Link Adaptation Algorithms for Dual Polarization Mobile Satellite Systems

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About me

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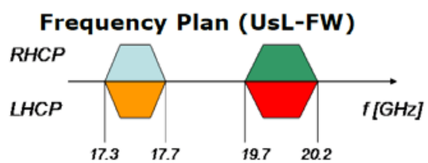
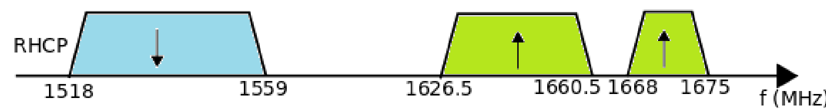
Contents

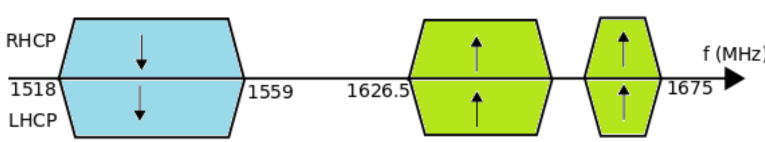
Motivation

- Increase the throughput of mobile satellite communications systems
  - Example: BGAN → ICE (Inmarsat Communications Evolution)
- Two technologies
  - Dual Polarization with Adaptive MIMO
  - ACM: Adaptive Coding and Modulation (Link adaptation)
- Currently

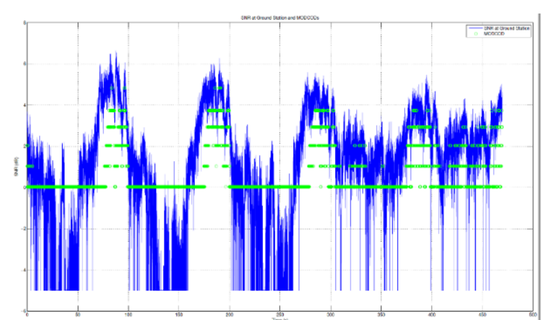




- Our proposal for L/S-bands



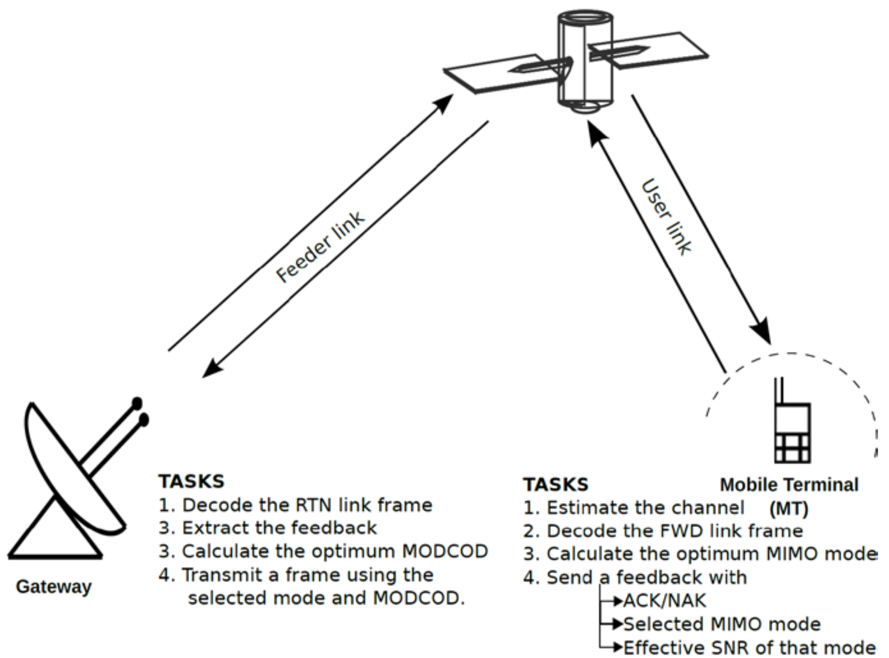
Dual Polarization +
MIMO signal processing



Link adaptation

System model

- Mobile sat. com. system in L-band (1.6 GHz)
  - 1 beam, 1 user
  - Use of Dual Polarization: RHCP & LHCP
  - Link adaptation in the forward link (direction gateway to user)
  - Narrowband and single carrier



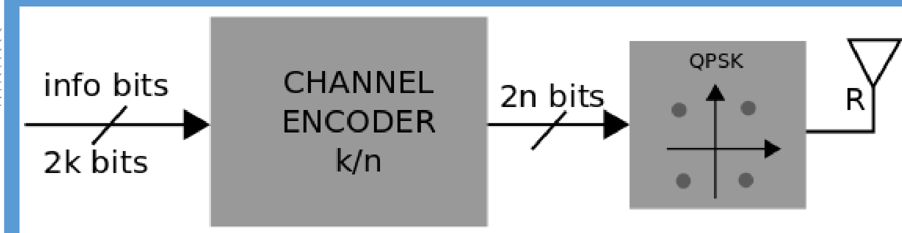
System model (II)

- Physical layer
  - Inspired by BGAN (ETSI TS 102 744)
  - QPSK modulation and 9 different coding rates (9 MODCODs)
  - Frames of 80 ms
  - Baud rate: 33,600 symbols/s
  - Round Trip Time: 560 ms (~ 7 frames)
  - 4 MIMO modes

bgan inmarsat

ETSI World Class Standards

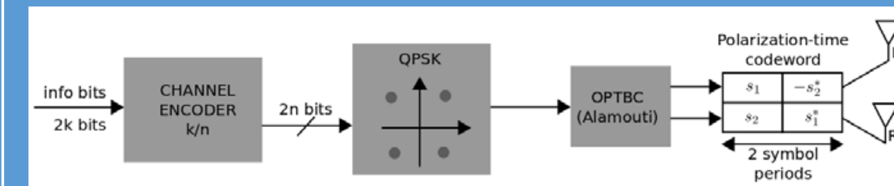
Four MIMO modes



SISO

Single polarization

bgan inmarsat

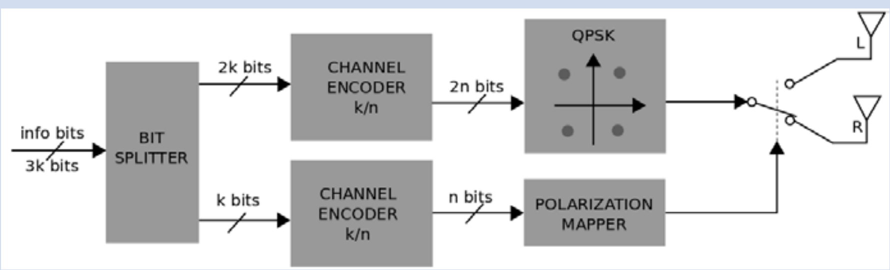


OPTBC

(Orthogonal Polarization-Time Block Code)

~Alamouti

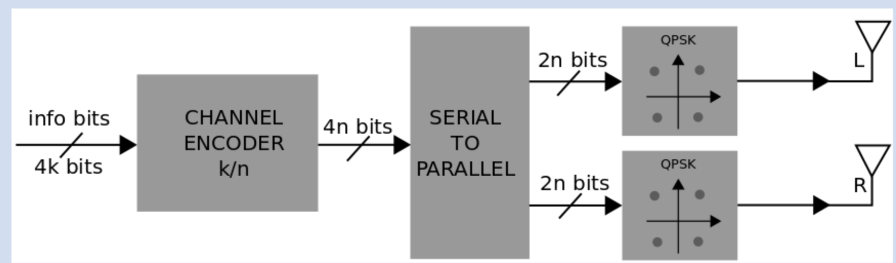
[Polarization diversity]



PMod

(Polarized Modulation)

[Index Modulation]



V-BLAST

(Vertical Bell Labs Space Time Coding)

[Polarization Multiplexing]

Nine MODCODs

QPSK constellation

		MODCODS (or MCS)								
	Name	L8	L7	L6	L5	L4	L3	L2	L1	R
	Coding rate	0.34	0.40	0.48	0.55	0.63	0.70	0.77	0.83	0.87
MIMO modes	SISO	0.68	0.80	0.96	1.10	1.26	1.40	1.54	1.66	1.74
	OPTBC	0.68	0.80	0.96	1.10	1.26	1.40	1.54	1.66	1.74
	PMod	1.02	1.20	1.44	1.65	1.89	2.10	2.31	2.49	2.61
	V-BLAST	1.36	1.60	1.92	2.20	2.52	2.80	3.08	3.32	3.48

Spectral efficiency, η, of the combination of MIMO modes – MODCODs [bps/Hz]

Signal model

$$\boldsymbol{y}_n = \sqrt{P}\boldsymbol{H}_n\boldsymbol{x}_n + \boldsymbol{w}_n \quad \begin{cases} \boldsymbol{x}_n \in \mathbb{C}^2 \quad \boldsymbol{y}_n \in \mathbb{C}^2 \\ \boldsymbol{H}_n \in \mathbb{C}^{2\times 2} \\ \boldsymbol{w}_n \sim \mathcal{CN}(\boldsymbol{0}, \sigma^2\boldsymbol{I}_2) \end{cases}$$

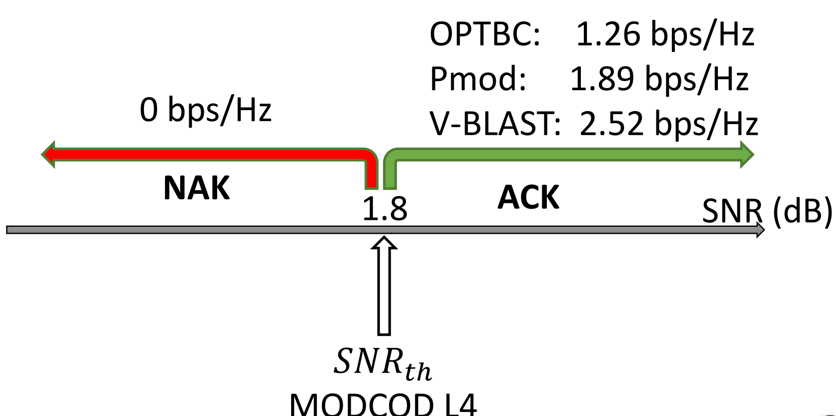
- Frames (codewords) of N=2560 symbols
- Physical layer abstraction
  - H_n → Symbol SNR γ_n

    N symbol SNRs $\{\gamma_n, n = 1, \ldots, N\}$ → Effective SNR:

$$\mathrm{SNR}_{eff} = \Phi^{-1}\left(\frac{1}{N}\sum_{n=1}^{N}\Phi(\gamma_n)\right)$$

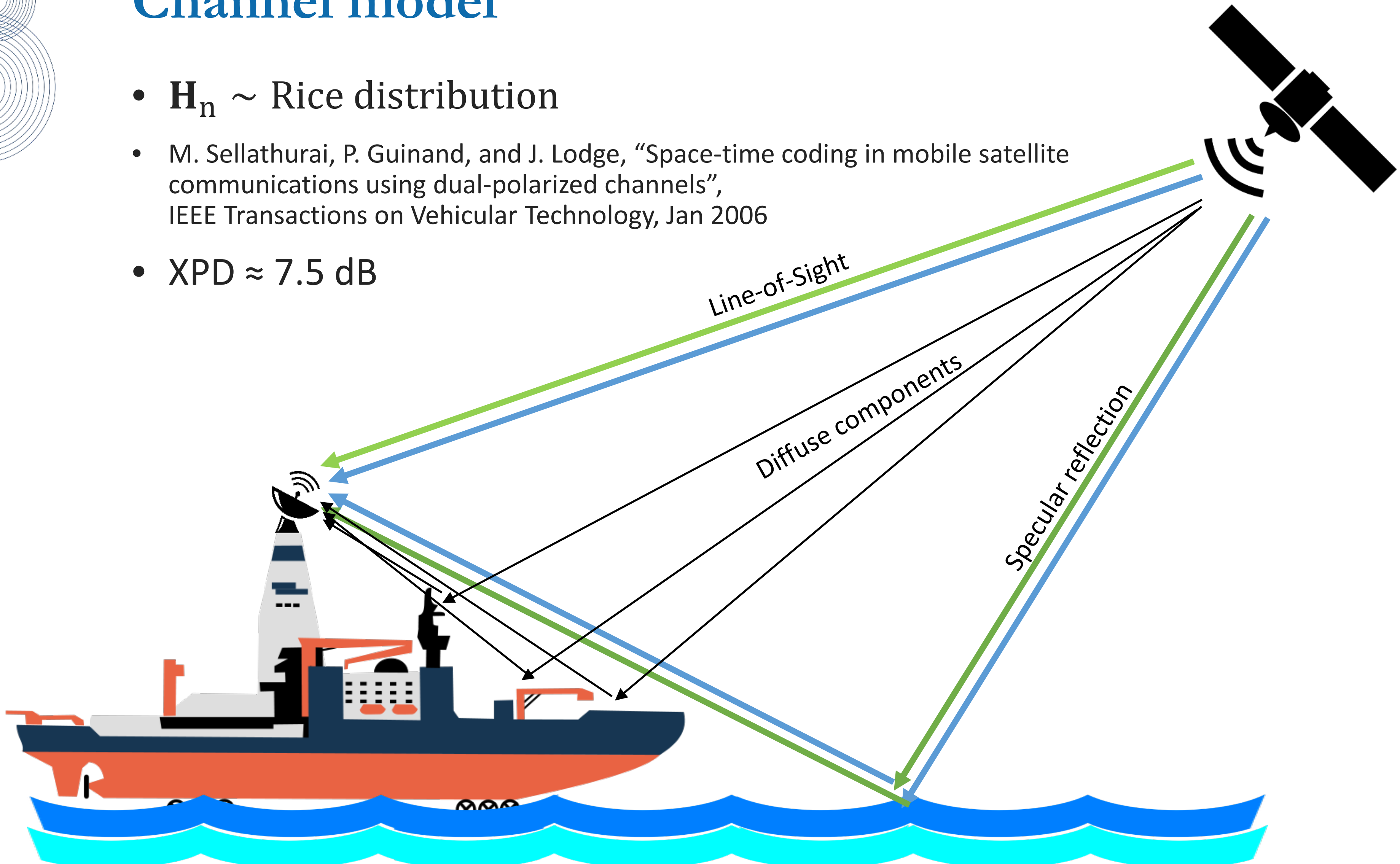
↓

Decision outcome of decoding: ACK/NAK



Channel model

- $\mathbf{H}_n \sim$ Rice distribution
  - M. Sellathurai, P. Guinand, and J. Lodge, "Space-time coding in mobile satellite communications using dual-polarized channels", IEEE Transactions on Vehicular Technology, Jan 2006
- XPD ≈ 7.5 dB



Algorithm for MIMO mode selection

- Example:

Mode	Effective SNR (dB)
SISO	2
OPTBC	3
PMod	1.9
V-BLAST	-1

Executed by Mobile Terminal

Feedbacks to gateway:

-Selected mode

-SNR of that mode

-ACK/NAK

$$\hat{T} = i \quad subject\ to \quad R_{ij} = \max_{i,j}\{R_{ij}\}$$

Selected mode: V-BLAST

Matrix R_{ij}

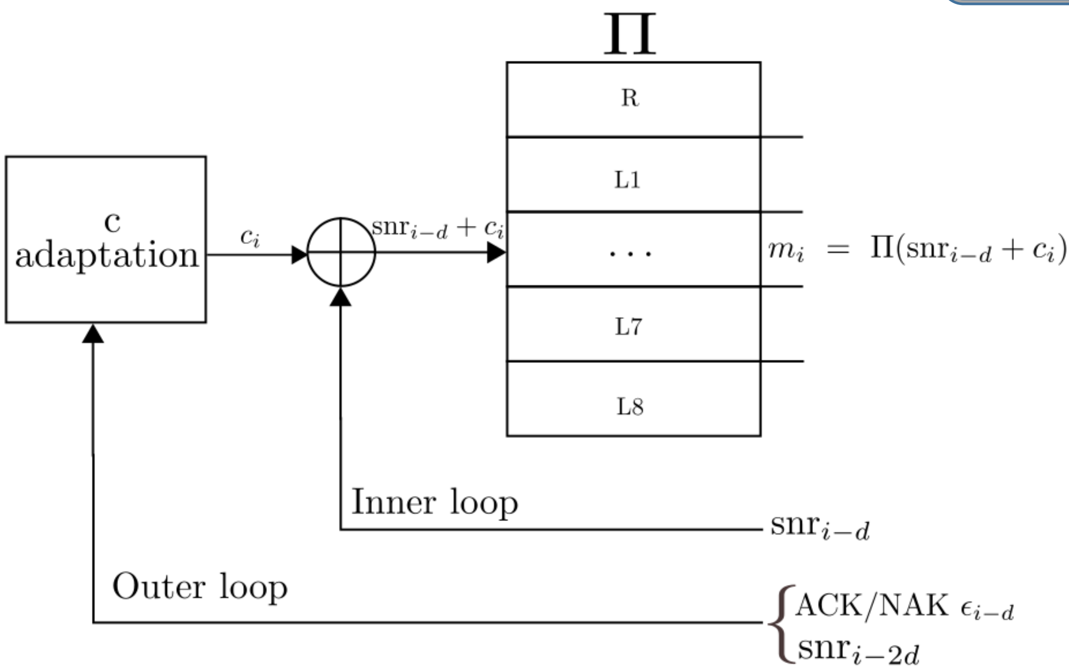
	MODCODS	L8	L7	L6	L5	L4	L3	L2	L1	R
	SNR_{th} (dB)	-2.15	-1.21	-0.09	0.83	1.84	2.74	3.67	4.54	5.19
MIMO modes	SISO	0.68	0.80	0.96	1.10	**1.26**	~~1.40~~	~~1.54~~	~~1.66~~	~~1.74~~
	OPTBC	0.68	0.80	0.96	1.10	1.26	**1.40**	~~1.54~~	~~1.66~~	~~1.74~~
	PMod	1.02	1.20	1.44	1.65	**1.89**	~~2.10~~	~~2.31~~	~~2.49~~	~~2.61~~
	V-BLAST	1.36	**1.60**	~~1.92~~	~~2.20~~	~~2.52~~	~~2.80~~	~~3.08~~	~~3.32~~	~~3.48~~

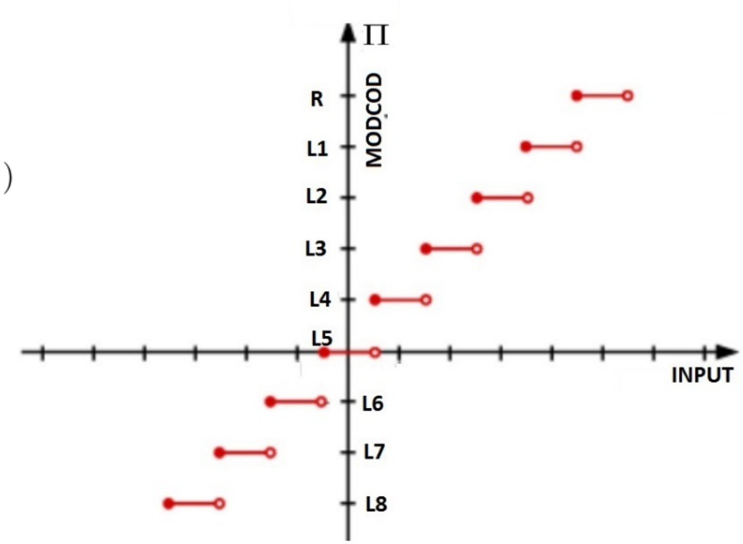
From QPSK constraint Capacity curve in AWGN

Algorithm for MODCOD selection

- Use of a LUT (Lookup Table)
  - Selected MODCOD: $m_i = \prod(SNR_{i-d} + c_i)$ Executed by the gateway
- and an adaptive margin c_i obtained from
  - $\min_c J(c) = \min_c |\mathbb{E}[\text{FER}] - p_0|^2$

Objective FER (Frame Error Rate)





Algorithm for MODCOD selection (II)

- Recursive equation for updating the margin

$$c_{i+1} = c_i - \frac{\mu}{\theta^2 + \mathrm{SNR}_{i-2d}^2}(\epsilon_{i-d} - p_0)\theta$$

SNR used in the LUT when MODCOD of frame *i-d* was selected

$\mu = 1, \ \theta = 10$ — Objective FER (p_0): **Fixed parameters**

$\epsilon_{i-d} = 1 \ (NAK, error)$
$\epsilon_{i-d} = 0 \ (ACK, success)$

- Received feedback with…
  - ACK
    - Slight increment of margin
      - Higher MODCODs will be selected on the long term
  - NAK (error)
    - Important decrement of margin
      - Lower MODCODs (more robust) will be selected soon

Simulation results

- Maritime scenario vessel moving at 50 km/h
- Carrier frequency: 1.6 GHz
- Average SNRs from -5 to 25 dB
- RTT: 7 frames (560 ms) typical of GEO satellite
- Simulation: transmission of 60,000 frames (1 h 20 min)
- Parameters:
  - Average spectral efficiency
  - Average FER

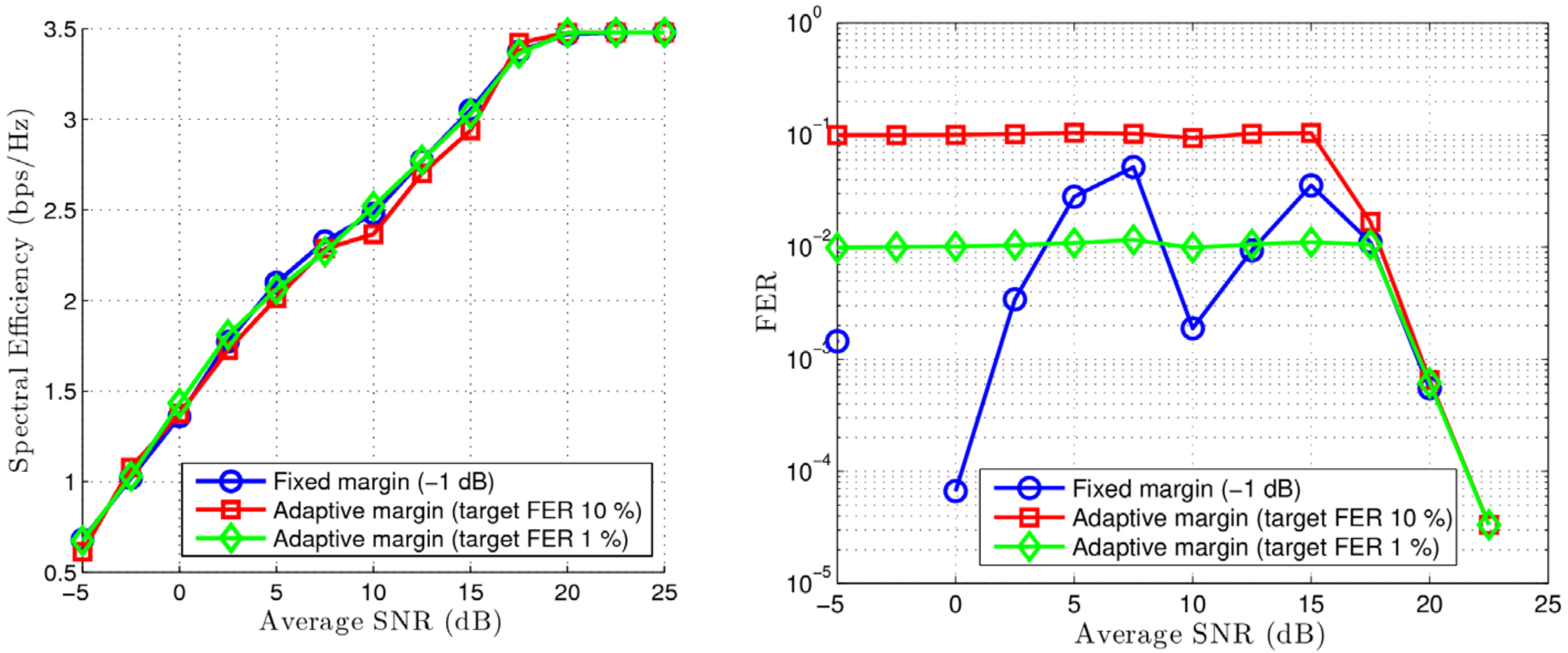
Single polarization vs Adaptive MIMO

- Comparison with ACM with fixed margin of -1 dB
  - SISO: single polarization
  - Dual polarization: Adaptive MIMO

Average SNR	Selected modes	Efficiency (SISO)	Efficiency (MIMO)	Gain
-5 dB	OPTBC	0 bps/Hz	0.68 bps/Hz	Inf
-2.5 to 7.5 dB	PMod	0.68 - 1.50 bps/Hz	1.02 - 2.32 bps/Hz	50 - 55 %
10 dB	PMod (30 %), BLAST (70 %)	1.69 bps/Hz	2.47 bps/Hz	47 %
12.5 to 25 dB	BLAST	1.73 - 1.74 bps/Hz	2.77 - 3.48 bps/Hz	60 - 100 %

- OPTBC allows operation with lower SNRs
- Throughput gains from 50 % to 100 % (2x) (PMod and V-BLAST)

Adaptive MIMO. Fixed vs Adaptive Margin



Conclusions and future work

- Dual polarization is worthwhile in L/S-band for mobile satellite communications.
- Throughput gains of 50 – 100 % with dual polarization even with interference between polarizations using the same transmit power and bandwidth.
- Polarization diversity mode (OPTBC) allows the operation with lower SNRS.
- The algorithm for MIMO mode selection permits choosing the optimum mode depending on the channel conditions maximizing throughput.
- Link adaptation with adaptive margin allows to guarantee a prescribed FER specified in the QoS parameters of the connection.
- Present work:
    - A more realistic approach of PMod scheme.

Thank you!

Questions and comments are welcome

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