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RESOURCE MANAGEMENT IN THE MULTIBEAM NOMA-BASED SATELLITE DOWNLINK

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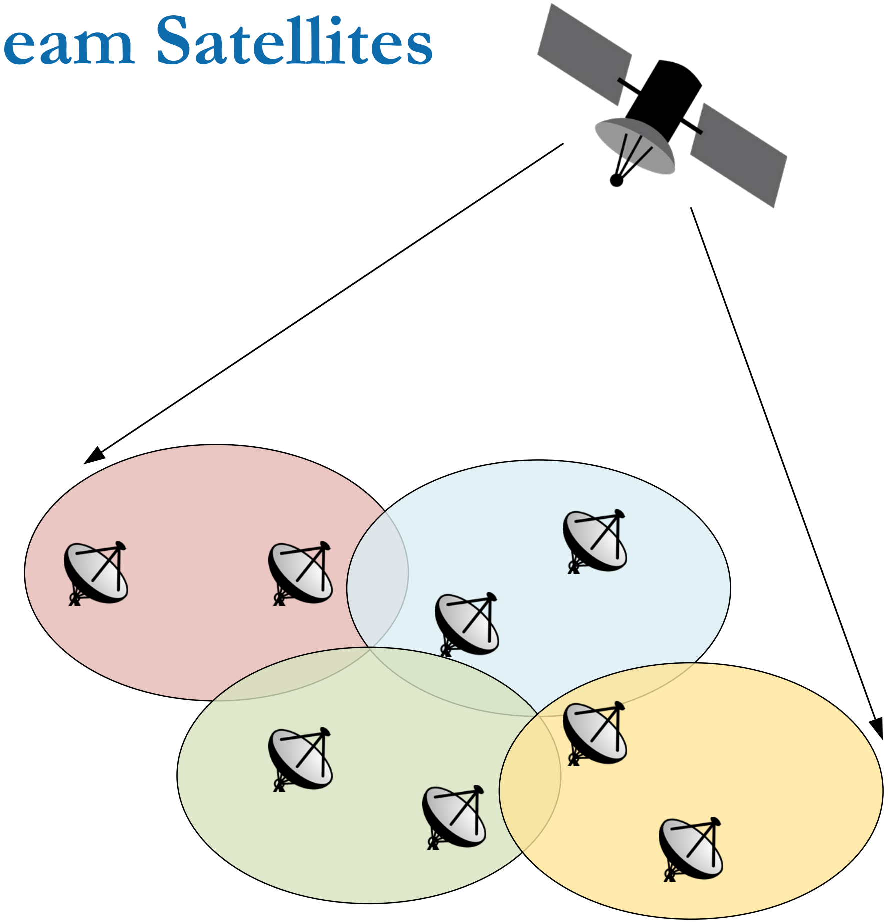
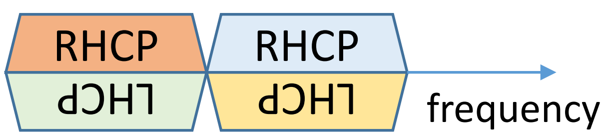
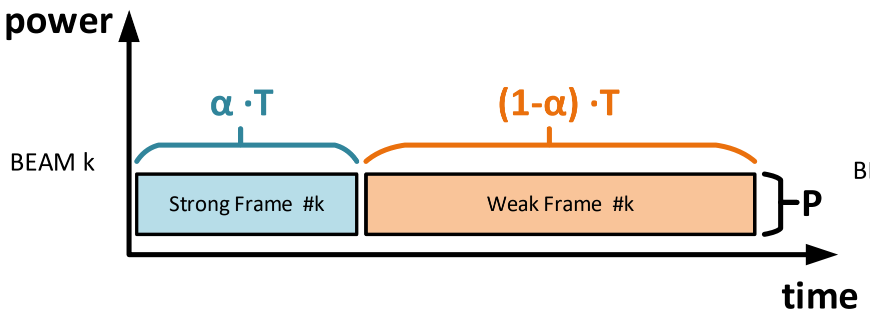
Introduction to Multibeam Satellites



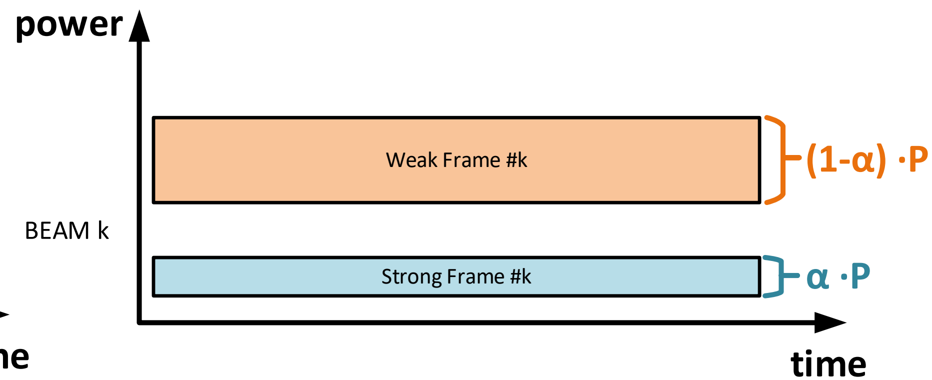
Neighbor beams use different spectral resources to minimize co-channel interference



Introduction to Non-Orthogonal Multiple Access

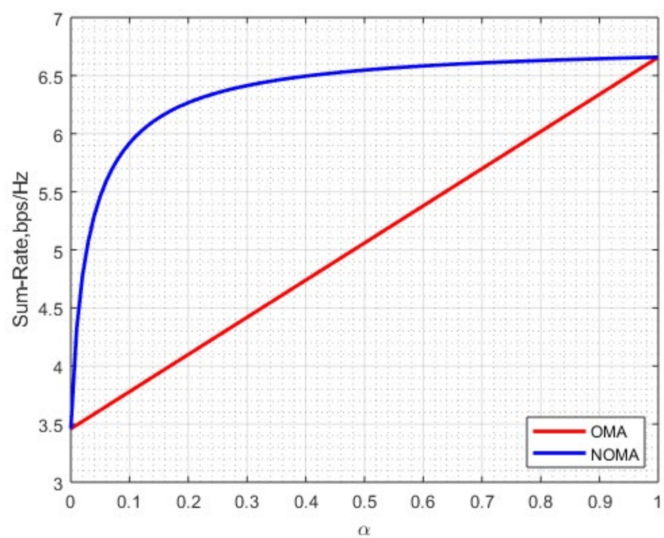


ORTHOGONAL MULTIPLE ACCESS (OMA)



NON-ORTHOGONAL MULTIPLE ACCESS (NOMA)

More efficient rate allocation

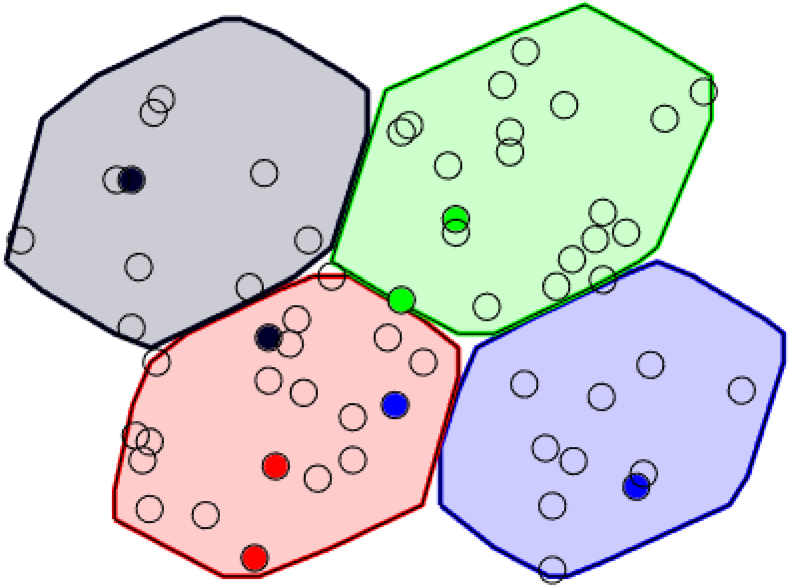


SNR1= 20 dB
(Strong user)

SNR2= 10 dB
(Weak user)

Objective

- GOAL: Improve the user rate metrics with traditional payloads
- BY MEANS OF: Resource pulling, with donor and recipient beams
- MAKING USE OF: Downlink NOMA
- THANKS TO: SNR unbalances due to beam radiation patterns



System Description

- Multibeam satellite system with **M beams** and **K users** across the coverage with **K > M**
- A four colour reuse scheme
- One **resource** per beam (frequency channel + polarization)
- Each user can only use one resource at a time
- Fixed duration V time transmission slots, two users max per slot and resource (color)
- **Downlink**

Optimization Problem

- **Proportional fair scheduling (PFS)** is employed for fair resource allocation to users
- The PFS system metric to maximize at each time slot is given by

$$F(t) = \sum_{k=1}^{K} \frac{r_k(t)}{R_k(t)} = \sum_{k=1}^{K} w_k(t) r_k(t)$$

with $r_k(t)$ and $R_k(t)$ the instantaneous rate and the PFS long-term rate of the *k-th* user.

Optimization problem: maximization of **the weighted sum-rate with user rates weights given by the PFS policy**

Optimization Problem

- **Achievable rates (for available bandwidth per beam *W*)**

OMA:

$$r_k^m = W \cdot \alpha_{kp}^m \cdot \log_2(1 + \mathrm{SNR}_k^m)$$
$$r_p^m = W \cdot (1 - \alpha_{kp}^m) \cdot \log_2(1 + \mathrm{SNR}_p^m)$$

r_k^m: achievable rate by user *k* when served by the *m*th beam

NOMA:

$$r_k^m = W \cdot \log_2(1 + \alpha_{kp}^m \, \mathrm{SNR}_k^m)$$
$$r_p^m = W \cdot \log_2\left(\frac{1 + \mathrm{SNR}_p^m}{1 + \alpha_{kp}^m \, \mathrm{SNR}_p^m}\right)$$
$$SNR_k^m \geq SNR_p^m$$

- **Optimization problem:**

u_{kp}^m : scheduling variable, equal to 1 if both *k*th and *p*th users are paired and assigned to the *m*th beam

$$\max_{u_{kp}^m, r_k^m, r_p^m} \sum_{m=1}^{M} \sum_{k=1}^{K} \sum_{p=1}^{K} u_{kp}^m (w_k r_k^m + w_p r_p^m)$$
$$\text{s. to } u_{kp}^m \in \{0,1\} \; ; \forall \, k, p, m$$
$$\mathrm{A1} : \sum_{k=1}^{K} \sum_{p=1}^{K} u_{kp}^m = 1 \, , \forall m$$
$$\mathrm{A2} : \sum_{m=1}^{M} \sum_{k=1}^{K} u_{kp}^m \leq 1 \, , \forall p, m$$
$$\mathrm{A3} : \sum_{m=1}^{M} \sum_{p=1}^{K} u_{kp}^m \leq 1 \, , \forall k, m$$

Power constraint per feed allows to split the problem into
- **Rate optimization for a given pair**
- **Scheduling and pairing**

Optimization Problem: OMA

- **Rate optimization:**
  - The maximization of WSR results in allocating the whole slot to a given user
- **Resource allocation:**
  - The optimization problem boils down to a **matching problem**
  - The **optimal solution** can be achieved through the **Hungarian algorithm**

$$\max_{u_k} \sum_{m=1}^{M} \sum_{k=1}^{K} u_k^m w_k r_k^m$$

$$\text{s. to } u_k^m \in \{0,1\} \; \forall\, k, m$$

$$r_k^m = W \cdot \log_2(1 + \mathrm{SNR}_k^m)$$

$$\mathrm{A1}: \sum_{k=1}^{K} u_k^m = 1\,, \forall m$$

$$\mathrm{A2}: \sum_{m=1}^{M} u_k^m \leq 1\,, \forall k.$$

Optimization Problem: NOMA

- **Rate optimization:**
  - Closed form expression for the optimum power allocation to maximize the WSR

1. $w_k \geq w_p,\ \alpha_{kp}^m = 1.$
2. $w_k < w_p,\ w_k\mathrm{SNR}_k < w_p\mathrm{SNR}_p,\ \alpha_{kp}^m = 0.$
3. $w_k < w_p,\ w_k\mathrm{SNR}_k \geq w_p\mathrm{SNR}_p,$

$$\alpha_{kp}^m = \min\left\{\frac{w_k\mathrm{SNR}_k^m - w_p\mathrm{SNR}_p^m}{\mathrm{SNR}_k^m\mathrm{SNR}_p^m(w_p - w_k)}, 1\right\}.$$

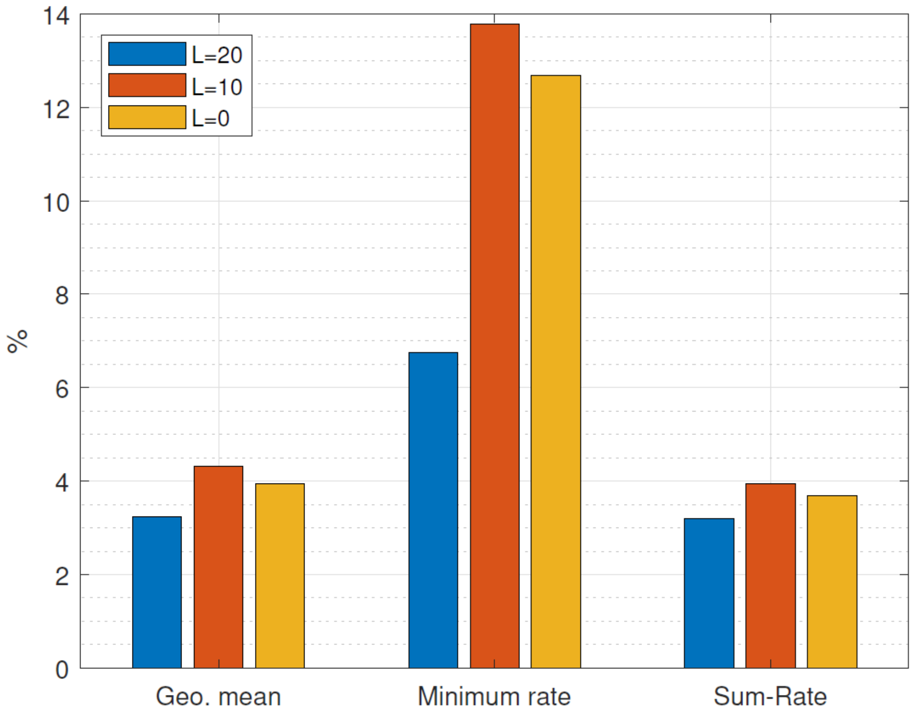
- **Resource allocation**
  - The resource assignment problem is **NP-Hard.**
  - For the case under study, each user can be only tuned to one carrier at a time.
  - We **resort to exhaustive search to obtain the results.**
  - **Suboptimal algorithms can be also devised.**

Simulation Scenario

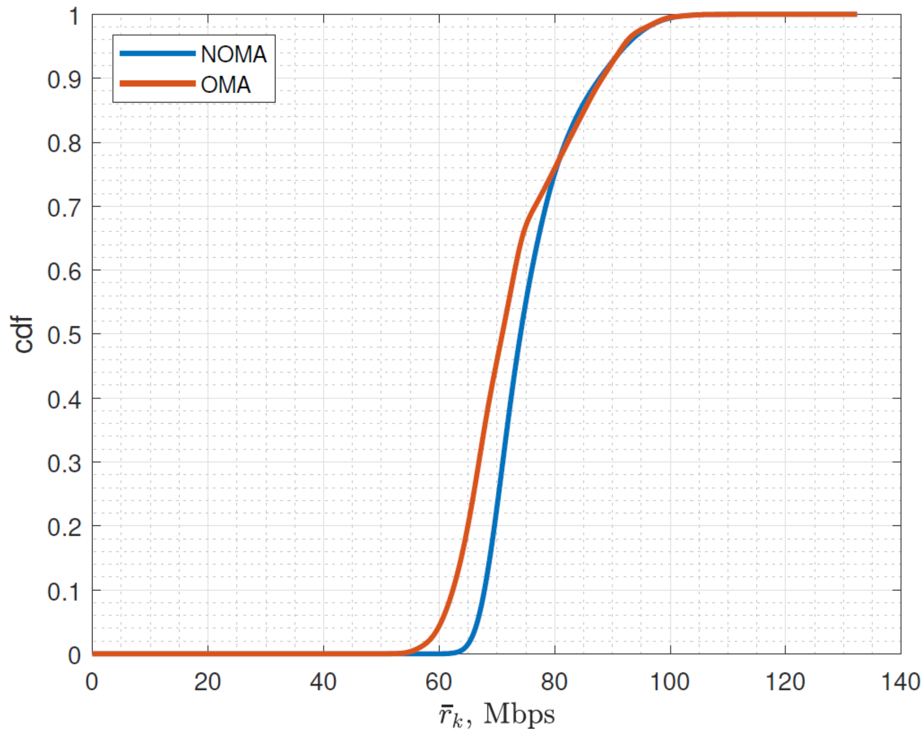
Number of beams	4
Diagram pattern	Provided by ESA
EIRP [dBW]	63
Frequency band [GHz]	20
Frequency coloring scheme	4
Number of polarizations	2
Total Bandwidth [MHz]	500
Terminal G/T [dB/K]	17.68
SIC at user terminal	Perfect
Traffic distribution	Uniform
User distribution within the beam	Uniform

- **Traffic imbalance**: To simulate an asymmetric traffic demand, half the beams will have 20 users and the remaining half **L users**
  - With **L=20** users we have a classical uniform user distribution
  - As L changes, the resource pulling is favoured
- Number of time slots **V = 300**, multiple transmissions per user are guaranteed
- **1200 Monte-Carlo** simulations

Numerical Results

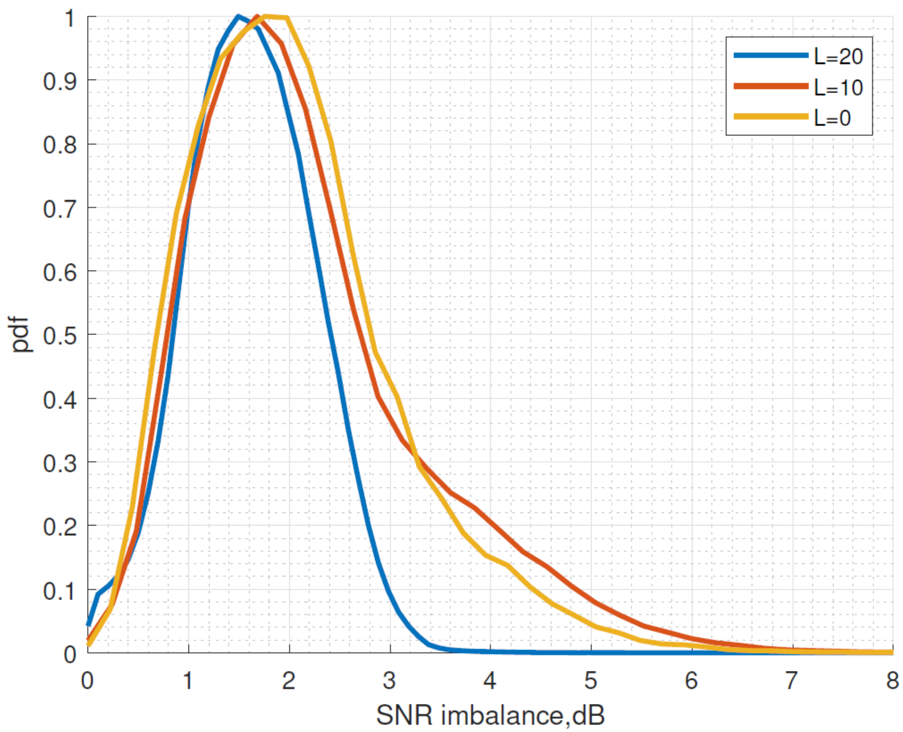


Improvement of NOMA over OMA

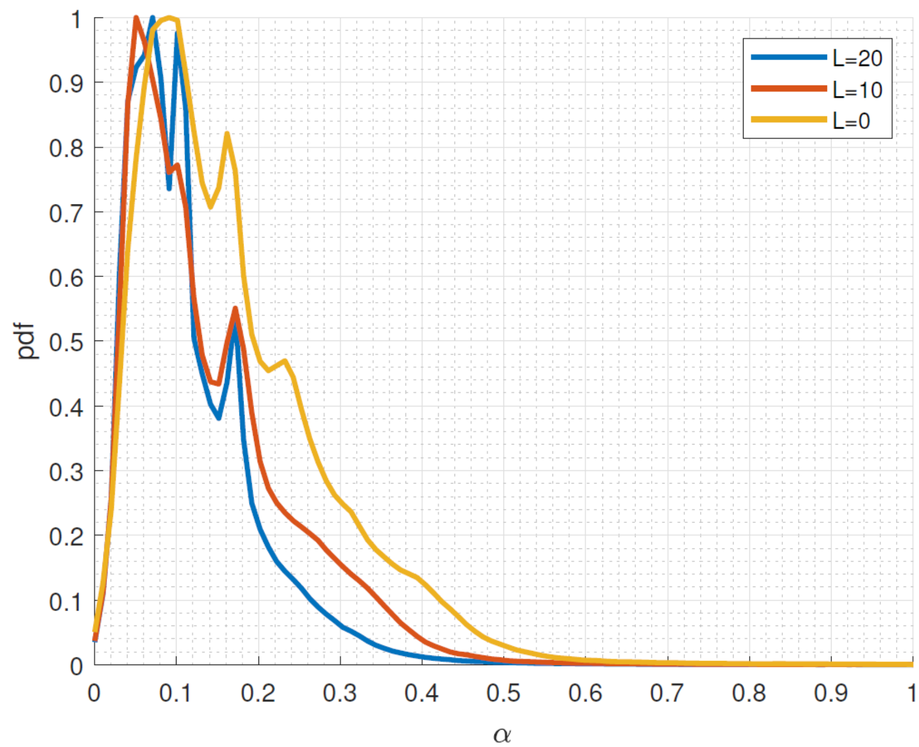


Cumulative distribution of the average rates for traffic symmetry of 50% (*L*=10)

Numerical Results



Probability distribution of the SNR imbalance within the pairs



Probability distribution of the power allocation in NOMA

Conclusions

- A beam free approach resource management has been presented, which makes use of resource pulling for resource allocation
- NOMA outperforms OMA, especially on the minimum rate of the coverage, by exploiting the non-uniform SNR distribution
- Conventional satellite payloads apply, users need to apply one stage of interference cancellation.
- Further improvements would come naturally from the coexistence of high gain and low gain terminals, for example due to different antenna sizes.

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ACK

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