Comparison of Limited Feedback Schemes for NOMA Transmission in mmWave Drone Networks

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Motivation

- Unmanned aerial vehicles (UAVs) can be used as aerial base stations (BSs) to deliver wireless connectivity during temporary events
- Since UAV-BSs are low power nodes, achieving higher energy efficiency (EE) and spectral efficiency (SE) are of paramount importance
- Further, efficient placement of UAV-BSs is important to reap the maximum capacity and coverage benefits

UAV-BSs serving during a fire

UAV-BSs serving at a stadium

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Objectives

- Introduce ***non-orthogonal multiple access*** (NOMA) to UAVs for hot spot scenario
- Introduce NOMA ***beamforming*** to serve multiple users within single UAV beam
- Understand NOMA performance with angle, distance feedbacks
- Understand NOMA performance with different ordering criteria for ***angle feedback***
- Investigate the impact of user region geometry on the NOMA feedback scheme

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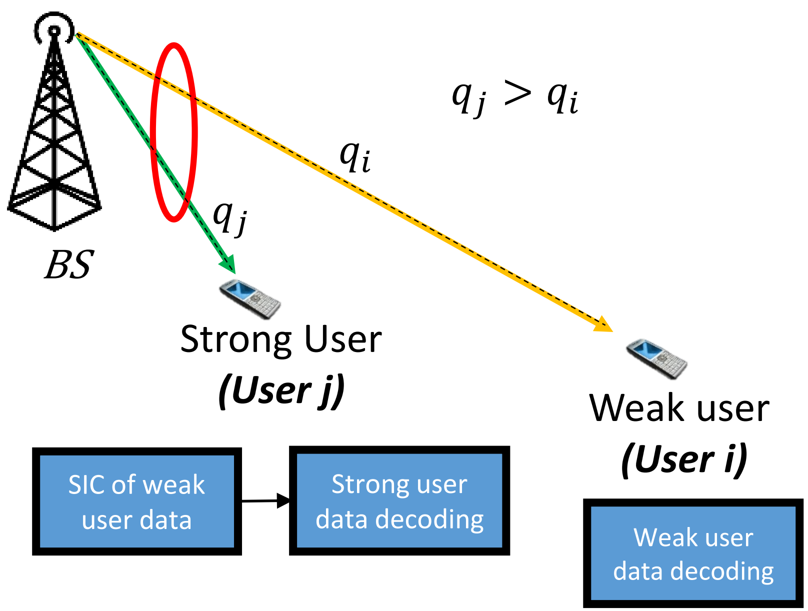
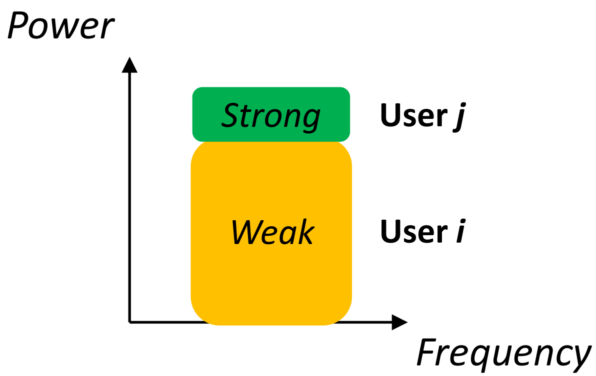
Non-Orthogonal Multiple Access (NOMA)

DL NOMA transmission

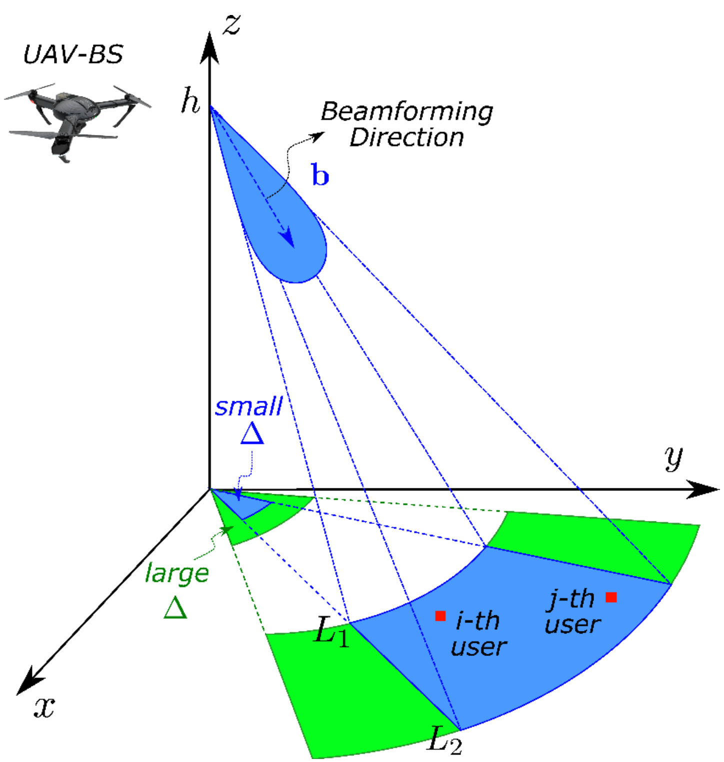


- BS superposes messages of both users together and generate DL signal



- Strong user first perform **successive-interference-cancellation** (SIC) and then decodes his data
- Weak user directly decodes his data considering strong user's data as noise

System Model



3D footprint of the beam generated by UAV-BS

- Each UAV-BS: M elements array, Each MS: single antenna
- User region : Δ, L_1, L_2 with K users
- User set, $\mathcal{N}_{\mathrm{U}} = \{1, \cdots K\}$
- Users are distributed following a HPPP
- MISO channel vector, $\boldsymbol{h}_k$ $(M \times 1)$ between UAV-BS and k-th MS in user region:

$$\mathbf{h}_k = \sqrt{M} \frac{\alpha_k \mathbf{a}(\theta_k)}{\sqrt{\mathrm{PL}\left(\sqrt{d_k^2 + h^2}\right)}}$$

α_k: Complex gain of line of sight (LoS) path

θ_k: Angle-of-departure

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NOMA Operation with Beamforming

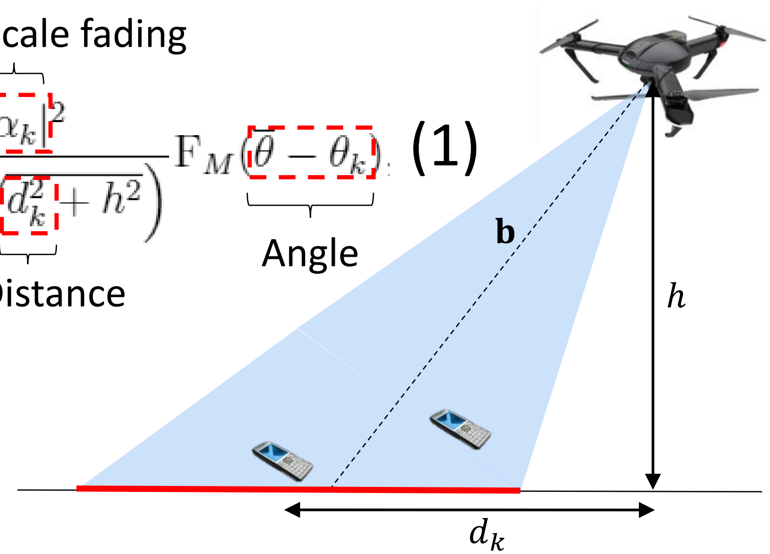
- UAV-BS generates beam **b** = $\boldsymbol{\alpha}(\bar{\boldsymbol{\theta}})$ with AoD, $\bar{\theta} \epsilon \{0, 2\pi\}$
- k-th user's effective channel gain $\left|\mathbf{h}_k^{\mathrm{H}}\mathbf{b}\right|^2$, with respect to UAV-BS beam **b** is

Small scale fading

$$|\mathbf{h}_k^{\mathrm{H}}\mathbf{b}|^2 \approx \frac{|\alpha_k|^2}{M \times \mathrm{PL}\left(\sqrt{d_k^2 + h^2}\right)} \left| \frac{\sin\left(\frac{\pi M(\bar{\theta}-\theta_k)}{2}\right)}{\sin\left(\frac{\pi(\bar{\theta}-\theta_k)}{2}\right)} \right|^2 = \frac{|\alpha_k|^2}{\mathrm{PL}\left(\sqrt{d_k^2 + h^2}\right)} \mathrm{F}_M(\bar{\theta} - \theta_k). \quad (1)$$

Distance Angle

$\mathrm{F}_M(\cdot)$: Fejer-Kernel



- Effective channel gain is a measure of the channel quality

NOMA for UAV-BS Downlink (1)

- Users are ordered from best to worst w.r.t their channel quality based on some criteria

$$q_1 > q_2 \cdots > q_K \quad (2)$$

- UAV-BS transmits signal **x**, by superposing messages of $\mathcal{N}_{\mathrm{N}} \subset \mathcal{N}_{\mathrm{U}}$ NOMA users

$$\mathbf{x} = \sqrt{P_{\mathrm{Tx}}}\mathbf{b} \sum_{k \in \mathcal{N}_{\mathrm{N}}} \beta_k s_k \quad (3)$$

β_k : k-th user power allocation coefficient

s_k : k-th user message

P_{Tx} : Transmit power

- k-th user receives signal y_k in the downlink

$$y_k = \mathbf{h}_k^{\mathrm{H}}\mathbf{x} + v_k = \sqrt{P_{\mathrm{Tx}}}\mathbf{h}_k^{\mathrm{H}}\mathbf{b} \sum_{k \in \mathcal{N}_{\mathrm{N}}} \beta_k s_k + v_k \quad (4)$$

v_k : Noise at k-th user

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NOMA for UAV-BS Downlink (2)

- k-th user, first SIC and then decode its data

$$\mathrm{SINR}_{m\rightarrow k} = \frac{P_{\mathrm{Tx}}|\mathbf{h}_k^{\mathrm{H}}\mathbf{b}|^2\beta_m^2}{P_{\mathrm{Tx}}\sum\limits_{l<m,\, l\in\mathcal{N}_{\mathrm{N}}}|\mathbf{h}_k^{\mathrm{H}}\mathbf{b}|^2\beta_l^2 + N_0} \quad (5)$$

- Assuming each user has a ***quality-of-service (QoS) based target rate*** $\overline{\boldsymbol{R}}_{\boldsymbol{k}}$, outage probability at k-th user can be given as

$$\mathrm{P}^o_{k|\mathcal{S}_K} = 1 - \Pr\left(\bigcap_{l\geq k,\, l\in\mathcal{N}_{\mathrm{N}}} R_{l\rightarrow k} > \overline{R}_l \,\middle|\, \mathcal{S}_K\right) = 1 - \Pr\left(\bigcap_{l\geq k,\, l\in\mathcal{N}_{\mathrm{N}}} \mathrm{SINR}_{l\rightarrow k} > \epsilon_l \,\middle|\, \mathcal{S}_K\right) \quad (6)$$

where $\epsilon_k = 2^{\bar{R}_k} - 1$ and $\mathcal{S}_K$ captures given condition on K

- Outage sum rate when $\mathcal{S}_K$ denotes range of integers

$$R^{\mathrm{NOMA}} = \sum_{\tau\geq 2}\Pr\{\mathcal{S}_{K_\tau}\}\sum_{k\in\mathcal{N}_{\mathrm{N}}}(1-\mathrm{P}^o_{k|\mathcal{S}_{K_\tau}})\overline{R}_k = \sum_{k\in\mathcal{N}_{\mathrm{N}}}(1-\mathrm{P}^o_k)\overline{R}_k \quad (7)$$

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Limited Feedback and User Ordering Strategy for NOMA

- We consider two limited feedback schemes as captured in (1)
  - Distance
  - Angle with respect to boresight direction of the beam

- Based on above feedback schemes, three user ordering strategies are considered
  - Distance based ordering: $d_1 \leq d_2 \leq \cdots \leq d_K$
  - Fejer-Kernel based ordering: $\mathrm{F}_M(\theta_1) \geq \mathrm{F}_M(\theta_2) \geq \cdots \geq \mathrm{F}_M(\theta_K)$
  - Absolute angle based ordering: $\tilde{\theta}_1 \leq \tilde{\theta}_2 \leq \cdots \leq \tilde{\theta}_K$ where $\tilde{\theta}_k = |\bar{\theta} - \theta_k|$

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Outage Probability with Limited Feedback

- Outage probability in (6) can be given as,

$$P^{o}_{k|\mathcal{S}_K} = P\left\{\left|\boldsymbol{h}_k^{2}\boldsymbol{b}\right|^2 < x\right\} = \int_{u_{\min}}^{u_{\max}} \int_{L_1}^{L_2} P\left\{\left|\boldsymbol{h}_k^{2}\boldsymbol{b}\right|^2 < x \mid d_k, \theta_k\right\} f_{d_k,\theta_k}(d,\theta)\, dd\, d\theta, \quad (8)$$

The distance and angle of an arbitrary user are statistically independent of each other

$$P^{o}_{k} = \int_{u_{\min}}^{u_{\max}} \int_{L_1}^{L_2} P\left\{\left|\boldsymbol{h}_k^{2}\boldsymbol{b}\right|^2 < x \mid r, \theta\right\} f_{d_k}(r) f_{\theta_k}(\theta)\, dr d\theta \quad (9)$$

- $f_{d_k}(r)$, $f_{\theta_k}(\theta)$ under different ordering criteria have been derived to evaluate outage probabilities analytically using (9)

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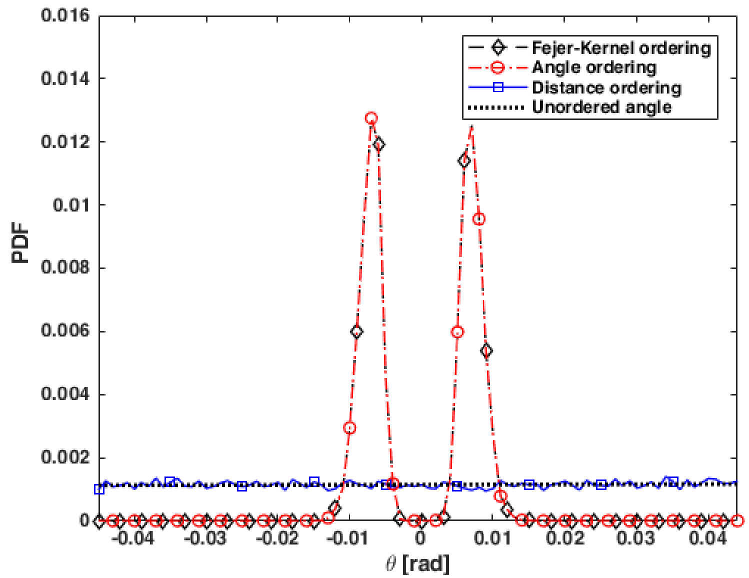
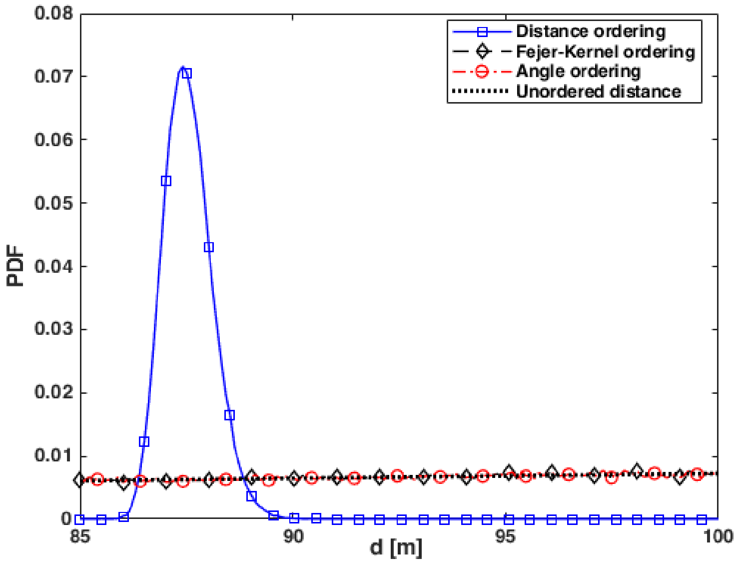
Impact of Ordering Strategy on Distance and Angle Distributions

- When the user ordering criteria is a function of a particular variable, that variable alters its unordered original distribution
- The other variable(s) follows its unordered original distribution



PDFs of angle distribution



PDFs of distance distribution

Ordered k-th user angle and distance distribution ($k = 20$)

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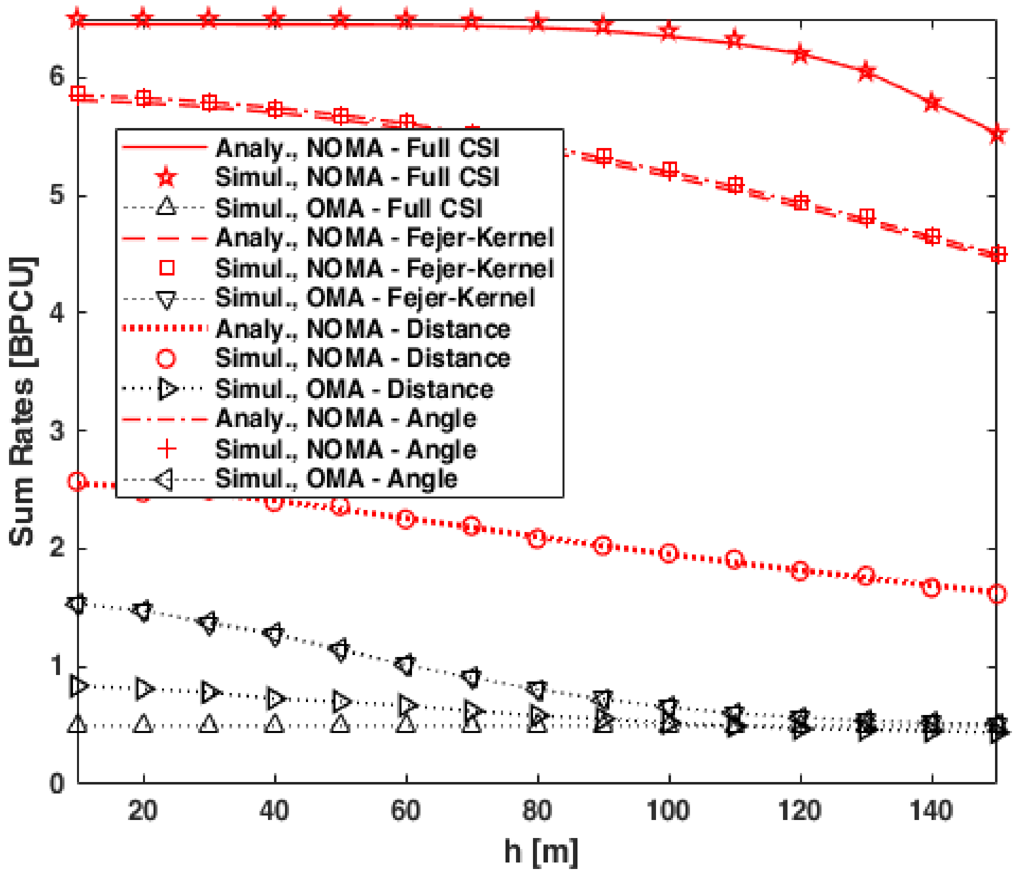
Simulation Settings

Parameter	Value
User distribution	Uniform
Outer radius, L_2	100 m
Inner radius, L_1	85 m
Horizontal angular width, Δ	$1^\circ, 5^\circ$
Vertical beamwidth, φ_e	28°
HPPP density, λ	1
Number of BS antennas, M	100
Noise, N_0	-35 dBm
Path-loss exponent, γ	2
jth user target rate, $\overline{R}_j$	6 BPCU
ith user target rate, $\overline{R}_j$	0.5 BPCU
jth user power allocation, β_j^2	0.25
ith user power allocation, β_i^2	0.75
UAV-BS operation altitude, h	10 m - 150 m

Two users are considered for NOMA transmission

We compare NOMA performance with orthogonal multiple access (OMA)

Sum Rates: NOMA vs OMA



Sum rates variation: j=20, i=25, $\Delta = 5$ deg

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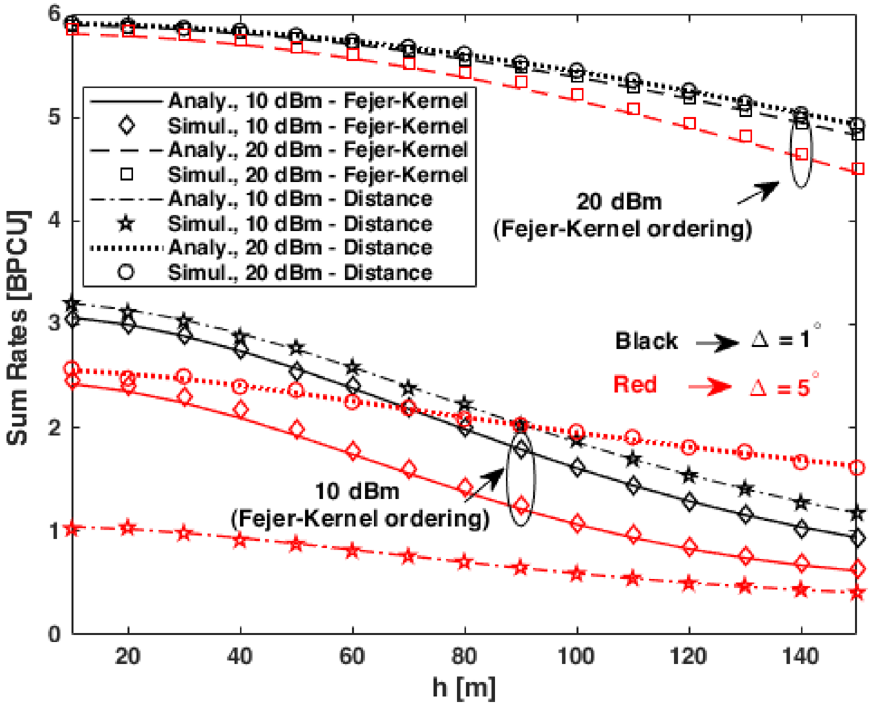
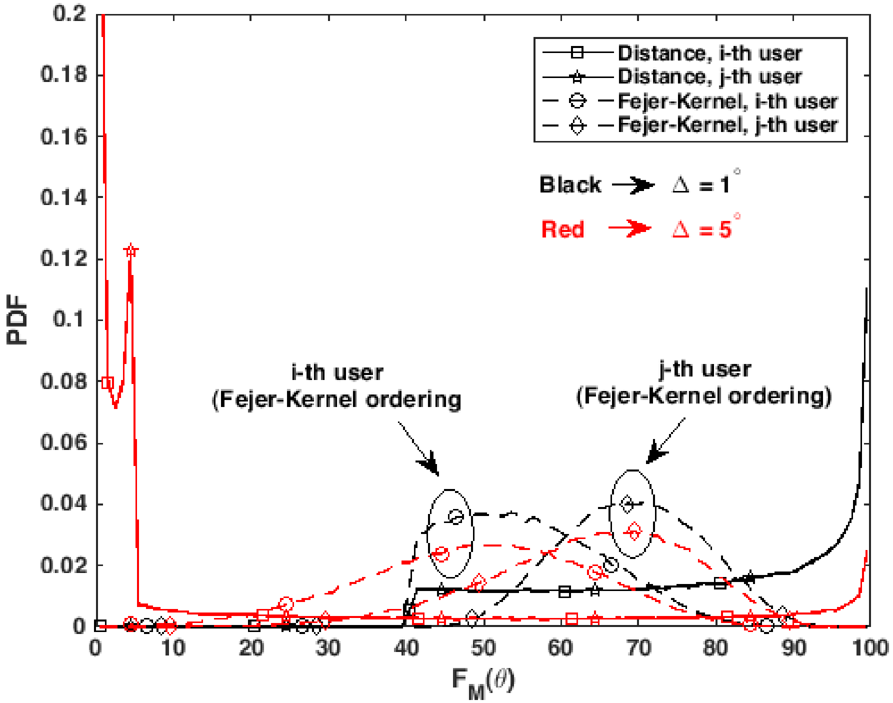
Sum Rates: Fejer-Kernel and Distance based Ordering



Sum rates variation: j=20, i=25



PDFs of Fejer-Kernel distribution

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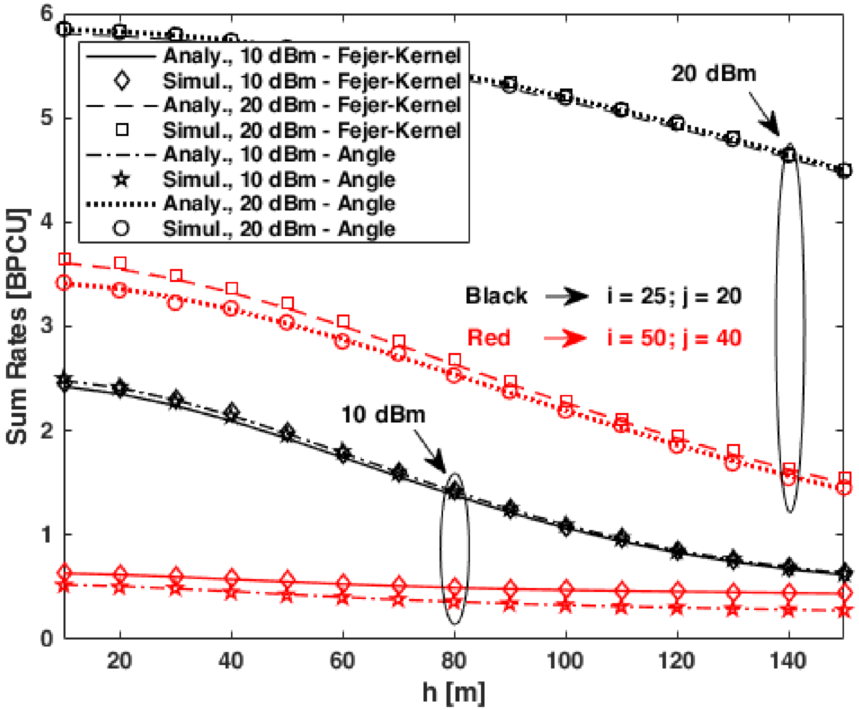
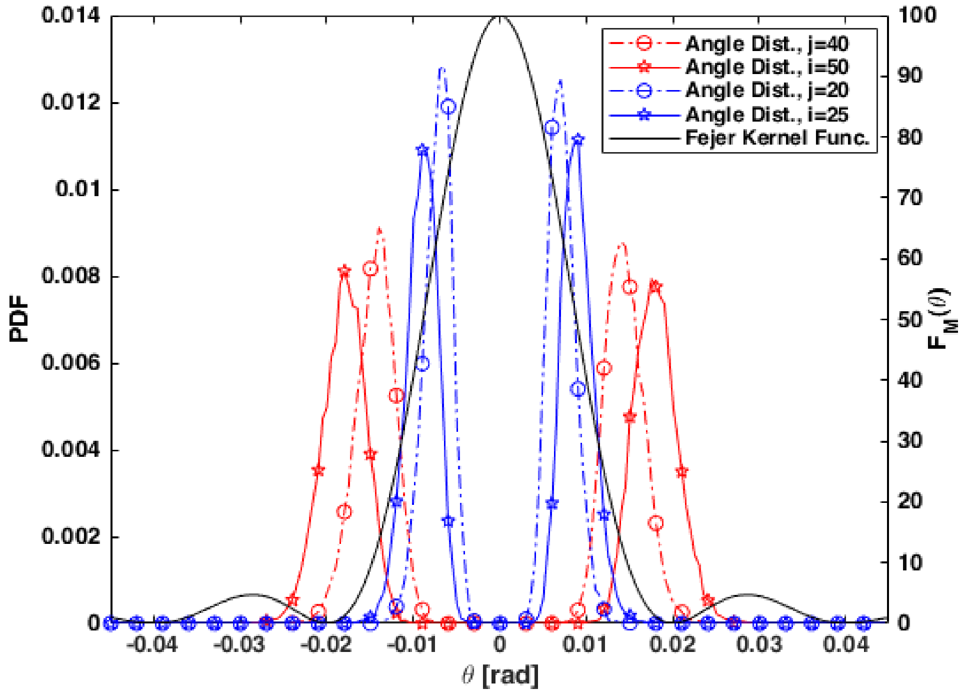
Sum Rates: Angle and Fejer-Kernel based Ordering

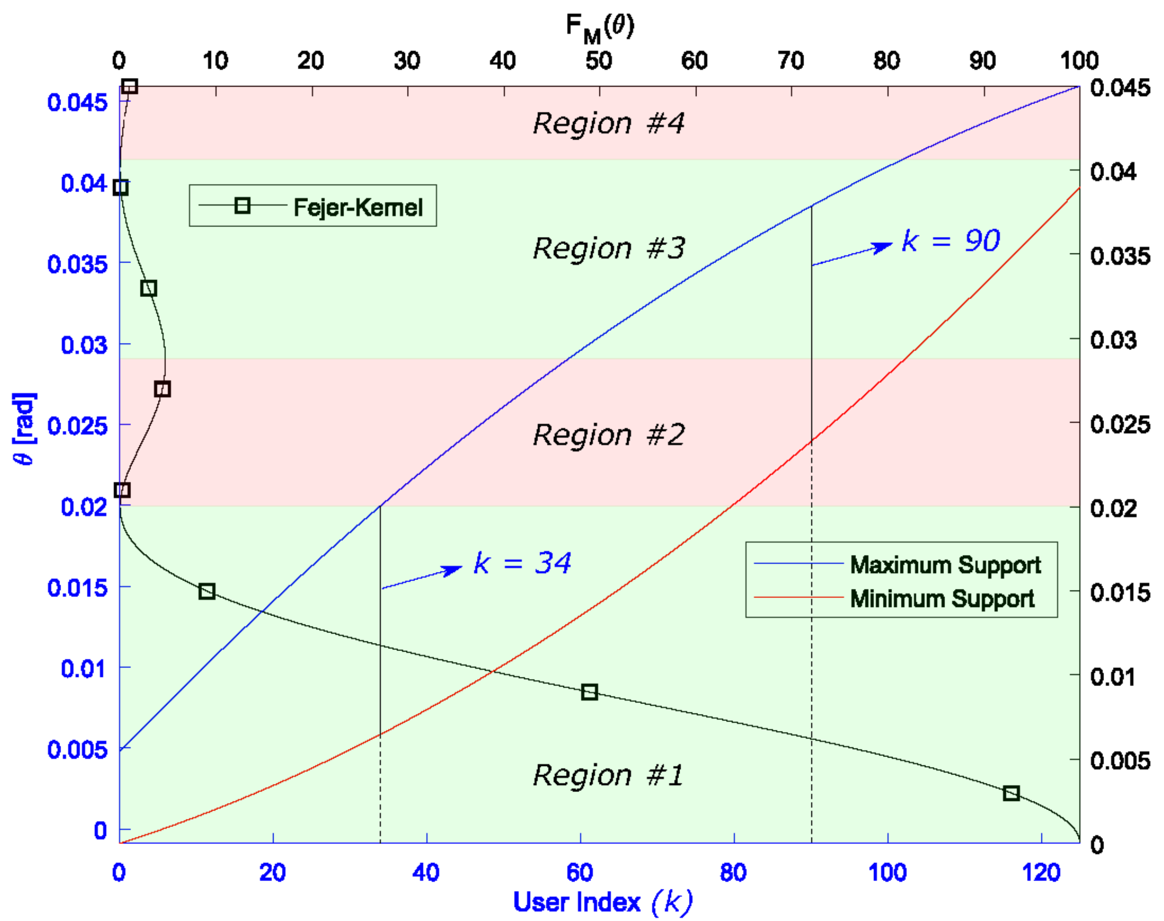


Sum rates variation: $\Delta = 5$ deg



PDFs of Angle Distribution

Variation of the Support of Angle PDFs



Support of the user angle PDFs: $K = 125$

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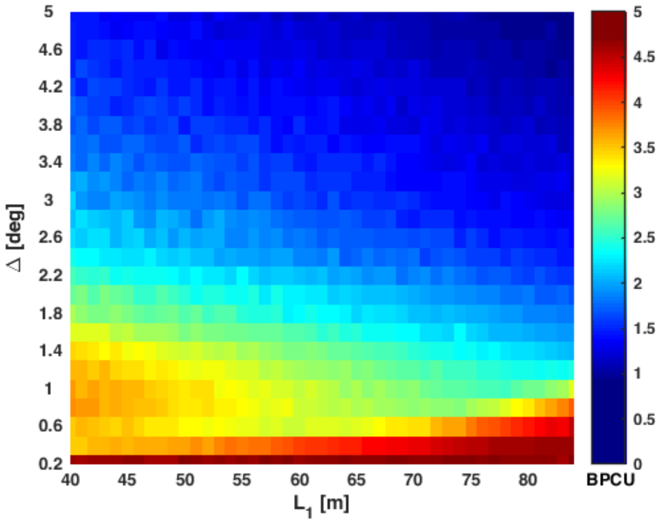
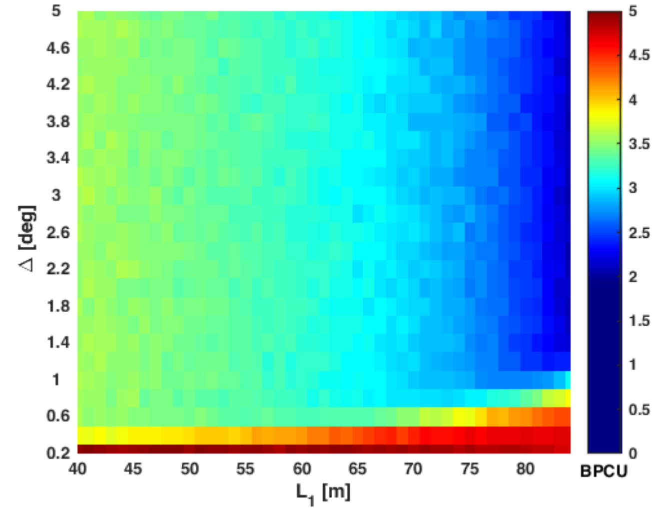
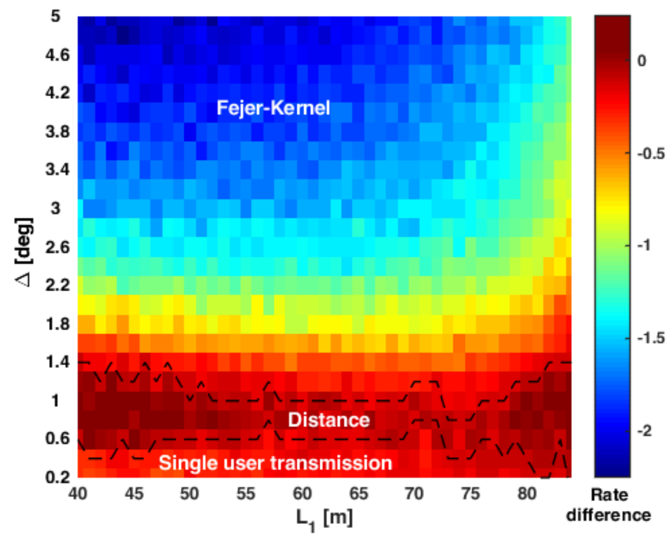
Sum Rates Variation with User Region Geometry



Distance ordering



Fejer-Kernel ordering



Rate difference (Distance-Fejer-Kernel)

Sum rates with different user region geometries:
$h = 50\ \mathrm{m}, P_{\mathrm{Tx}} = 10\ \mathrm{dBm}$

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Conclusion

- NOMA with beamforming enhances spectral efficiency of UAV-BSs
- NOMA with angle, distance feedback provide better sum rates compared to OMA
- Feedback scheme for NOMA needs to be determined considering user region geometry
- If Fejer-Kernel function is monotonically varying over the angle support of NOMA users, both Fejer-Kernel and angle based ordering provide similar sum rates

- **N. Rupasinghe**, Y. Yapici, I. Guvenc and Y. Kakishima, 'Non-Orthogonal Multiple Aceess for mmWave Drone Networks with Limited Feedback', *arXiv: https://arxiv.org/pdf/1801.04504.pdf*
- **N. Rupasinghe**, Y. Yapici, I. Guvenc and Y. Kakishima, 'Comparison of Different Feedback Schemes for NOMA Transmission in mmWave Drone Networks', *arXiv: https://arxiv.org/pdf/1803.04265.pdf*

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