...                % Prototype filter and OQAM or QAM
    8, ...                             % Overlapping factor
    0, ...                             % Initial phase shift
    true ...                          % Polyphase implementation
);

s = FBMC.Modulation(x);               % Modulate data stream
y = FBMC.Demodulation(s);            % Demodulate received signal
```

Some additional methods (small subset):

```
FBMC.PlotTransmitPower(R_x);         % Plot average transmit power over
FBMC.PlotPowerSpectralDensity;      % Plot the power spectral density
```

FBMC.PlotTransmitPower

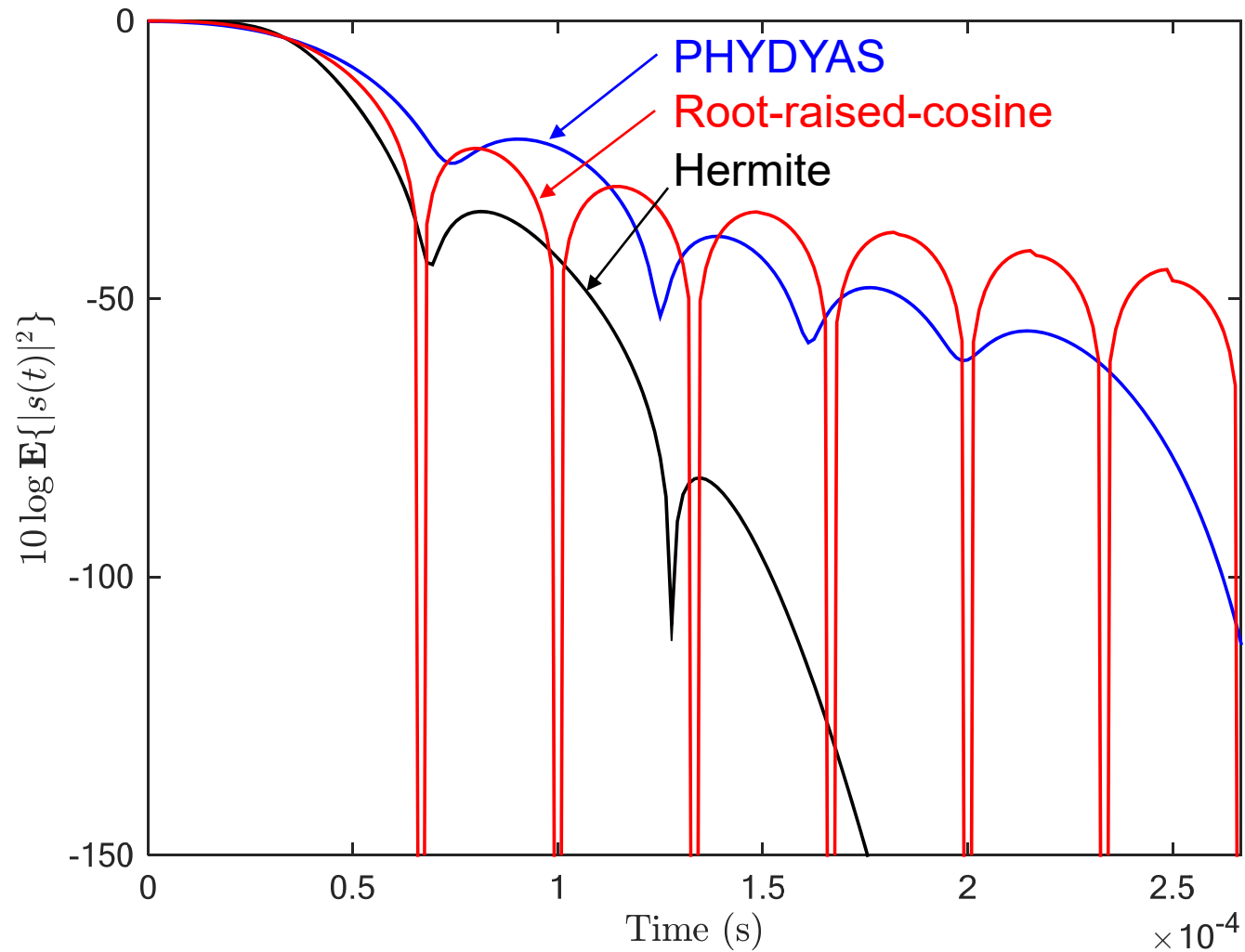


- OFDM: $\mathcal{O}\{L \log_2(L)\}$
- FBMC: $\mathcal{O}\{2(L \log_2(L) + OL)\}$

K...Number of FBMC symbols
 T...Time spacing
 O...Overlapping factor
 L...Number of Subcarriers

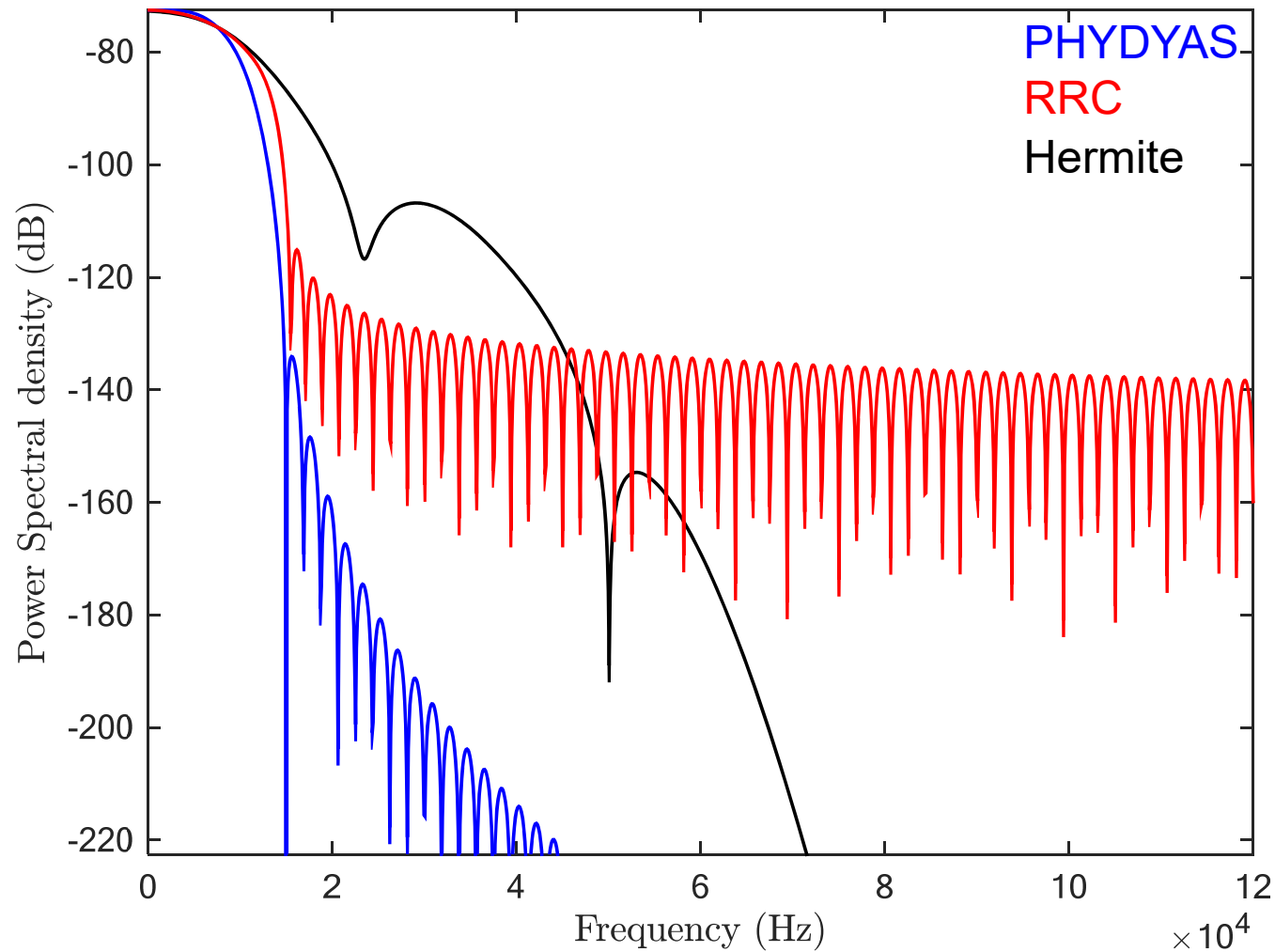
Overlapping Factor 8

- Average transmit signal in dB



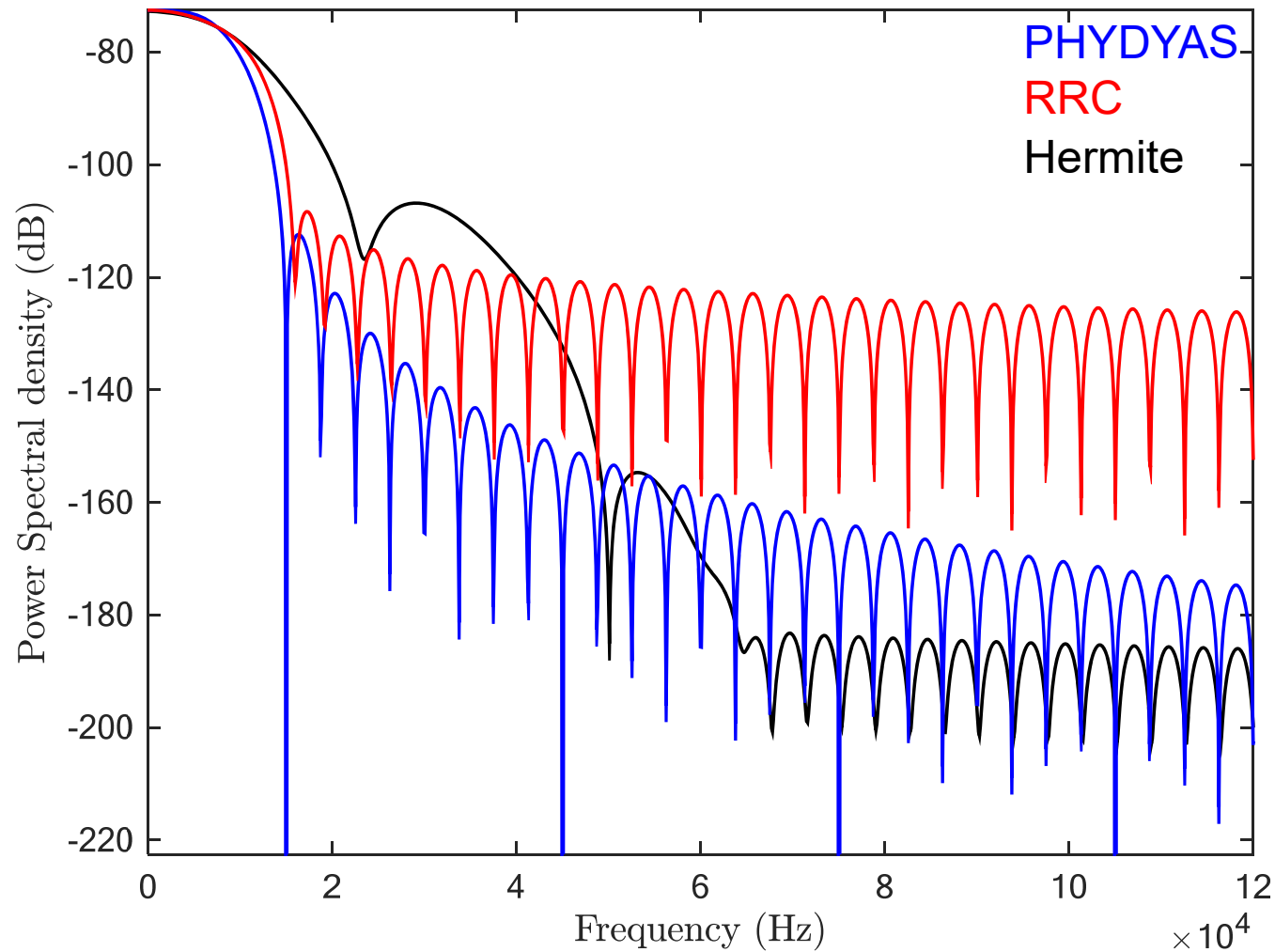
Overlapping Factor 8

- Power spectral density



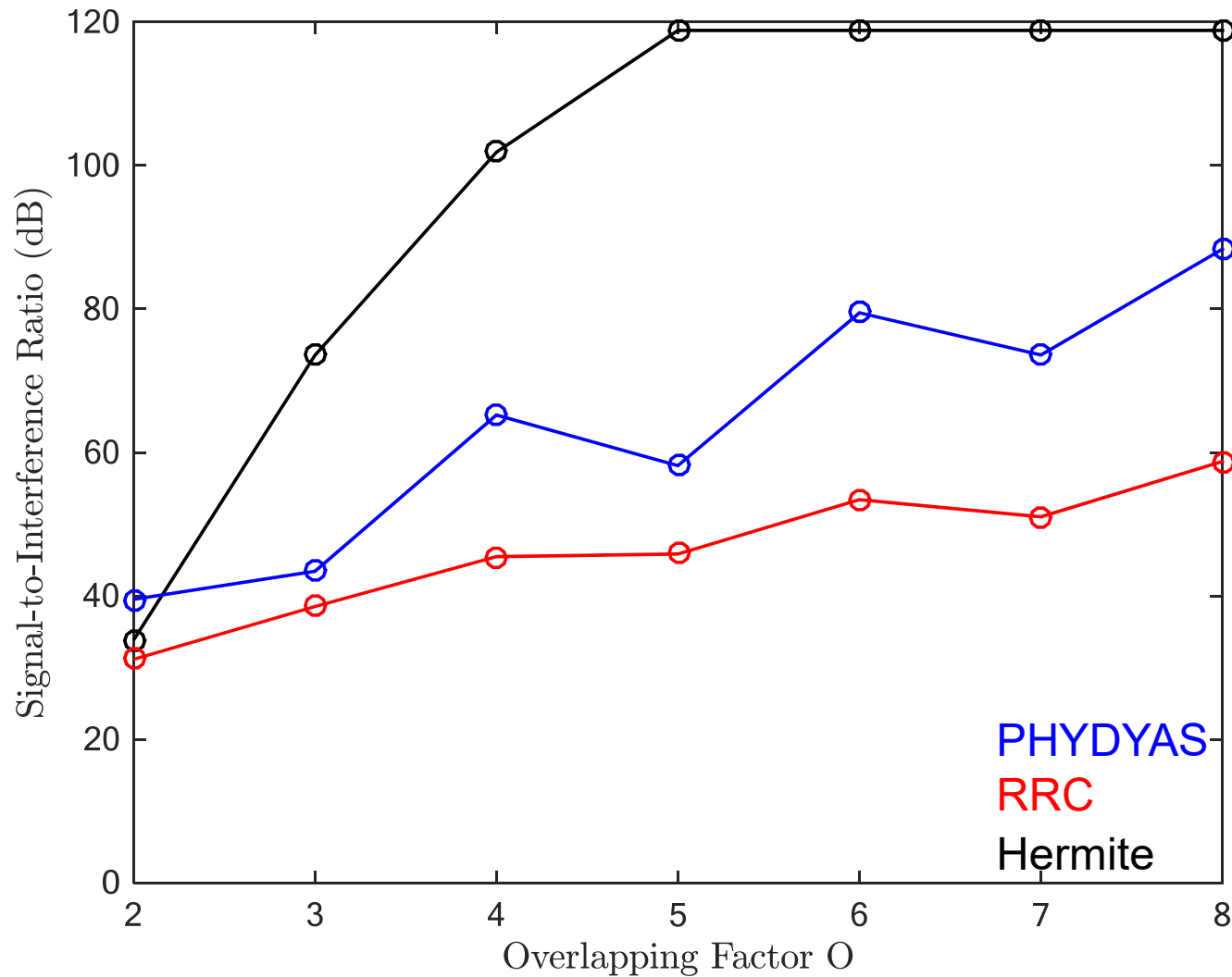
Overlapping Factor 4

- Power spectral density



Overlapping Factor

- Signal-to-Interference Ratio

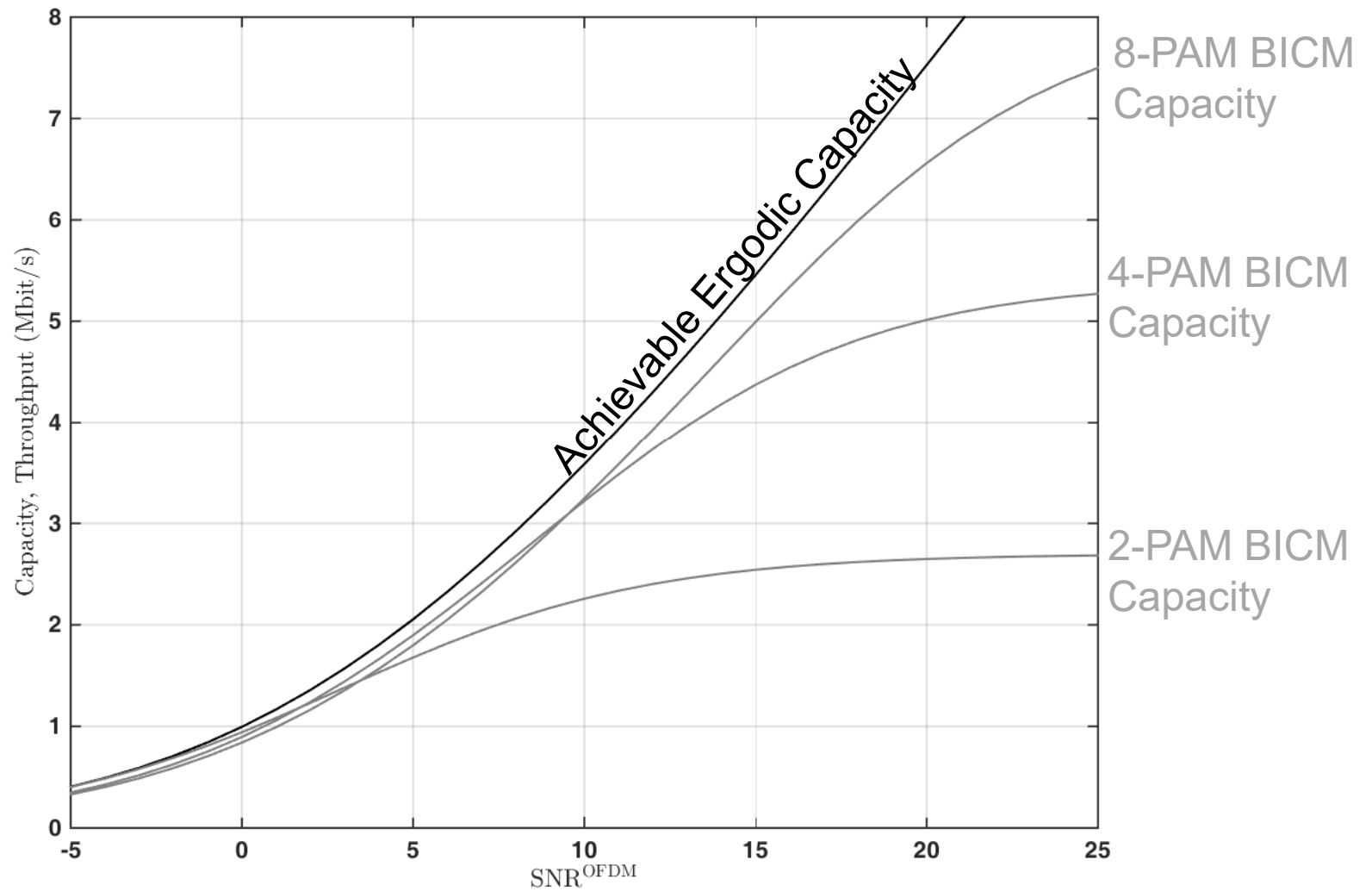


FBMC vs. OFDM

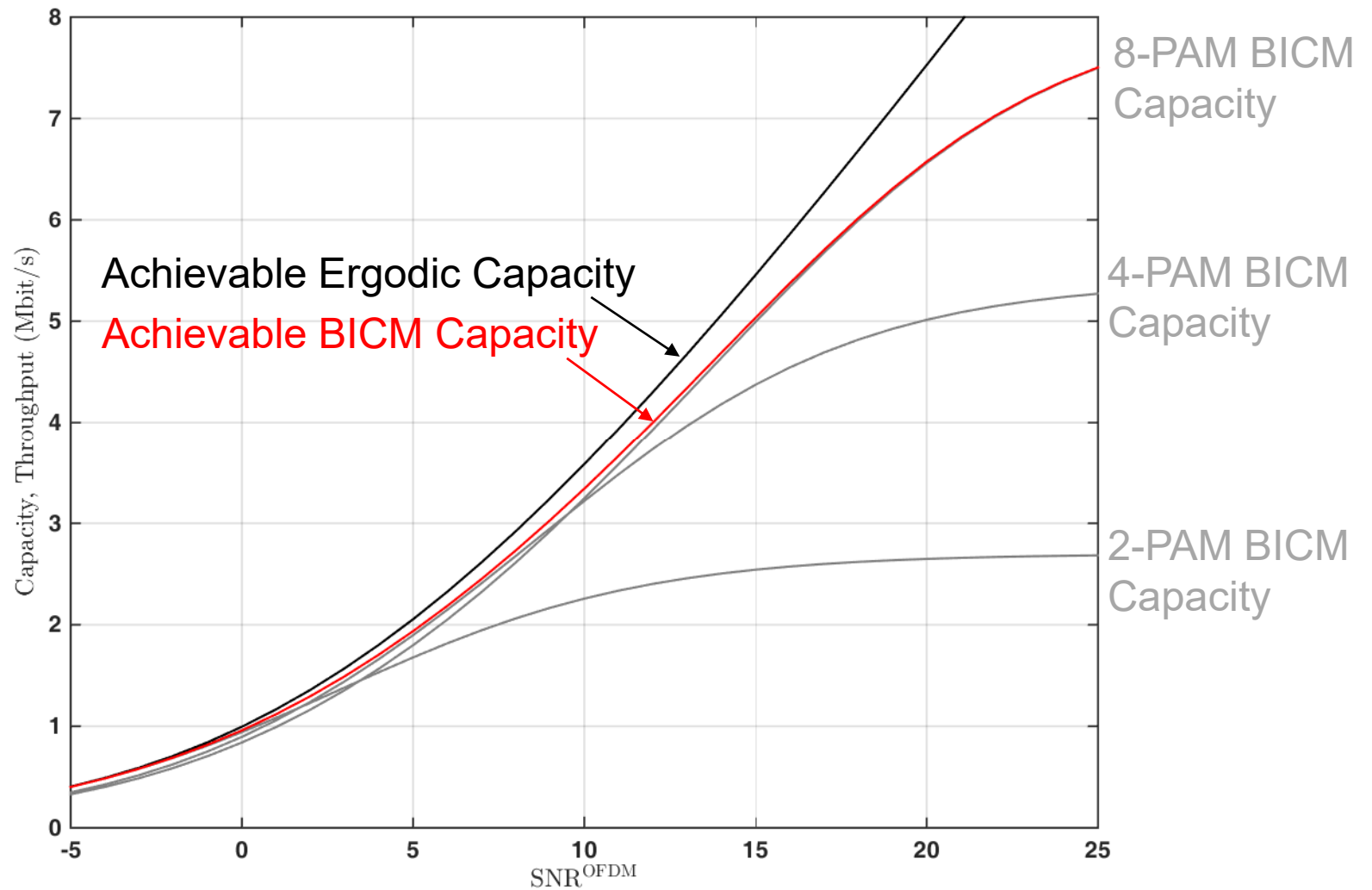
- 1.4MHz LTE
- Doubly-flat Rayleigh fading

	OFDM	FBMC
Number of subcarriers	72	90
Number of time symbols	14	30 (real) (equivalent to 15 complex symbols)

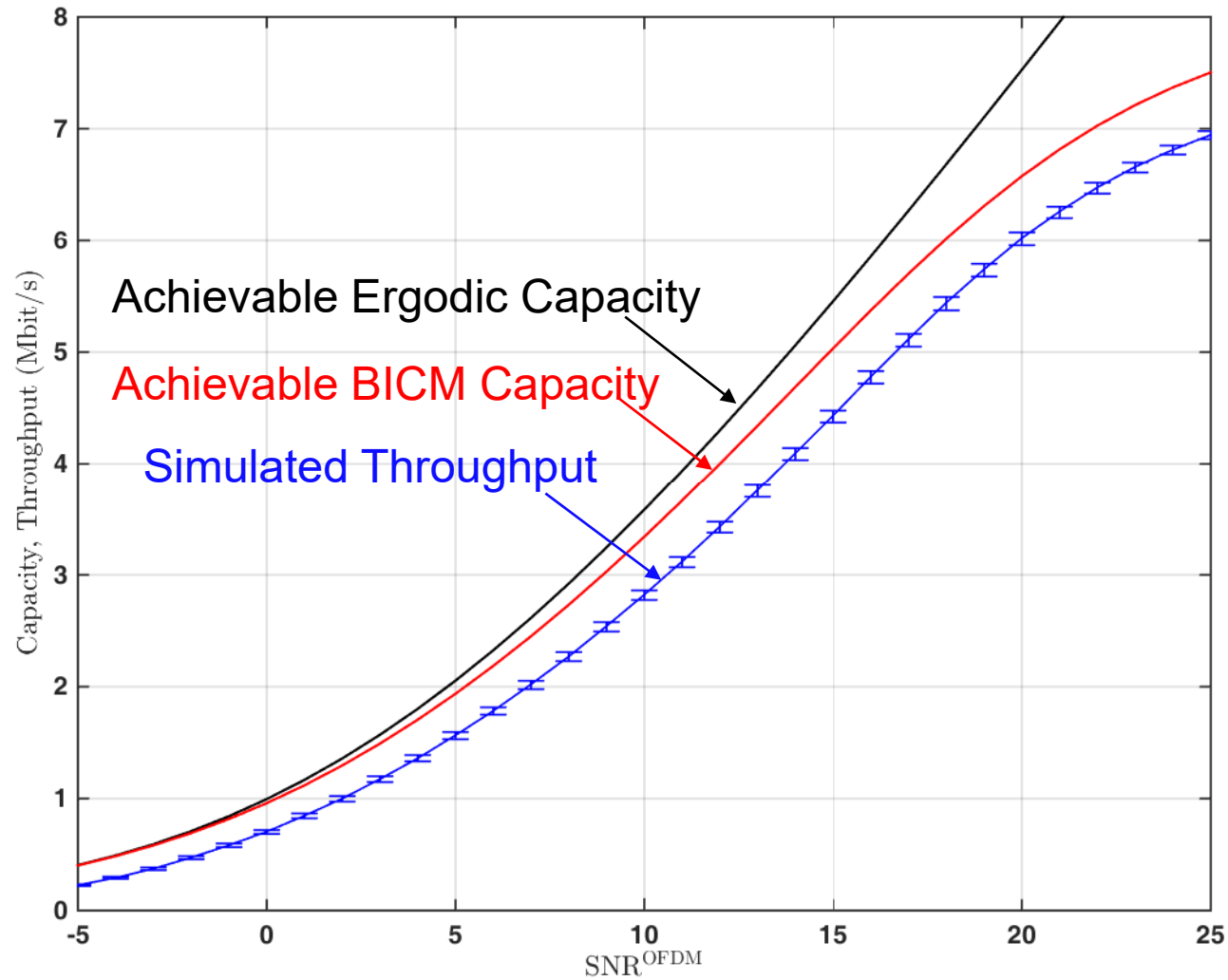
FBMC



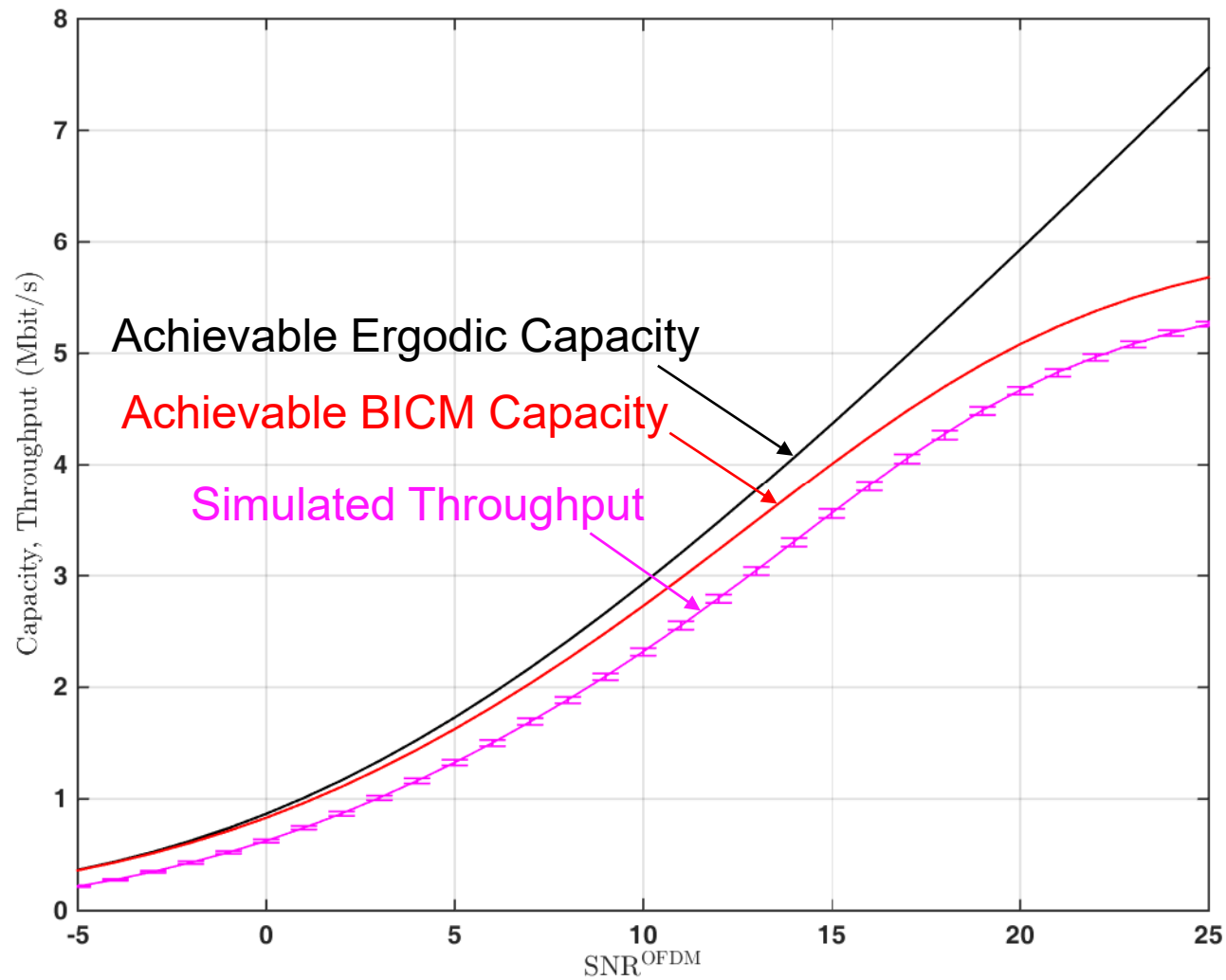
FBMC



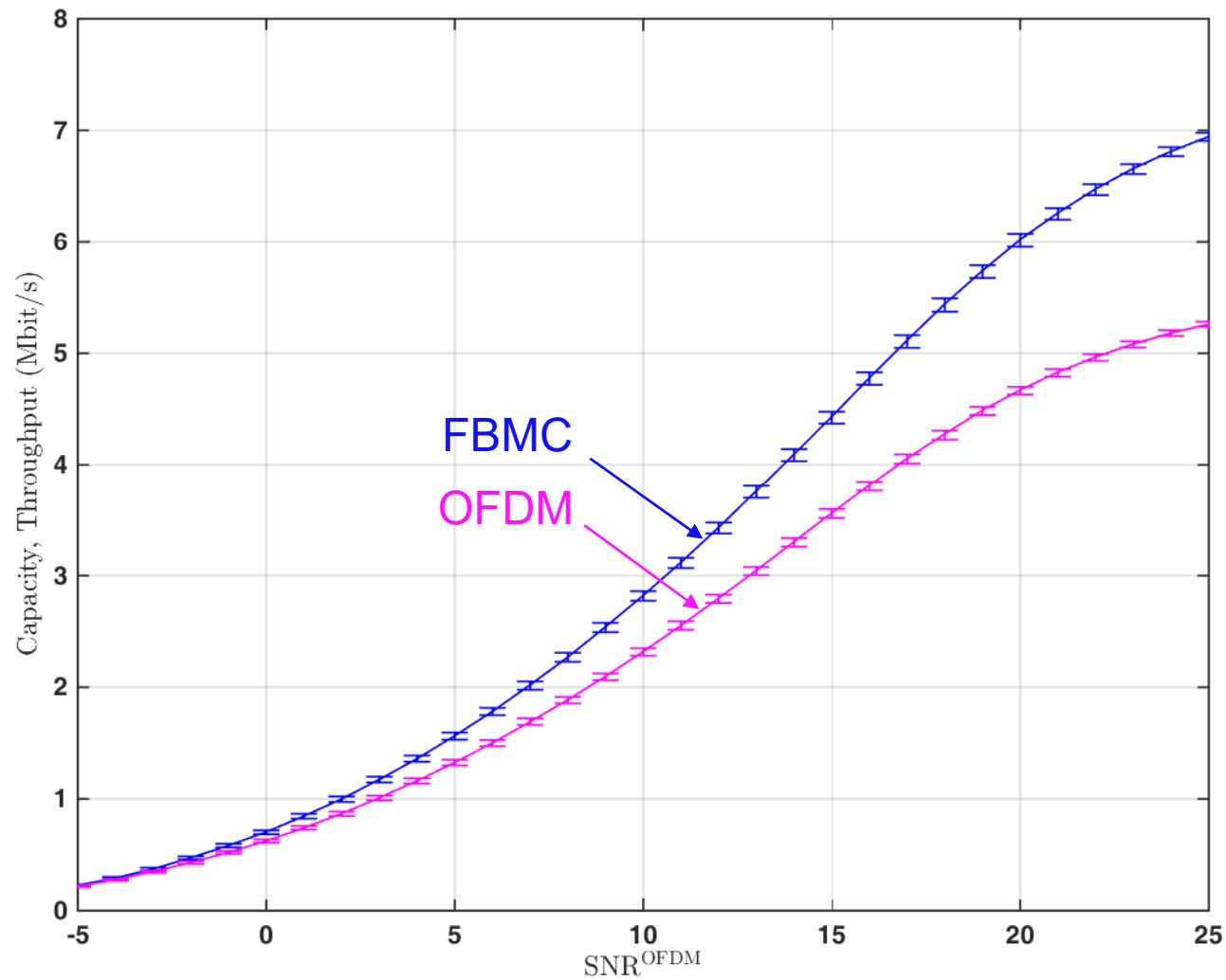
FBMC



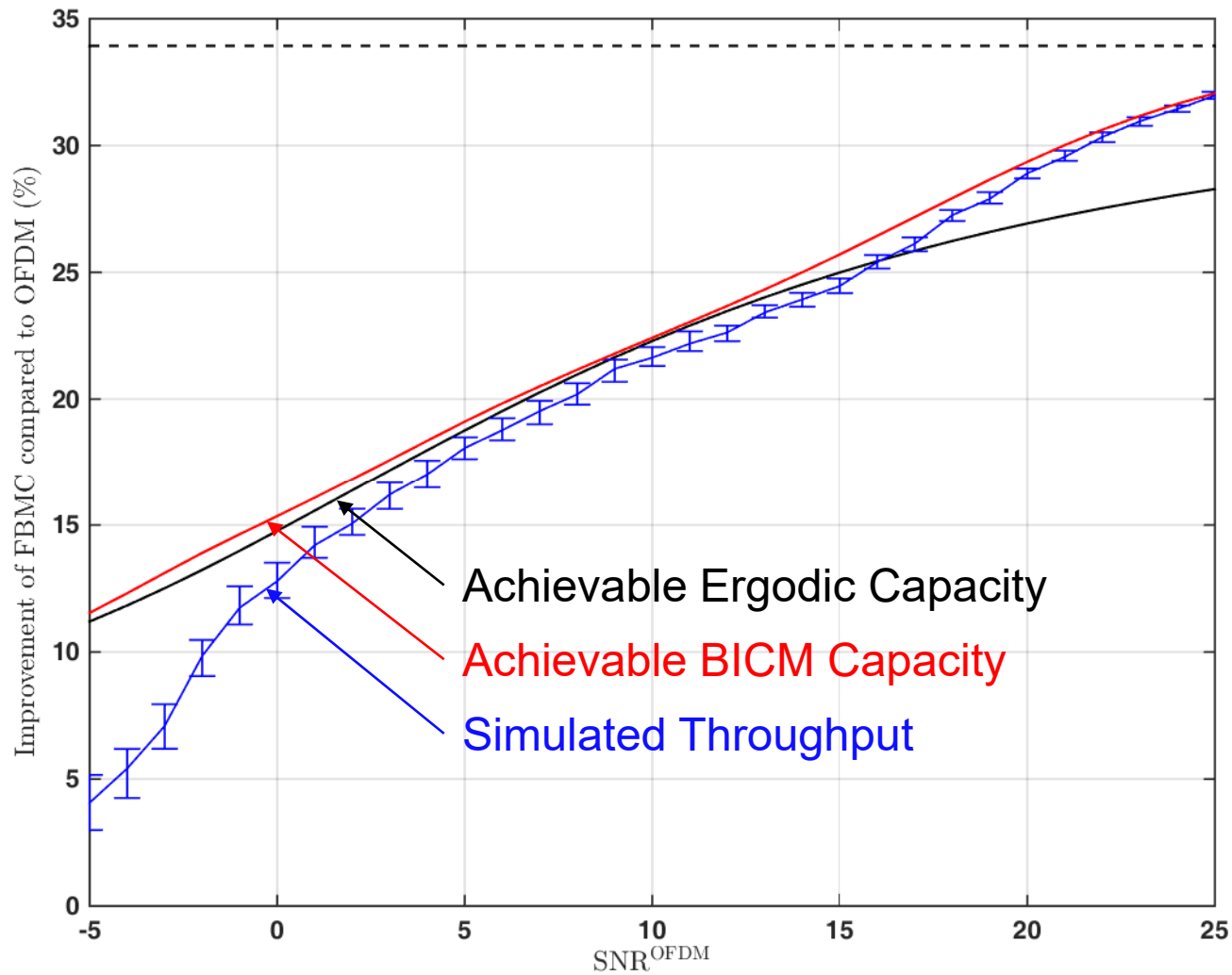
OFDM



Simulated Throughput: FBMC vs OFDM



FBMC vs OFDM

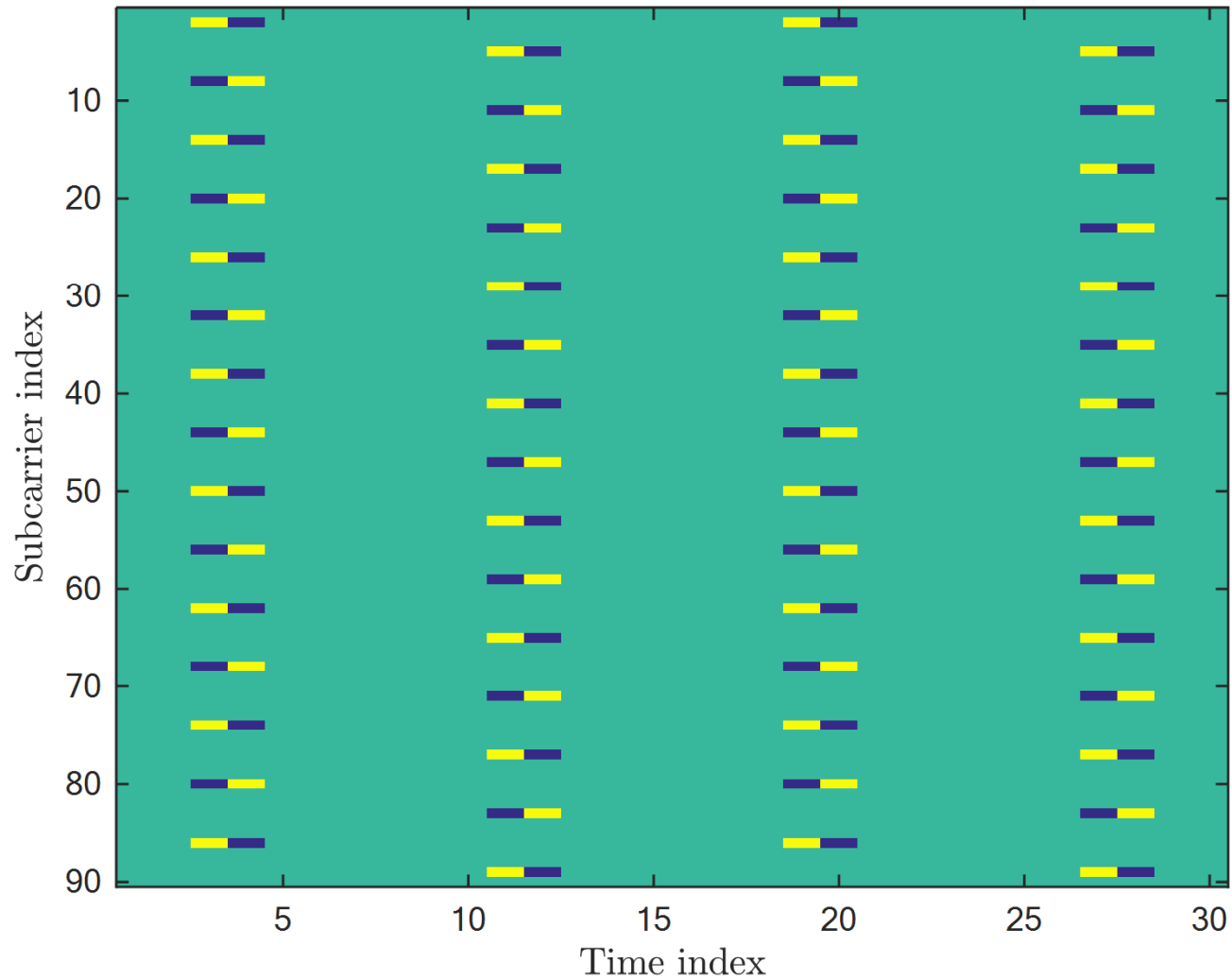


Channel Estimation

- Doubly-flat Rayleigh fading
- Cancel imaginary interference at pilot position
 - Auxiliary pilot symbols
 - Coding
- Channel estimation (interpolation)
 - Linear
 - MMSE
- LLR assumes perfect channel knowledge

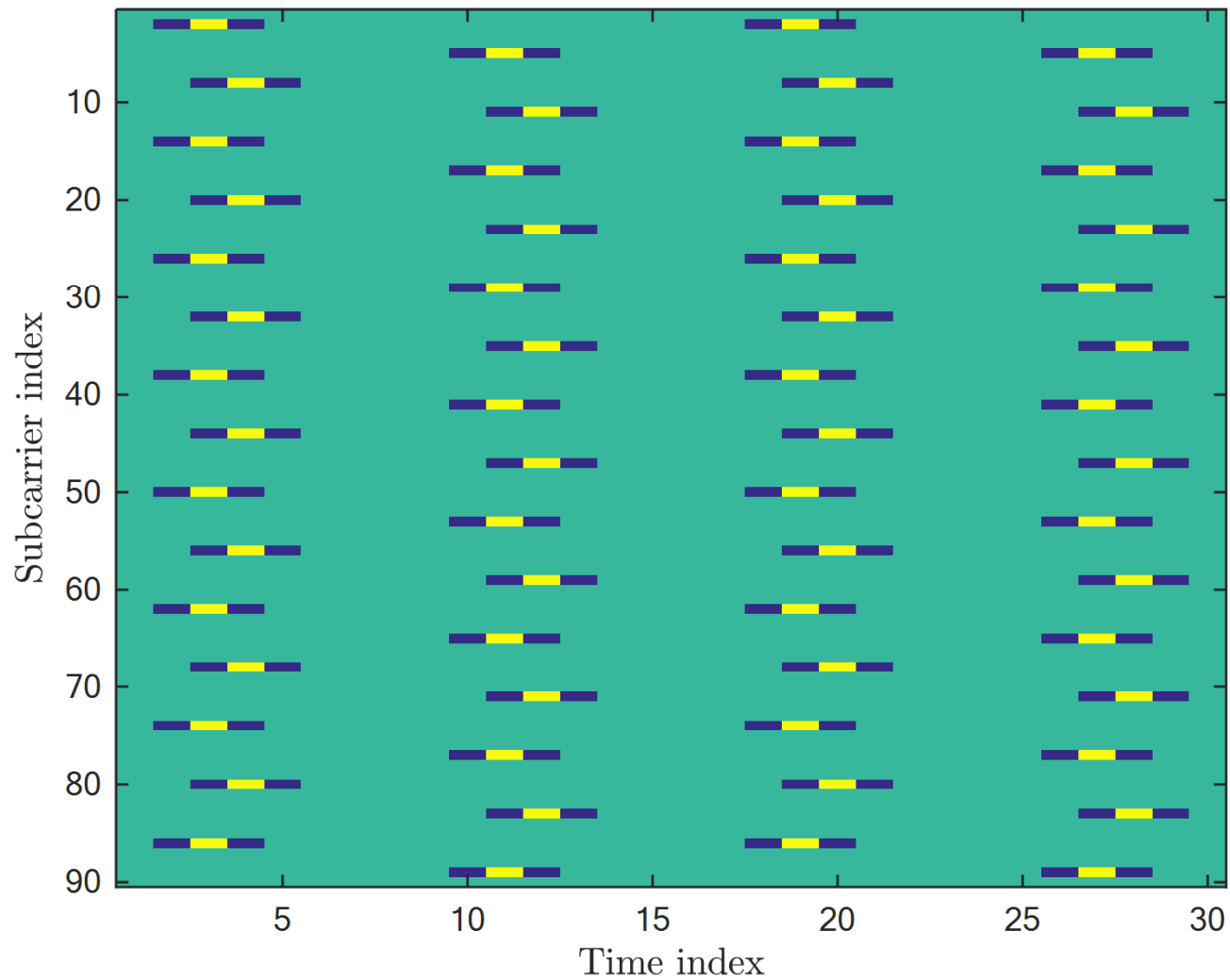
1 Auxiliary Symbol per Pilot

- Power offset 4.3, **High PAPR**



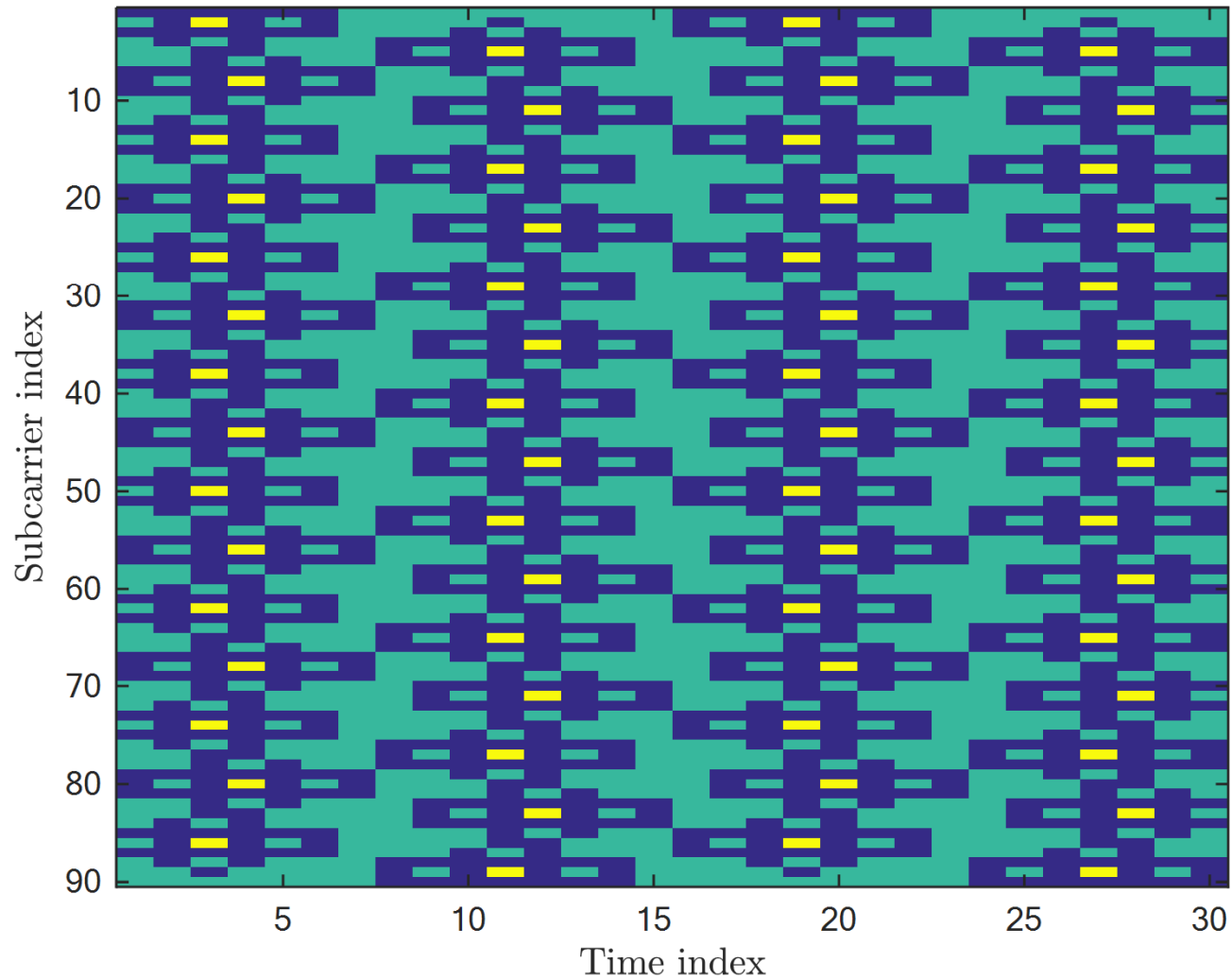
2 Auxiliary Symbol per Pilot

- Power offset 0.8



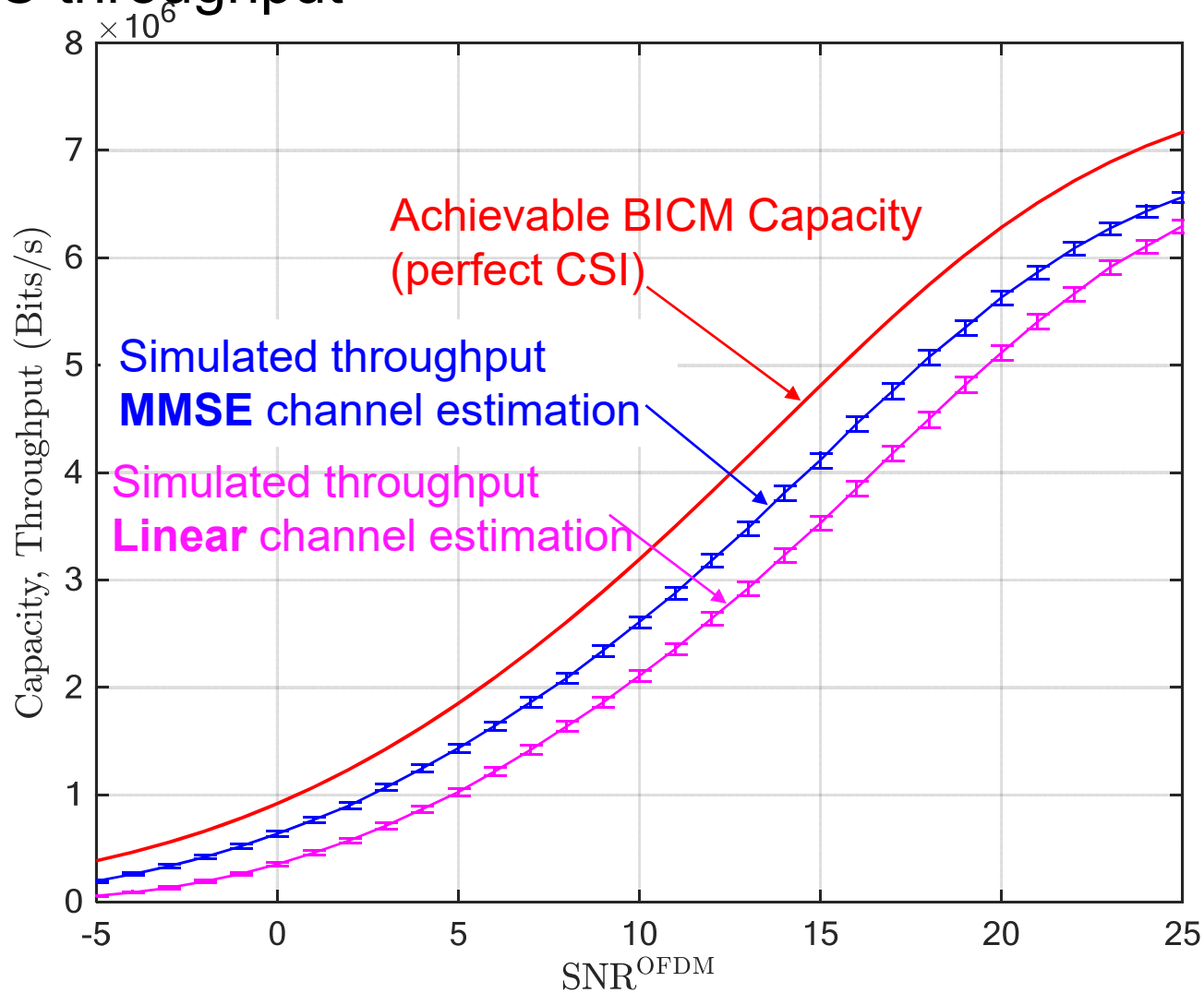
Coding

- Power offset 0



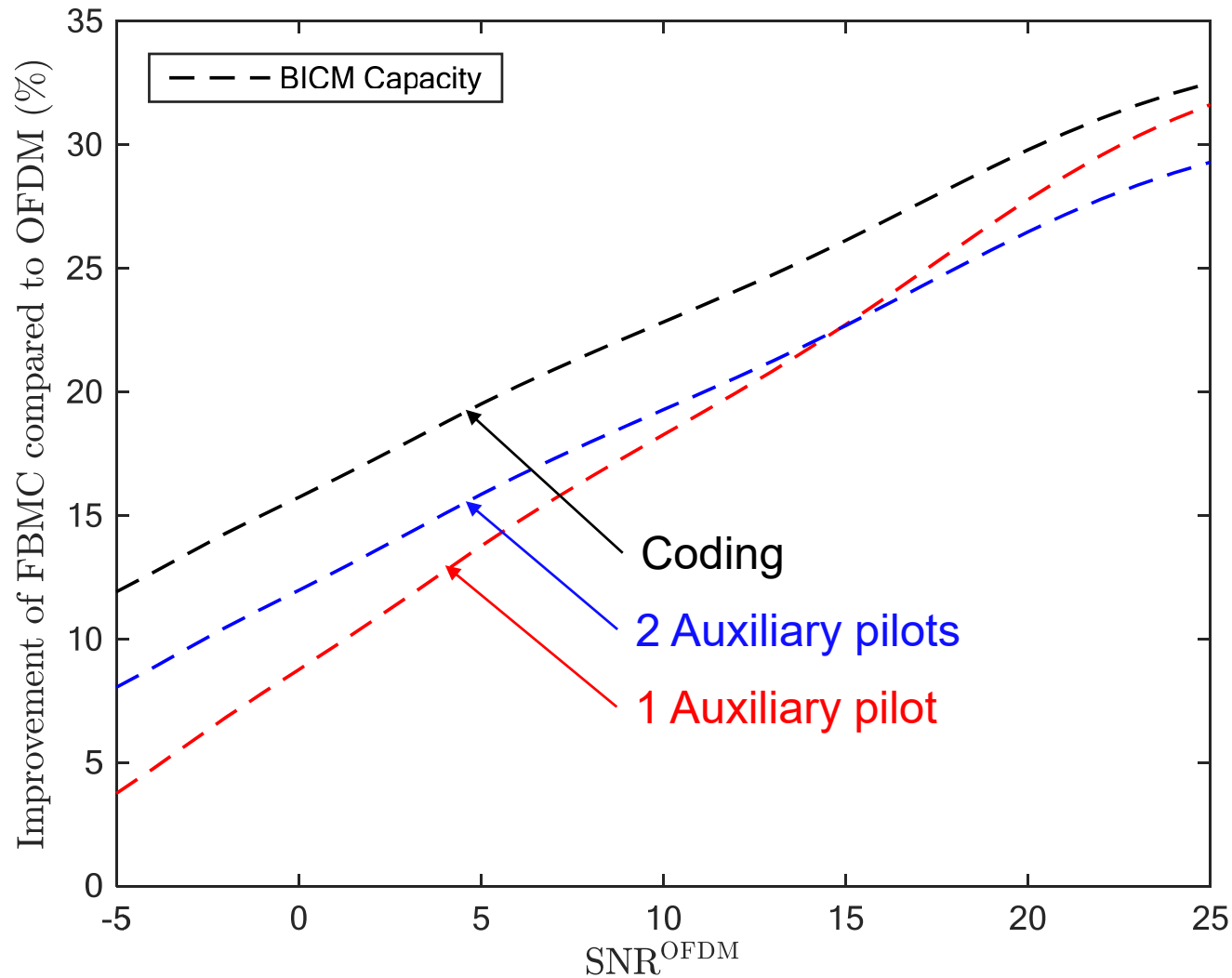
FBMC: MMSE vs Linear for Coding

- FBMC throughput



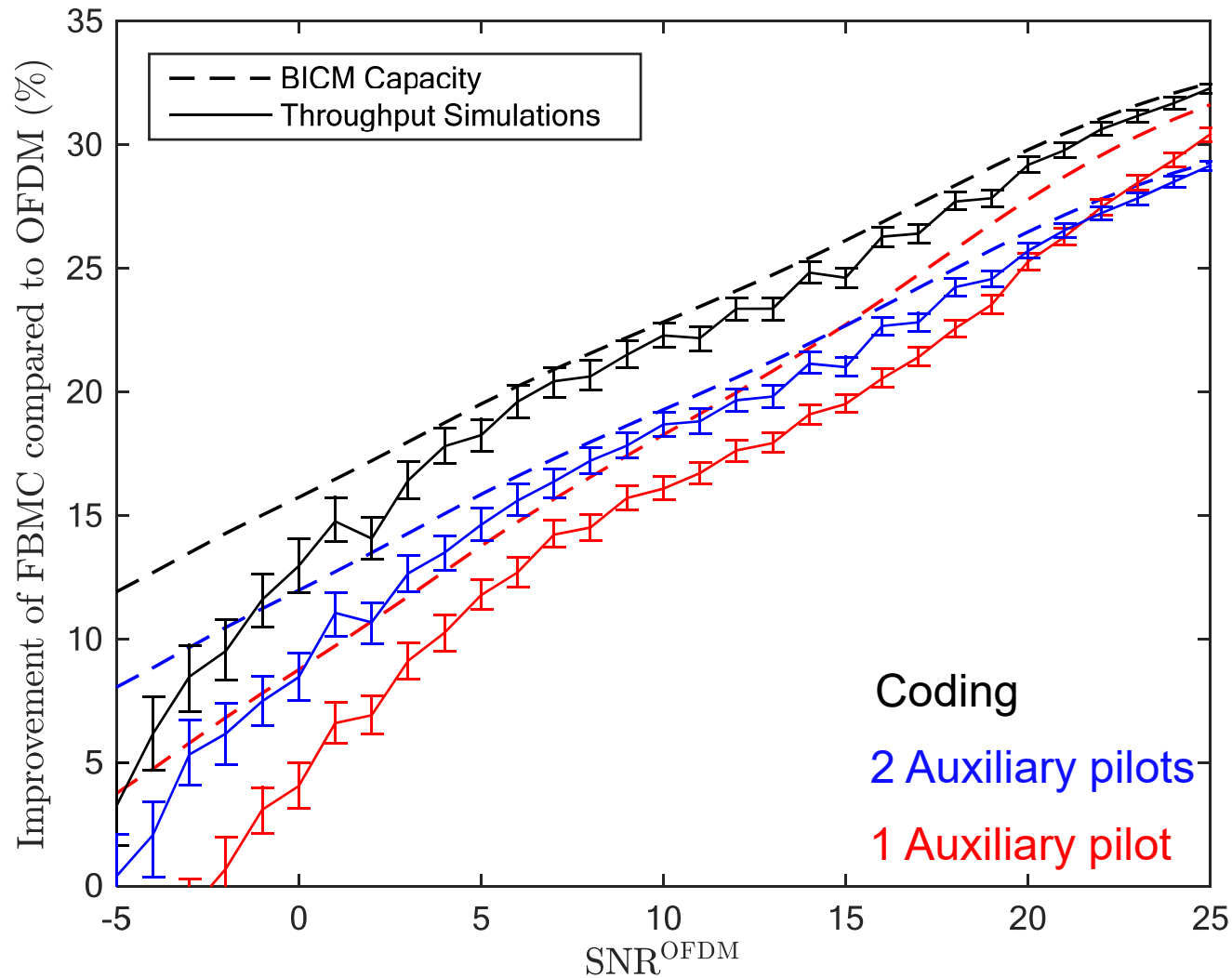
FBMC vs OFDM for **MMSE** Channel Estimation

- BICM Capacity (perfect CSI)



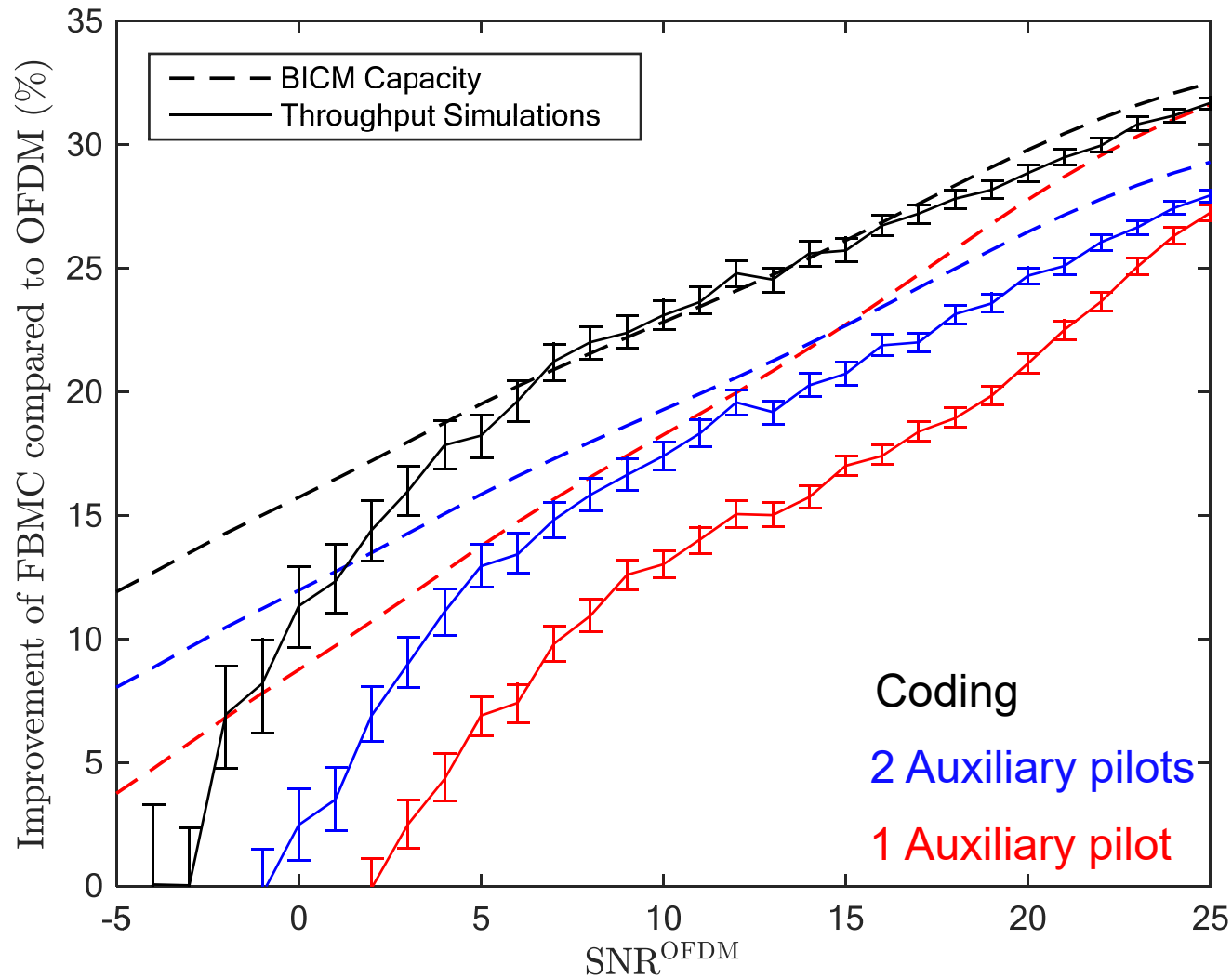
FBMC vs OFDM for **MMSE** Channel Estimation

- Throughput simulations



FBMC vs OFDM for **Linear** Channel Estimation

- Throughput simulations

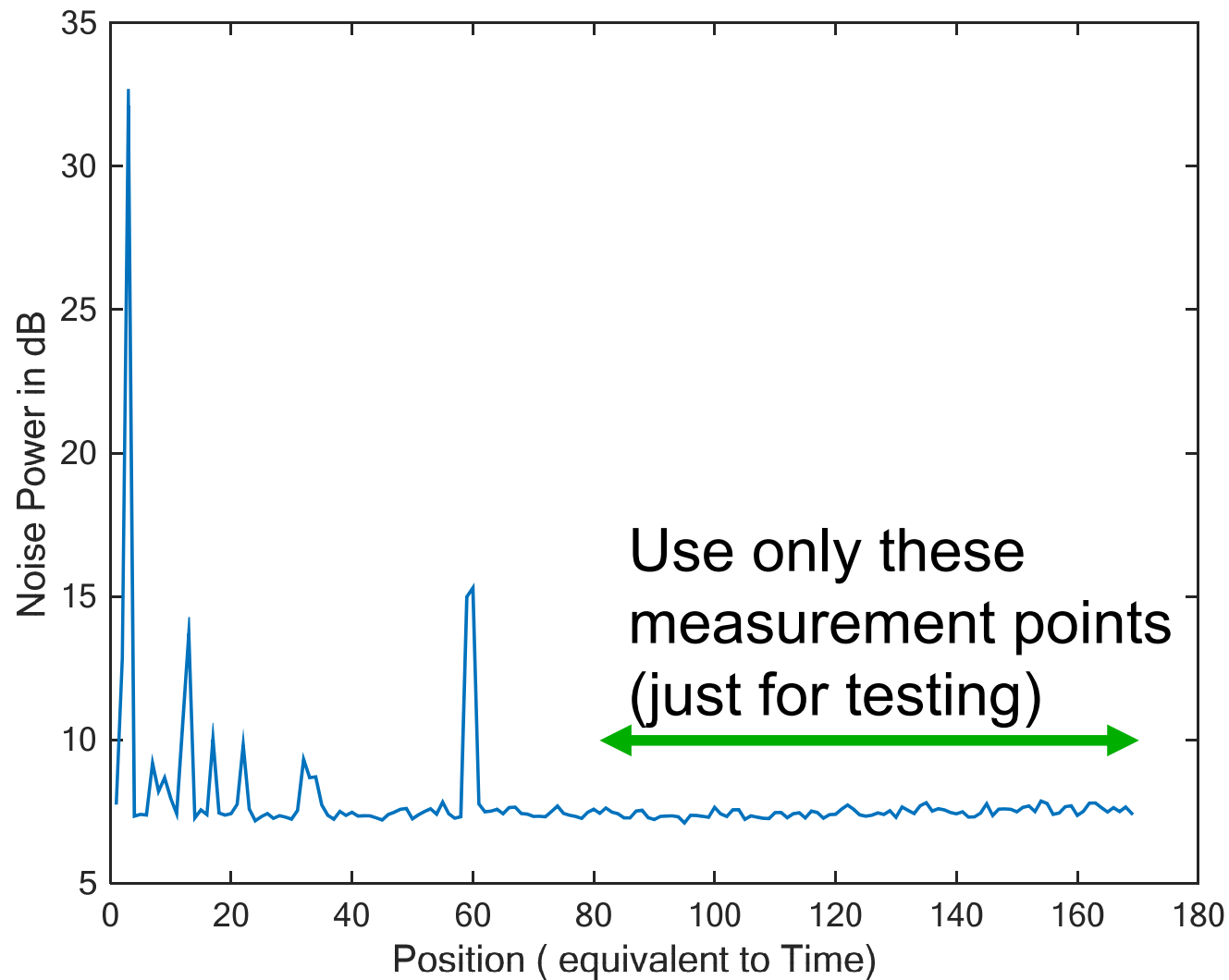


Recent Results – Measurements



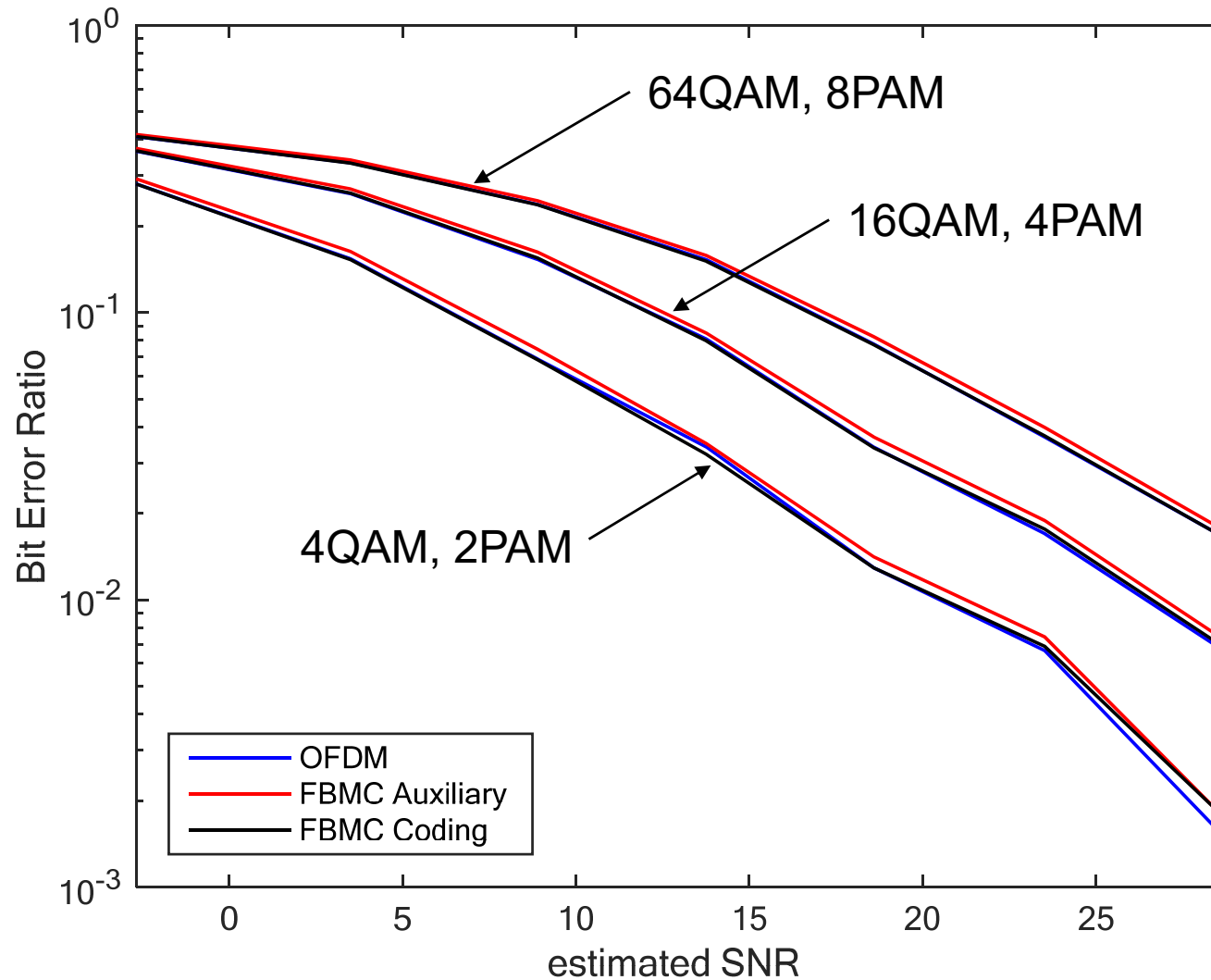
Recent Results – Measurements

- Interference from the LTE Uplink



Recent Results – Measurements

- FBMC and OFDM perform similar (as theory suggest)



Outlook

- Throughput measurements for 2,3,4... auxiliary pilot symbols, submit to SAM 2016 in Rio de Janeiro
- Performance of FBMC in doubly-selective channels
 - Signal to interference ratio
 - Effects on channel estimation
- (Massive) MIMO in FBMC