FACULTY OF ENGINEERING AND ARCHITECTURE

SYMBOL-ASYNCHRONOUS TRANSMISSION IN MULTIBEAM SATELLITE USER DOWN-LINK: RATE REGIONS FOR NOVEL SUPERPOSITION CODING SCHEMES

N. Noels, M. Moeneclaey, T. Ramírez, C. Mosquera, M. Caus, A. Pastore

GHENT UNIVERSITY

AtlantTIC
Research Center for
Information & Communication Technologies

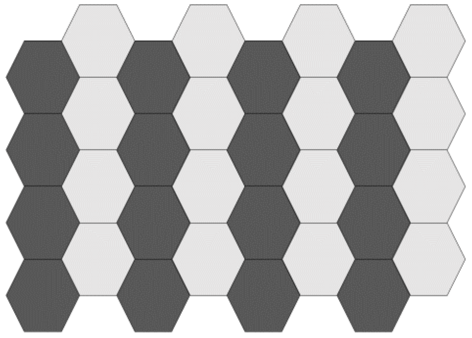
CTTC
Centre Tecnològic de Telecomunicacions de Catalunya

SATNEX IV

esa

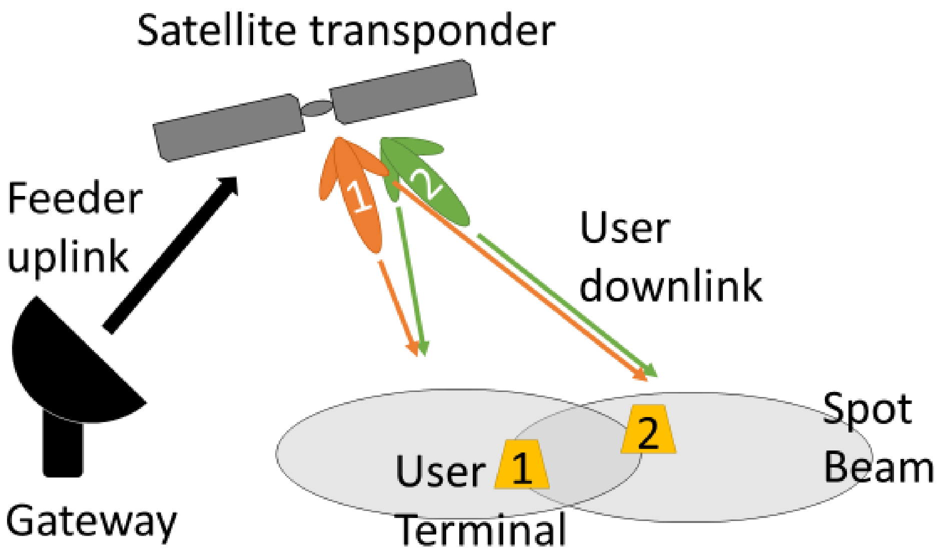
MULTIBEAM SATELLITE USER DOWNLINK

- 5G Satellite Networks envisage very high throughput demands
- Multibeam systems with very high spectral reuse
- Co-channel interference becomes major issue



Forward link

1. Precoding at gateway
2. MUD at user terminal
3. Novel intermediate approach
   - SC-SCD
   - NCRS



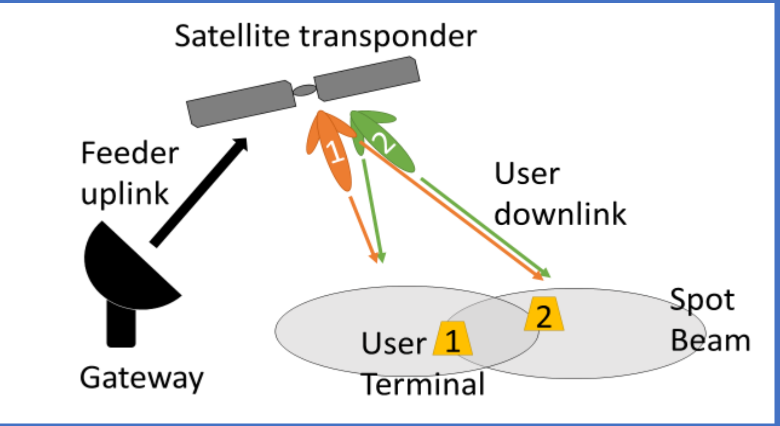
TRANSCEIVER STRATEGIES

- M. Caus, A. Pastore, M. Navarro, T. Ramírez, C. Mosquera, N. Noels, N. Alagha, and A. I. Perez-Neira, "EXPLORATORY ANALYSIS OF SUPERPOSITION CODING AND RATE SPLITTING FOR MULTIBEAM SATELLITE SYSTEMS," in *Proc. 15th Int. Symp. Wireless Commun. Syst.*, Lisbon, Portugal, Aug. 2018.

- T. Ramírez, C. Mosquera, M. Caus, A. Pastore, M. Navarro, and N. Noels, "MESSAGE SPLITTING FOR INTERFERENCE CANCELLATION IN MULTIBEAM SATELLITE SYSTEMS," in *Proc. 9th Advanced Satellite Multimedia Syst. Conf. (ASMS)*, Berlin, Germany, Sept. 2018.

- T. Ramírez, C. Mosquera, M. Caus, A. Pastore, N. Alagha, and N. Noels, "ADJACENT BEAMS RESOURCE SHARING TO SERVE HOT-SPOTS: A RATE-SPLITTING APPROACH," in *Proc. 36th Int. Commun. Satellite Syst. Conf. (ICSSC)*, Niagara Falls, Canada, Oct. 2018.

- Achievable rates analysis under Gaussian signaling, system level simulations.
- Time offset between cooperating beam signals…Implications?

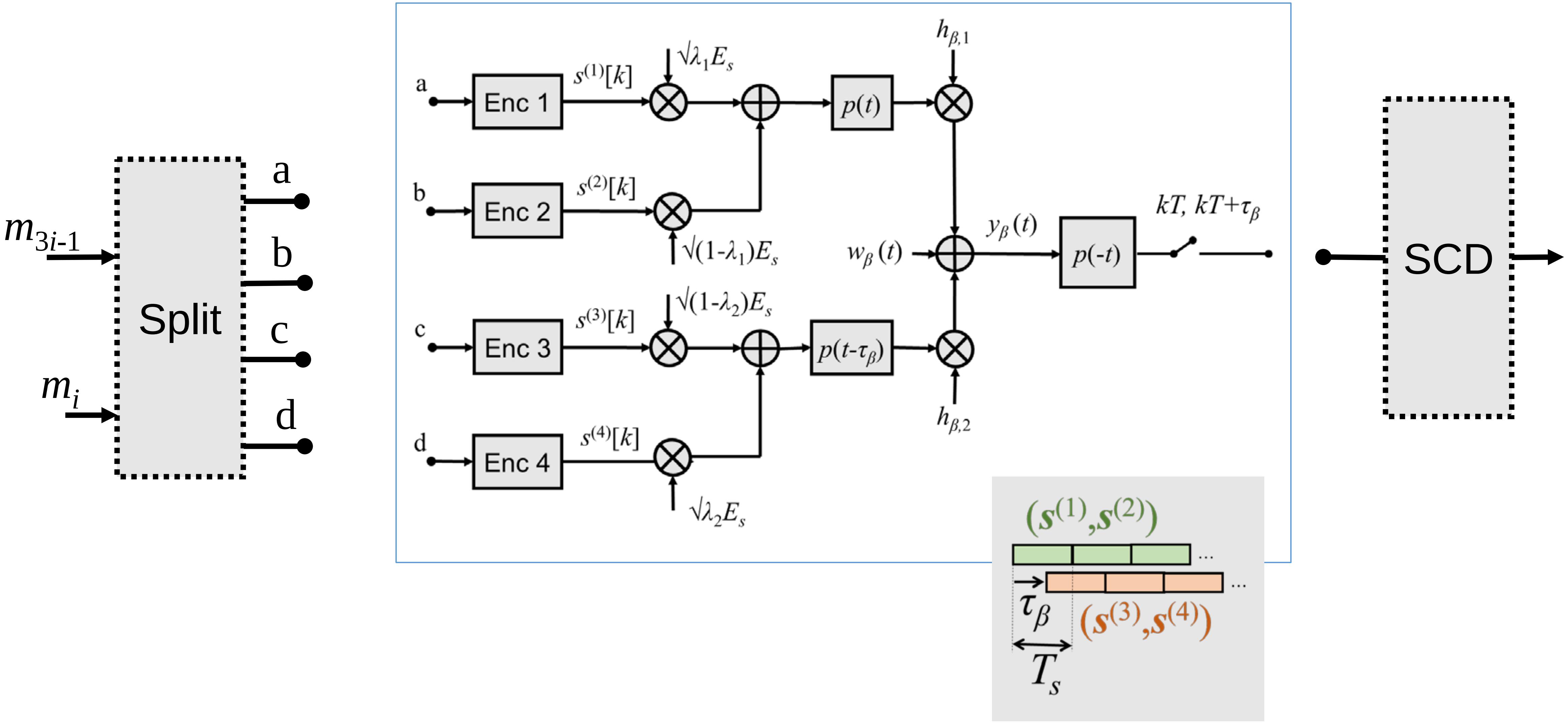


TRANSCEIVER STRATEGIES

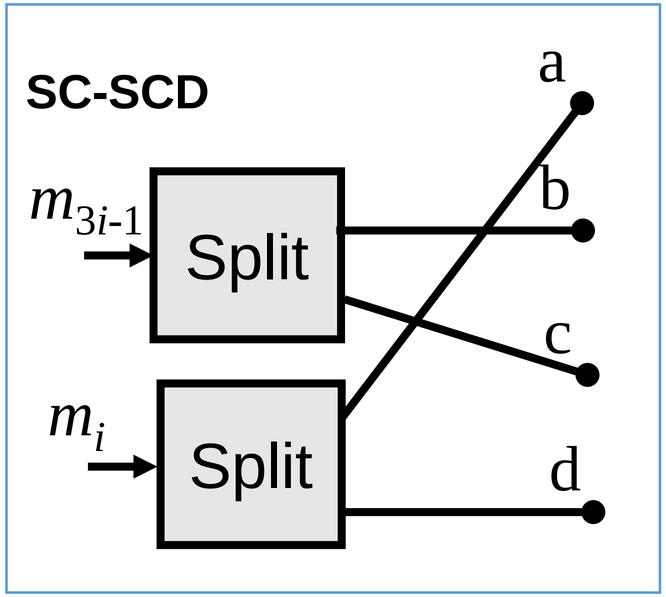
- ✓ Take advantage of CCI → rate splitting, superposition coding
- ✓ Limited amount of CSIT needed → only channel amplitudes

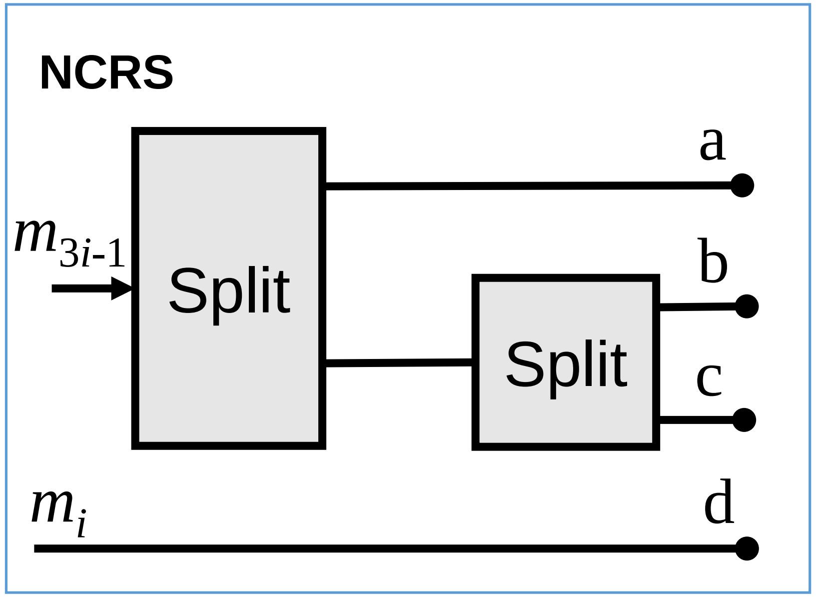
Superposition coding with successive cancellation decoding (SC-SCD)	**Non-coherent rate splitting (NCRS)**
Suitable scheme for degraded broadcast channels • weak/strong user • Public and private messages • Suitable rate assignment	Evolved from idea to increase the GDoF metric in MIMO channels • Interference enhancement (ENH) • Common and private messages • Suited rate assignment
Appealing since insensitive to the channel phase	Modification required to avoid channel phase dependence

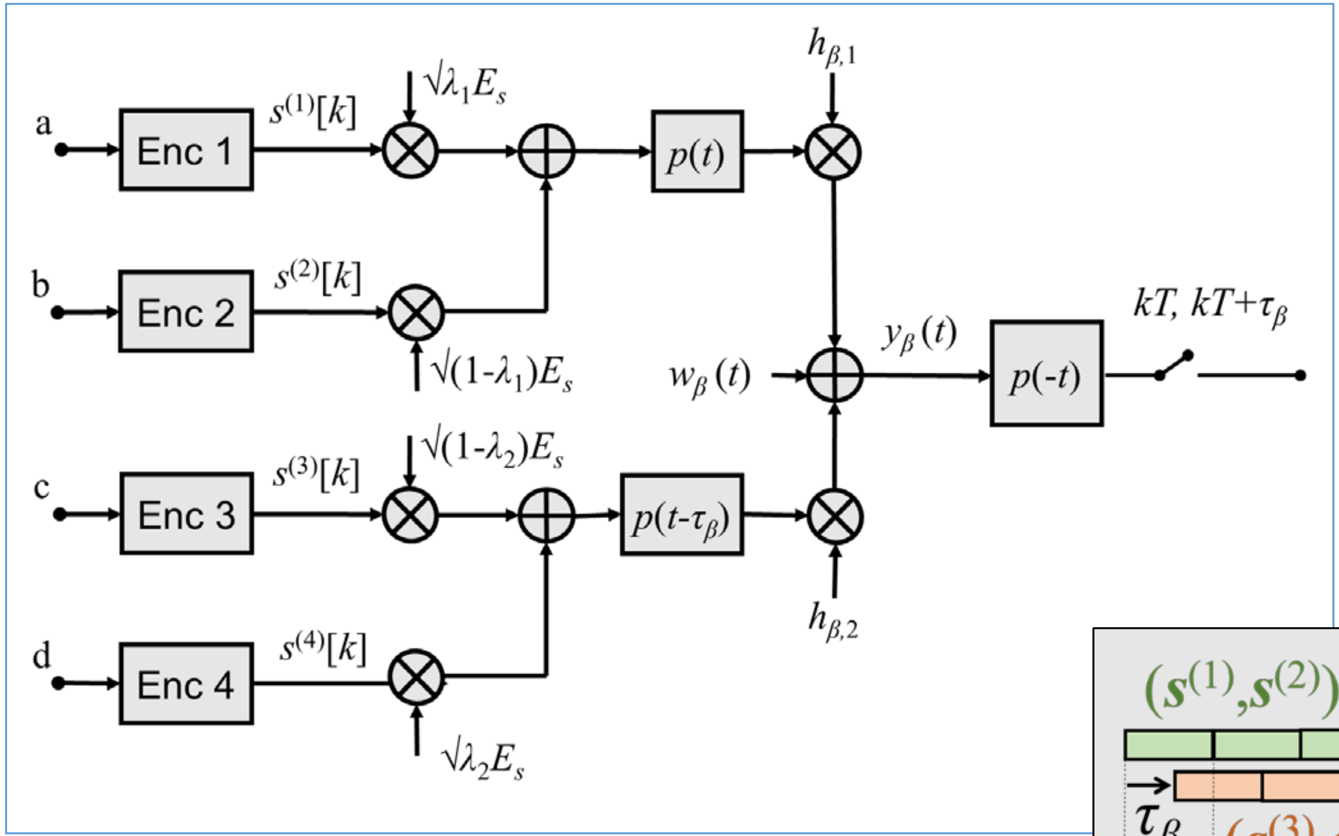
TRANSCEIVER STRATEGIES

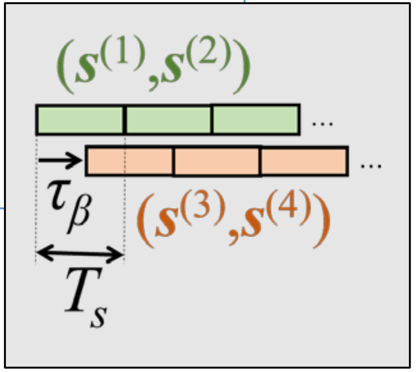


TRANSCEIVER STRATEGIES

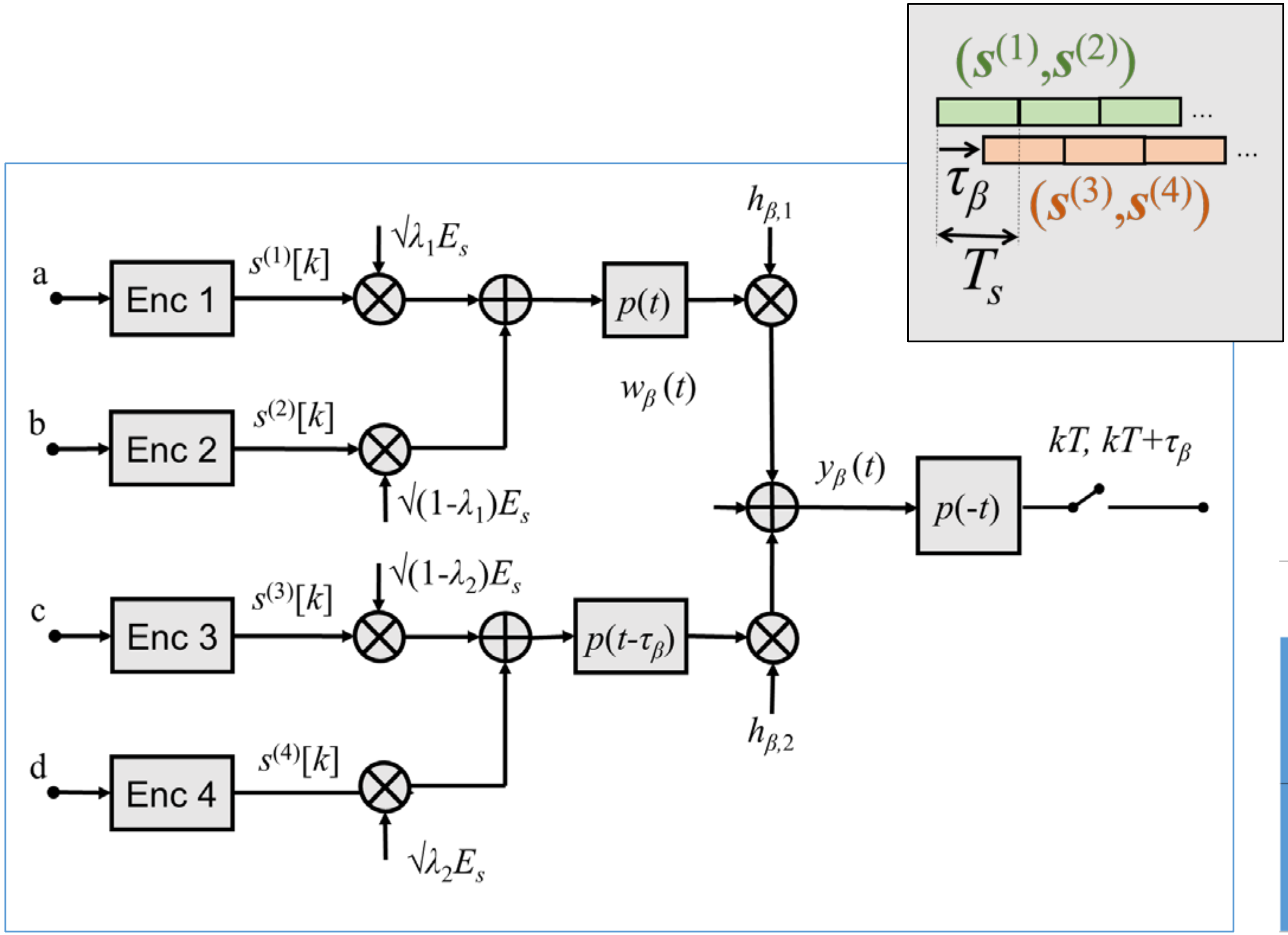


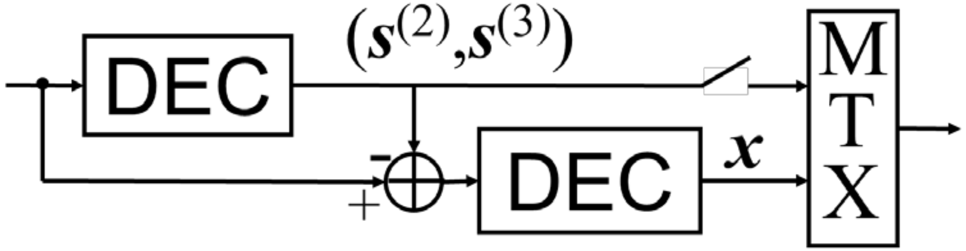






TRANSCEIVER STRATEGIES



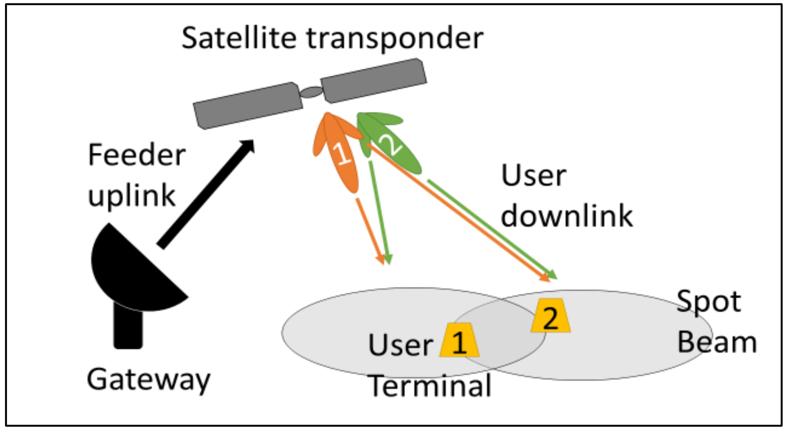


		UT $\beta=i$	UT $\beta=(3-i)$
SC-SCD	$\boldsymbol{x}$	$(s^{(1)},s^{(4)})$	void
	switch	open	closed
NCRS	$\boldsymbol{x}$	$s^{(4)}$	$s^{(1)}$
	switch	open	closed

TRANSCEIVER STRATEGIES

1. $\sqrt{E_s\lambda_1}x_1[k] + \sqrt{E_s(1-\lambda_1)}x_2[k]$

2. $\sqrt{E_s\lambda_2}x_4[k] + \sqrt{E_s(1-\lambda_2)}x_3[k]$



TRANSCEIVER STRATEGIES

– **SC-SCD**

1. $\sqrt{E_s \lambda_1} x_1[k] + \sqrt{E_s (1 - \lambda_1)} x_2[k]$

2. $\sqrt{E_s \lambda_2} x_4[k] + \sqrt{E_s (1 - \lambda_2)} x_3[k]$

i — SCD

$3i$-1 — SUD

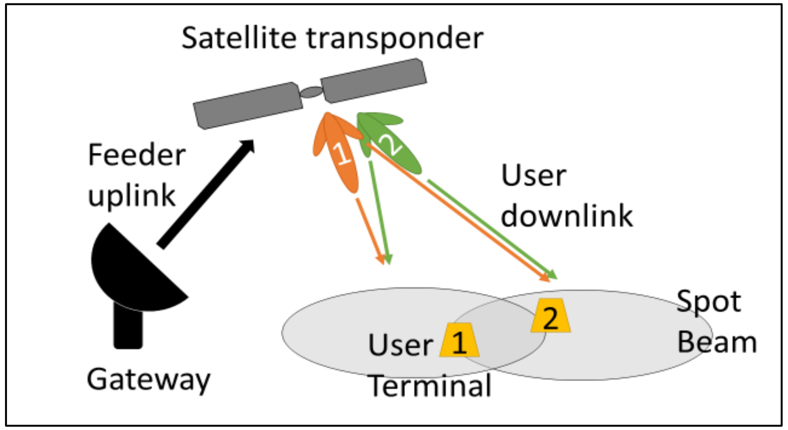
NCRS

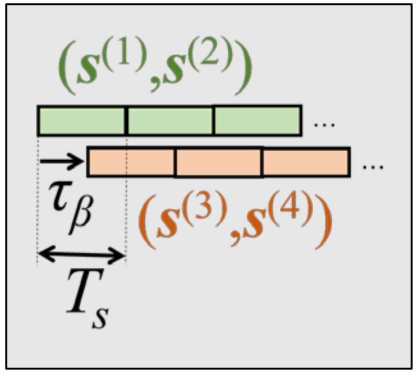
1. $\sqrt{E_s \lambda_1} x_1[k] + \sqrt{E_s (1 - \lambda_1)} \boldsymbol{x}_2[\boldsymbol{k}]$

2. $\sqrt{E_s \lambda_2} x_4[k] + \sqrt{E_s (1 - \lambda_2)} \boldsymbol{x}_3[\boldsymbol{k}]$

i — SCD

$3i$-1 — SCD





ACHIEVABLE RATE REGION ANALYSIS

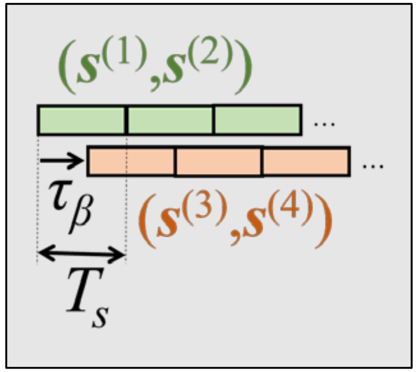
Mutual information rates M_β

Symbols modeled as:
- Long sequences.
- i.i.d. complex-Gaussian RVs (mean 0, variance 1).

Closed-form expressions using
- Schur complement.
- Asymptotic properties of sequences Toeplitz matrices.

$$h_{\beta,1}\sqrt{\lambda_1}\begin{bmatrix} \boldsymbol{G}(0) \\ \boldsymbol{G}(\tau_\beta) \end{bmatrix}\boldsymbol{s}^{(1)} + h_{\beta,1}\sqrt{\bar{\lambda}_1}\begin{bmatrix} \boldsymbol{G}(0) \\ \boldsymbol{G}(\tau_\beta) \end{bmatrix}\boldsymbol{s}^{(2)}$$
$$+ h_{\beta,2}\sqrt{\lambda_2}\begin{bmatrix} \boldsymbol{G}(-\tau_\beta) \\ \boldsymbol{G}(0) \end{bmatrix}\boldsymbol{s}^{(3)} + h_{\beta,2}\sqrt{\bar{\lambda}_2}\begin{bmatrix} \boldsymbol{G}(-\tau_\beta) \\ \boldsymbol{G}(0) \end{bmatrix}\boldsymbol{s}^{(4)}$$
$$+ \boldsymbol{w}_\beta, \quad (1)$$

$\in \mathbb{C}^{2N\times 1}$, $\boldsymbol{w}_\beta \in \mathbb{C}^{2N\times 1}$ a Gaussian noise vector with zero mean and co-variance matrix $\mathbb{E}\left[\boldsymbol{w}_\beta \boldsymbol{w}_\beta^H\right] = \frac{N_{0,\beta}}{E_s}\begin{bmatrix} \boldsymbol{G}(0) & \boldsymbol{G}(-\tau_\beta) \\ \boldsymbol{G}(\tau_\beta) & \boldsymbol{G}(0) \end{bmatrix}$, $\boldsymbol{G}(\tau) \in \mathbb{C}^{N\times N}$ a Wiener class Toeplitz matrix [13] with components $(\boldsymbol{G}(\tau))_{k,l} = g((k-l)T_s + \tau)$, where $g(t) = \int p(u)\, p(u-t)\, du$ denotes the impulse response of the cascade of the transmit filter $p(t)$ and the receive filter $p^*(t)$



ACHIEVABLE RATE REGION ANALYSIS

Mutual information rates $M_\beta,\ \beta \in \{1,2\}$

For given

- Weight factors $\boldsymbol{\lambda}$=(λ_1, λ_2)
- UT role distribution, (i)
- Channel coefficients ($\boldsymbol{H}$=$(h_{1,1}, h_{1,2}, h_{2,1}, h_{2,2})$)
- TO ($\boldsymbol{\tau}$=(τ_1, τ_2))

→ Region of achievable rate pairs

$$\mathcal{R}_i(\boldsymbol{H}, \boldsymbol{\lambda}, \boldsymbol{\tau}) = \{(R_1, R_2): 0 \le R_1 \le M_1, 0 \le R_2 \le M_2\}$$

Main observations:

1. Independent of integer part of $\frac{\tau_\beta}{T_s}$
2. Independent of sign of TO
3. Independent of channel phases
4. **Minimum for zero TO**

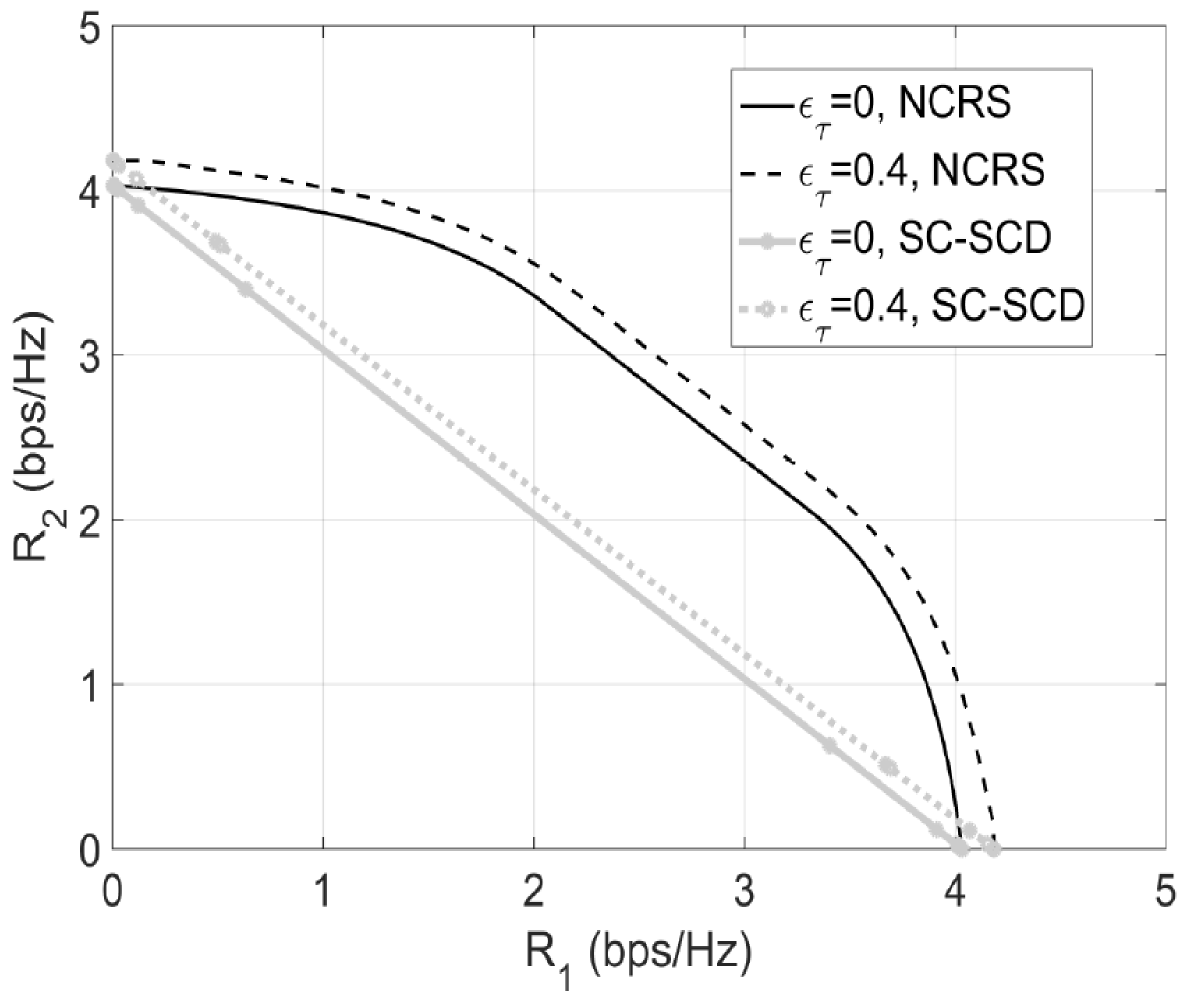
$$\mathcal{R}(\boldsymbol{H}, \boldsymbol{\tau}) = \text{conv}\left\{\bigcup_{\lambda, i} \mathcal{R}_i(\boldsymbol{H}, \boldsymbol{\lambda}, \boldsymbol{\tau})\right\}$$

$$\mathcal{R}(\boldsymbol{H}) = \text{conv}\left\{\bigcup_{\tau} \mathcal{R}(\boldsymbol{H}, \boldsymbol{\tau})\right\} \quad \textbf{or} \quad \mathcal{R}(\boldsymbol{H}, \boldsymbol{0})$$

NUMERICAL RESULTS

Achievable rate region $\mathcal{R}(\boldsymbol{H}, \boldsymbol{\tau})$ in bps/Hz

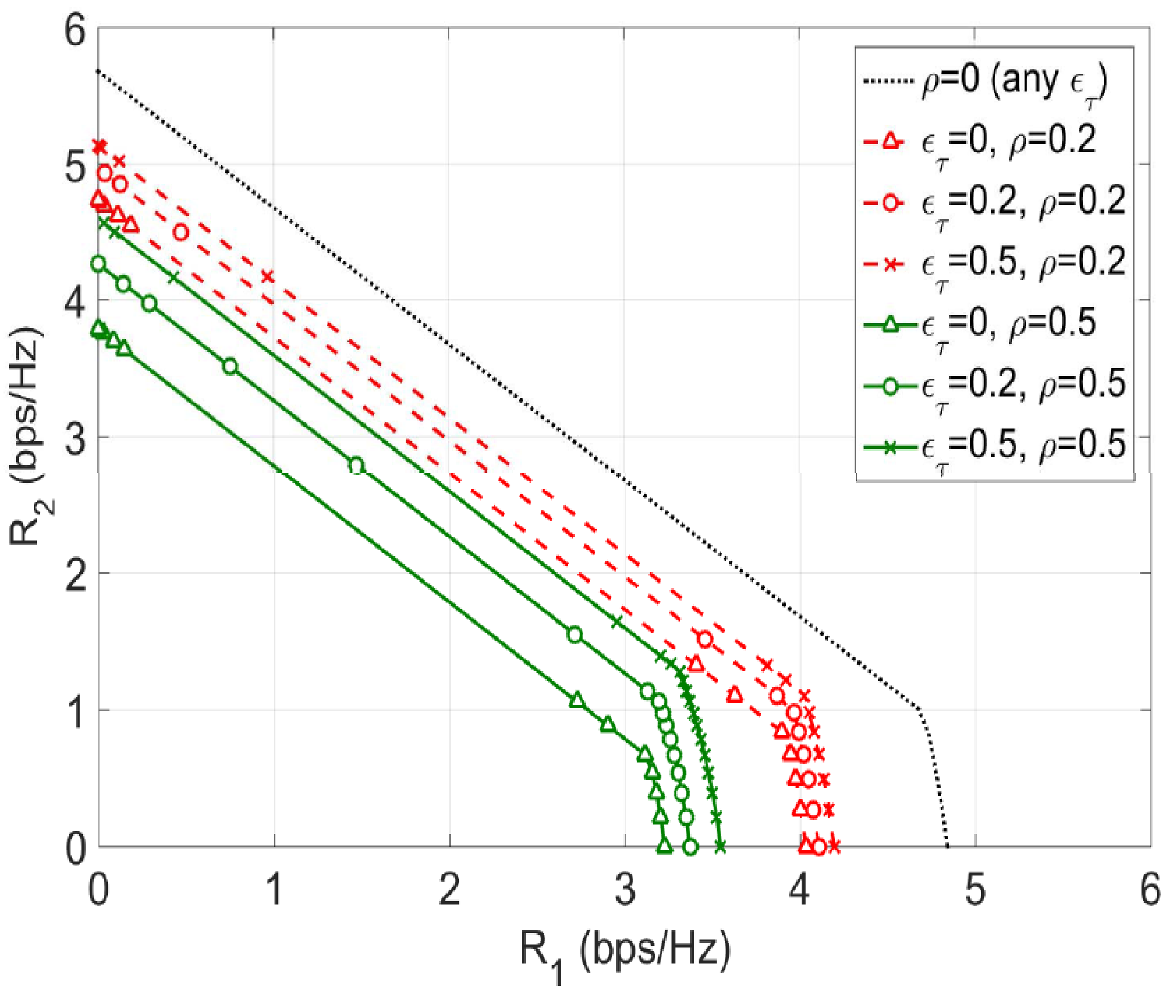
- SC-SCD, NCRS
- $p(t)$: square-root cosine rolloff
- 20% rolloff
- Fractional part $\frac{\tau_\beta}{T_s}$: $\mathcal{E}_\tau \in \{0,0.4\}$
- $\gamma_{i,j} = \frac{E_s |h_{i,j}|^2}{N_{0,i}}$, $(\gamma_{1,1}, \gamma_{1,2}, \gamma_{2,1}, \gamma_{2,2})$ = (14, 4, 4, 14) dB



NUMERICAL RESULTS

Achievable rate region $\mathcal{R}(\boldsymbol{H}, \boldsymbol{\tau})$ in bps/Hz

- SC-SCD
- $p(t)$: square-root cosine rolloff
- 0%, 20%, 50% rolloff
- Fractional part $\frac{\tau_\beta}{T_s}$: $\mathcal{E}_\tau \in \{0, 0.2, 0.5\}$
- $\gamma_{i,j} = \frac{E_s |h_{i,j}|^2}{N_{0,i}}$, $(\gamma_{1,1}, \gamma_{1,2}, \gamma_{2,1}, \gamma_{2,2})$ = (14, 4, 14, 14) dB



CONCLUSIONS

Achievable rates for SC-SCD and NCRS

- Closed-form expressions for **non-zero TO,** $\mathcal{R}_i(\boldsymbol{H}, \boldsymbol{\lambda}, \boldsymbol{\tau})$
- Independent of integer part of $\frac{\tau_\beta}{T_s}$, sign of TO and channel phases
- **Minimum for TO = 0**

No TO information at GW
→ achievable rates are those for TO = 0