The Myths, Realities and Futures of NOMA

A Historic Perspective on FDMA, TDMA, CDMA, MC-CDMA, SDMA, IDMA, CCDMA and All That...

Lajos Hanzo

School of Electronics and Computer Science,

University of Southampton, SO17 1BJ, UK.

http://www-mobile.ecs.soton.ac.uk

Acknowledgements

- Sincere thanks for the cordial invitation to this vivacious journey to 5G Square...
- To the Team back at 'base' in Southampton, UK;
- To the Sponsors: EPSRC, the ERC, RS;
- To the entire VTS/NOMA Community;

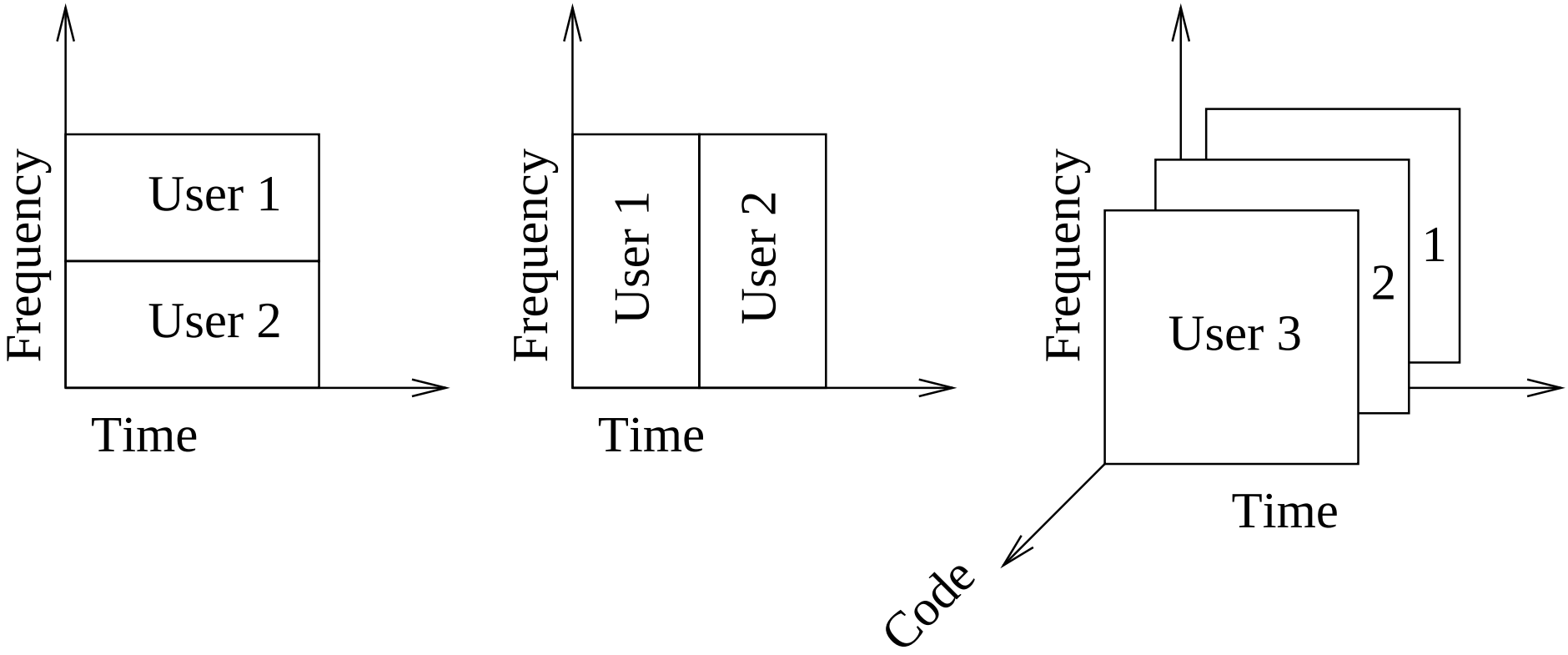
Evolution from Marconi to NOMA & 5G...


DRAPER
LATEST FASHIONS
NICHOLS BROS
H.W.
R. Steele

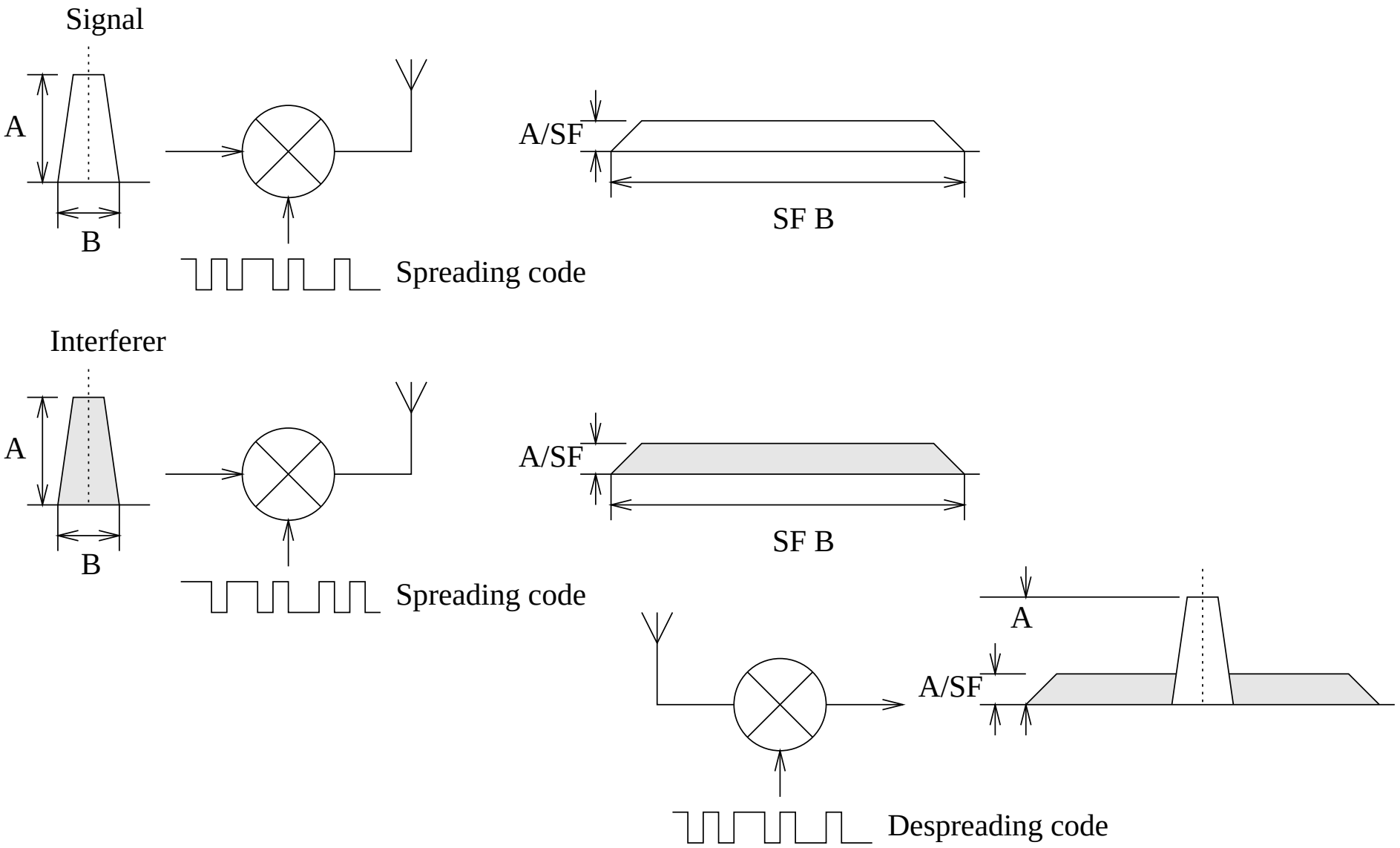
The Myths, The Realities & The Challenges

- The Myth: Channel capacity is arbitrarily approached - **zero error and cost-effective, flawless 'telepresence' for anyone, anywhere, anytime!**
- The Reality: The moment we leave the office, our ability to access multimedia services becomes desperately limited - if not unfeasible - especially on the move!
- The **channel quality fluctuates by as much as 40dB**, hence it is unrealistic to expect that any fixed-mode wireless system provides a near-constant QoS - especially in the face of realistic channel estimation and synchronization...
- The Challenges...

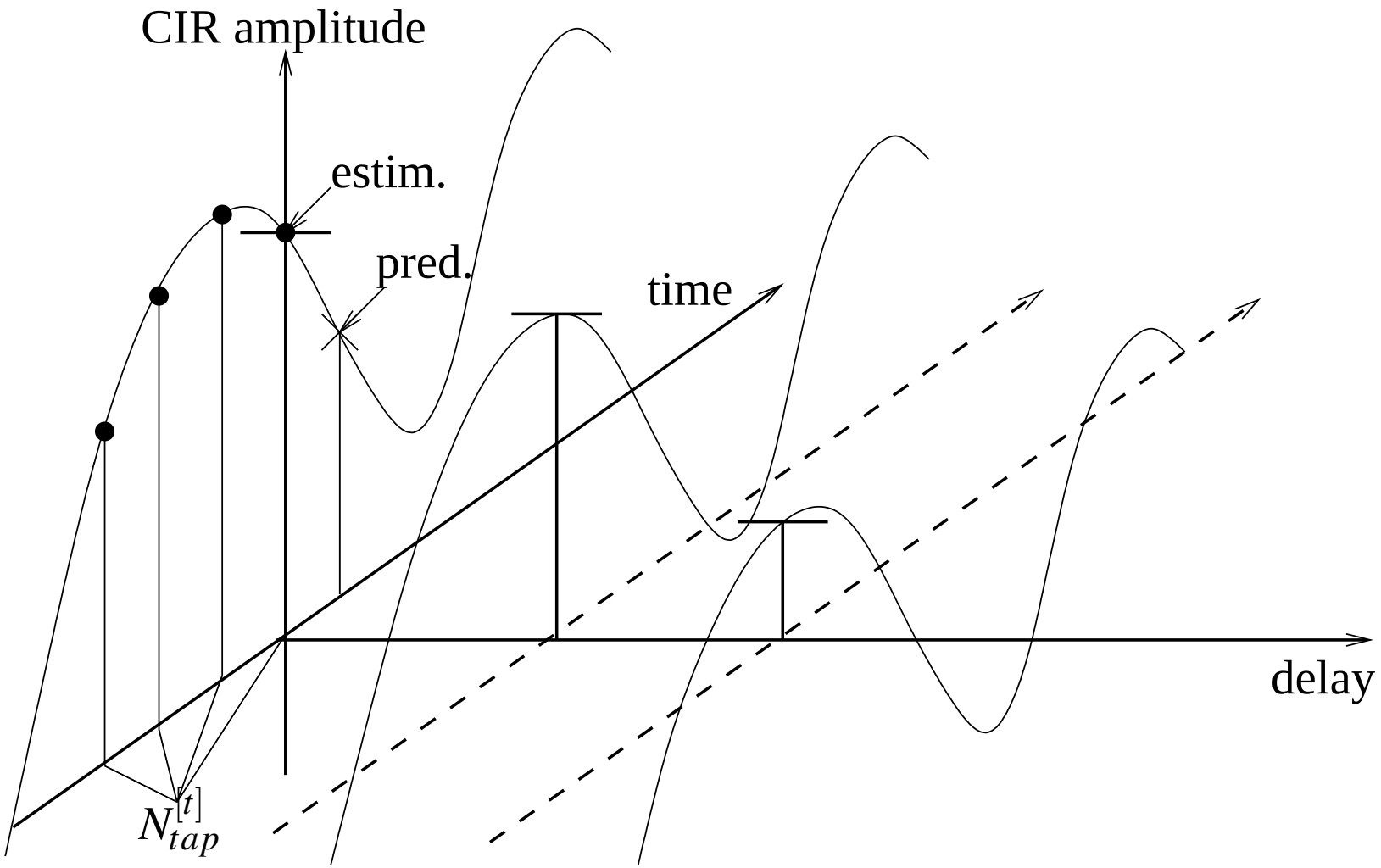
Orthogonal multiple access schemes: FDMA, TDMA and CDMA



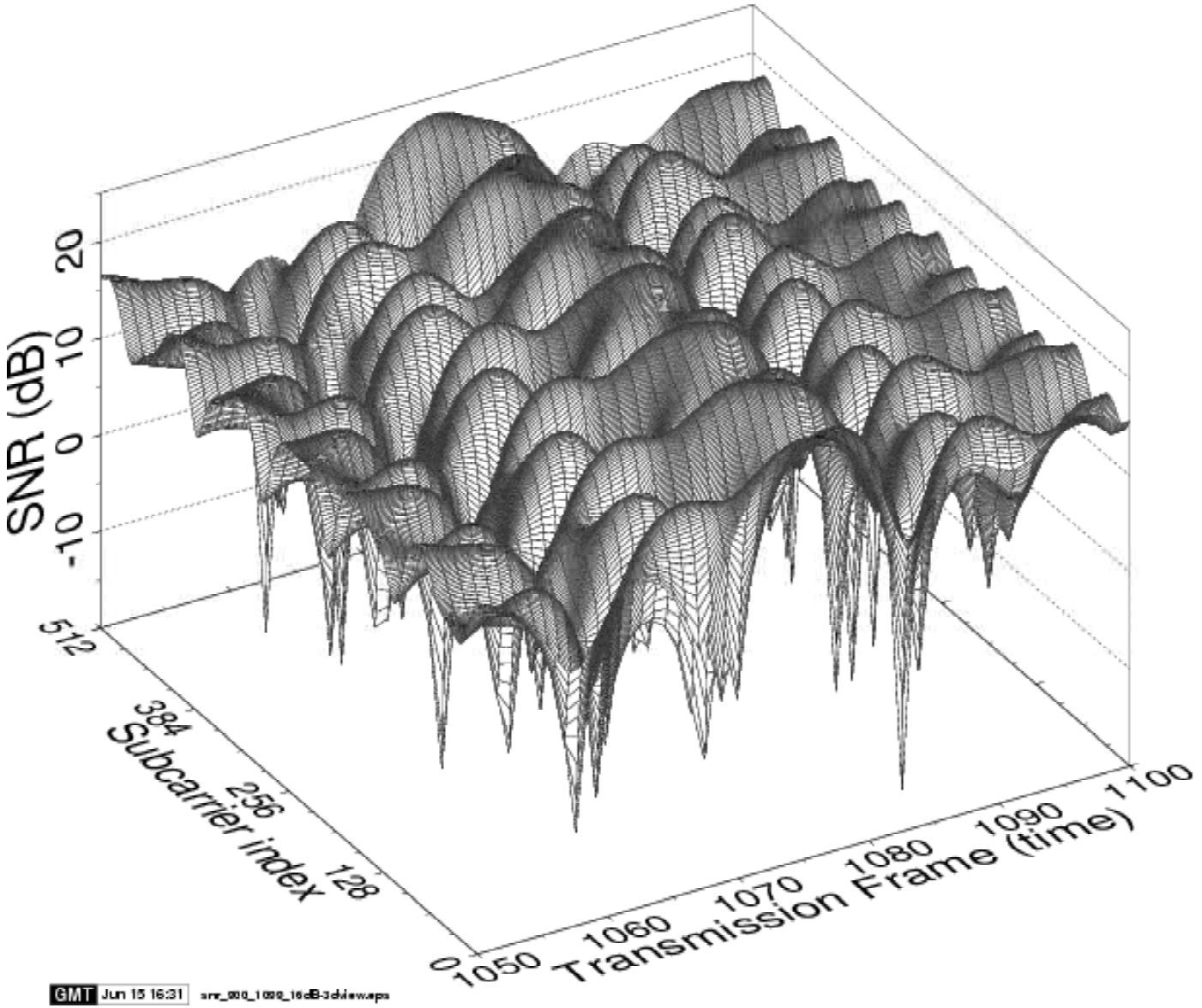
Intentional DS-CDMA Spreading



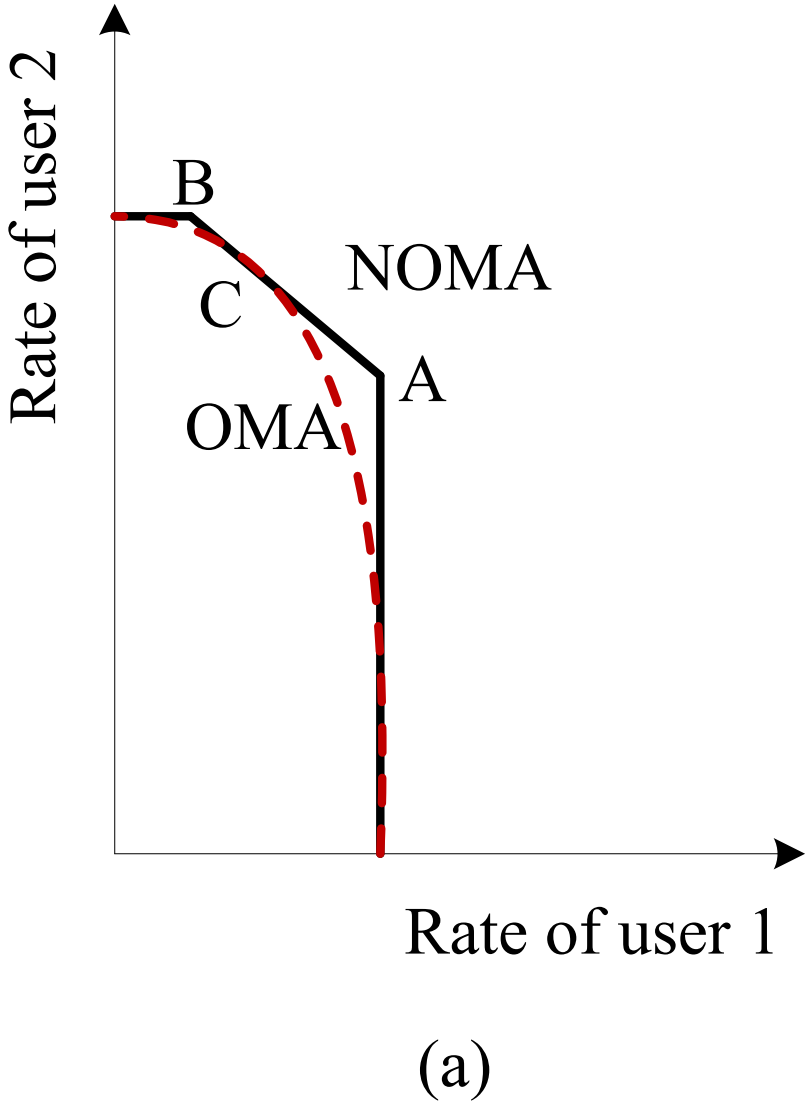
Unintentional Channel-Induced Spreading

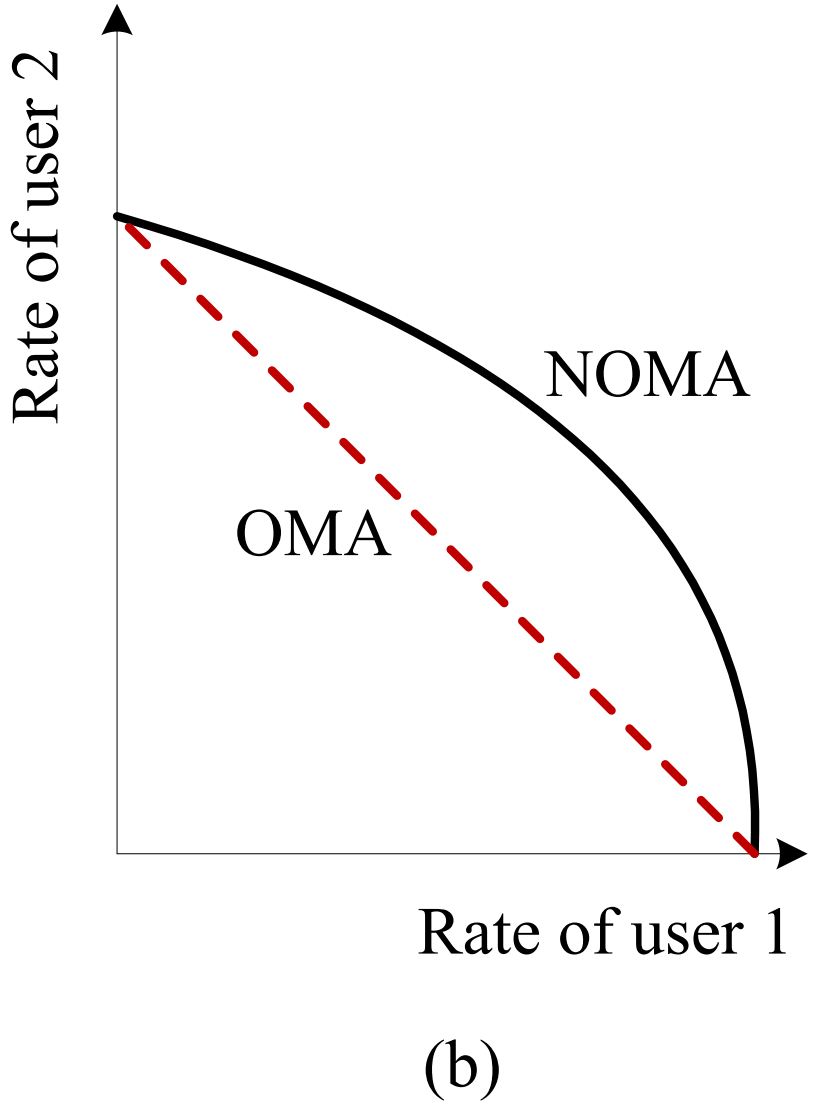


Unintentional Spreading in the FD



Capacity of OMA vs. NOMA in AWGN channel: (a) Uplink; (b) Downlink.





Diverse NOMA contributions from Southampton Wireless

- R. Zhang and L. Hanzo, "A unified treatment of superposition coding aided communications: Theory and practice," *IEEE Commun. Surveys Tutorials*, vol. 13, no. 3, pp. 503–520, Mar. 2011.
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NOMA Beamforming Example

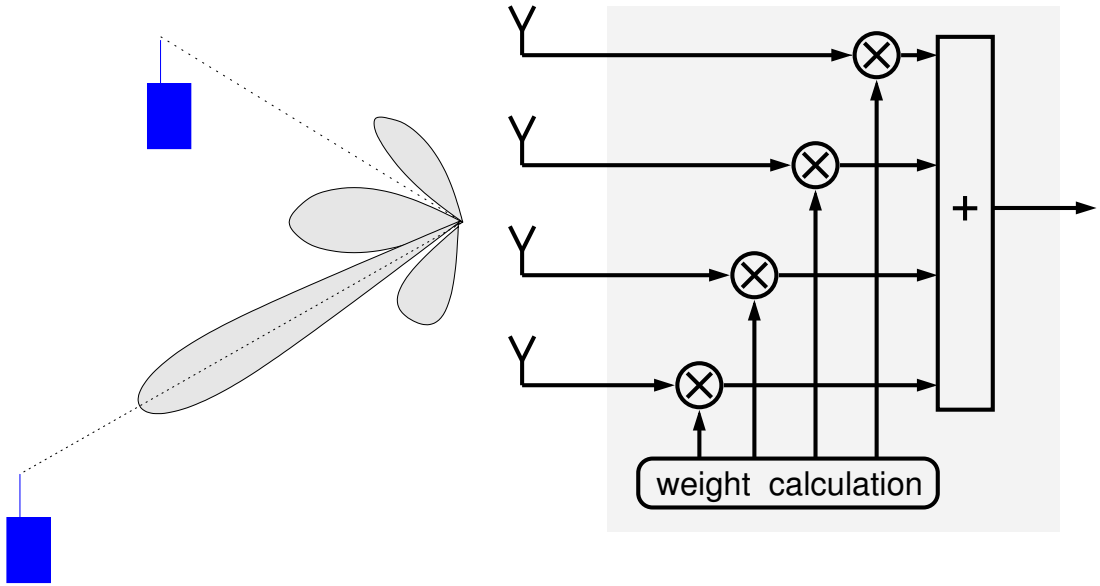
Uplink/Downlink Beamforming

- Why?

  Increase of capacity

- How?

  Spatially separated interfering signals are suppressed



$$y = \mathbf{w}^H \mathbf{x}$$

MMSE Based Beamforming

- Weights are calculated in order to minimize:

$$\varepsilon(t)^2 = \left(\mathbf{w}^H \mathbf{x}(t) - r(t)\right)^2$$

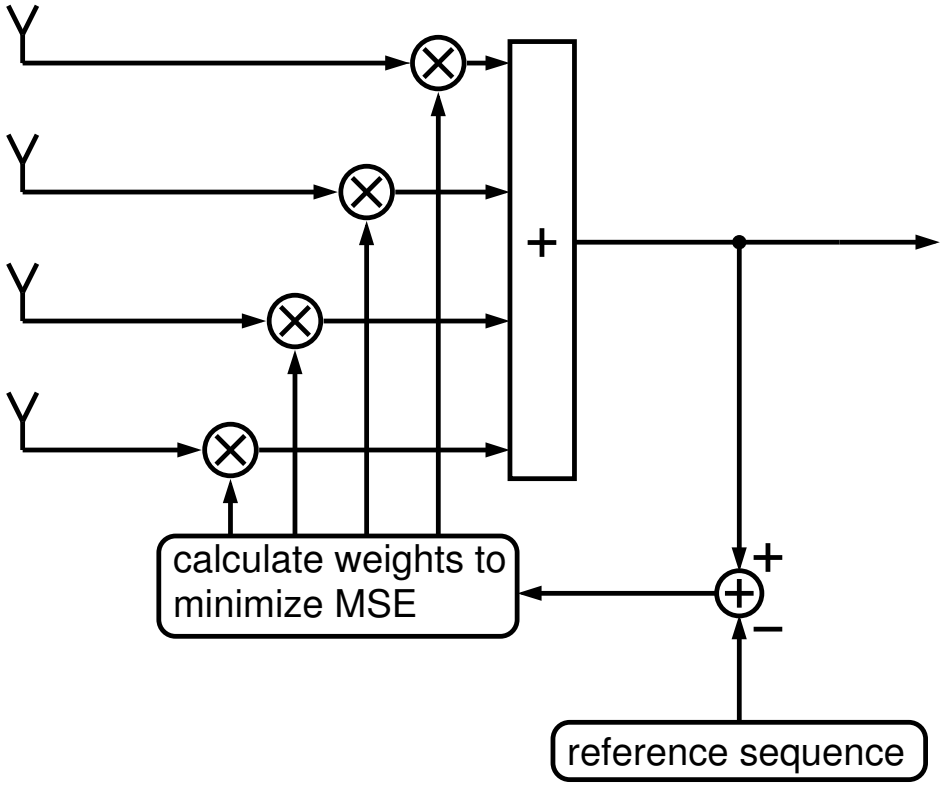
  $\mathbf{w}$: Beamformer weights

  $\mathbf{x}(t)$: Channel output

  $r(t)$: Reference symbol

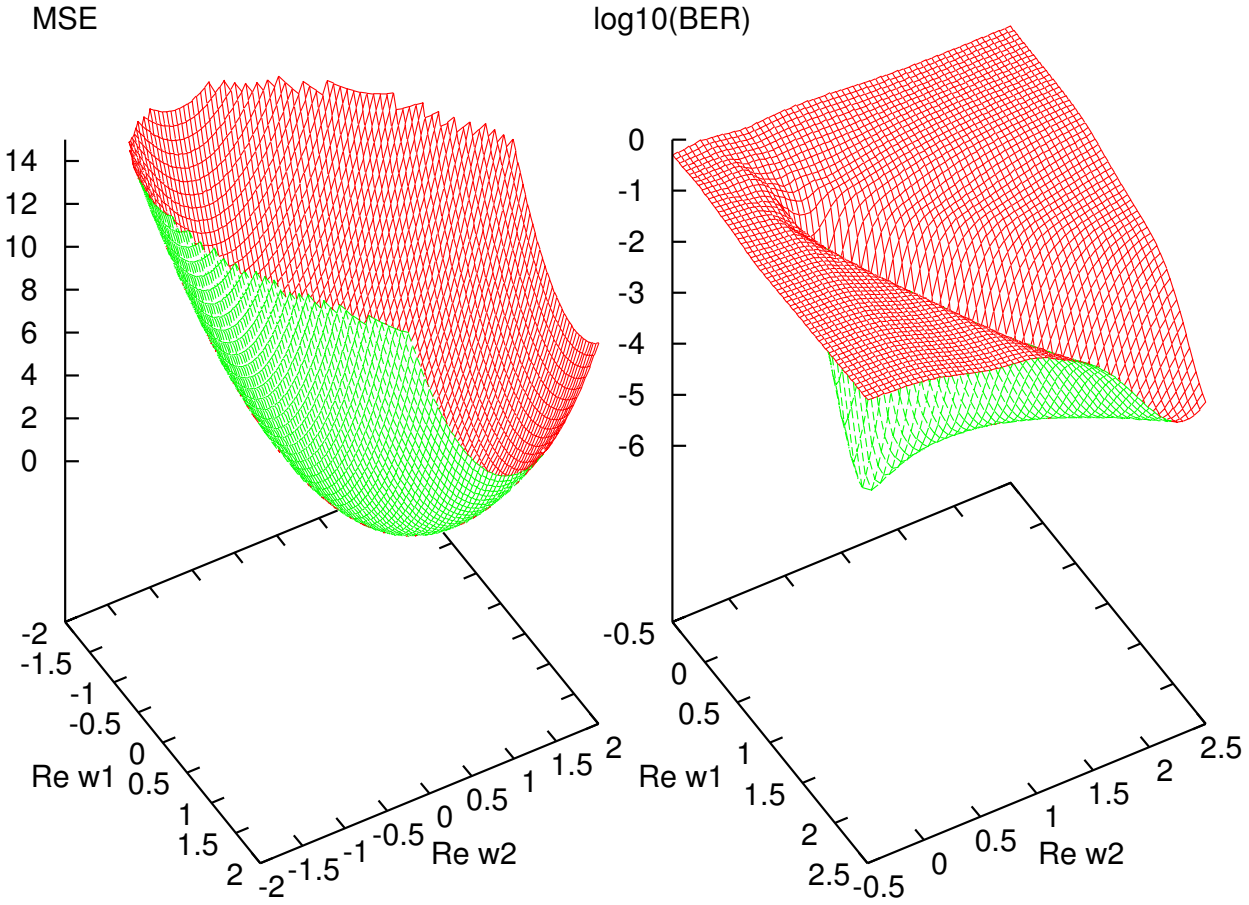
- For AWGN channels MMSE weights can be calculated using a closed form expression

- Realizations: LMS, RLS, SMI



MSE and BER Surfaces at the Output of a [5 x 2] NOMA Beamformer

Error surfaces at the receiver's output calculated for five BPSK modulated sources having equal received power and communicating over AWGN channels at SNR=10 dB.

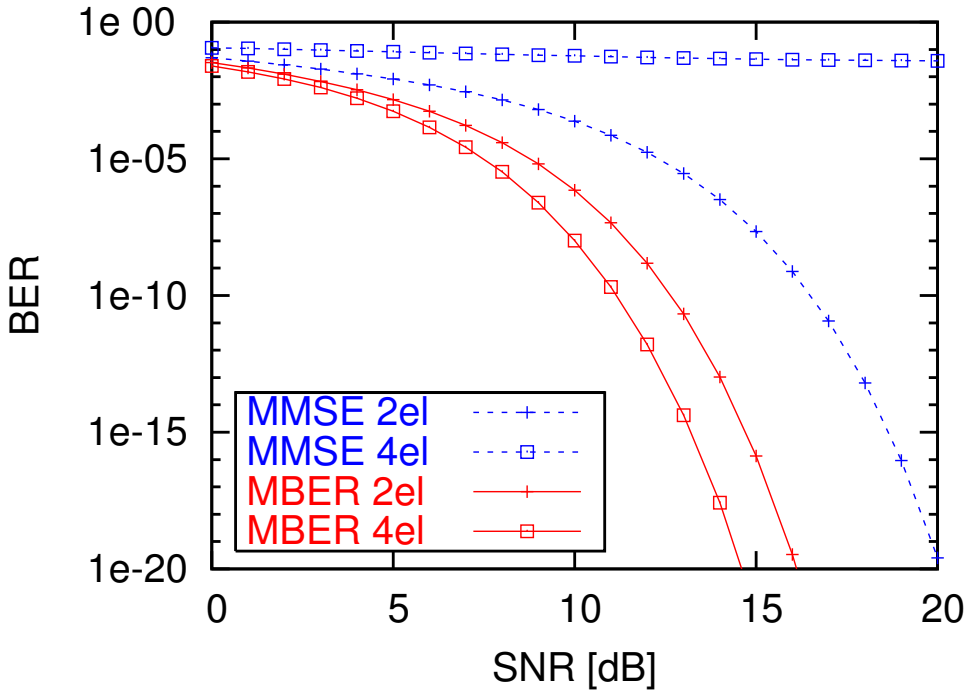


The imaginary part of both weights of the 2-element array was fixed.

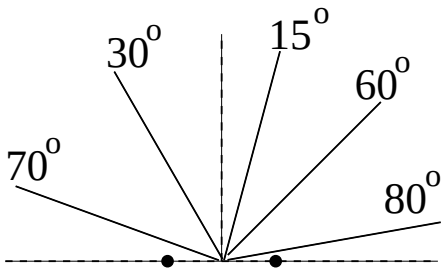
- **Is MBER detection the next stage of evolution?**

MMSE vs MBER NOMA Beamforming

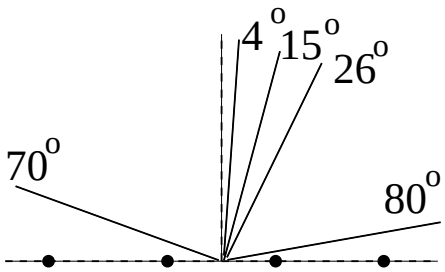
- Test case: BPSK modulated sources having equal received power and communicating over AWGN channels
- MMSE solution calculated analytically
- MBER solution obtained with the aid of conjugate gradient algorithm



Scenario S (2el.)

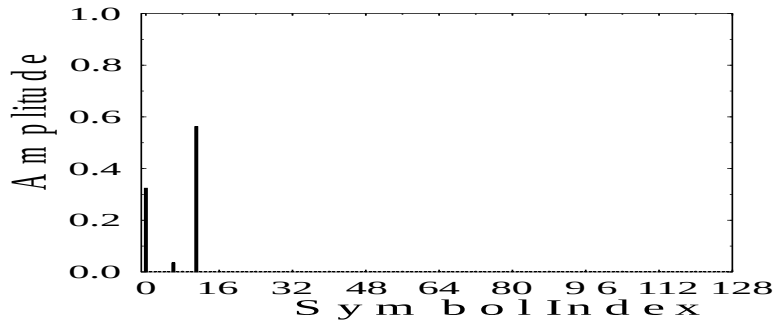


Scenario U (4el.)

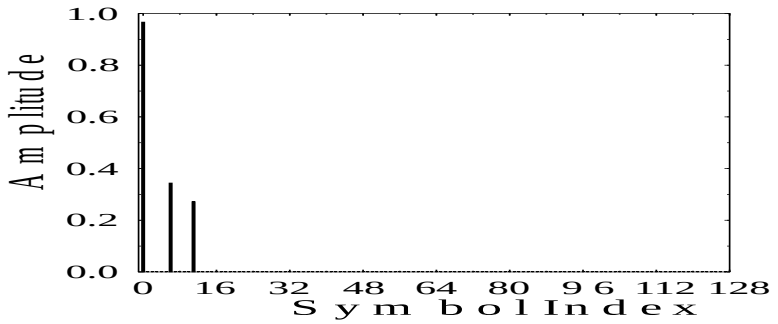


NOMA SDMA Example

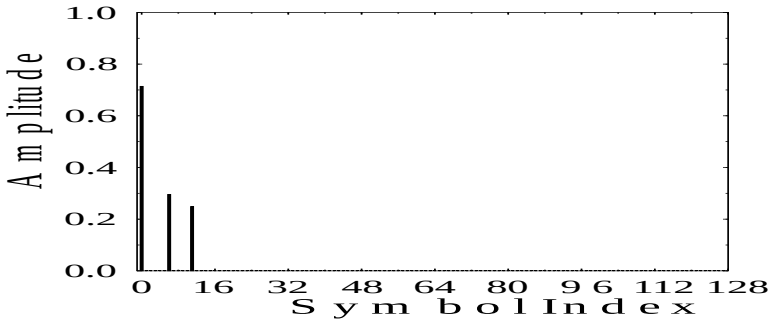
Evolution from CDMA-NOMA to SDMA-NOMA



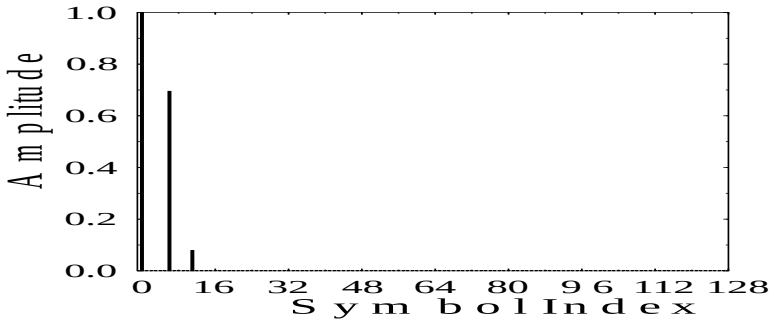
(a) CIR 1: user 1, antenna 1



(b) CIR 2: user 1, antenna 2

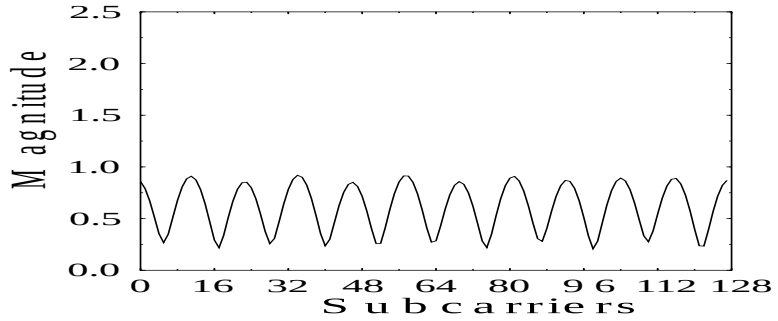


(c) CIR 3: user 2, antenna 1

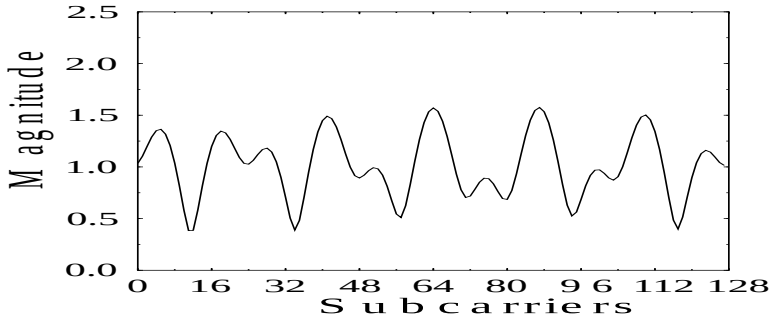


(d) CIR 4: user 2, antenna 2

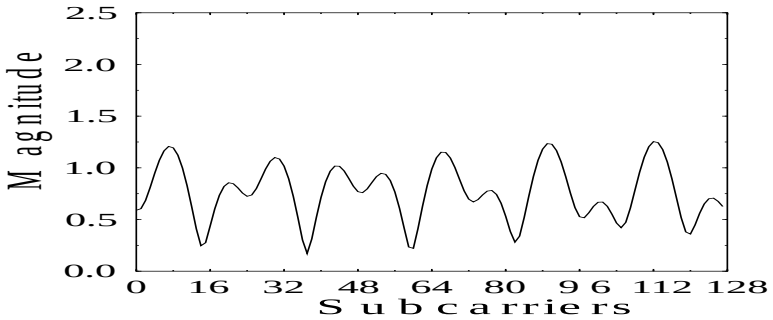
Unique Stream-Specific FD-CTF of CIRs 1-4



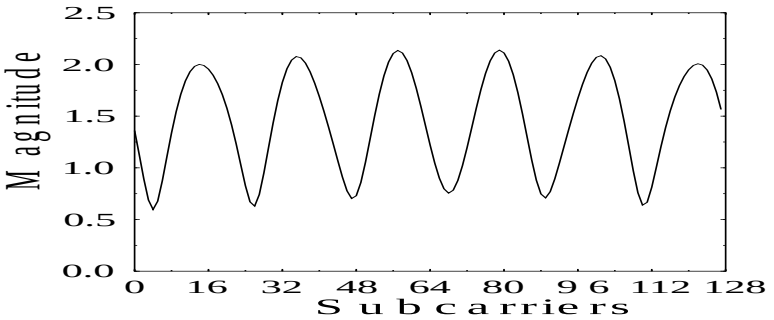
(e) CTF 1: user 1, antenna 1



(f) CTF 2: user 1, antenna 2



(g) CTF 3: user 2, antenna 1



(h) CTF 4: user 2, antenna 2

Figure 1: FD Channel transfer functions (FD-CTF) for the CIRs seen in Figure 20 (a) FD-CTF 1, (b) FD-CTF 2, (c) FD-CTF 3, and (d) FD-CTF 4.

Quantum-Search Aided MUD in NOMA

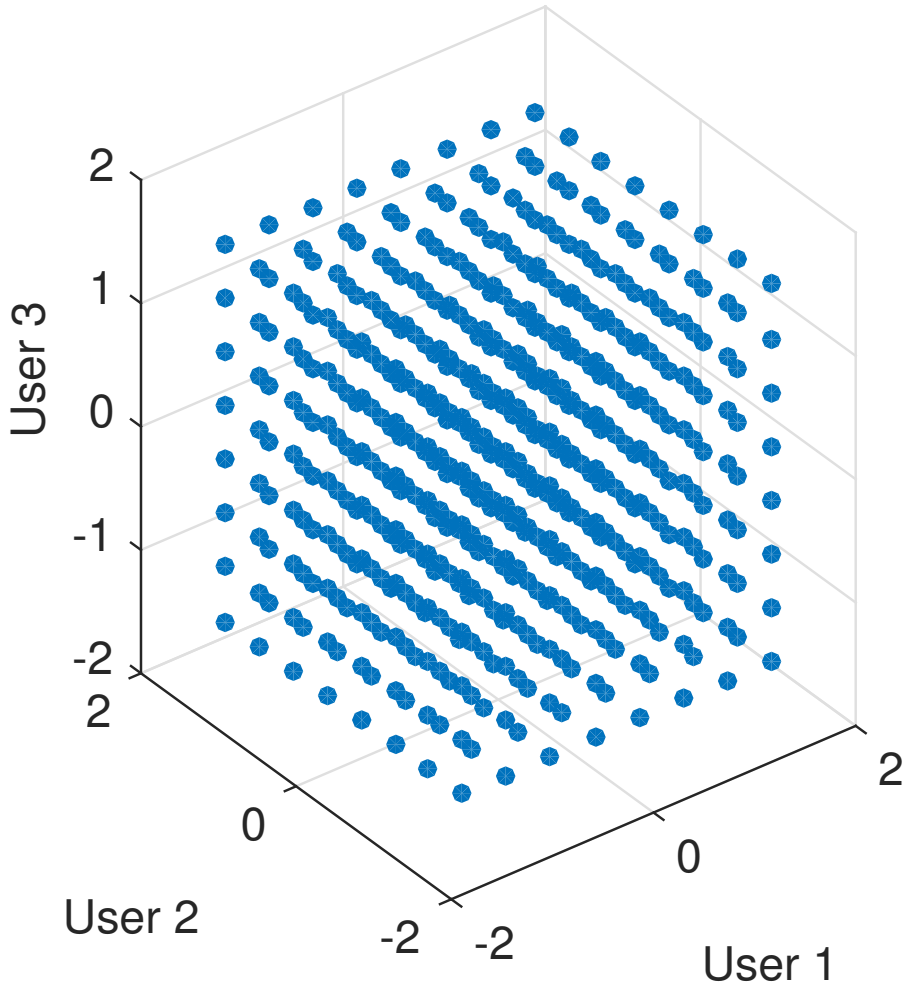
Multiple Access	SDMA-OFDM
Number of Users	$U = 3$
Number of AEs at the BS	$P = 1$
Normalized User-Load	$U_L = U_q/P = 3$
Modulation	8-PAM $M = 8$
E_b/N_0	0 dB
Channel Code	Turbo Convolutional Code,
	8 trellis states,
	$R = 1/2$
Channel Model	Extended Typical Urban (ETU)
Mobile Velocity	$v = 130$ km/h
Carrier Frequency	$f_c = 2.5$ GHz
Sampling Frequency	$f_s = 15.36$ GHz (77 delay taps)
Doppler Frequency	$f_d = 70$ Hz
Number of Subcarriers	$Q = 1024$
Cyclic Prefix	CP $= 128$
Interleaver Length	$10\,240$ bits per user
Channel Estimation	Perfect

Quantum-Search Aided MUD in NOMA

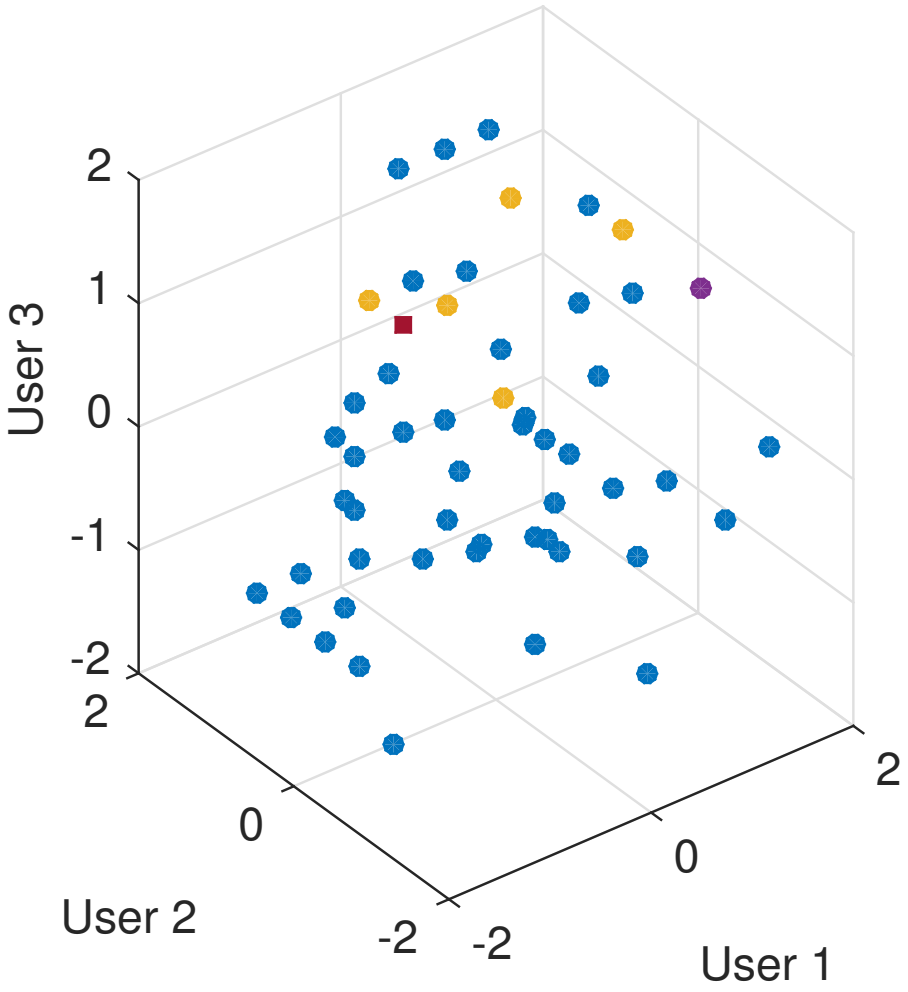
- There are 8^3 = 512 symbols in the full constellation, while 53 and 46 symbols are obtained by the randomly-initialized and ZF-initialized DHA, respectively.
- The purple circle denotes the random initial input, or the ZF detector's output, which may be used as an initial input. The ZF is as bad as the random one in this rank-deficient scenario.
- By using the DHA, we find symbols better than the previously found symbols, which are denoted by the yellow circles in the 3D figure.
- But we also find symbols that are "worse" than the previously found symbols, as represented by the blue circles in the 3D figure.
- The red square is the optimal symbol which is eventually found.

Dürr-Høyer MUD for CDMA/SDMA NOMA - Userload=2

Full Constellation



Randomly Initialized DHA



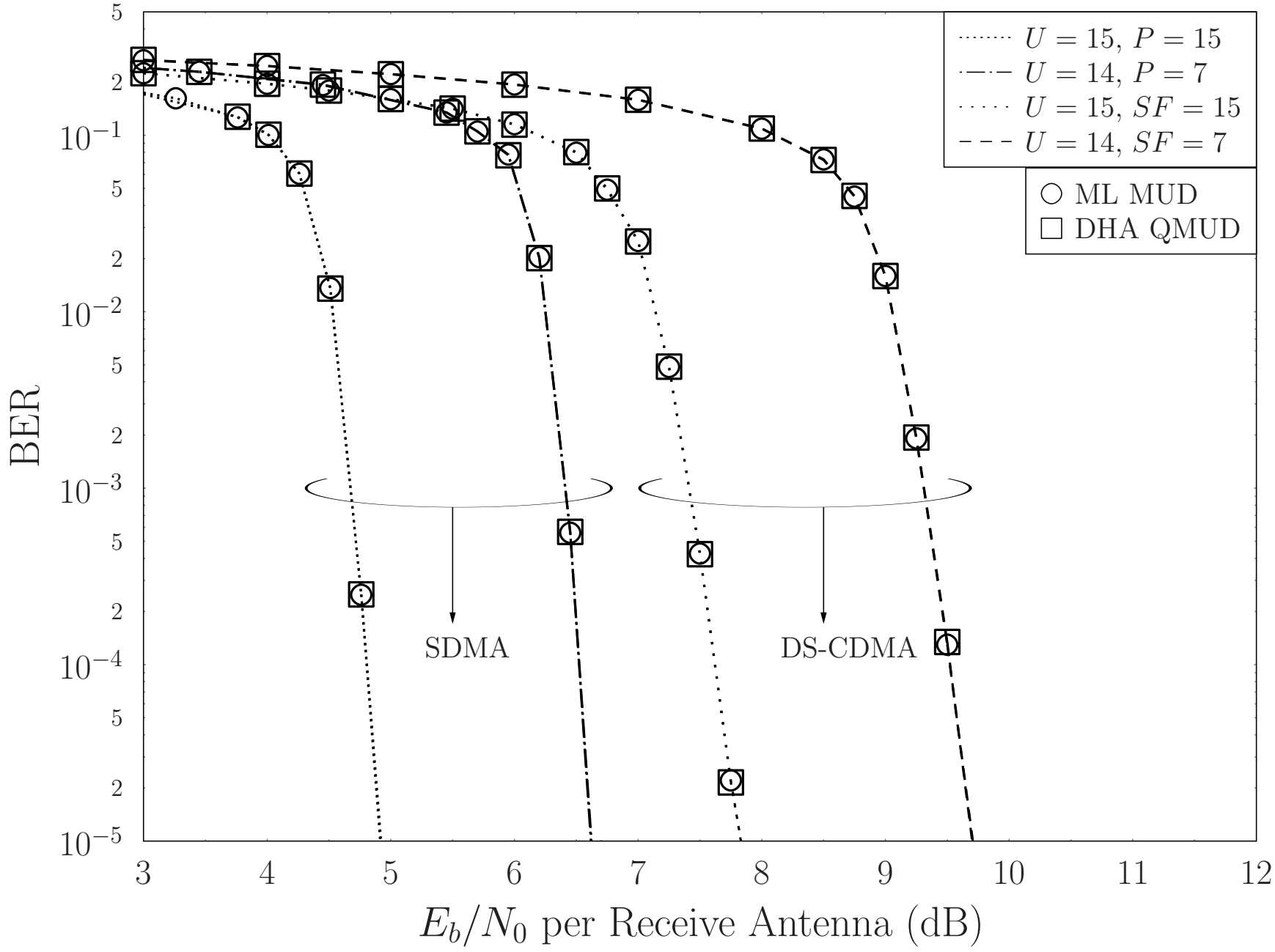
Quantum Computing Meets MUD

NOMA CDMA vs SDMA

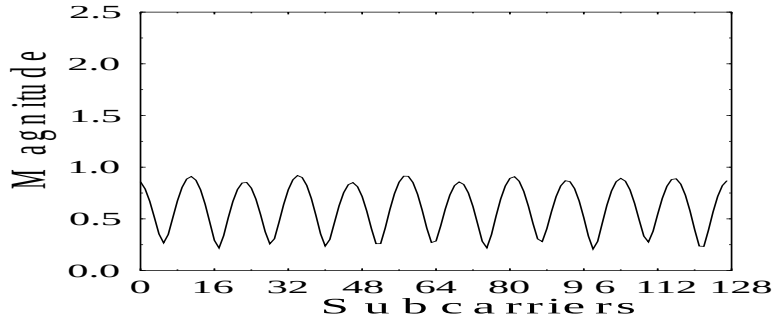
DS-CDMA vs SDMA NOMA Systems

	System 1	System 2	System 3	System 4
Number of Users	$U = 14$	$U = 14$	$U = 15$	$U = 15$
Multiple Access Scheme	DS-CDMA	SDMA	DS-CDMA	SDMA
Number of AEs at the BS	$P = 1$	$P = 7$	$P = 1$	$P = 15$
Spreading Factor	$SF = 7$	N/A	$SF = 15$	N/A
Spreading Codes	m-sequences	N/A	Gold Codes	N/A
Normalized User Load	$U_L = 2$	$U_L = 2$	$U_L = 1$	$U_L = 1$
Bit-based Interleaver Length	42 000	42 000	40 000	40 000
Number of AEs per User	$N_{T_x} = 1$			
Modulation	BPSK $M = 2$			
Channel Code	Turbo Code, $R = 1/2$, 8 Trellis states $I_{inner} = 4$ iterations			
Channel	Uncorrelated Rayleigh Channel			
Channel Estimation	Perfect			

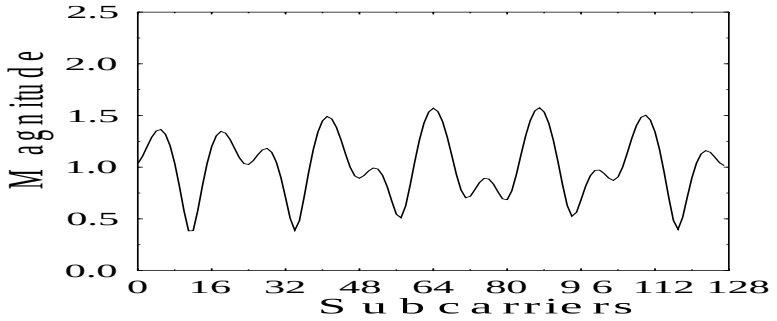
Dürr-Høyer CDMA/SDMA NOMA AT Userload=2



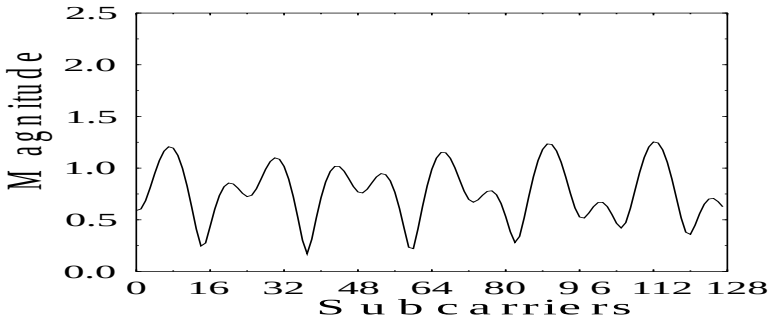
Unique Stream-Specific FD-CTF of CIRs 1-4



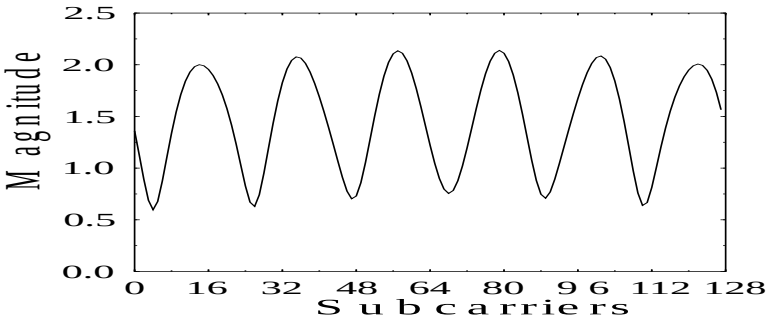
(a) CTF 1: user 1, antenna 1



(b) CTF 2: user 1, antenna 2



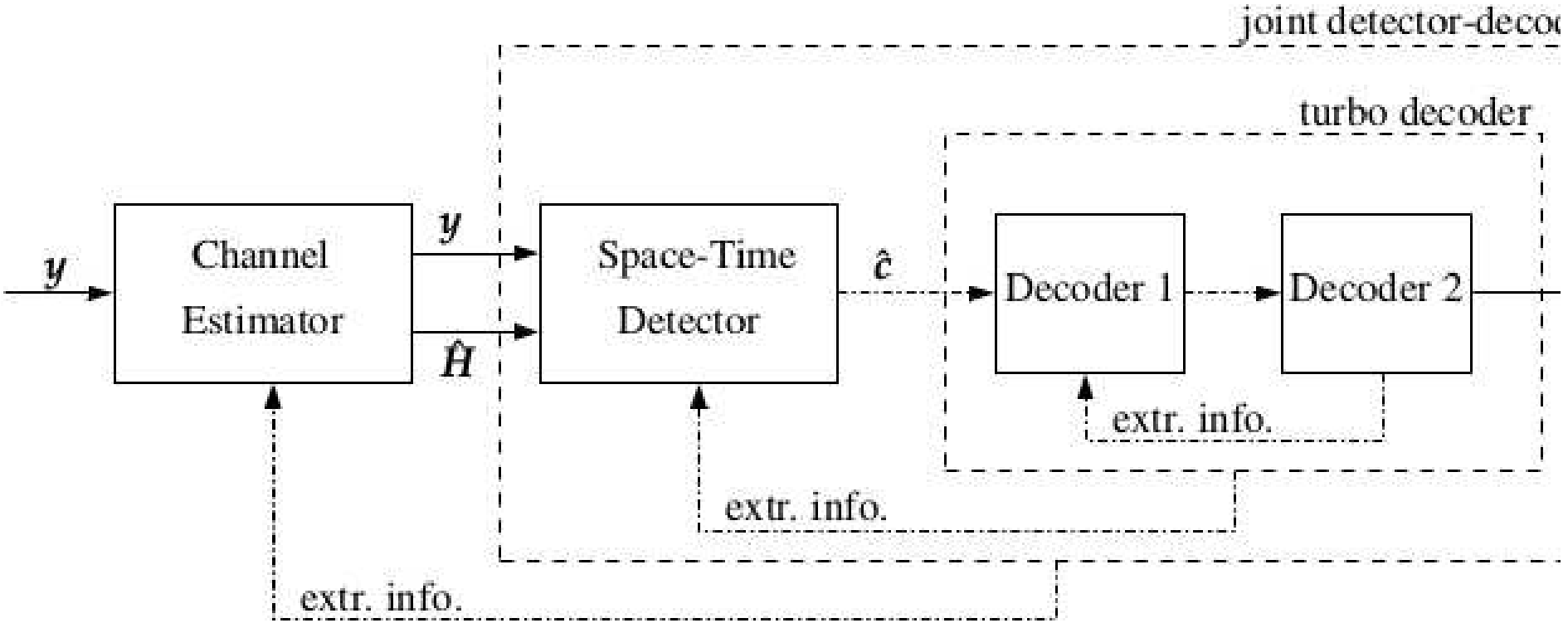
(c) CTF 3: user 2, antenna 1



(d) CTF 4: user 2, antenna 2

Figure 2: FD Channel transfer functions (FD-CTF) for the CIRs seen in Figure 20 (a) FD-CTF 1, (b) FD-CTF 2, (c) FD-CTF 3, and (d) FD-CTF 4.

Iterative Joint Channel & Data Estimation Turbo-Receivers for NOMA



Thank you...