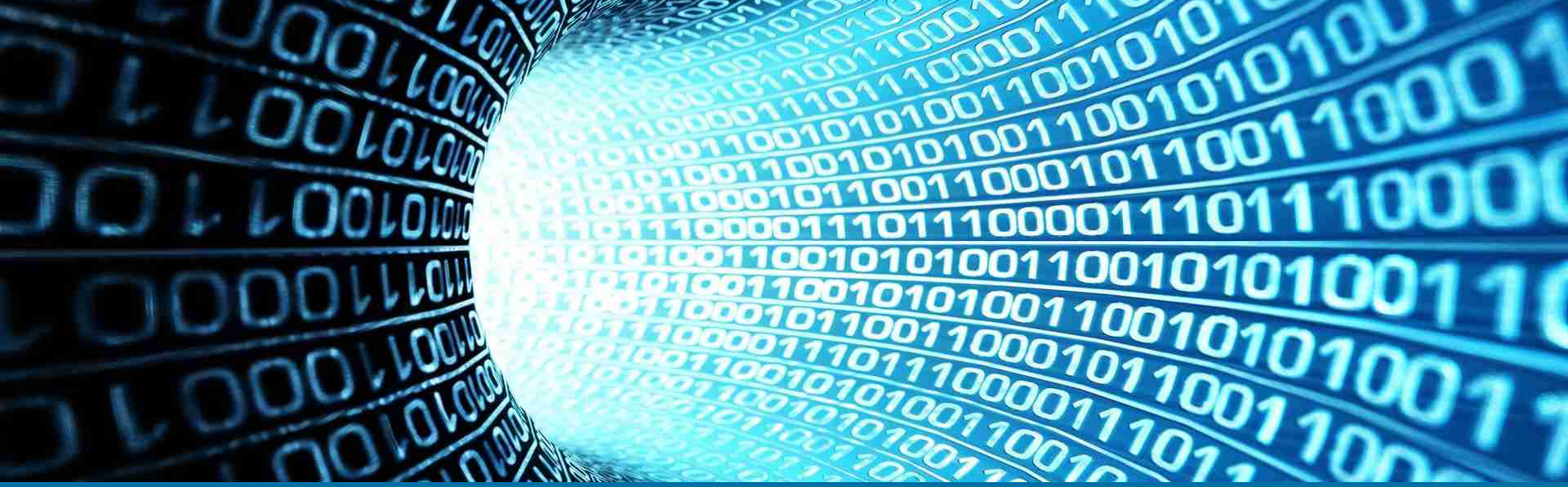

Narrowband Interference Mitigation in SC-FDMA Using Bayesian Sparse Recovery

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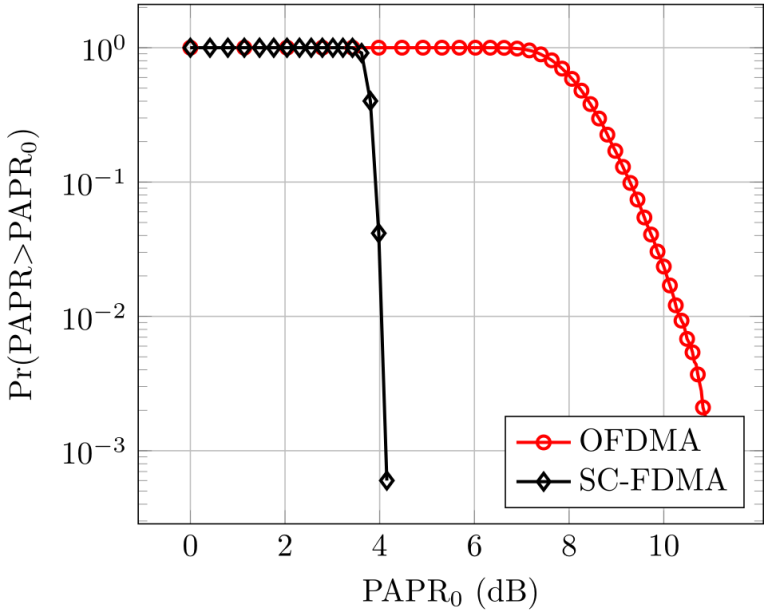
SC-FDMA and Narrowband Interference (NBI)

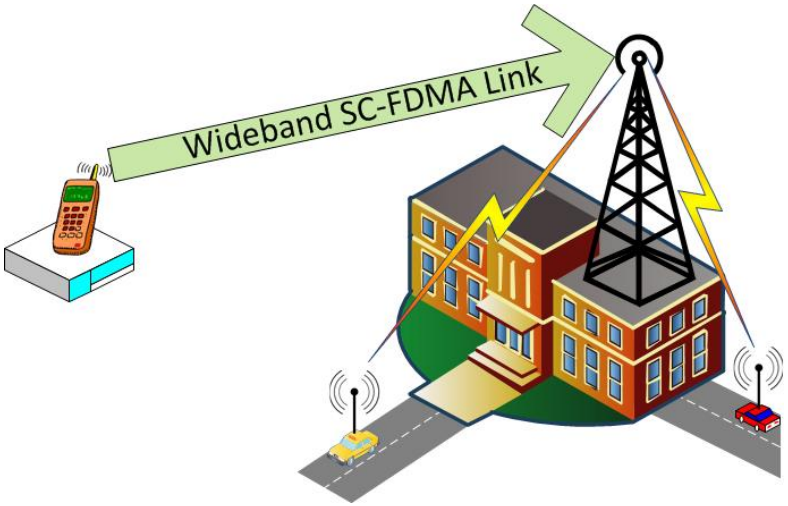
Why SC-FDMA?

- Performance comparable to OFDMA
- Additional Advantage of low PAPR
- Used in LTE uplink [1]



NBI Sources

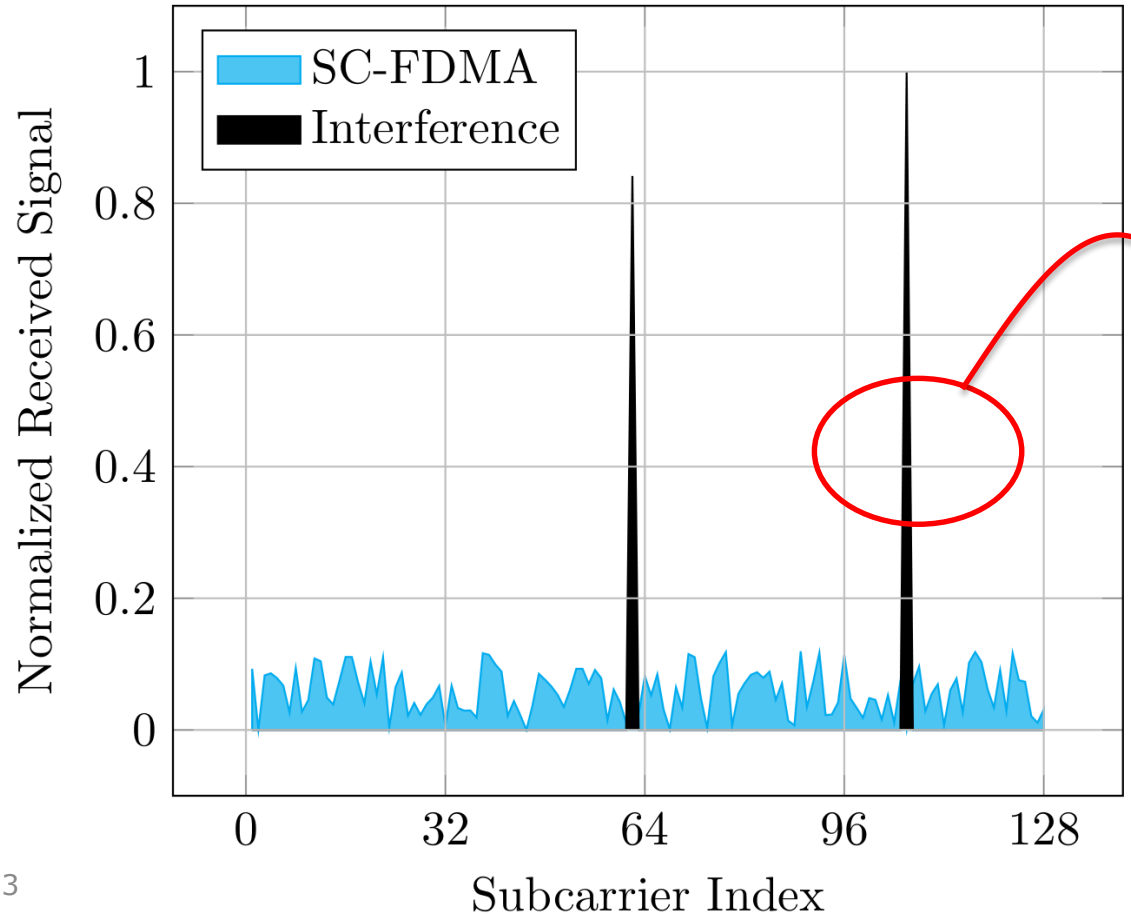
- Coexisting systems in unlicensed bands
- Garage door openers
- Cordless phones etc.

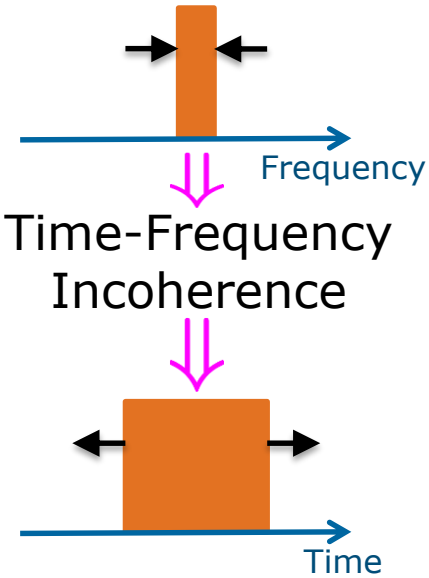


[1] H. G. Myung, J. Lim, and D. Goodman, "Single carrier FDMA for uplink wireless transmission," *IEEE Veh. Technol. Mag.*, vol. 1, no. 3, pp. 30-38, 2006.

NBI's Sparse Nature and Impact on SC-FDMA

- NBI is sparse in frequency-domain
- In SC-FDMA data is encoded in time-domain



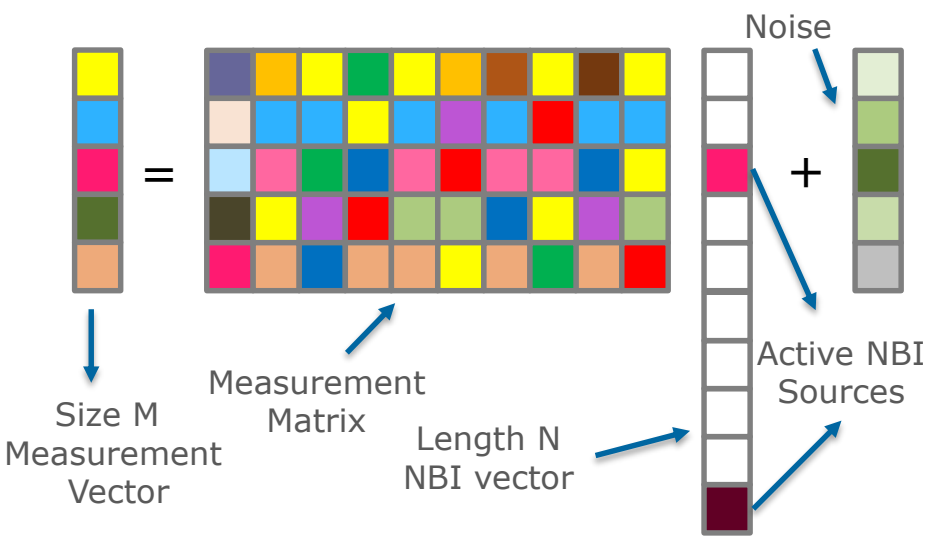


Single strong interference can completely destroy the data in SC-FDMA

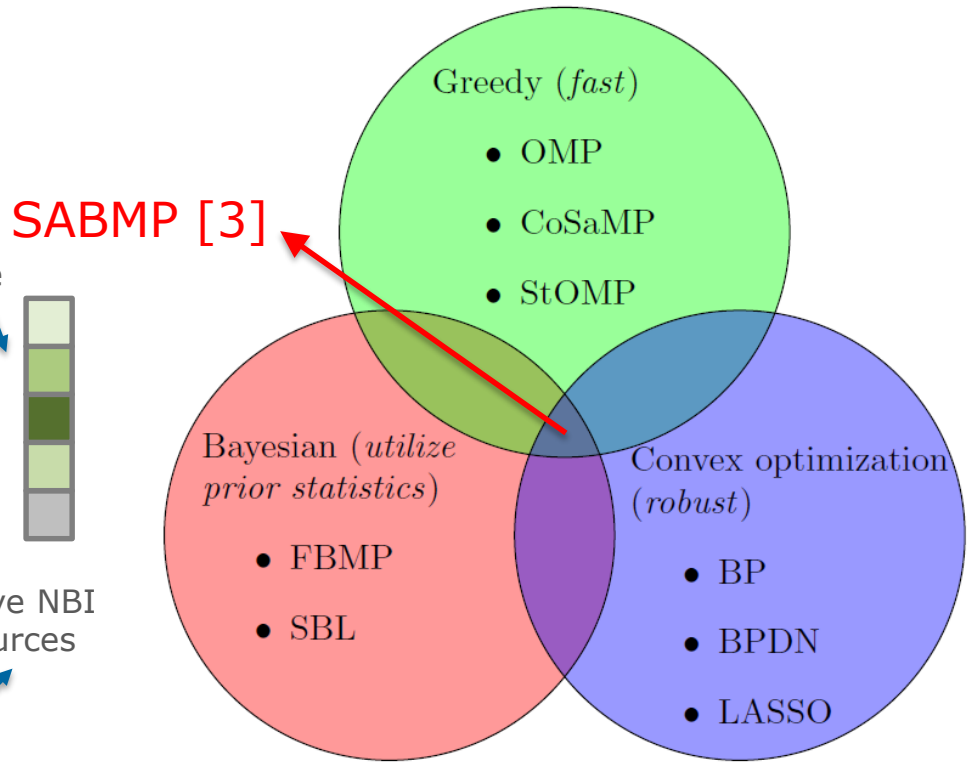
Sparse Bayesian NBI Recovery

Sparse Signal Recovery

- Exploit NBI sparsity
- Reserve few data-points and solve an under-determined system for NBI recovery [2]



Sparse Signal Recovery Schemes



[2] E. J. Candes and M. B. Wakin, "An introduction to compressive sampling," IEEE Signal Process. Mag., vol. 25, no. 2, pp. 21–30, Mar. 2008.

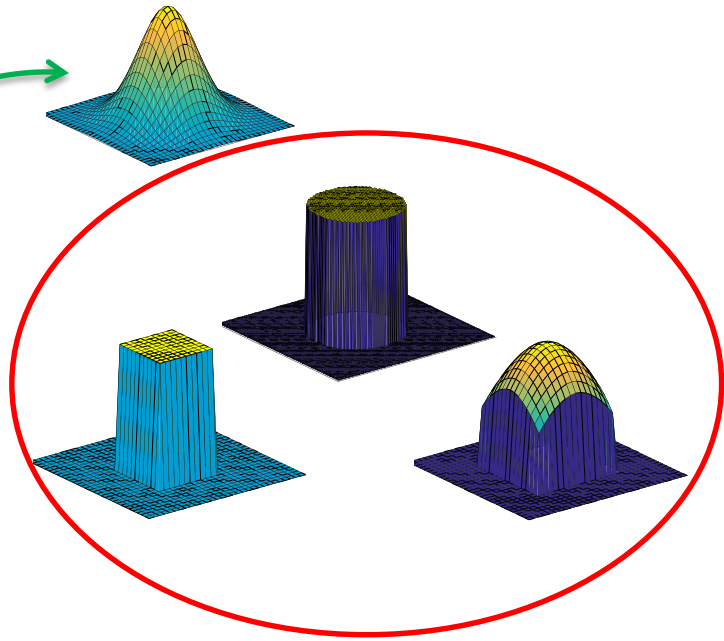
[3] M. Masood and T. Y. Al-Naffouri, "Sparse reconstruction using distribution agnostic Bayesian matching pursuit," IEEE Trans. Signal Process., vol. 61, no. 21, pp. 5298–5309, Nov. 2013.

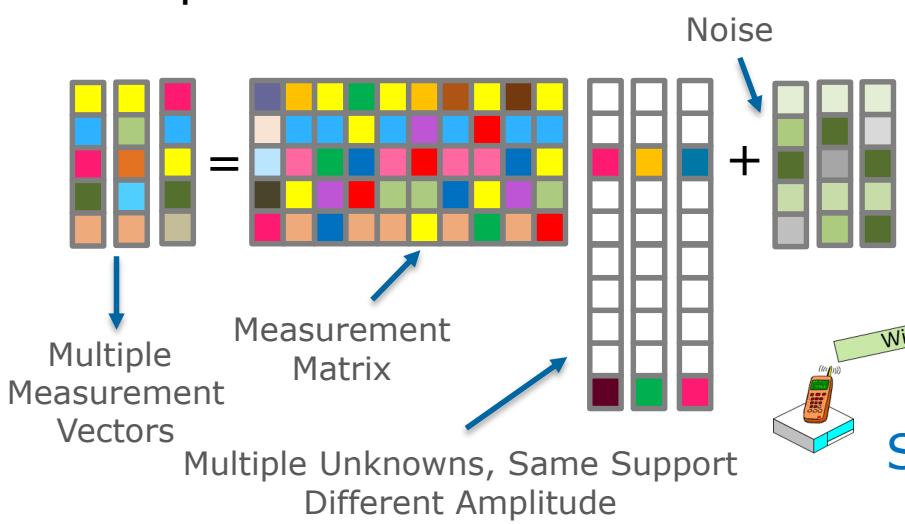
Support Agnostic Bayesian Matching Pursuit (SABMP)?

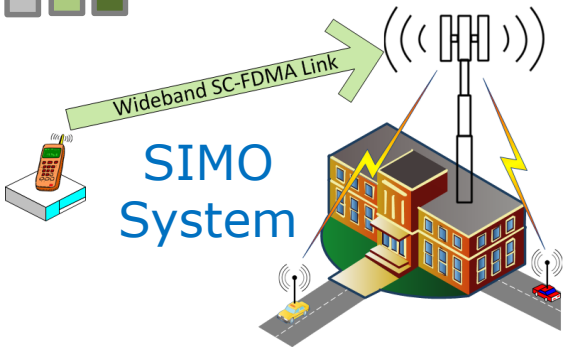
- Acknowledges Gaussianity of the Noise
- Agnostic to the distribution of the *active elements* of the signal

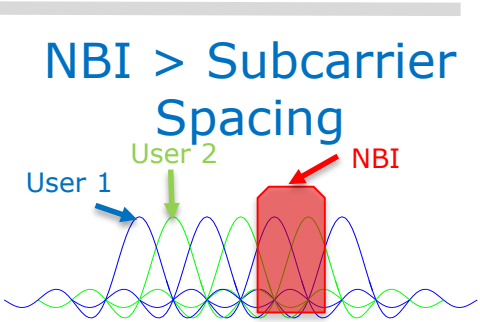
Essential for NBI mitigation

- Multiple Measurement vector SABMP[4]





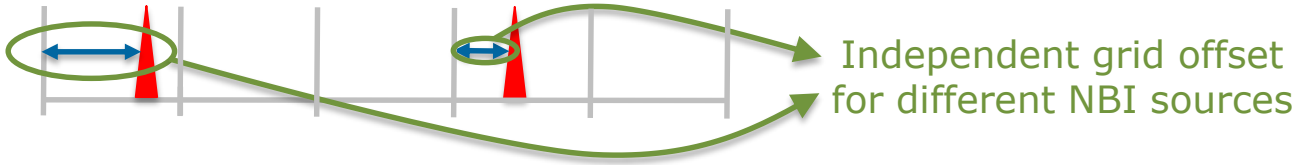




[4] M. Masood and T. Y. Al-Naffouri, "Support agnostic Bayesian recovery of jointly sparse signals," in *Proc. Eur. Signal Process. Conf. (EUSIPCO)*, 2014, pp. 1741–1745.

Grid Offset precludes direct CS

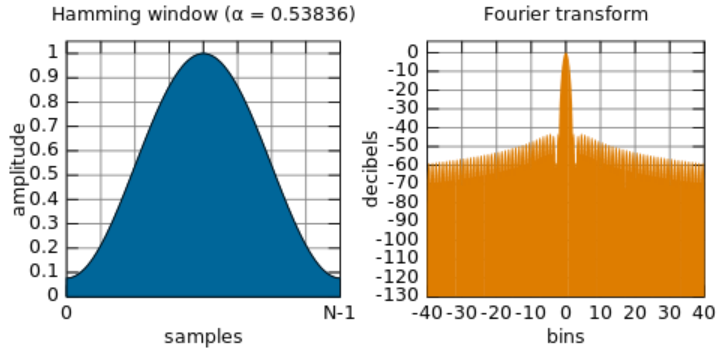
- Model



- Solution

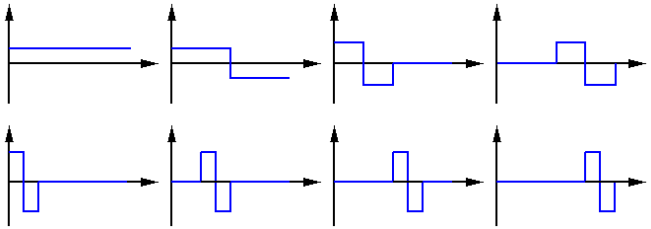
Traditional - Windowing [5]

Spectrally contain the spread signal



Proposed – Haar Transform

Not Sparse in Fourier Basis, Expand in Haar Basis

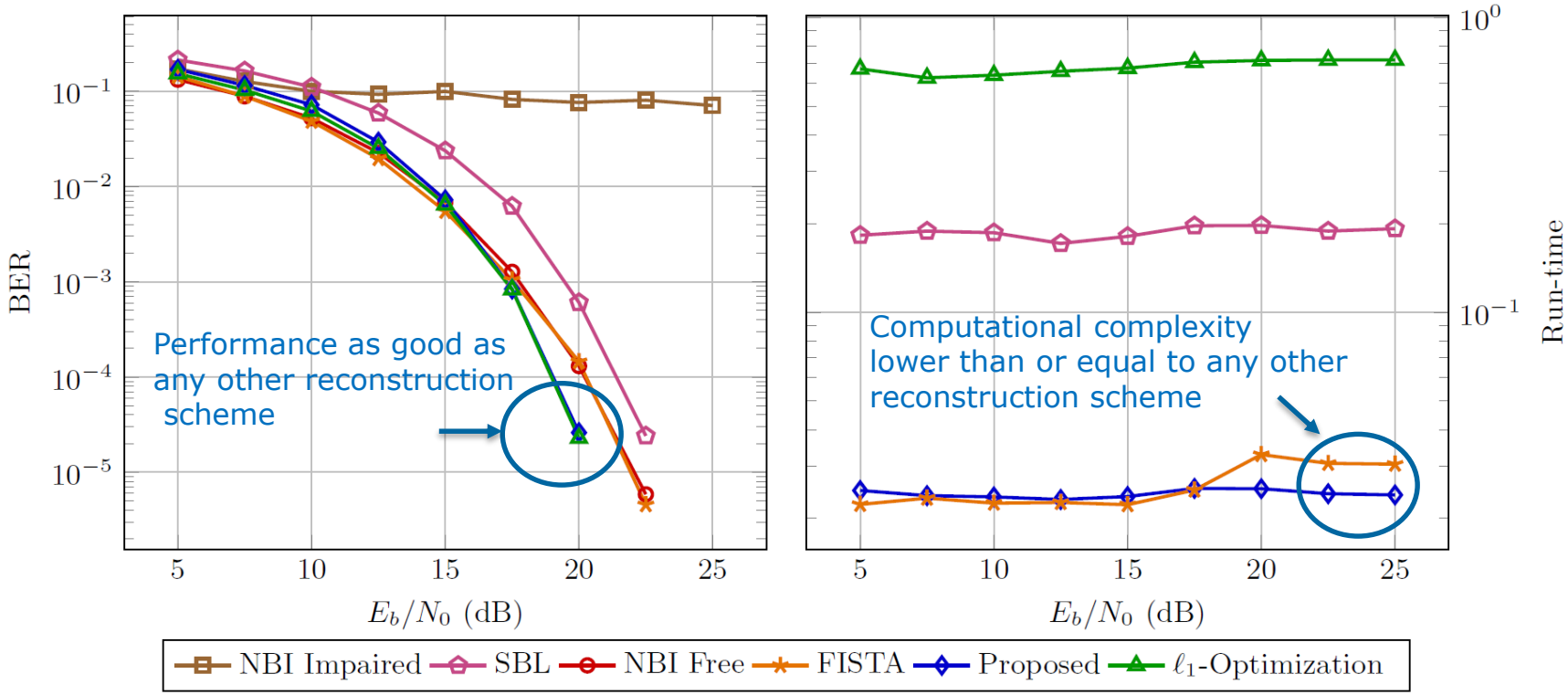


Unitary unlike Windowing (desirable for CS)

Numerical Observation: Better Sparsification

[5] A. Gomaa and N. Al-Dhahir, "A sparsity-aware approach for NBI estimation in MIMO-OFDM," IEEE Trans. Wireless Commun., vol. 10, no. 6, pp. 1854–1862, Jun. 2011.

Simulation Results (No Grid Offset)



Simulation Parameters:

Subcarriers N=512	Users U=2	Delay Spread N_c=N/4	Modulation 16 QAM
SIR=10 dB	NBI sources 1-4	Reserved data-points 25%	

MATLAB codes available from the website of T. Y. Al-Naffouri

Simulation Results (Sparsification)

Gini Index [6]

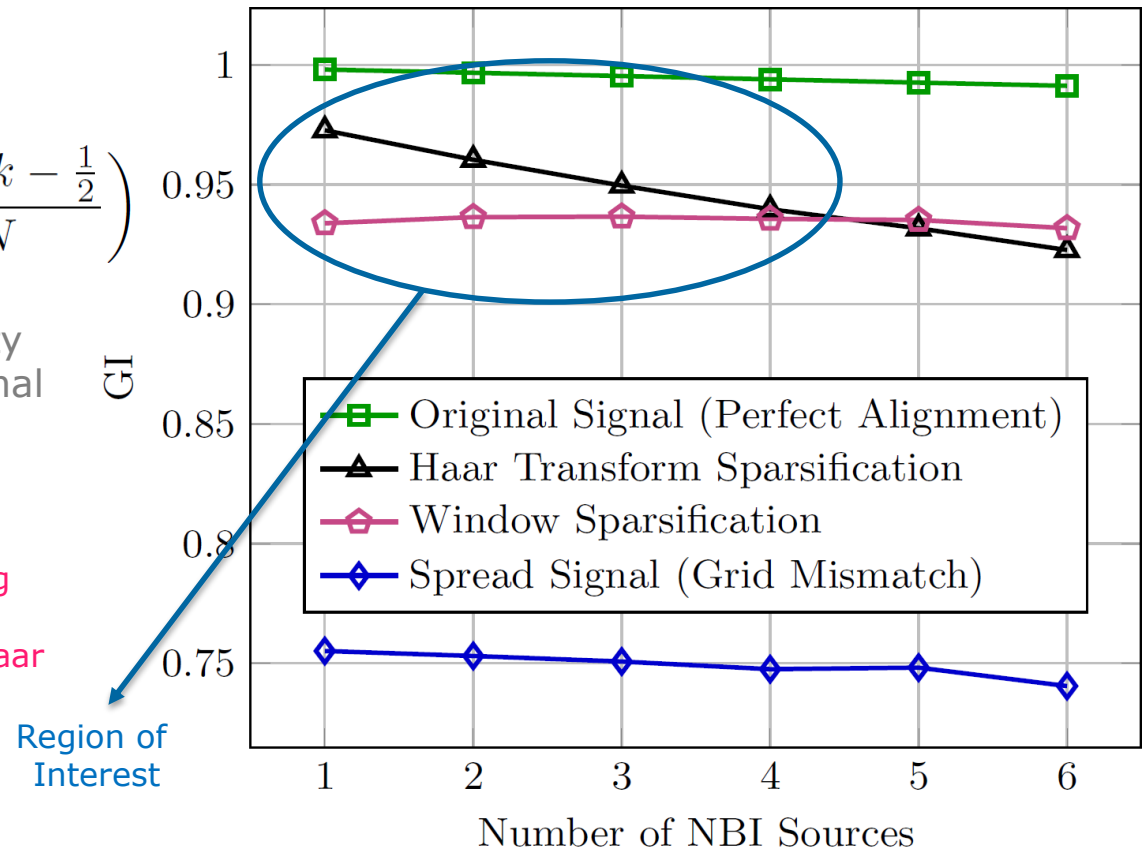
$$\mathrm{GI}(\underline{\mathcal{I}}') = 1 - 2\sum_{k=0}^{N-1} \frac{|\underline{\mathcal{I}}'(k)|}{\|\underline{\mathcal{I}}'\|_{\ell_1}} \left(\frac{N-k-\frac{1}{2}}{N} \right)$$

1. Normalized Measure of Sparsity
2. Higher GI -> More Sparse Signal

Observations:

Fewer NBI Sources: Haar > Windowing

Plentiful NBI Sources: Windowing > Haar

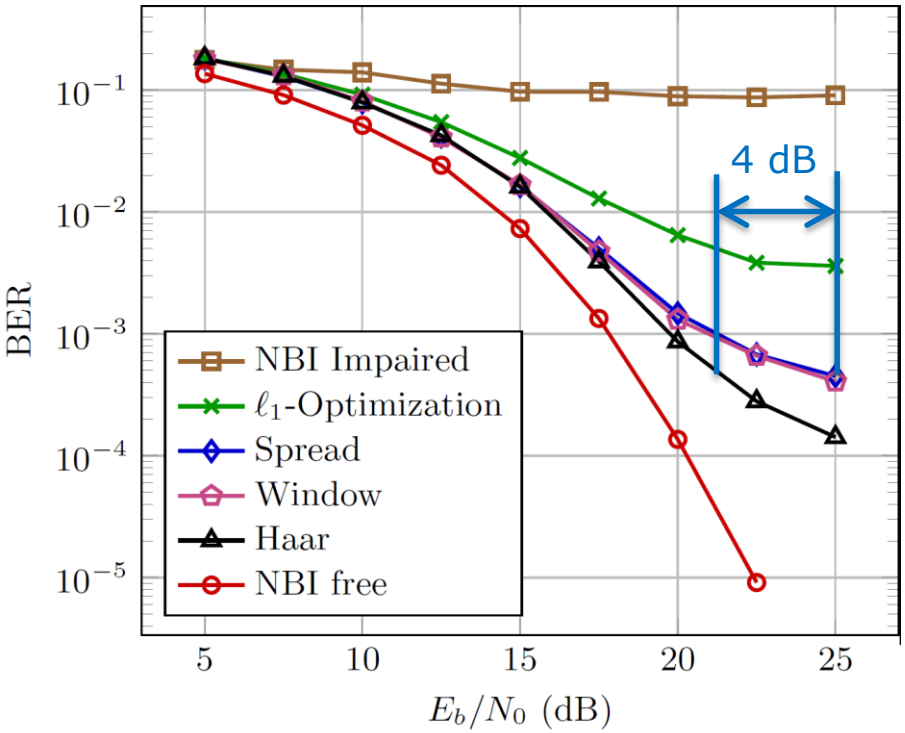


Simulation Parameters:

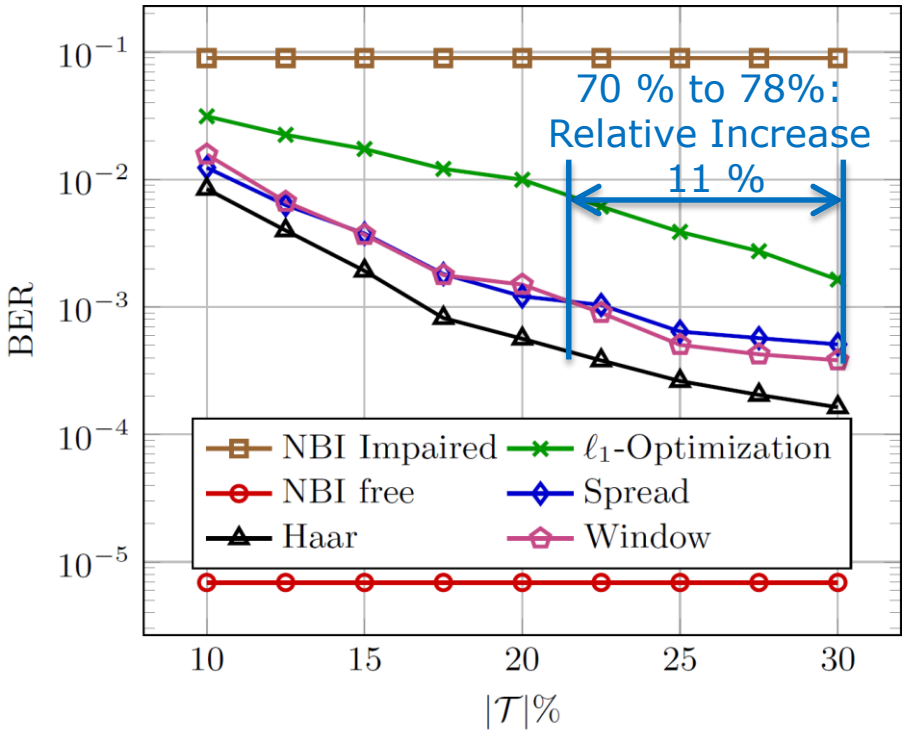
Subcarriers N=512 Ind. Grid Offsets Experiments=1000 NBI sources 1-6

[6] D. Zonoobi, A. A. Kassim, and Y. V. Venkatesh, “Gini index as sparsity measure for signal reconstruction from compressive samples,” IEEE J. Sel. Topics Signal Process., vol. 5, no. 5, pp. 927–932, Sep. 2011.

Simulation Results (Grid Offset)



Reserved data-points 25%



E_b/N_0 17.5 dB

Simulation Parameters:

Subcarriers N=512 Users U=2 Delay Spread N_c=N/4 Modulation 16 QAM

SIR=10 dB NBI sources 1-4

Improving Spectral Efficiency

- Four Step Data-Aided Procedure

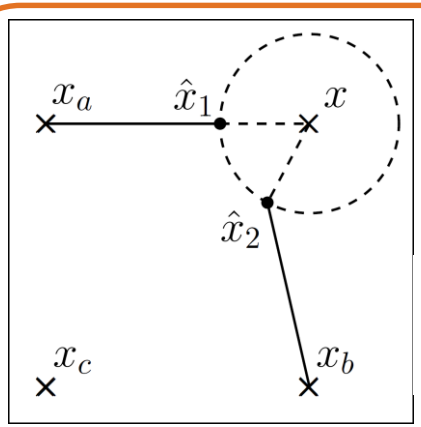
Step 1 — Reserve Few Tones

Step 2 — Estimate and compensate for NBI

Step 3 — Find Reliable Data Points

Step 4 — Estimiate NBI using Rel. Data + Res. Points

Same as Before
Tones ↓
Est. Error or Residual ↑



- Residual not strong
- Most data–points in correct decision regions
- Find a subset of most reliable ones [7]

$$\Re(i) = \frac{p(d(i) = \hat{x}(i) - \lfloor \hat{x}(i) \rfloor)}{\sum_{q=0, \mathcal{A}(q) \neq \lfloor \hat{x}(i) \rfloor}^{Q-1} p(d(i) = \hat{x}(i) - \mathcal{A}(q))}$$

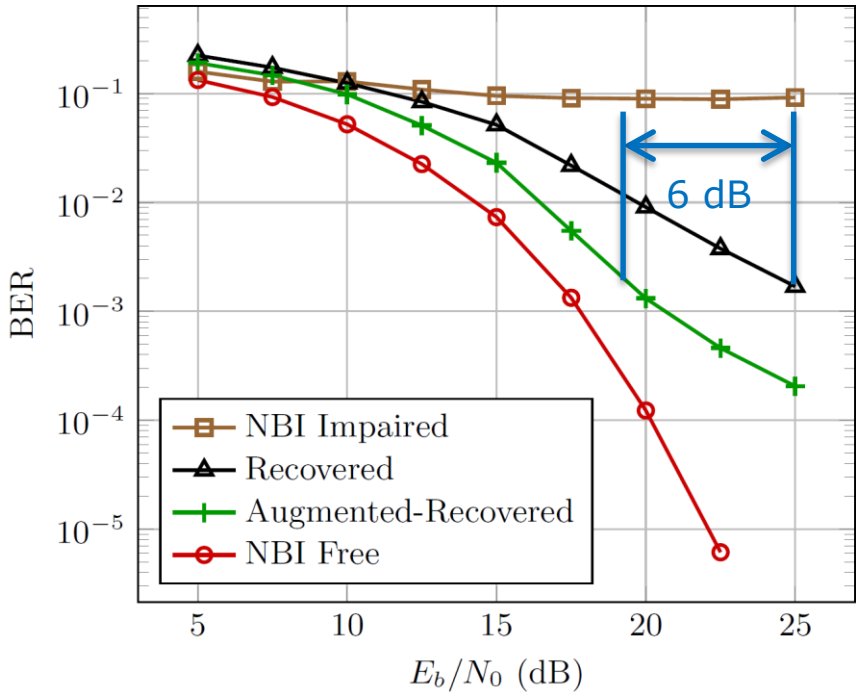
Estimate Again with Measurements

Spectral Efficiency ↑
vs
Computational Complexity ↑

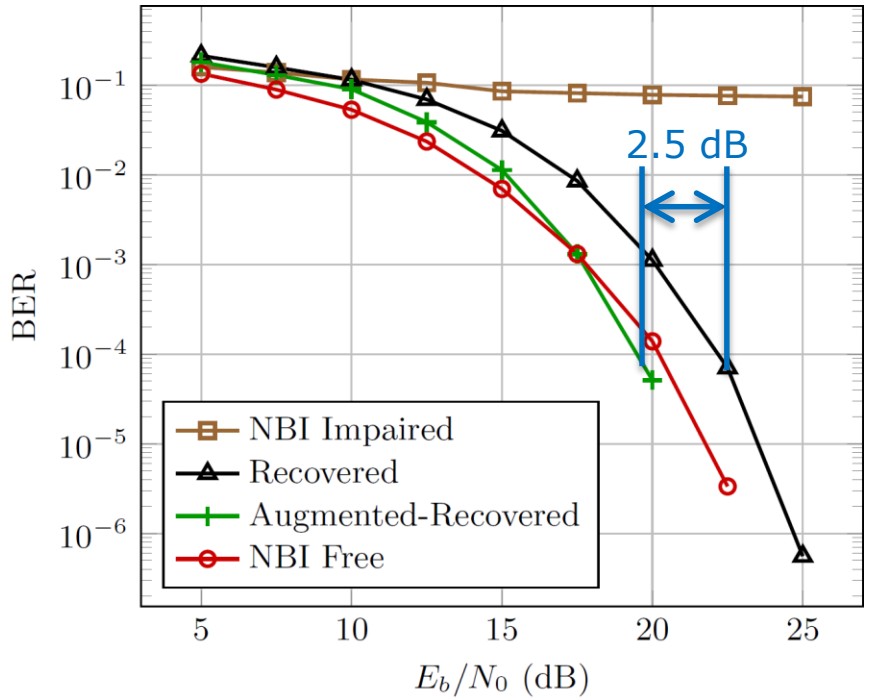
Trade off

[7] E. B. Al-Safadi and T. Y. Al-Naffouri, "Pilotless recovery of nonlinearly distorted OFDM signals by compressive sensing over reliable data carriers," in Proc. SPAWC, 2012, pp. 580–584.

Simulation Results (Spectral Efficiency)



Grid Offset



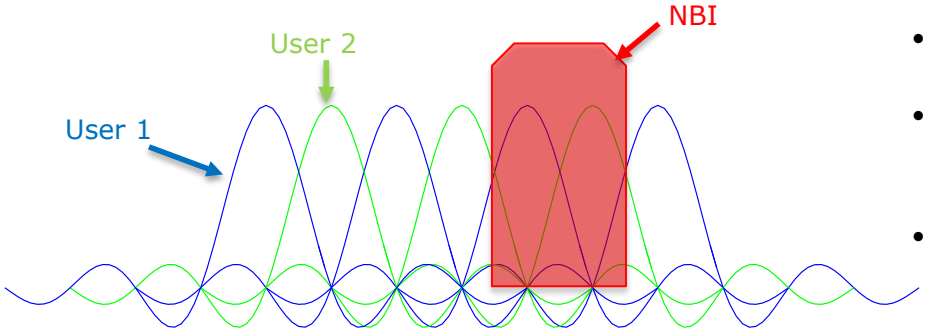
No Grid Offset

Simulation Parameters:

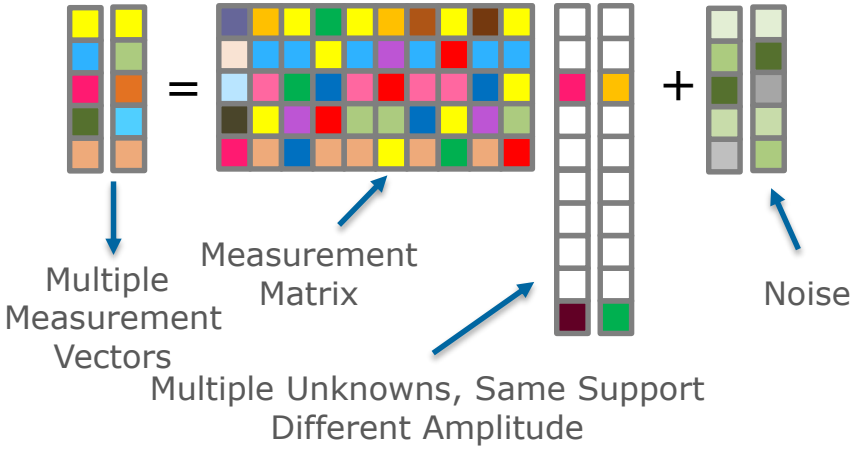
Subcarriers N=512	Users U=2	Delay Spread N_c=N/4	Modulation 16 QAM
SIR=10 dB	NBI sources 1-4	Reserved data-points 12.5%	Reliable data-points 12.5%

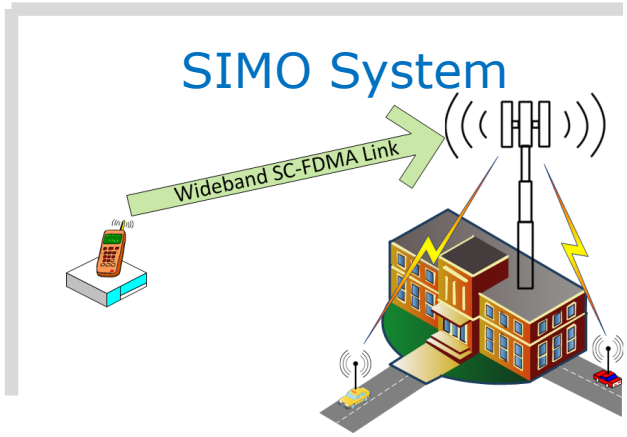
Wider NBI sources

NBI Width > Subcarrier Spacing



- Interleaved sub-carrier assignment
- At basestation: Joint NBI support recovery using MMV-SABMP [4]
- Individual magnitude recovery

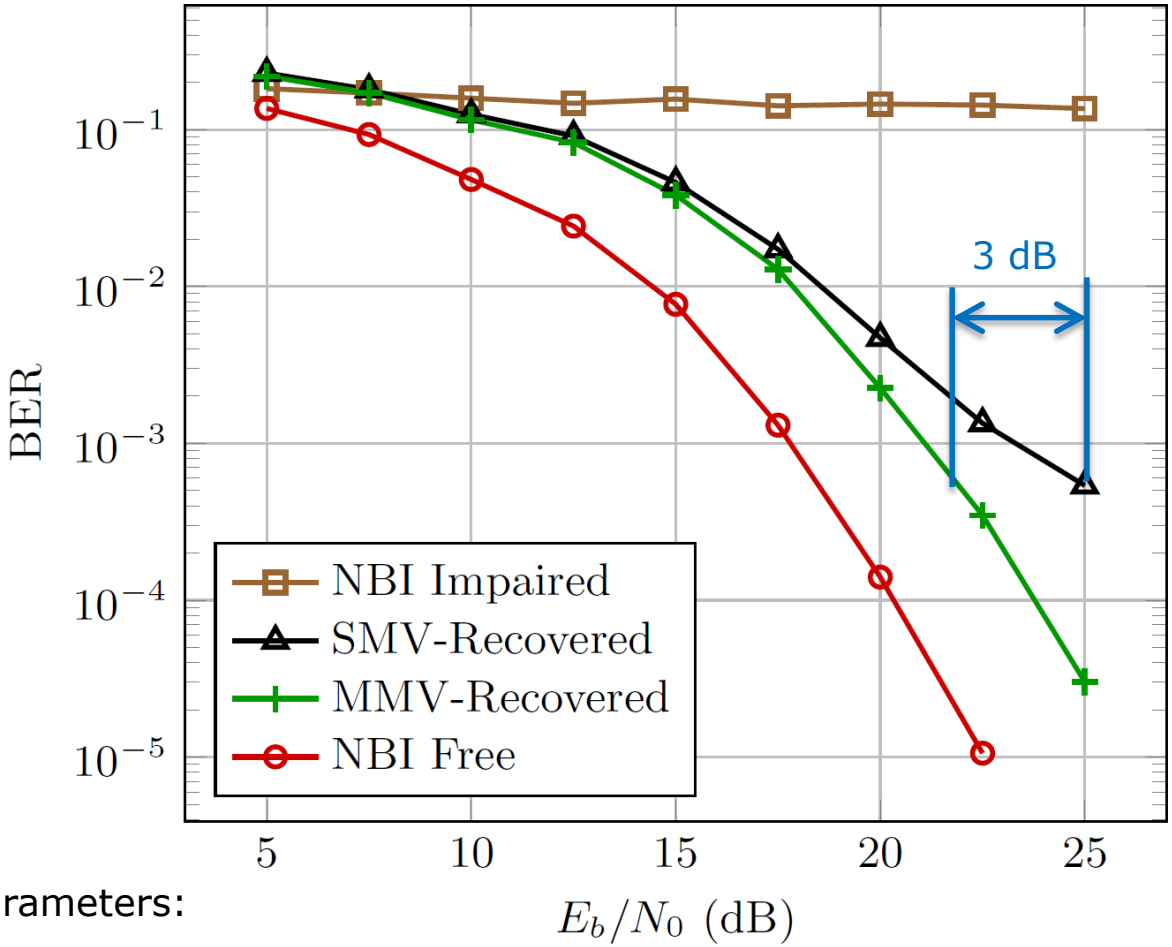




Possibility: Block sparse recovery; High computational complexity

[4] M. Masood and T. Y. Al-Naffouri, "Support agnostic Bayesian recovery of jointly sparse signals," in *Proc. Eur. Signal Process. Conf. (EUSIPCO)*, 2014, pp. 1741–1745.

Simulation Results (Wider NBI)

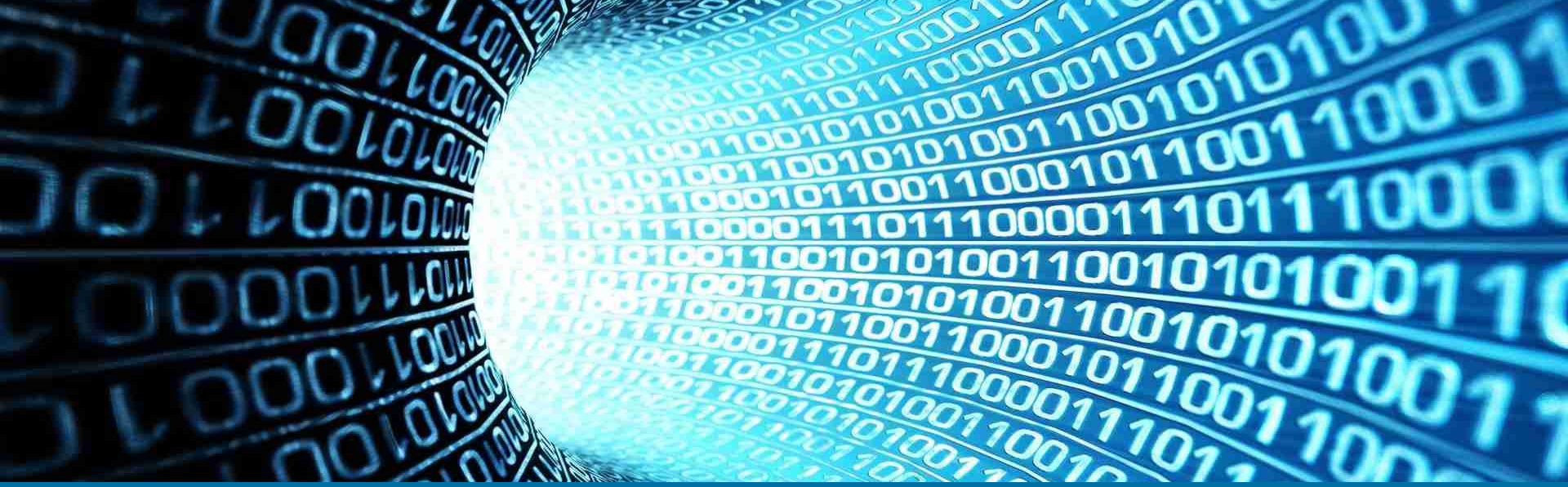


Simulation Parameters:

Subcarriers N=512	Users U=2	Delay Spread Nc=N/4	Modulation 16 QAM
SIR=10 dB	NBI sources 1-4	Reserved data-points 8%	No Grid Offset

Summary

- Interference has a dire impact on SC-FDMA systems
- Compressed sensing can be used to mitigate interference
- SABMP has good performance and low computational complexity
- The grid offset issue can be overcome by using the Haar transform
- The spectral efficiency can be improved by using data-aided approach
- Other structure can be exploited, offered e.g., by wider NBI sources and SIMO systems



Thank you for you attention!

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