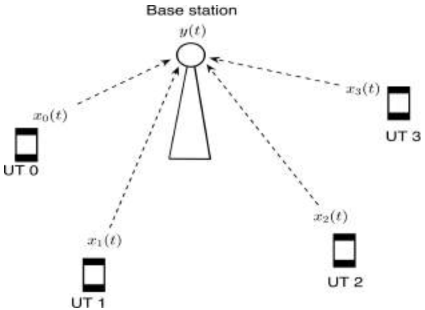
OTFS Based Orthogonal Multiple Access (OMA)

Prof. Saif Khan Mohammed,
Dept. of Electrical Engineering, I.I.T. Delhi, India

13 March 2023

Outline

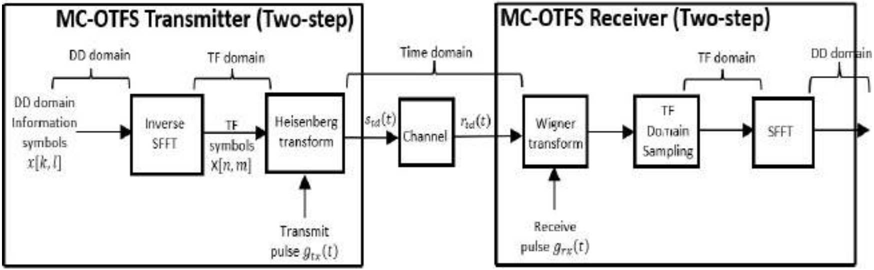
- **OTFS Modulation**
- **Resource Element in DD and TF domain**
- **GB based MA**
- **Interleaved DD MA (IDDMA)**
- **Interleaved TF MA (ITFMA)**
- **SE performance comparison**
- **Conclusions**



- Single-antenna multi-user (MU) uplink
- Doubly-spread channels
- OTFS modulation

OTFS Modulation

- OTFS modulator and demodulator*

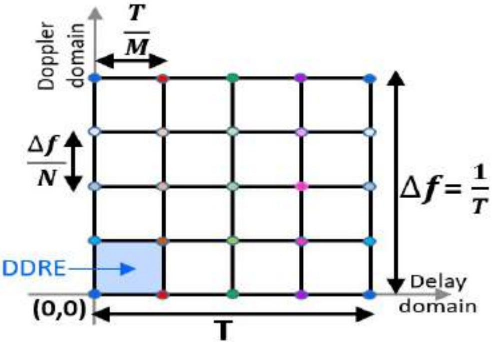


- Communication in delay-Doppler (DD) domain
- Robust to delay and Doppler spread compared to OFDM

*** R. Hadani, S. Rakib, M. Tsatsanis, A. Monk, A. J. Goldsmith, A. F. Molisch, and R. Calderbank, "Orthogonal time frequency space modulation," IEEE WCNC'2017, pp. 1-6, Mar. 2017.**

Resource Element in DD domain

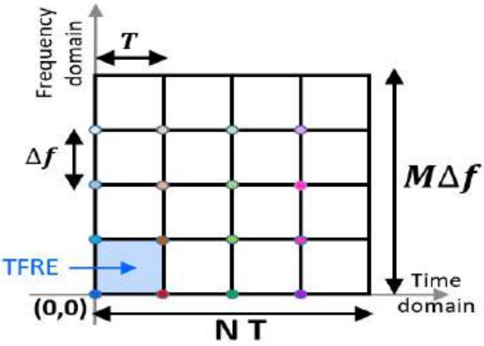
- Carrier: Pulses* on information grid (delay and Doppler spread is $\frac{T}{M}$ and $\frac{\Delta f}{N}$)
- DDRE: DD domain resource element
  - Smallest resource unit
  - 1 DDRE = 1 degree of freedom
  - Total: MN DDREs



* S. K. Mohammed, "Derivation of OTFS Modulation From First Principles," IEEE Transactions on Vehicular Technology, vol. 70, no. 8, pp. 7619-7636, Aug. 2021.

Resource Element in TF domain

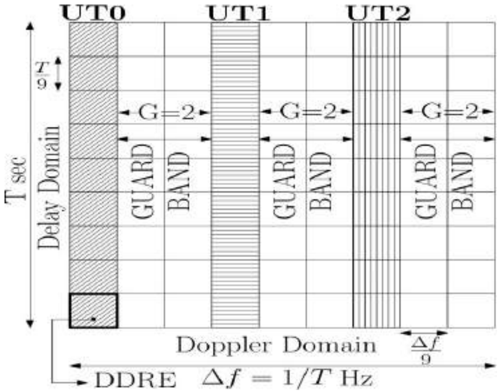
- Carrier bandwidth*: Inverse of DD pulse delay spread $\frac{1}{T/M} = M\Delta f$
- Carrier time duration*: Inverse of DD pulse Doppler spread $\frac{1}{\Delta f/N} = NT$
- TFRE: TF domain resource element
  - Smallest resource unit in TF domain
  - 1 TFRE $=$ 1 degree of freedom
  - No. of degrees of freedom: Time-bandwidth product $M\Delta f \times NT = MN$



* S. K. Mohammed, "Derivation of OTFS Modulation From First Principles," IEEE Transactions on Vehicular Technology, vol. 70, no. 8, pp. 7619-7636, Aug. 2021.

Guard-band (GB) based Orthogonal Multiple Access

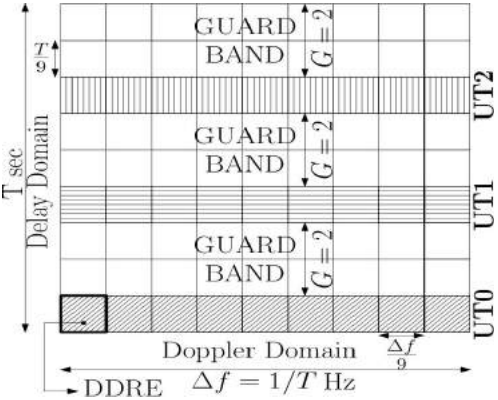
- Non-overlapping multi-user (MU) resource allocation in DD domain



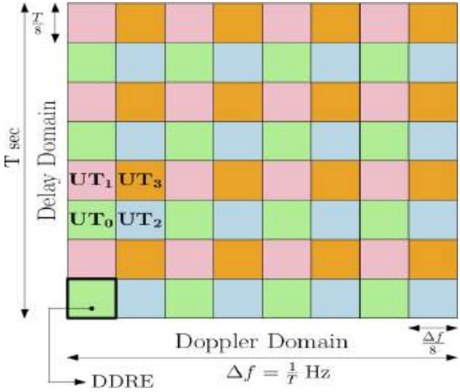
- Allocated MU resource separated by guard bands (GBs)
- GBs required to reduce MU interference (MUI)
- GBs are an overhead: Do not carry information

GBs along delay domain

- GBs along delay domain



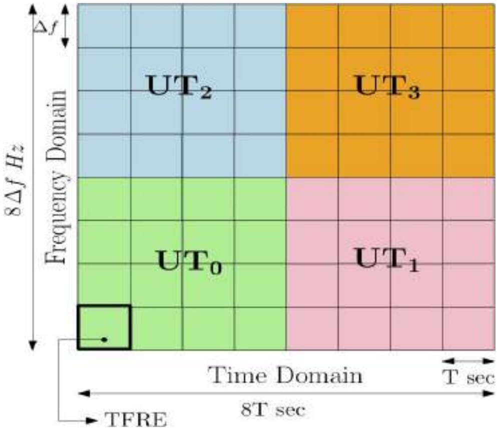
Interleaved DD domain MA (IDDMA)



- Each DD pulse has twice the delay and Doppler spread
- TF signal restricted to $\frac{1}{2\Delta f/N} \times \frac{1}{2T/M}$ i.e., $\frac{NT}{2} \times \frac{M\Delta f}{2}$

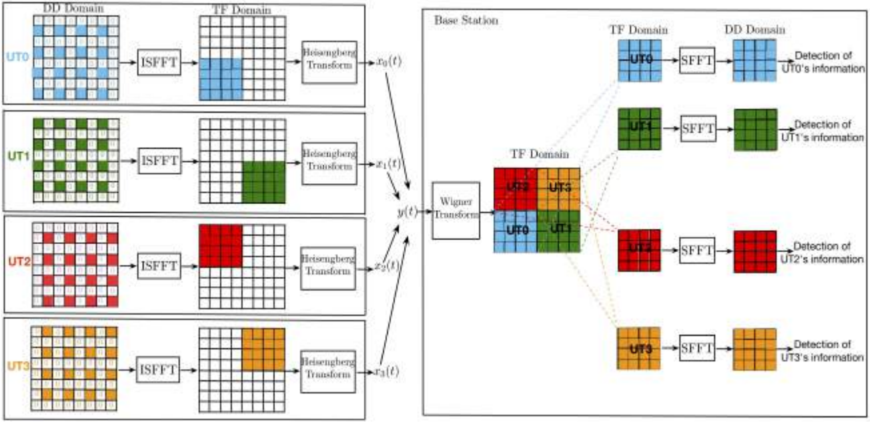
V. Khammammetti and S. K. Mohammed, "OTFS-Based Multiple-Access in High Doppler and Delay Spread Wireless Channels," IEEE Wireless Communications Letters, vol. 8, no. 2, pp. 528-531, April 2019.

Interleaved DD domain MA (IDDMA)



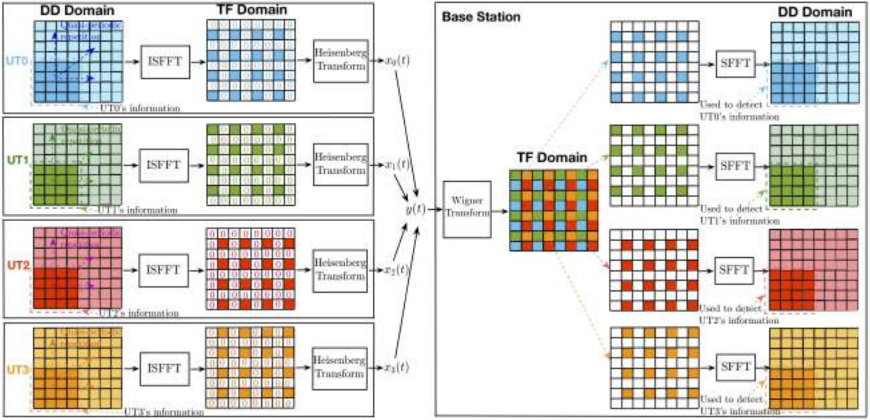
- Each UT is restricted to non-overlapping TFREs ($\frac{NT}{2} \times \frac{M\Delta f}{2}$)
- No guard band overhead

IDDMA



DD Domain
TF Domain
UT0
UT1
UT2
UT3
ISFFT
Heisengberg Transform
$x_0(t)$
$x_1(t)$
$x_2(t)$
$x_3(t)$
$y(t)$
Base Station
Wigner Transform
TF Domain
DD Domain
SFFT
Detection of UT0's information
Detection of UT1's information
Detection of UT2's information
Detection of UT3's information

Interleaved TF MA (ITFMA)



- Interleaved allocation in TF domain*
- No guard band overhead

*** R. M. Augustine and A. Chockalingam, "Interleaved Time-Frequency Multiple Access Using OTFS Modulation," 2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall), pp. 1-5, Sept. 2019.**

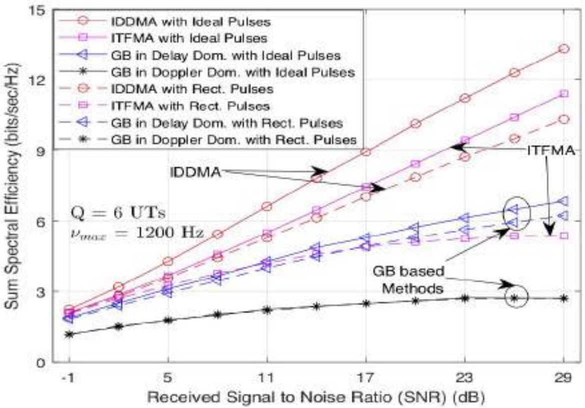
Spectral Efficiency (SE) performance comparison

- ETU channel model

Path no. i	1	2	3	4	5	6	7	8	9
Rel. Delay τ_i (μs)	0	0.05	0.12	0.2	0.23	0.5	1.6	2.3	5.0
Rel. Power $\frac{\mathbb{E}[\|h_i\|^2]}{\mathbb{E}[\|h_1\|^2]}$ (dB)	-1	-1	-1	0	0	0	-3	-5	-7

- Path Doppler shift: $\nu_i = \nu_{max} \cos(\theta_i)$, $\theta_i \sim$ i.i.d. Unif$([0\,,\,2\pi)])$
- Path channel gain: Rayleigh faded, $\sum_{i=1}^{9} \mathbb{E}[|h_i|^2] = 1$
- $\Delta f = 15$ KHz, $T = \frac{1}{\Delta f} = 66.66\,\mu s$
- Avg. Received SNR: Ratio of recvd. signal power from a UT to noise power at Rx $(M\,\Delta f\,N_0)$
- Q: No. of UTs, $N = M = 36$
- IDDMA: DD pulse delay domain spread $g_1\,T/M$, Doppler domain spread $g_2 \Delta f/N$, $Q = g_1 g_2$
- ITFMA: Repetition factors, g_3 along delay domain, g_4 along Doppler domain, $Q = g_3 g_4$

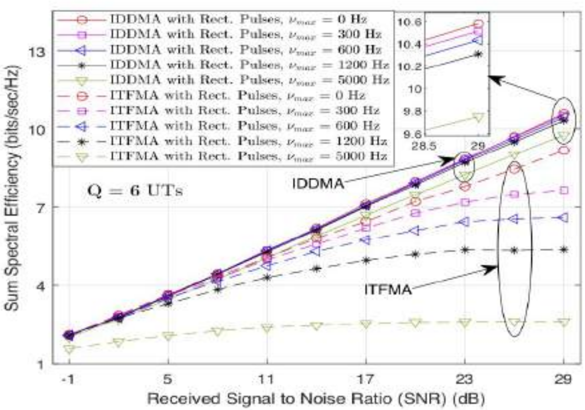
Sum SE: IDDMA vs. ITFMA vs. GBMA



- $g_1 = g_3 = 3, g_2 = g_4 = 2$
- IDDMA is better than both ITFMA and GBMA

V. Khammammetti and S. K. Mohammed, "Spectral Efficiency of OTFS Based Orthogonal Multiple Access With Rectangular Pulses," IEEE Trans. on Vehicular Technology, vol. 71, no. 12, Dec. 2022.

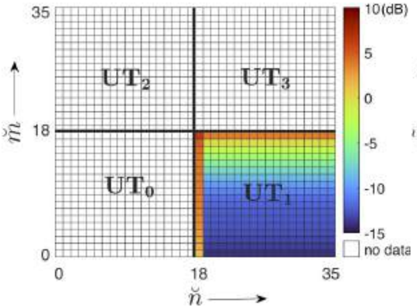
Sum SE: IDDMA vs. ITFMA



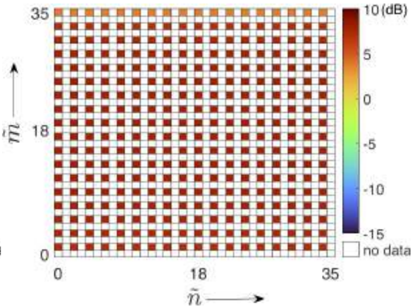
- $g_1 = g_3 = 3, g_2 = g_4 = 2$
- IDDMA is more robust to Doppler spread than both ITFMA and GBMA

V. Khammammetti and S. K. Mohammed, "Spectral Efficiency of OTFS Based Orthogonal Multiple Access With Rectangular Pulses," IEEE Trans. on Vehicular Technology, vol. 71, no. 12, Dec. 2022.

Why is IDDMA better than ITFMA?



(a) IDDMA



(b) ITFMA

- $g_1 = g_3 = 2, g_2 = g_4 = 2, \nu_{max} = 5$ KHz, $M = N = 36$
- Ratio of variance of MUI to that of useful signal in TF domain

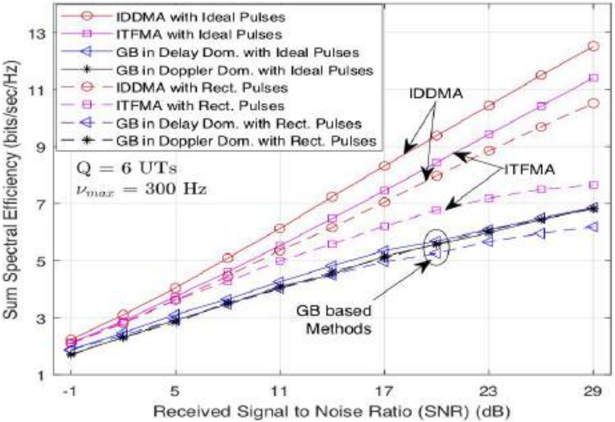
V. Khammammetti and S. K. Mohammed, "Spectral Efficiency of OTFS Based Orthogonal Multiple Access With Rectangular Pulses," IEEE Trans. on Vehicular Technology, vol. 71, no. 12, Dec. 2022.

Conclusions

- IDDMA is more robust to delay/Doppler spread than ITFMA and GBMA
  - GBMA: No information in guard bands
  - ITFMA: Experiences high MUI from neighbouring TFREs of other UTs
  - IDDMA: Contiguous allocation of TFREs, interior TFREs experience less MUI
- Next possibilities
  - Windowing to reduce the impact of MUI on boundary TFREs in IDDMA
  - Impact of channel estimation errors

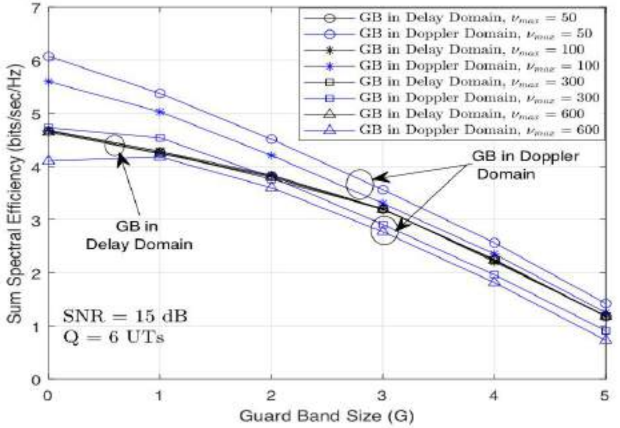
Thank you

Sum SE: IDDMA vs. ITFMA vs. GBMA (small ν_{max})



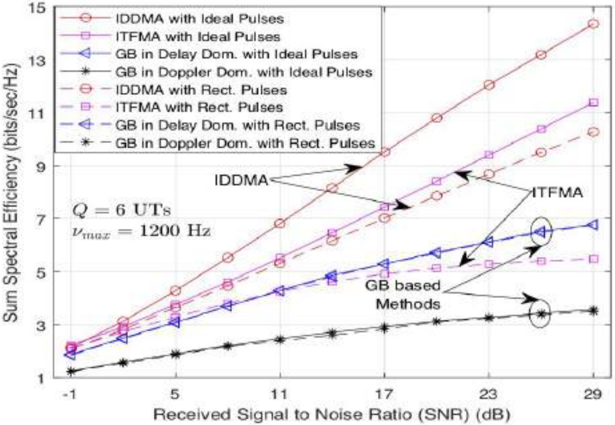
- $g_1 = g_3 = 3, g_2 = g_4 = 2$
- Small Doppler spread: IDDMA is better than ITFMA which is better than GBMA

GBMA (SE) vs. GB size (G)



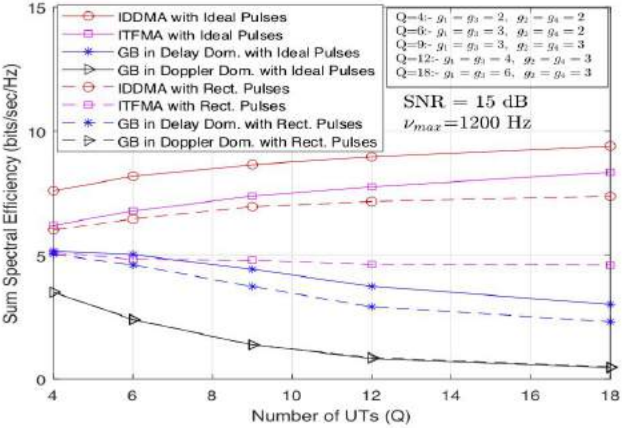
- Larger G → increase in overhead → reduction in SE

SE: large $N = 144$



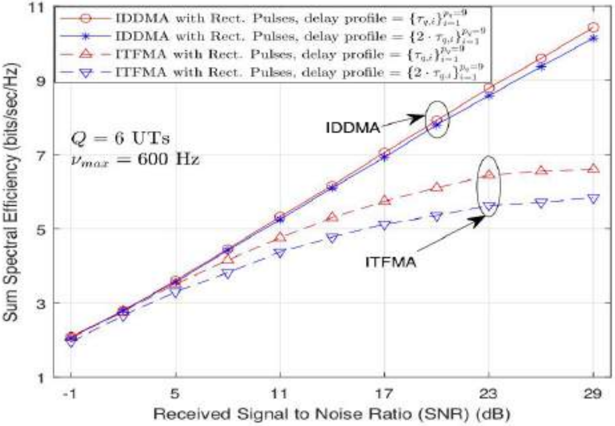
- Same observations as for $N = 36$

SE vs Q



- IDDMA, ITFMA: Sum SE almost constant with increasing Q

Impact of delay spread on SE



- IDDMA is more robust to increase in delay spread