TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

MIMO-OTFS Communication System

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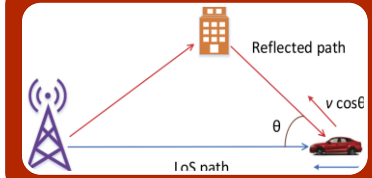
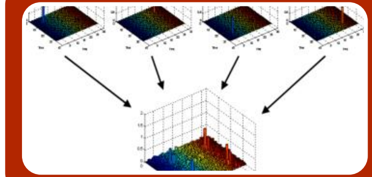
Sommario

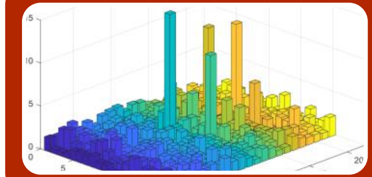


Introduzione alla modulazione OTFS

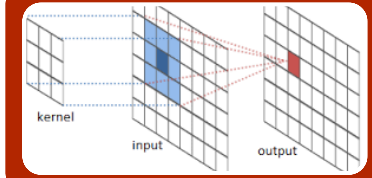
Introduzione alle tecniche MIMO



Sistema MIMO-OTFS

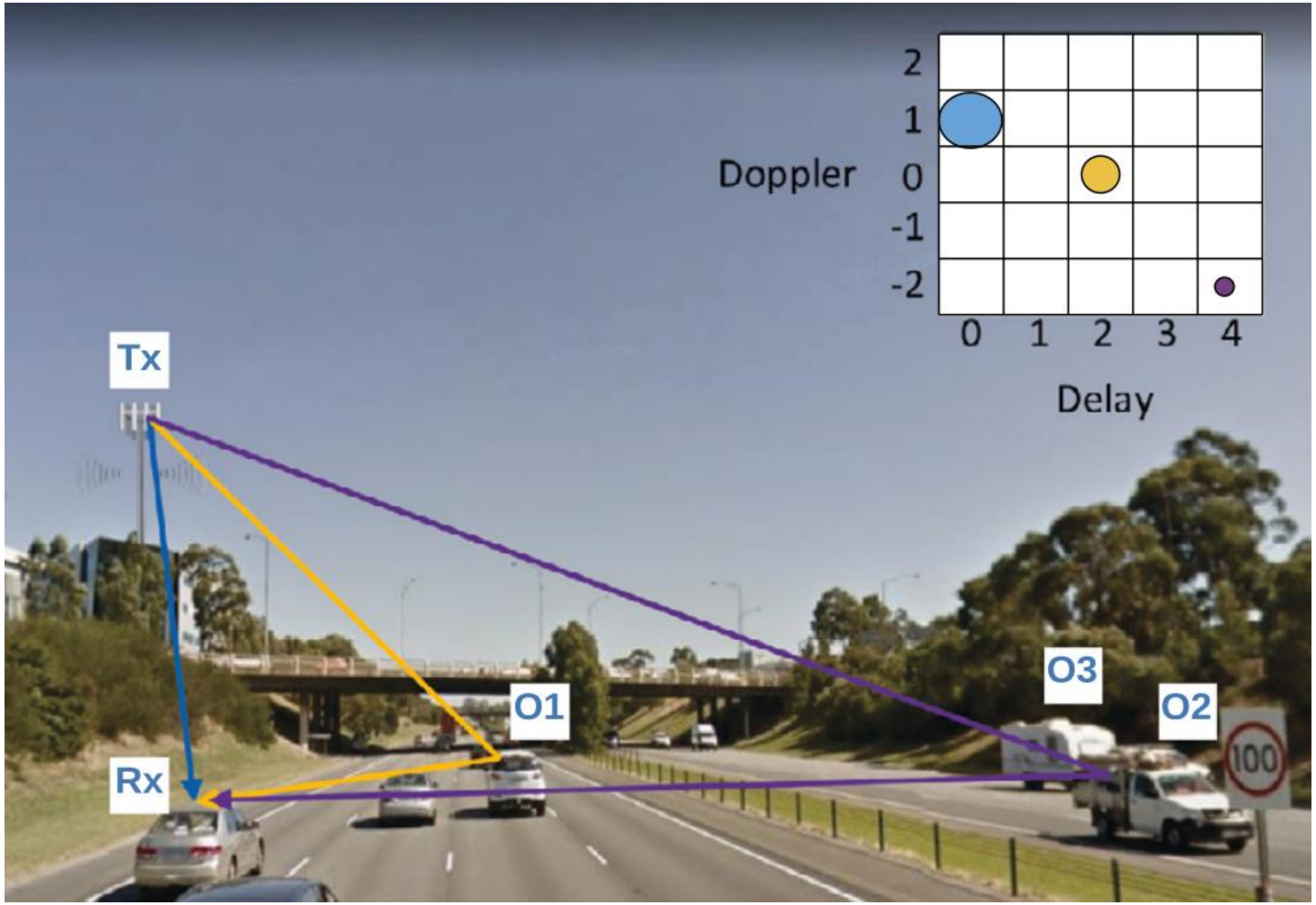


Risultati



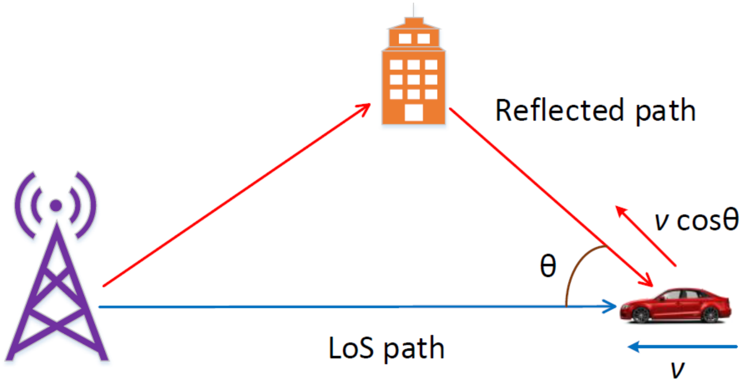
Conclusioni e sviluppi futuri

OTFS: High-mobility wireless channel



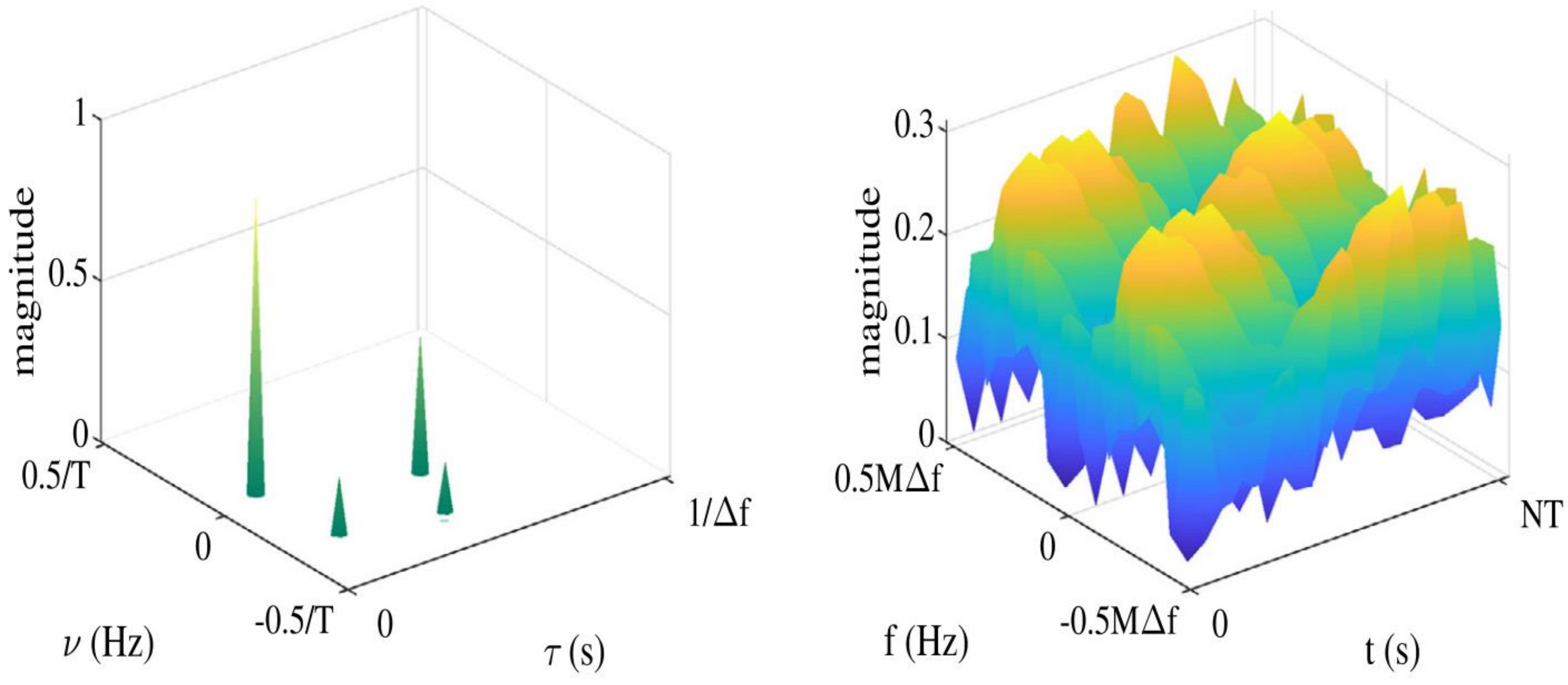
- È un canale dove trasmettitori, ricevitori e vari riflettori, si muovono con velocità e direzioni differenti

- Il problema è che i segnali trasmessi sono afflitti da multipli Doppler shift e ritardi



OTFS: Dominio delay–Doppler

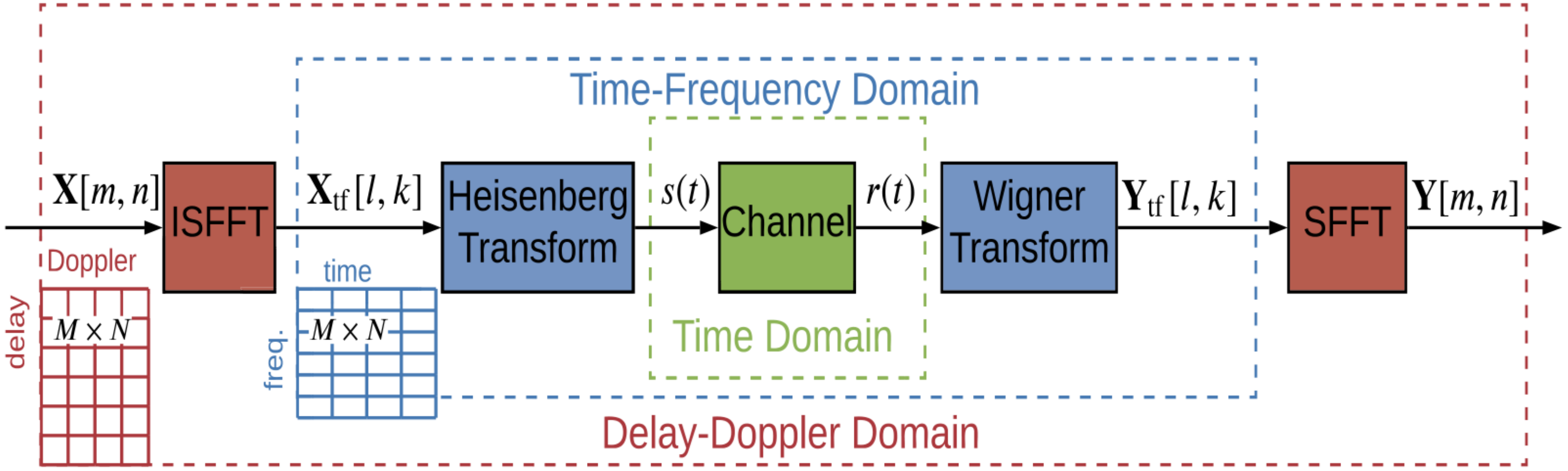
In questo contesto, una rappresentazione nel dominio delay-Doppler, assumendo un numero limitato di riflettori nelle vicinanze del ricevitore, permette di avere una rappresentazione compatta del canale fisico.

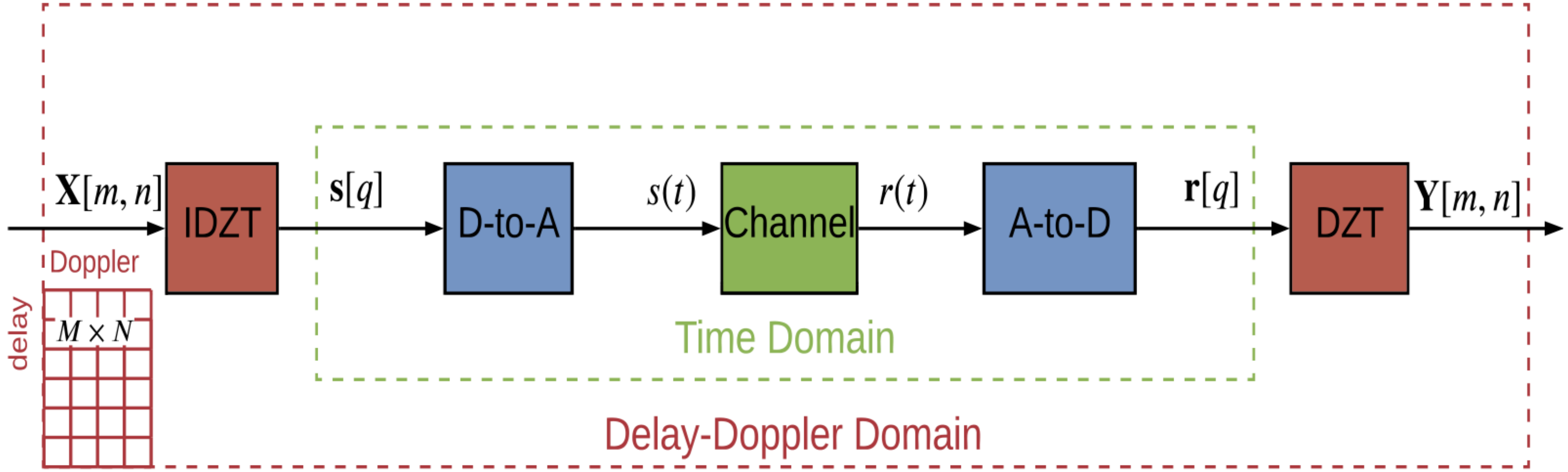


(a) $h(\tau, \nu)$ **(b)** $H(f, t)$

Nella modulazione OTFS, i simboli di informazione sono posizionati nel frame nel dominio delay-Doppler.

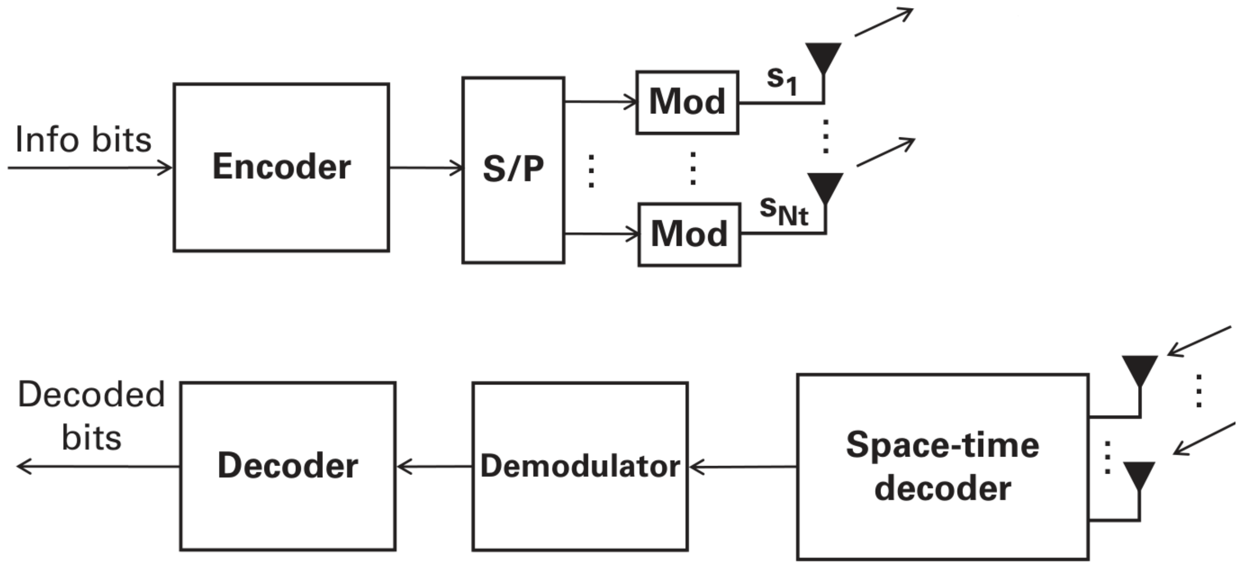
OTFS: Modulazione e demodulazione



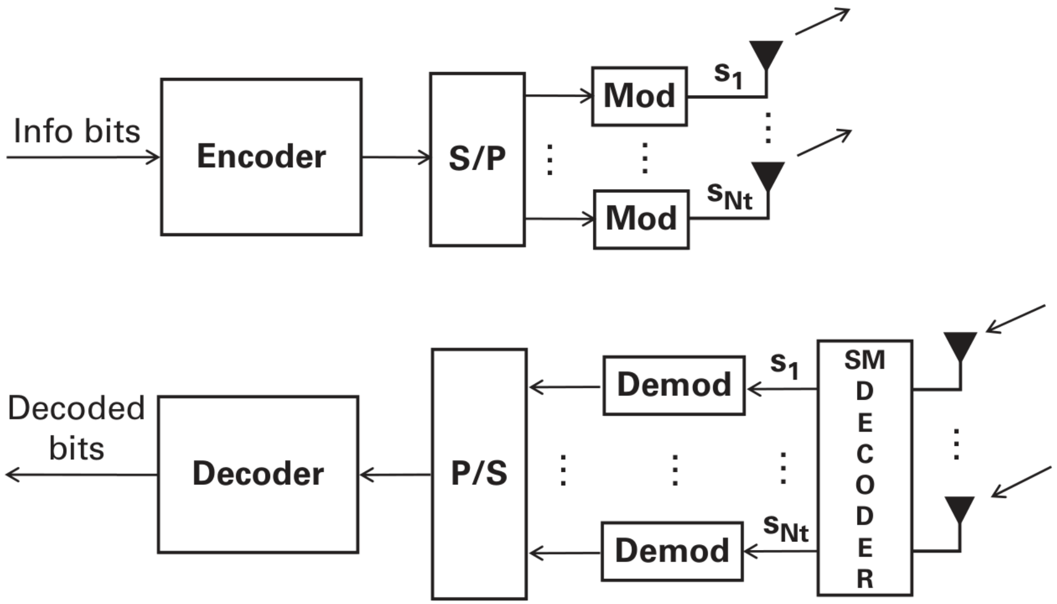


Per MIMO ci si riferisce all'insieme delle tecniche di signal processing che sono state sviluppate per migliorare le performance dei sistemi di comunicazione wireless, usando molteplici antenne sia in trasmissione che in ricezione.

MIMO →
- Spatial Diversity
- Spatial Multiplexing



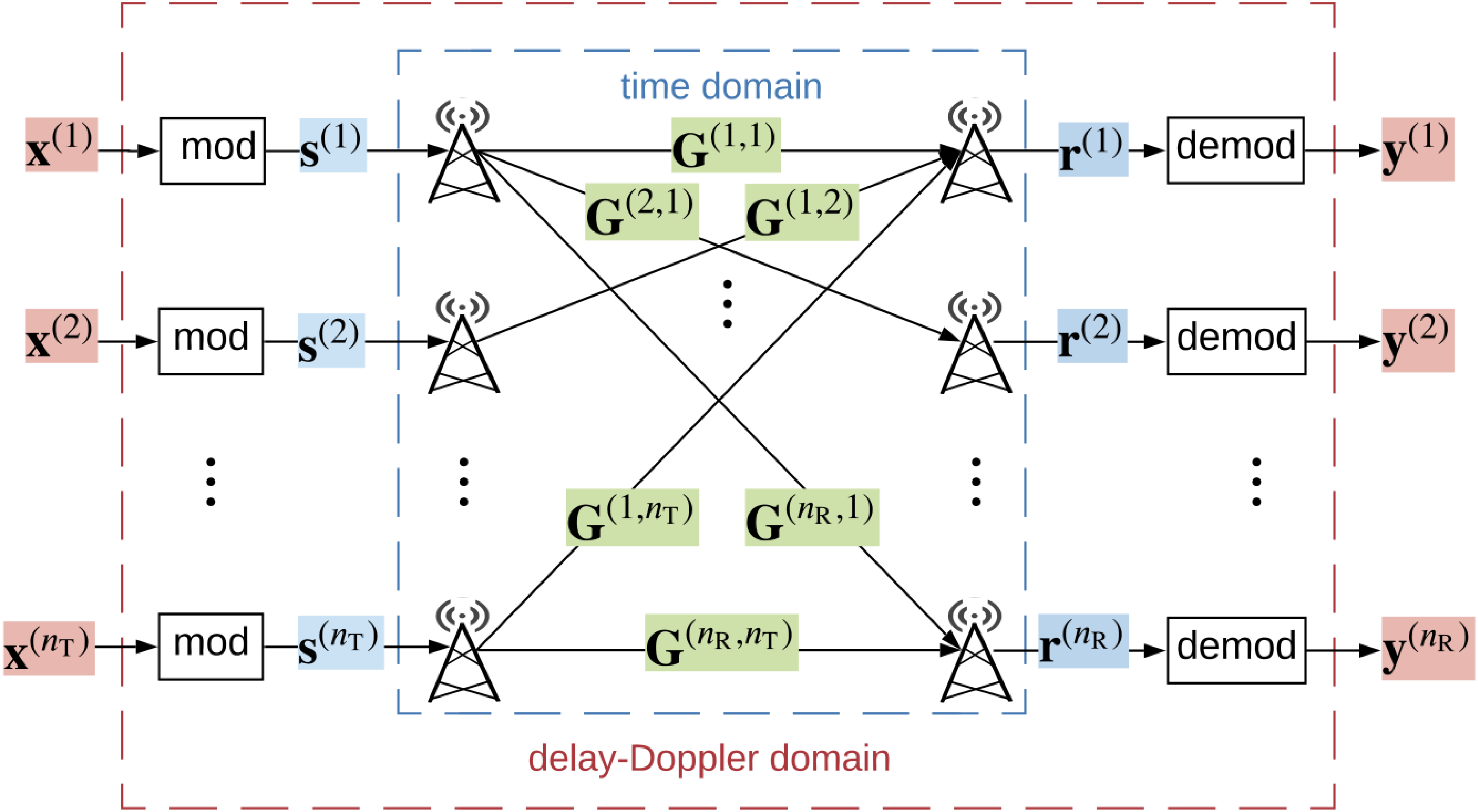
A MIMO system for *spatial diversity*.



A MIMO system for *spatial multiplexing*.

[1] Jerry R. Hampton, Introduction to MIMO Communications, 2014

MIMO-OTFS: Sistema di comunicazione



MIMO-OTFS: Relazioni Input-Output

$$\bar{g}^{(r,t)}[l,q] = \sum_{i=1}^{P^{(r,t)}} g_i^{(r,t)} z^{(q-l)\kappa_i^{(r,t)}} \delta[l - l_i^{(r,t)}] \Longrightarrow \mathbf{G}^{(r,t)}[m+nM, m+nM-l] = \bar{g}^{(r,t)}[l, m+n(M+L_{\mathrm{ZP}})], \quad m \geq l,$$

$$\underbrace{\begin{bmatrix} \mathbf{r}^{(1)} \\ \mathbf{r}^{(2)} \\ \vdots \\ \mathbf{r}^{(n_\mathrm{R})} \end{bmatrix}}_{\mathbf{r}_{\mathrm{MIMO}}} = \underbrace{\begin{bmatrix} \mathbf{G}^{(1,1)} & \mathbf{G}^{(1,2)} & \cdots & \mathbf{G}^{(1,n_\mathrm{T})} \\ \mathbf{G}^{(2,1)} & \mathbf{G}^{(2,2)} & \cdots & \mathbf{G}^{(2,n_\mathrm{T})} \\ \vdots & \ddots & \ddots & \vdots \\ \mathbf{G}^{(n_\mathrm{R},1)} & \mathbf{G}^{(n_\mathrm{R},2)} & \cdots & \mathbf{G}^{(n_\mathrm{R},n_\mathrm{T})} \end{bmatrix}}_{\mathcal{G}} \underbrace{\begin{bmatrix} \mathbf{s}^{(1)} \\ \mathbf{s}^{(2)} \\ \vdots \\ \mathbf{s}^{(n_\mathrm{T})} \end{bmatrix}}_{\mathbf{s}_{\mathrm{MIMO}}} + \underbrace{\begin{bmatrix} \mathbf{w}^{(1)} \\ \mathbf{w}^{(2)} \\ \vdots \\ \mathbf{w}^{(n_\mathrm{R})} \end{bmatrix}}_{\mathbf{w}_{\mathrm{MIMO}}}$$

[2] Yi Hong, Tharaj Thaj, Emanuele Viterbo, Delay-Doppler Communications: Principles and Applications, 2022

MIMO-OTFS: Relazioni Input-Output

$$\mathbf{x}^{(t)} = \text{vec}\left((\mathbf{X}^{(t)})^{\mathrm{T}}\right)$$
$$\mathbf{y}^{(r)} = \text{vec}\left((\mathbf{Y}^{(r)})^{\mathrm{T}}\right)$$

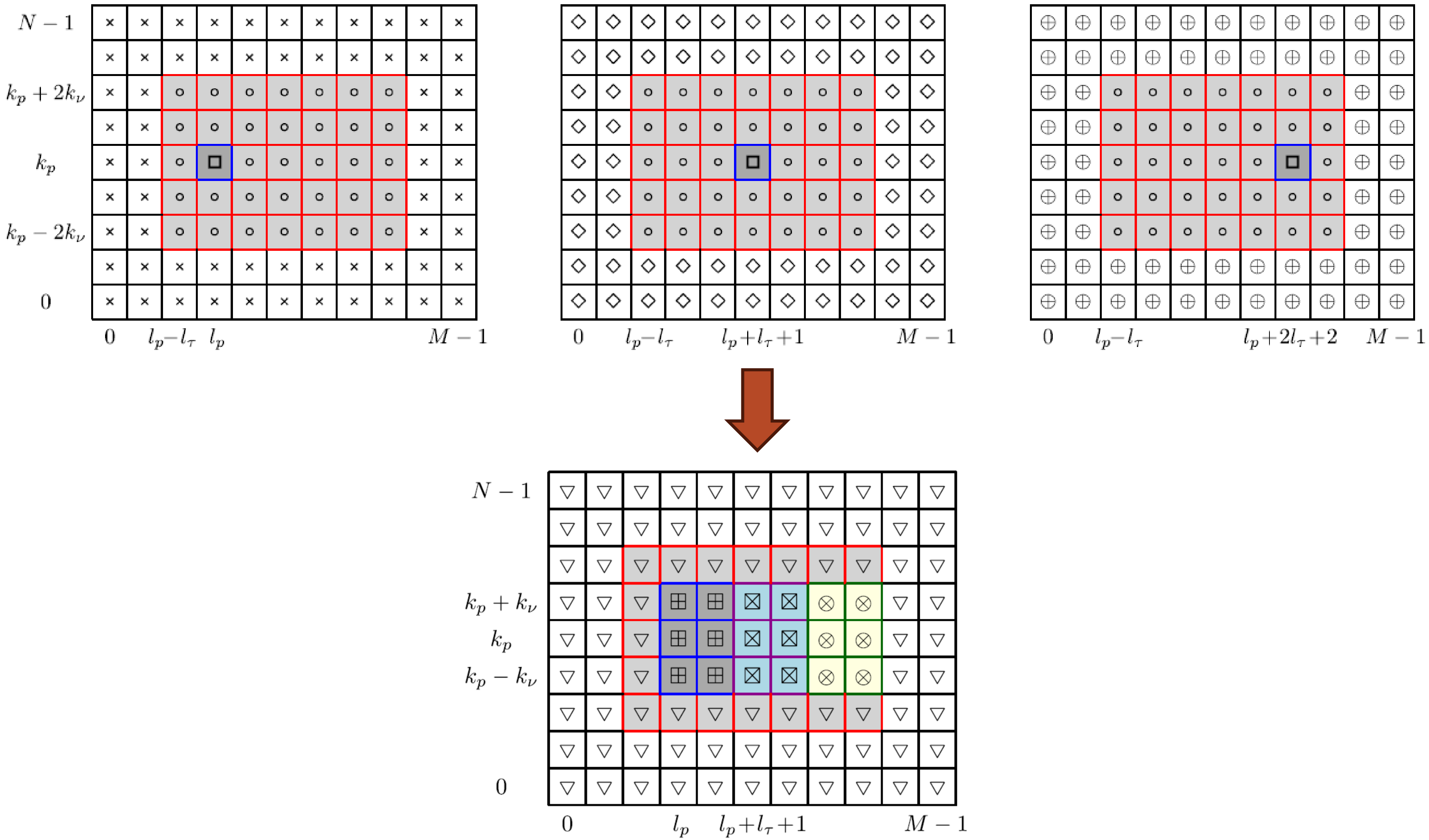
$\Rightarrow$

$$\mathbf{H}^{(r,t)} = (\mathbf{I}_M \otimes \mathbf{F}_N) \cdot (\mathbf{P}^{\mathrm{T}} \cdot \mathbf{G}^{(r,t)} \cdot \mathbf{P}) \cdot (\mathbf{I}_M \otimes \mathbf{F}_N^{\dagger}) \in \mathbb{C}^{NM \times NM}$$
$$\mathbf{z}^{(r)} = (\mathbf{I}_M \otimes \mathbf{F}_N) \cdot (\mathbf{P}^{\mathrm{T}} \cdot \mathbf{w}^{(r)}) \in \mathbb{C}^{NM \times 1}$$

$$\underbrace{\begin{bmatrix} \mathbf{y}^{(1)} \\ \mathbf{y}^{(2)} \\ \vdots \\ \mathbf{y}^{(n_\mathrm{R})} \end{bmatrix}}_{\mathbf{y}_{\mathrm{MIMO}}} = \underbrace{\begin{bmatrix} \mathbf{H}^{(1,1)} & \mathbf{H}^{(1,2)} & \cdots & \mathbf{H}^{(1,n_\mathrm{T})} \\ \mathbf{H}^{(2,1)} & \mathbf{H}^{(2,2)} & \cdots & \mathbf{H}^{(2,n_\mathrm{T})} \\ \vdots & \ddots & \ddots & \vdots \\ \mathbf{H}^{(n_\mathrm{R},1)} & \mathbf{H}^{(n_\mathrm{R},2)} & \cdots & \mathbf{H}^{(n_\mathrm{R},n_\mathrm{T})} \end{bmatrix}}_{\mathcal{H}} \underbrace{\begin{bmatrix} \mathbf{x}^{(1)} \\ \mathbf{x}^{(2)} \\ \vdots \\ \mathbf{x}^{(n_\mathrm{T})} \end{bmatrix}}_{\mathbf{x}_{\mathrm{MIMO}}} + \underbrace{\begin{bmatrix} \mathbf{z}^{(1)} \\ \mathbf{z}^{(2)} \\ \vdots \\ \mathbf{z}^{(n_\mathrm{R})} \end{bmatrix}}_{\mathbf{z}_{\mathrm{MIMO}}}$$

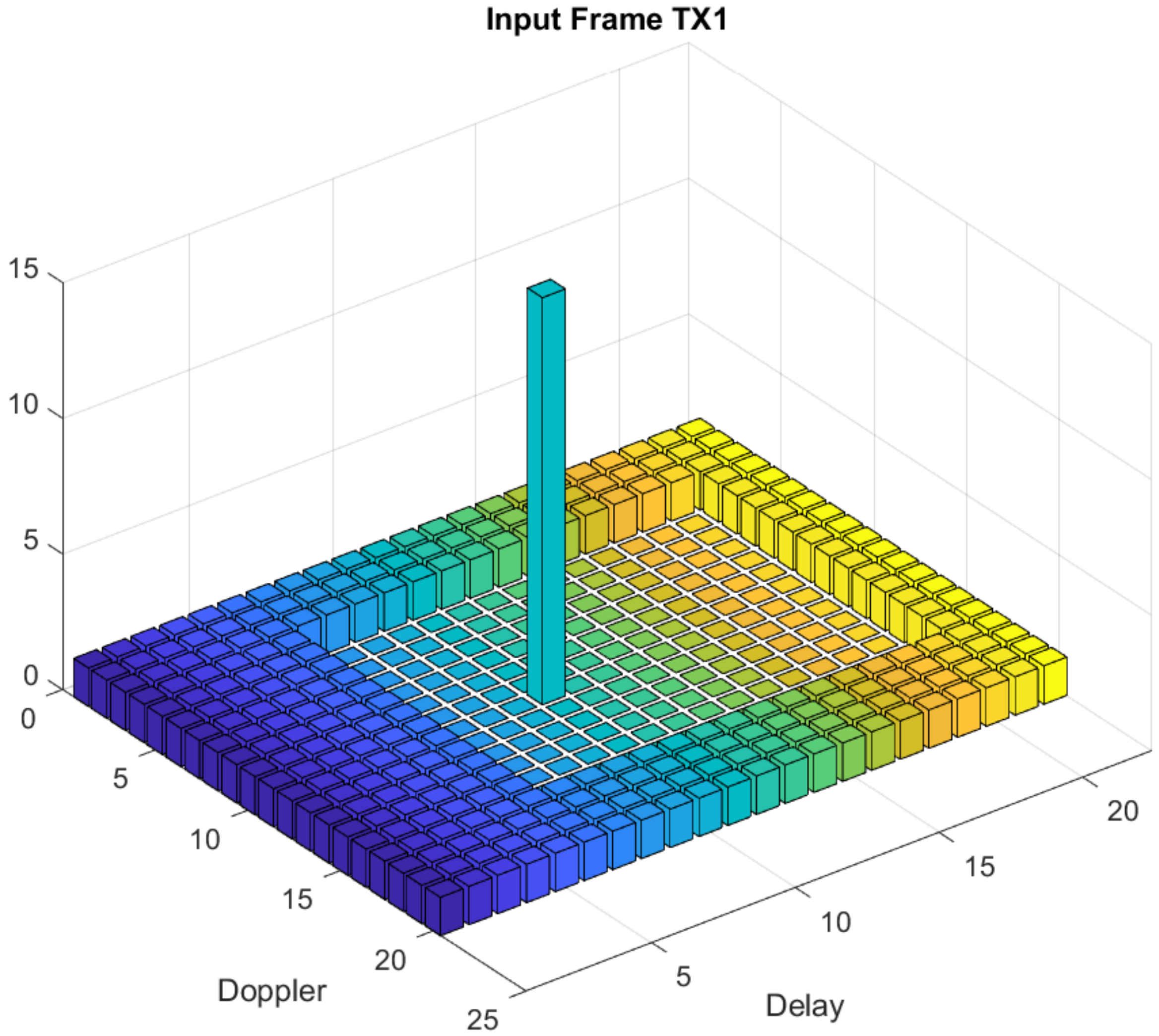
[2] Yi Hong, Tharaj Thaj, Emanuele Viterbo, Delay-Doppler Communications: Principles and Applications, 2022

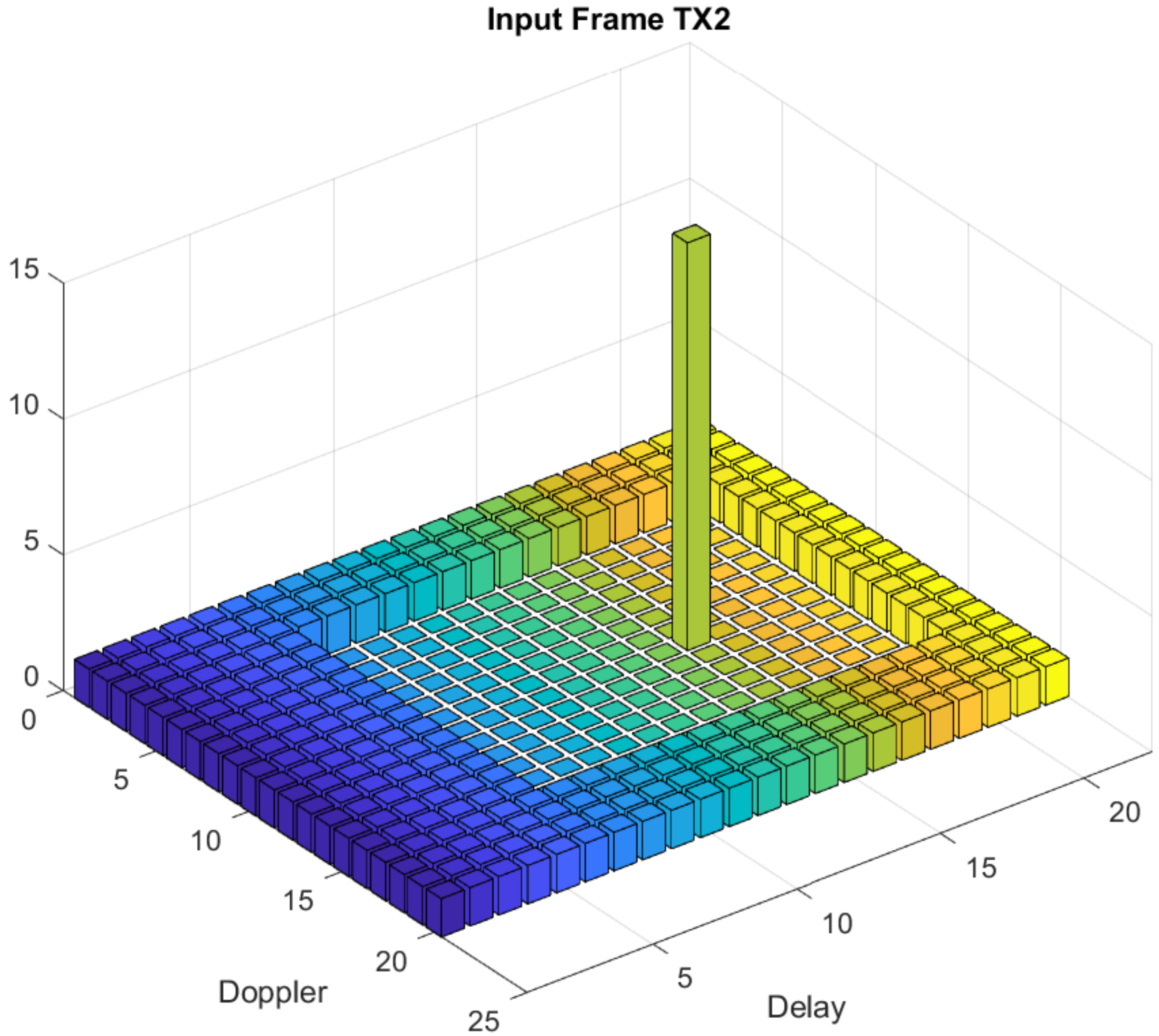
MIMO-OTFS: Pilot Placement



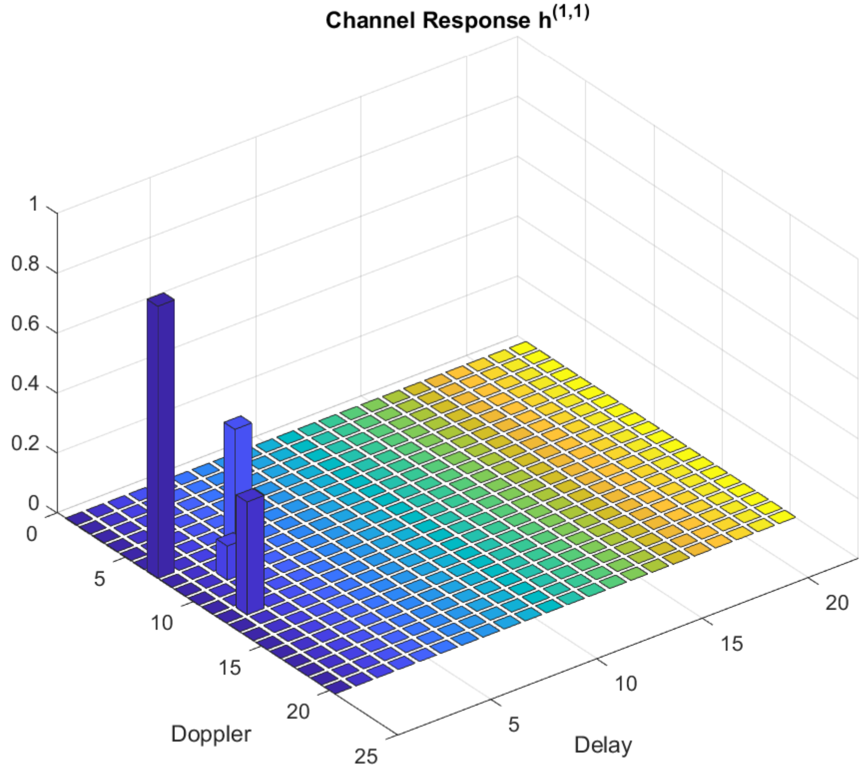
[3] P. Raviteja, Khoa T. Phan, Yi Hong, Embedded Pilot-Aided Channel Estimation For OTFS in Delay-Doppler Channel, 2019
[4] M. Kollengode Ramachandran, A. Chockalingam, MIMO-OTFS in High-Doppler Fading Channels: Signal Detection and Channel Estimation, 2018

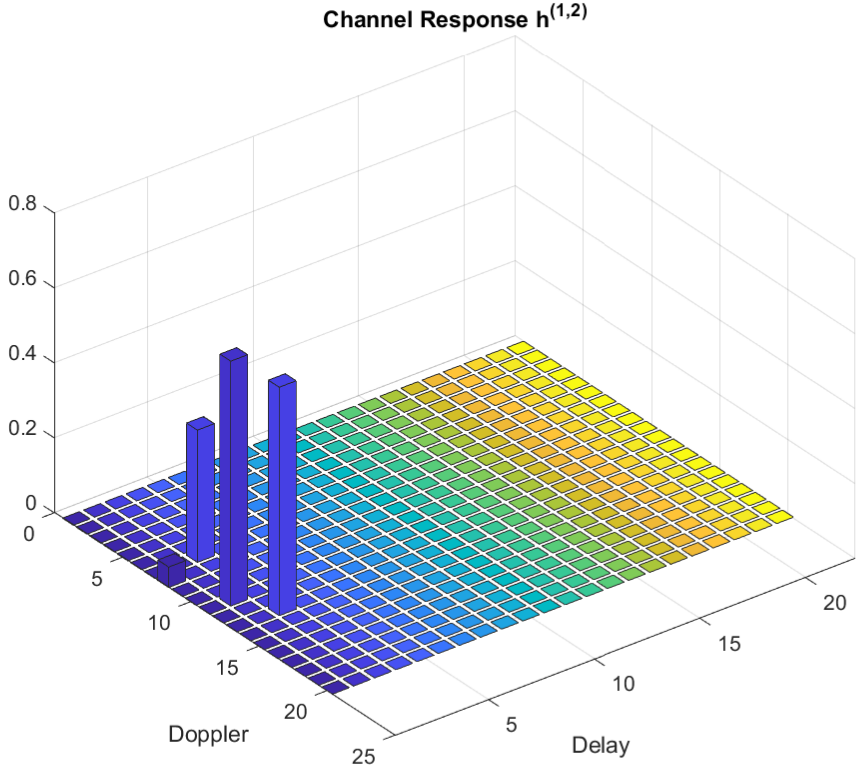
MIMO-OTFS: Risultati Tx Frame – 2x1





MIMO-OTFS: Channel Response – 2x1

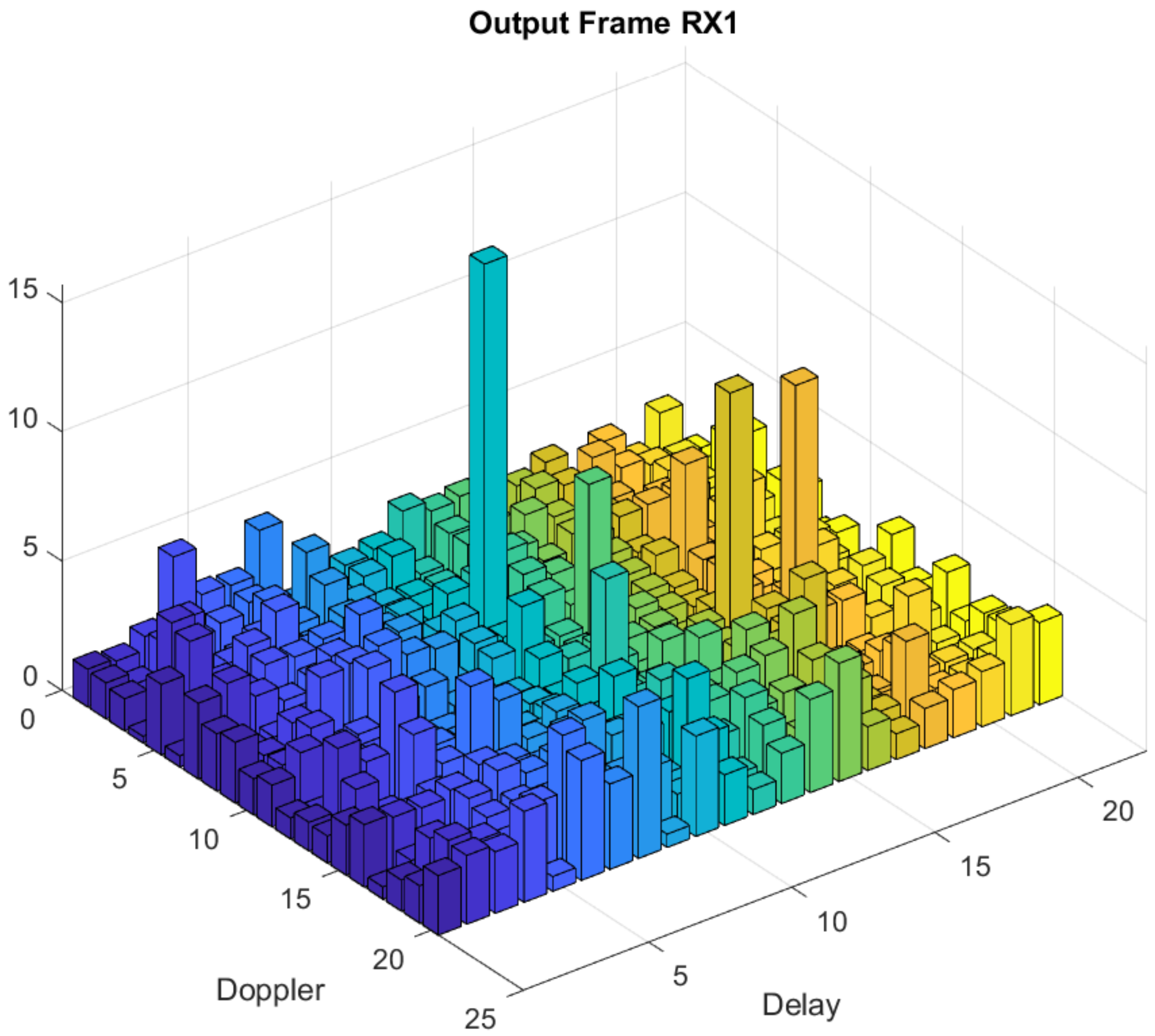




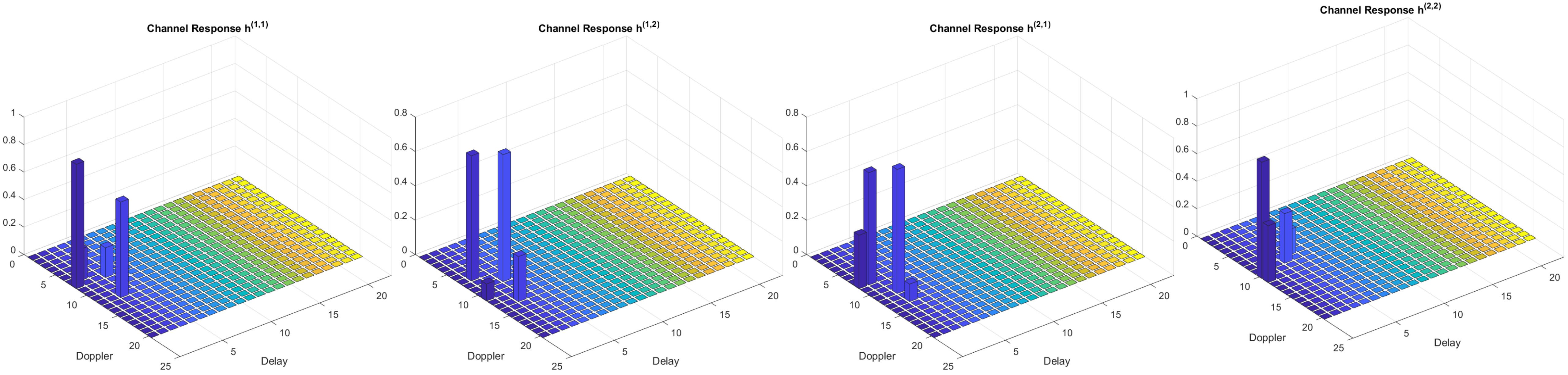
Path (1,1)	g	l	k
1	0.4466	3	-2
2	0.1136	2	1
3	0.3769	1	2
4	0.9091	0	-3

Path (1,2)	g	l	k
1	0.6095	2	3
2	0.0545	0	-2
3	0.6533	1	1
4	0.3528	2	-3

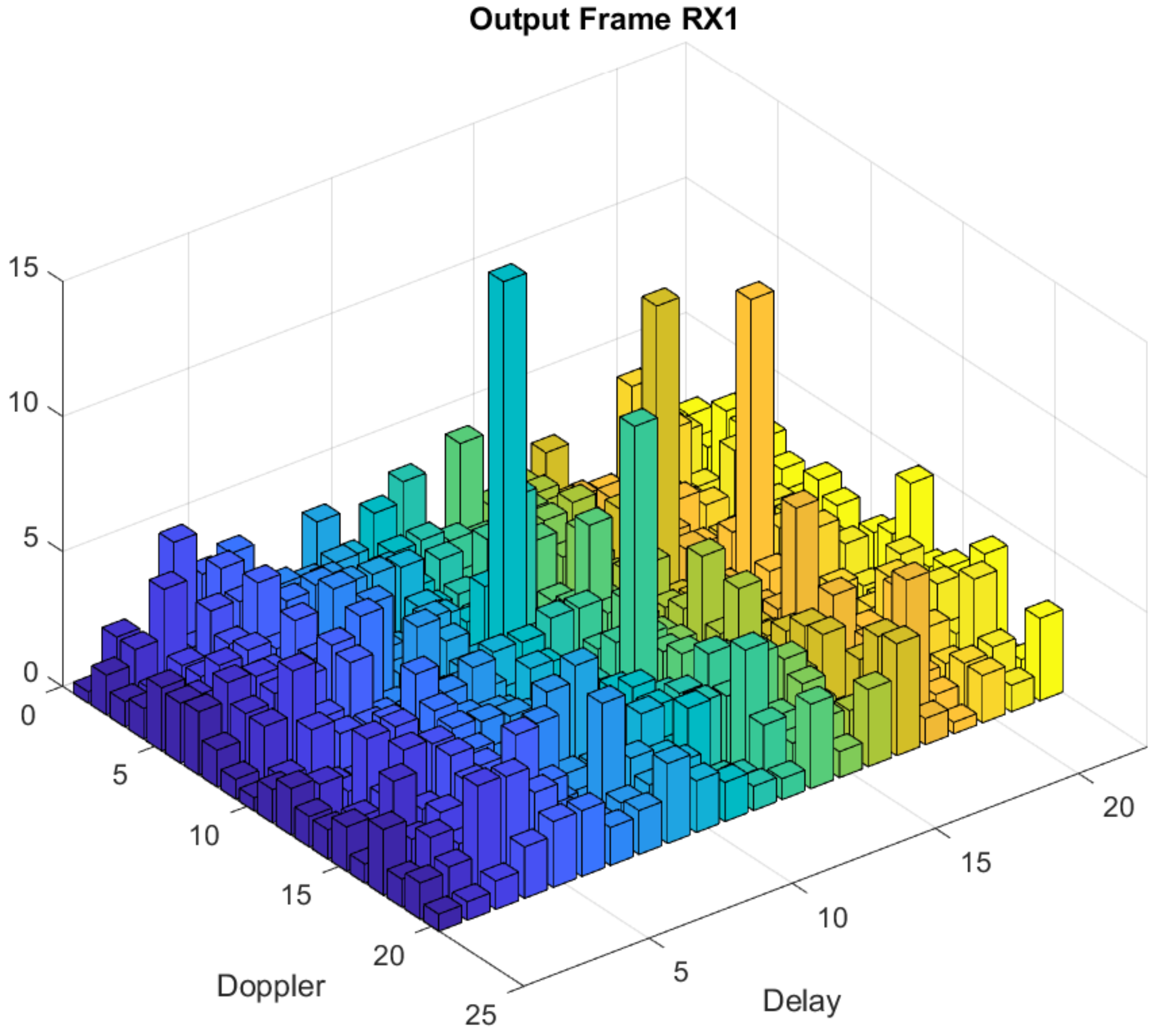
MIMO-OTFS: Risultati Rx Frame – 2x1

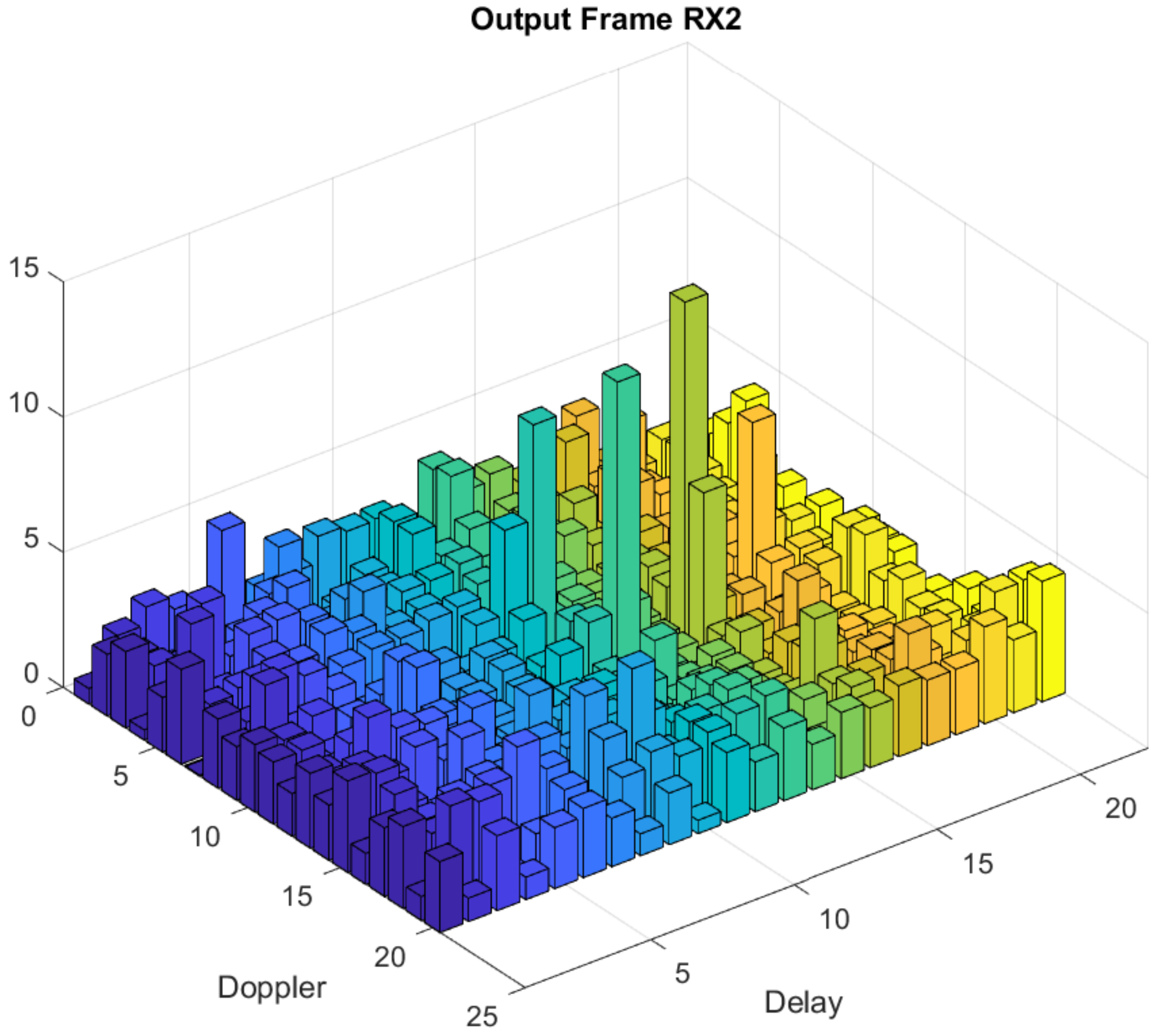


MIMO-OTFS: Channel Response – 2x2

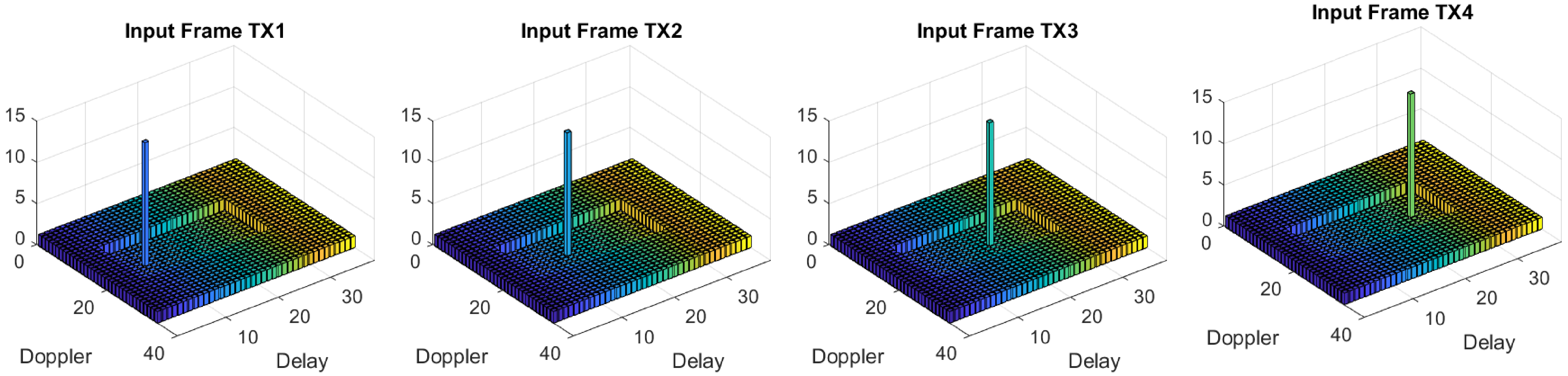


MIMO-OTFS: Risultati Rx Frame – 2x2

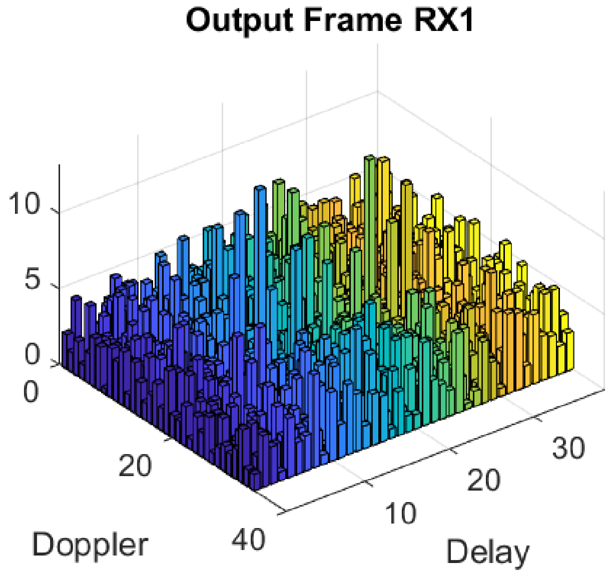


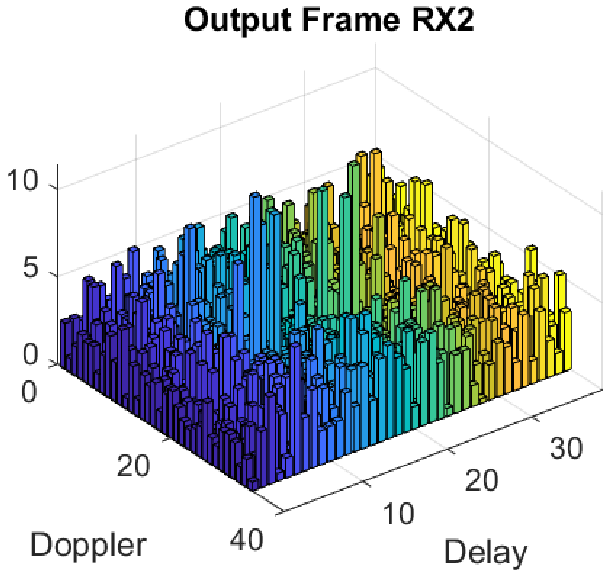


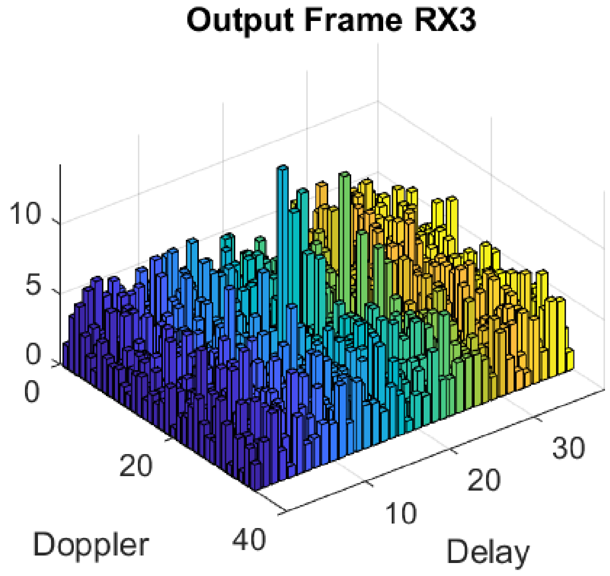
MIMO-OTFS: Risultati Tx Frame – 4x4

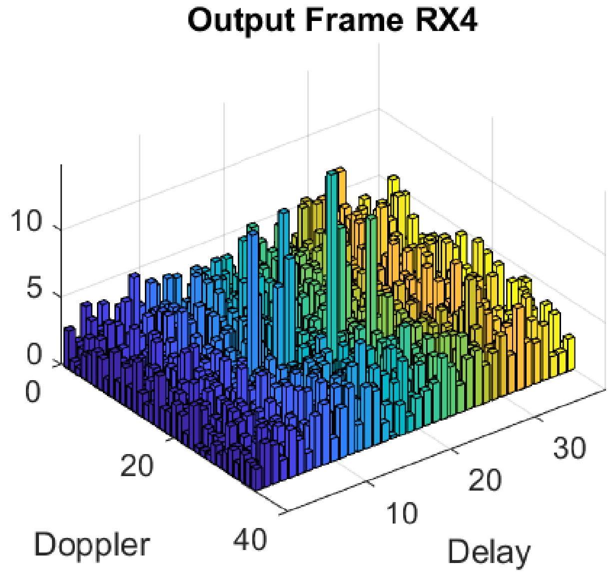


MIMO-OTFS: Risultati Rx Frame – 4x4





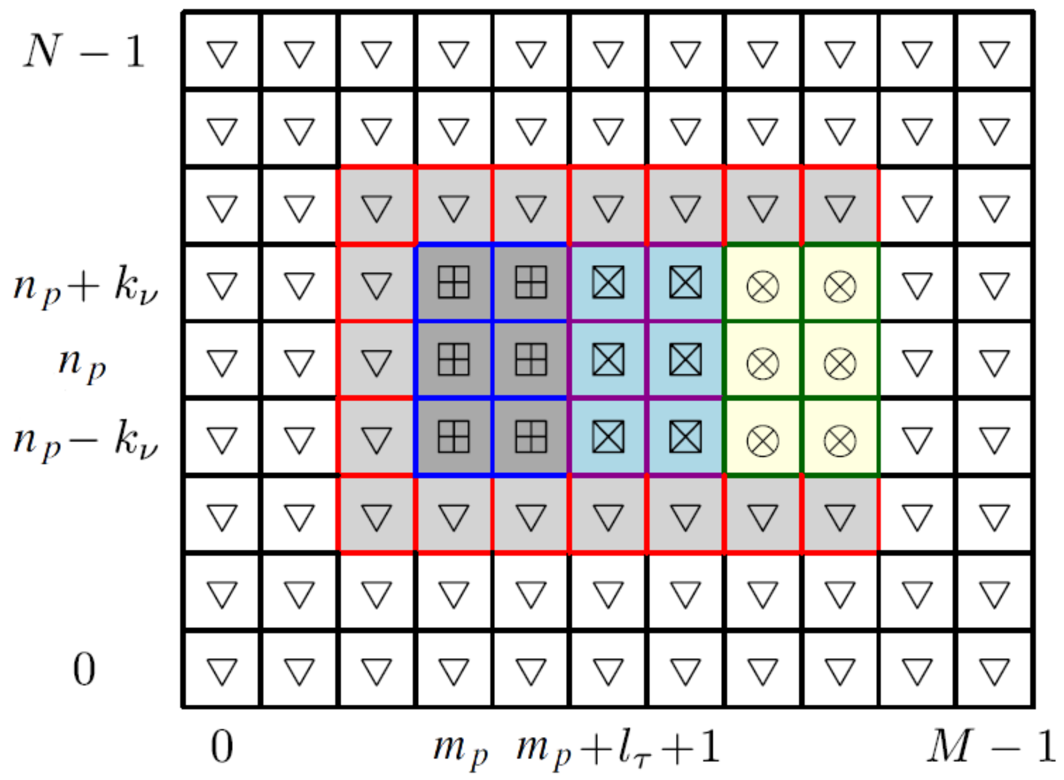




$$b[l,k] = \begin{cases} 1, & |\mathbf{Y}[m_p + l, n_p + k]| \geq \mathcal{T} \\ 0, & \text{otherwise} \end{cases}$$

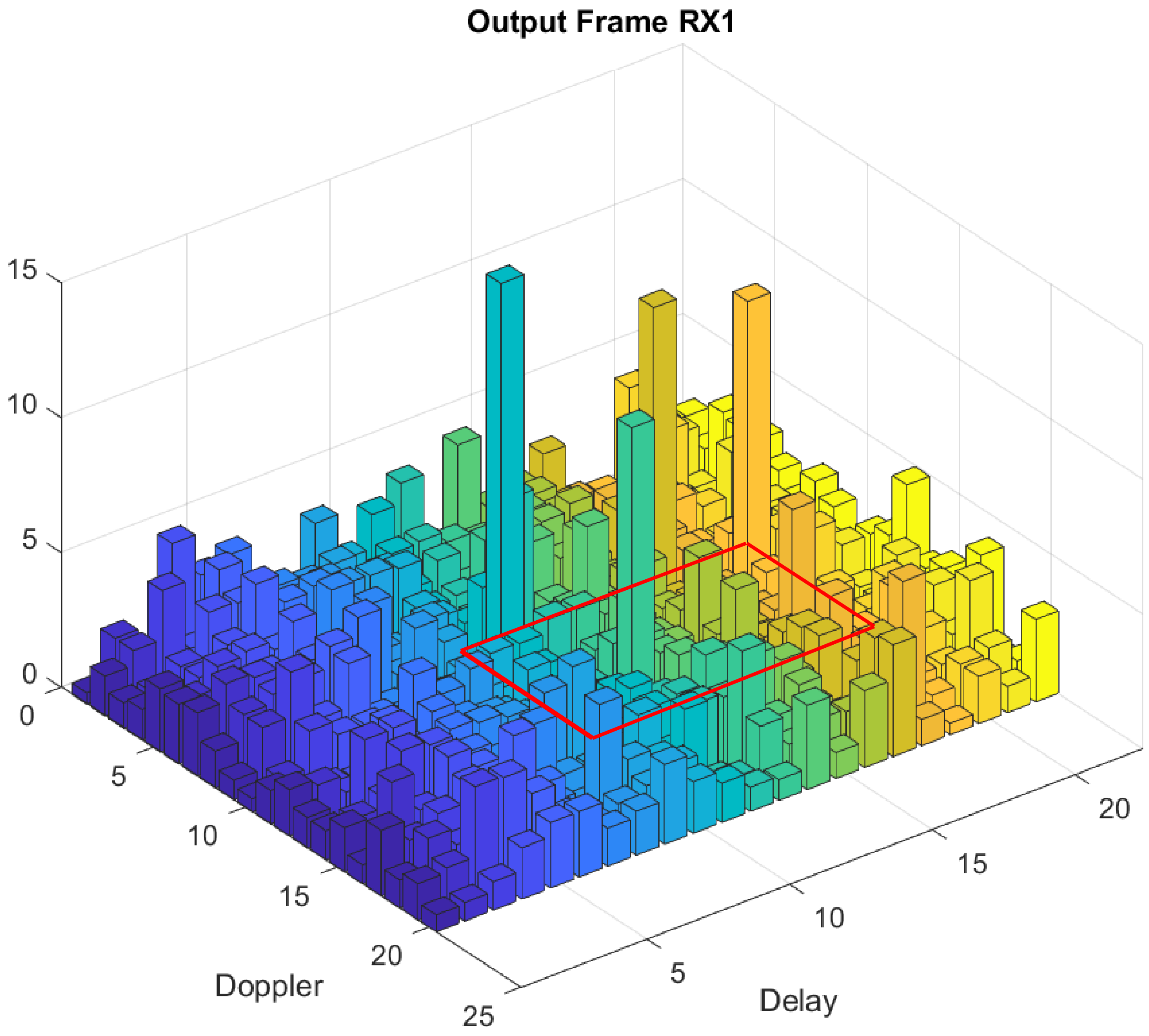
$$z = \frac{2 \cdot \pi \cdot j}{N \cdot M}$$

$$\hat{g}[l,k] = \frac{\mathbf{Y}[m_p + l, n_p + k]}{x_p z^{k m_p}}$$

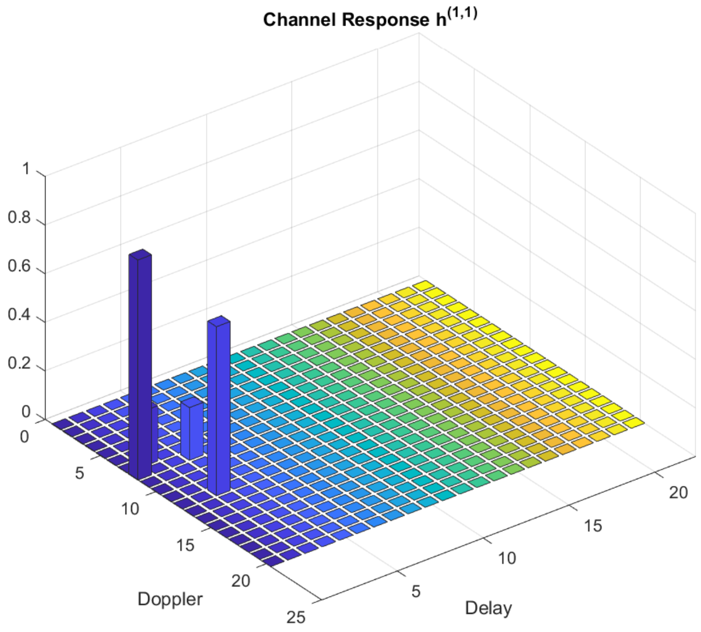


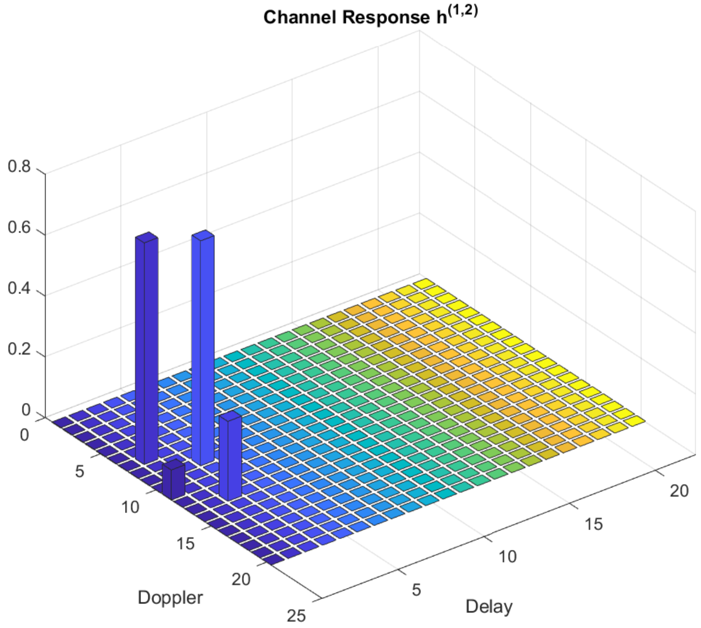
[2] Yi Hong, Tharaj Thaj, Emanuele Viterbo, Delay-Doppler Communications: Principles and Applications, 2022

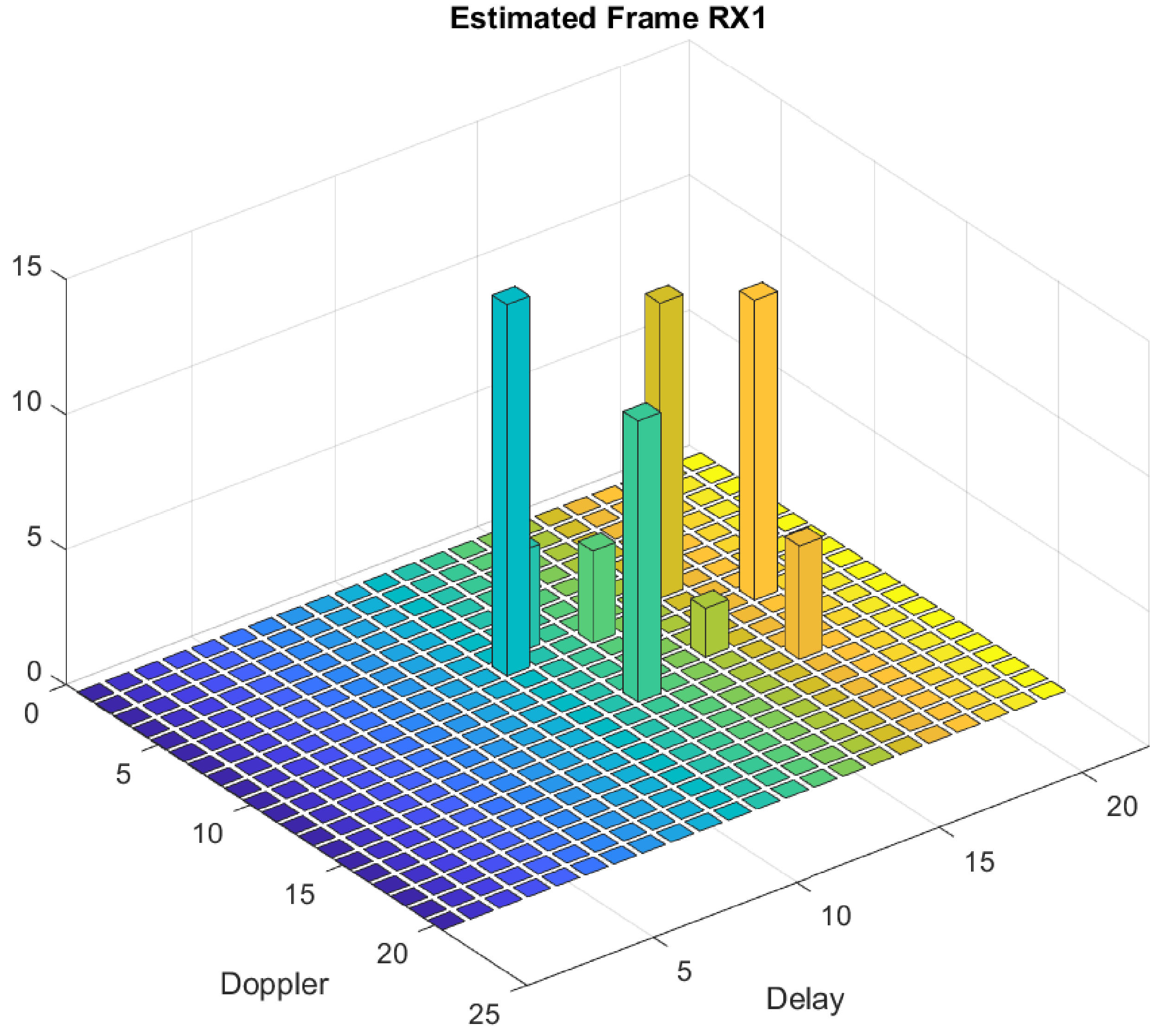
Channel Estimation - Output Frame Rx1



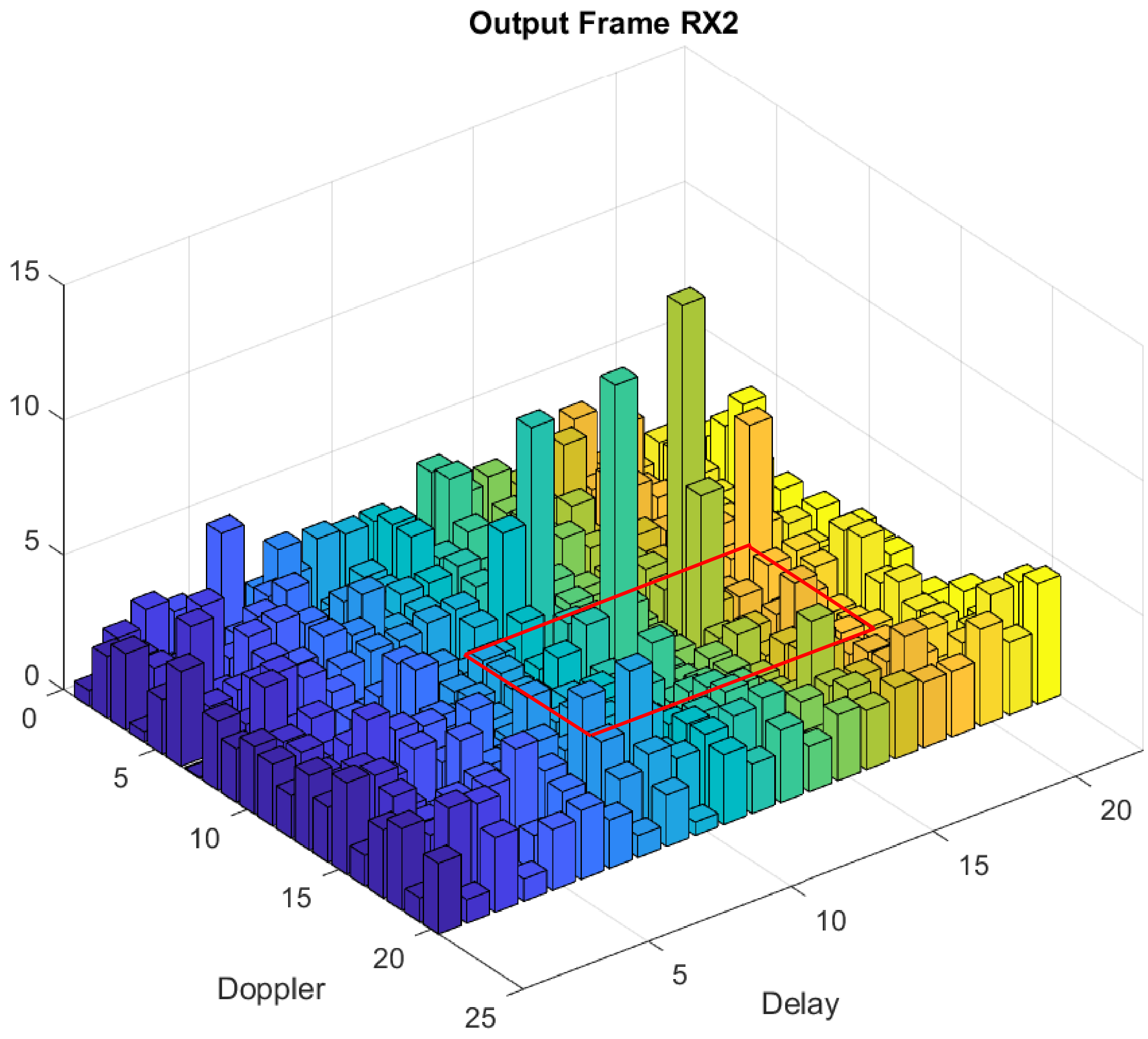
Channel Estimation - Output Frame Rx1



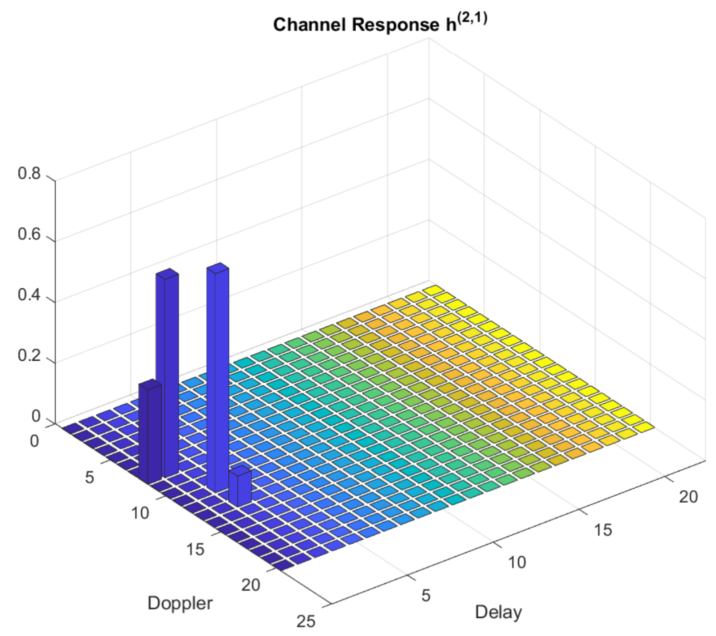


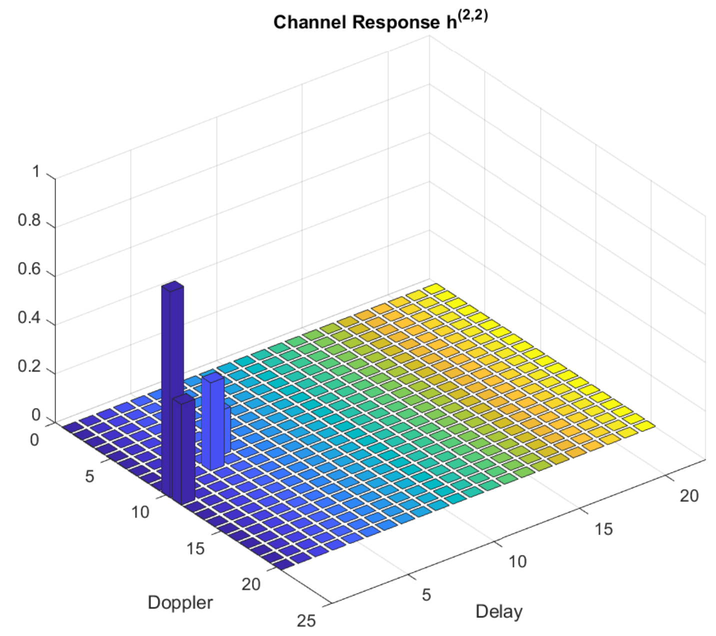


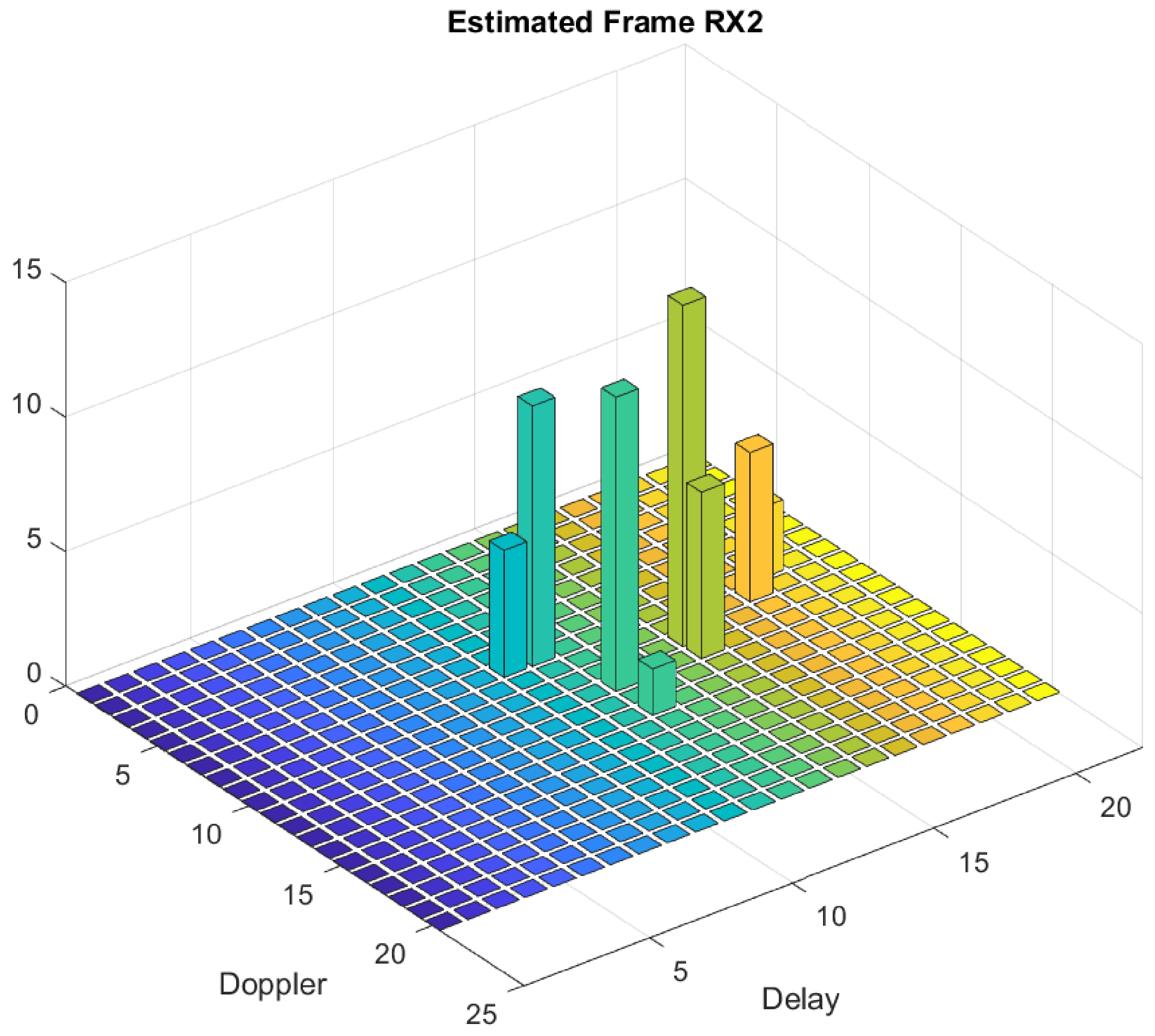
Channel Estimation - Output Frame Rx2



Channel Estimation - Output Frame Rx2







Conclusioni e sviluppi futuri

Conclusioni

- Implementazione MIMO-OTFS NtxNr tramite Matlab
- Analisi risultati di trasmissione
- Implementazione Channel Estimation
- Analisi Channel Estimation

Sviluppi Futuri

- Detection Algorithm
- Fractional Delay-Doppler
- Massive MIMO Multiuser
- Machine Learning (CNN)