On Bursty Multi-Pair Two-Way Relay Channels

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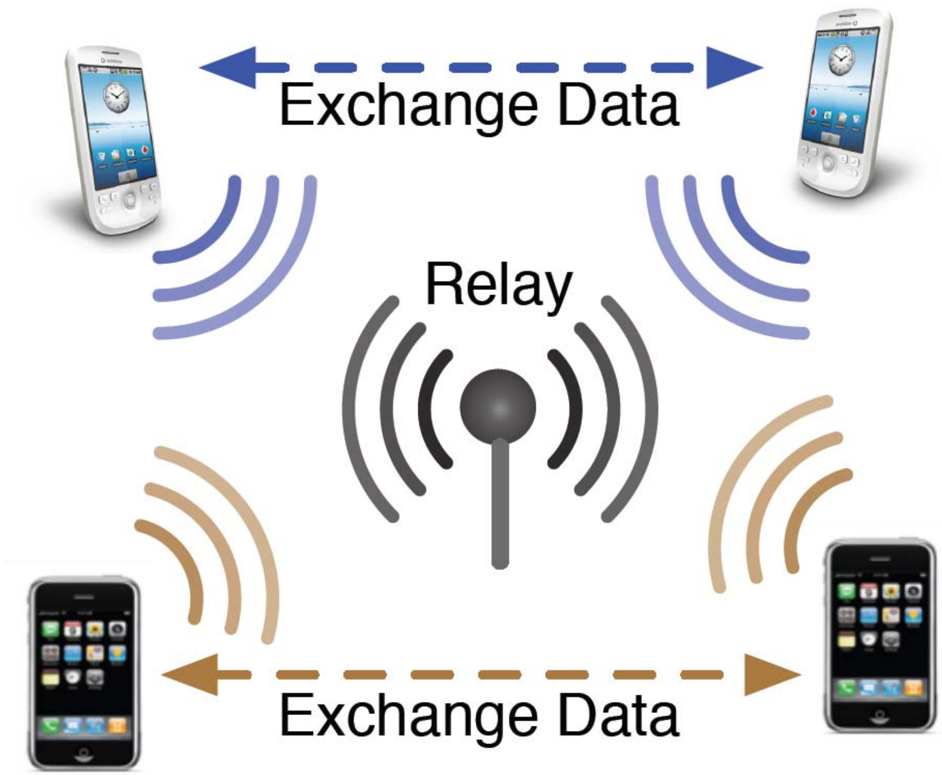
Outline

- Introduction
  - Multi-pair two-way relay channels
  - Bursty interference
  - Burstness state information (delayed/instantaneous)
- Capacity region of two-pair symmetric case
  - Binary expansion model
  - Gaussian model (bounded gap)
- Conclusion

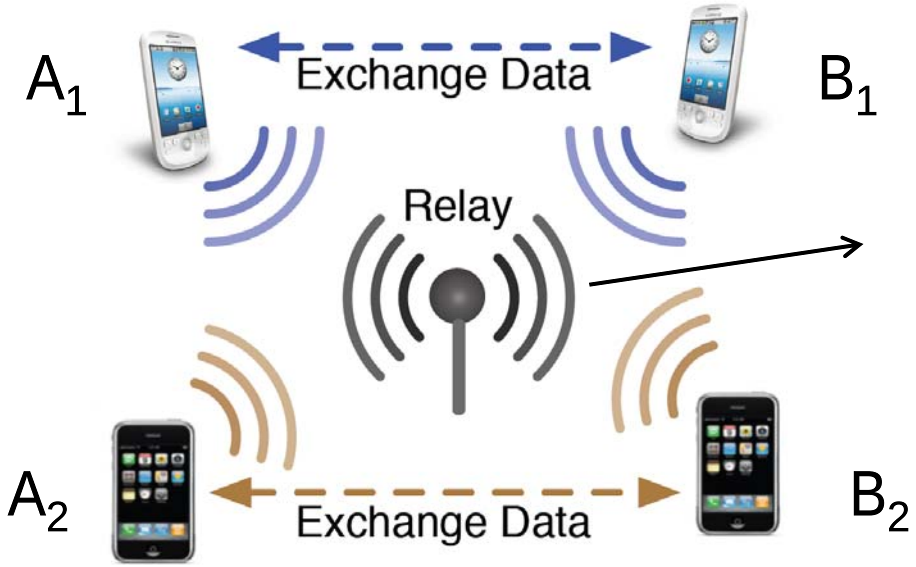
Multi-Pair Two-Way Relay Channel

- Multiple pairs of users exchange their messages within their own pairs, with the help of a shared relay



Bursty interference

- Uncoordinated frequency hopping



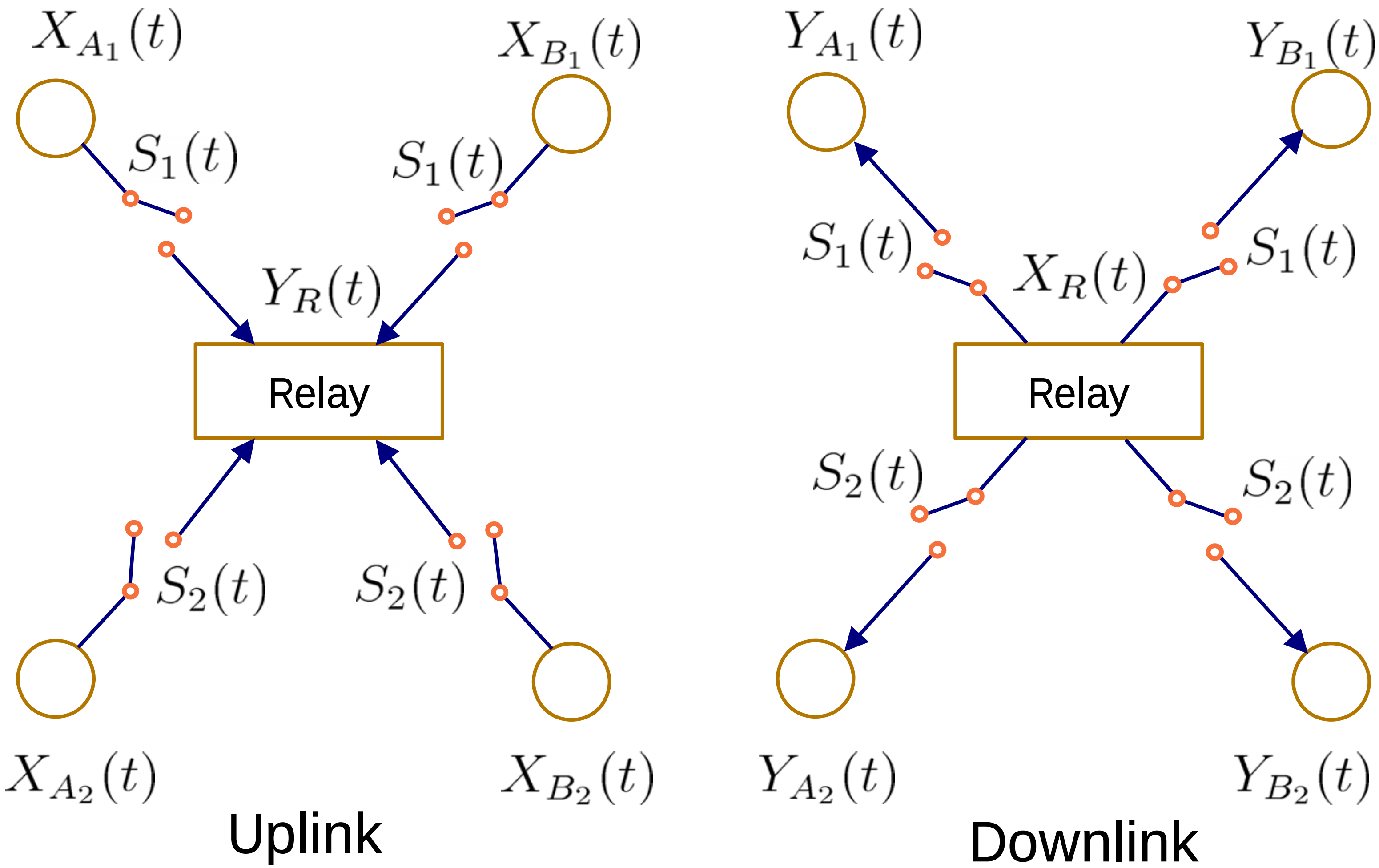
Third party intermittent relay [EU METIS 5G]

Freq.		
	Relay (A_1 B_1) (A_2 B_2)	**Relay (A_1 B_1)**
		(A_2 B_2)

Time

- Bursty data traffic with energy saving receiver
- Shadowing

Mathematical model



Burstness State Information

- Delayed State Information
  - Terminal user : $X_{A_1}[t] \stackrel{\mathrm{f}}{=} (w_{A_1}, Y_{A_1}^{t-1}, S_1^{t-1}, S_2^{t-1})$
  - Relay : $X_R[t] \stackrel{\mathrm{f}}{=} (Y_R^{t-1}, S_1^{t-1}, S_2^{t-1})$
- Instantaneous State Information
  - Terminal user : $X_{A_1}[t] \stackrel{\mathrm{f}}{=} (w_{A_1}, Y_{A_1}^{t-1}, S_1^N, S_2^t)$
  - Relay : $X_R[t] \stackrel{\mathrm{f}}{=} (Y_R^{t-1}, S_1^t, S_2^t)$

Related works

- Non-bursty multihop relay network
  - Two-pair two-way relay channel
    [A. Sezgin, A.S. Avestimehr, M.A. Khajehnejad, and B. Hassibi TIT 12]
  - General multicast relay network
    [S.-H. Lim, Y.-H. Kim, A. El Gamal, and S.-Y. Chung TIT 11]
    [A. S. Avestimehr, S. Diggavi and D. Tse TIT 11]

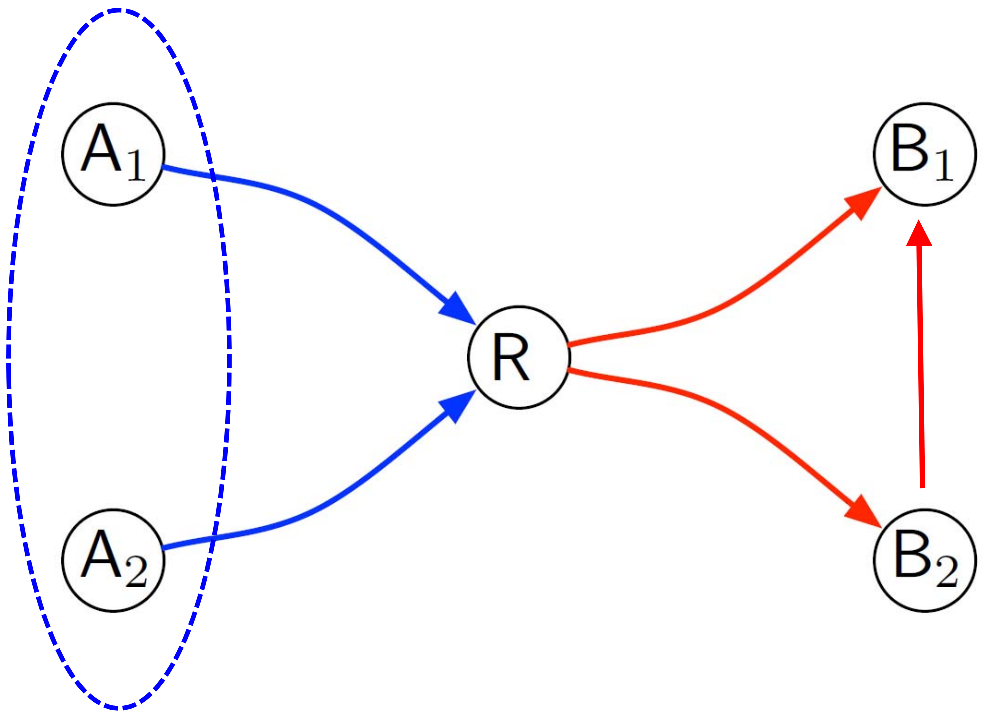
- One-hop bursty interference channel
  - Degraded message set approach
    [N. Khude, V. Prabhakaran and P. Viswanath, ISIT 09]
  - With output feedback
    [I.-H. Wang, C. Suh, S. Diggavi and P. Viswanath, ISIT 13]
  - Binary expansion model with burstness state feedback
    [A. Vahid, M. A. Maddah-Ali, and A. S. Avestimehr, TIT to appear]

Contributions

- Identify capacity region to within a bounded gap in a two-pair, symmetric setting (both delayed and instantaneous state information)

- Decomposition of outer and inner bounds
  - Uplink :
    Outer-bound : Cooperation
    Inner-bound : Compute and forward with
    joint lattice decoding
  - Downlink :
    Outer-bound : Degraded channel argument
    Inner-bound : 3-Phase retransmission (delayed)
    Superposition coding (instantaneous)

Decomposition : outer-bounds



erasure prob. p

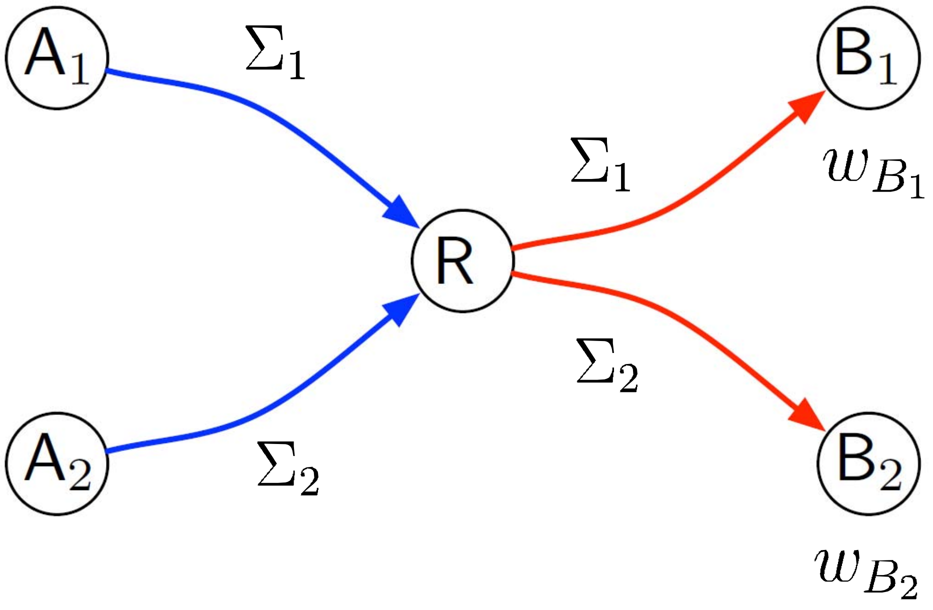
- DoF outer-bounds with delayed burstness state information
  - **Uplink** (A_1&A_2 cooperation)

$$d_1 + d_2 \leq 2p(1-p) + p^2,$$
$$d_1 \leq p,$$
$$d_2 \leq p$$

  - **Downlink** (Degraded channel argument)

$$\frac{d_1}{p} + \frac{d_2}{p(2-p)} \leq 1,$$
$$\frac{d_1}{p(2-p)} + \frac{d_2}{p} \leq 1,$$

Decomposition : inner-bounds



- Uplink phase:
  Relay decodes XOR

$$\Sigma_1 = w_{A_1} \oplus w_{B_1}$$

$$\Sigma_2 = w_{A_2} \oplus w_{B_2}$$

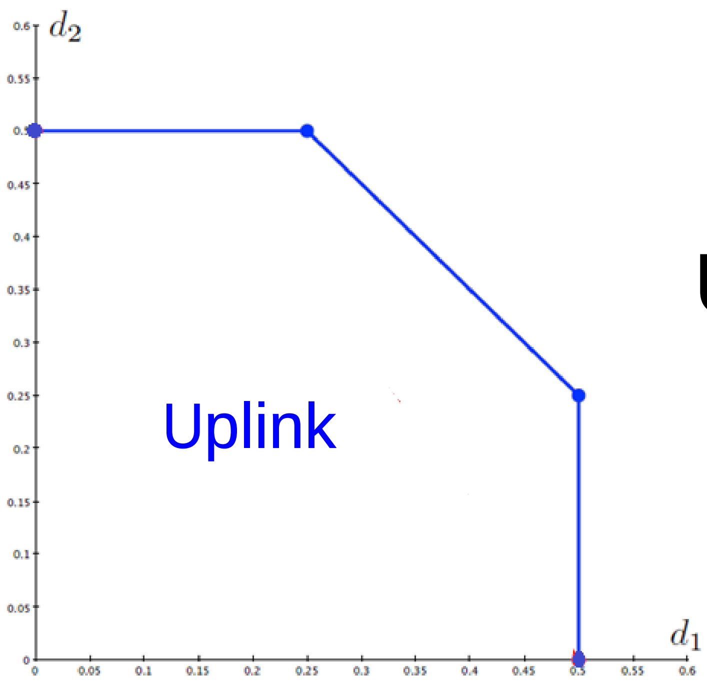
- Downlink :
  3-Phase retransmission in [Georgiadis & Tassiulas 09]

Σ_1	Σ_2	erased $\Sigma_1 \oplus \Sigma_2$

Receiver side information

$$\Sigma_1 - w_{B_1} = w_{A_1}$$

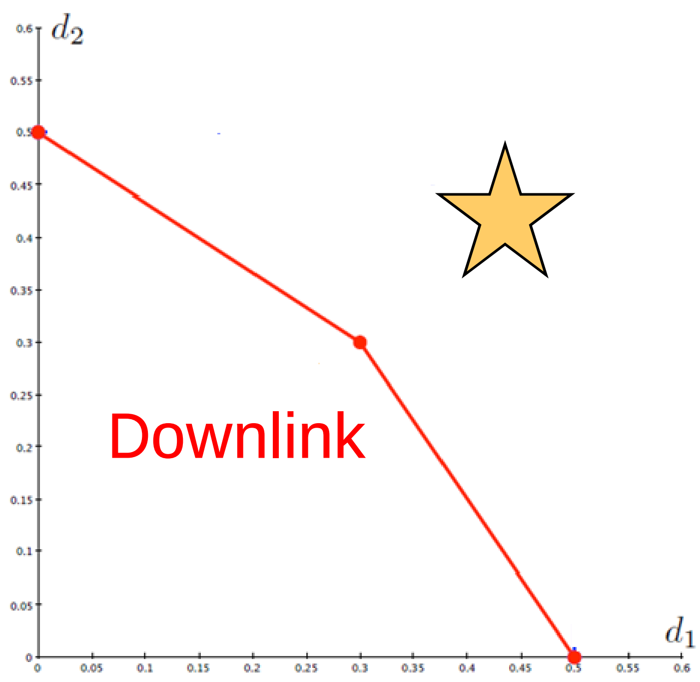
DoF region : union of uplink and downlink



$p = 0.5$

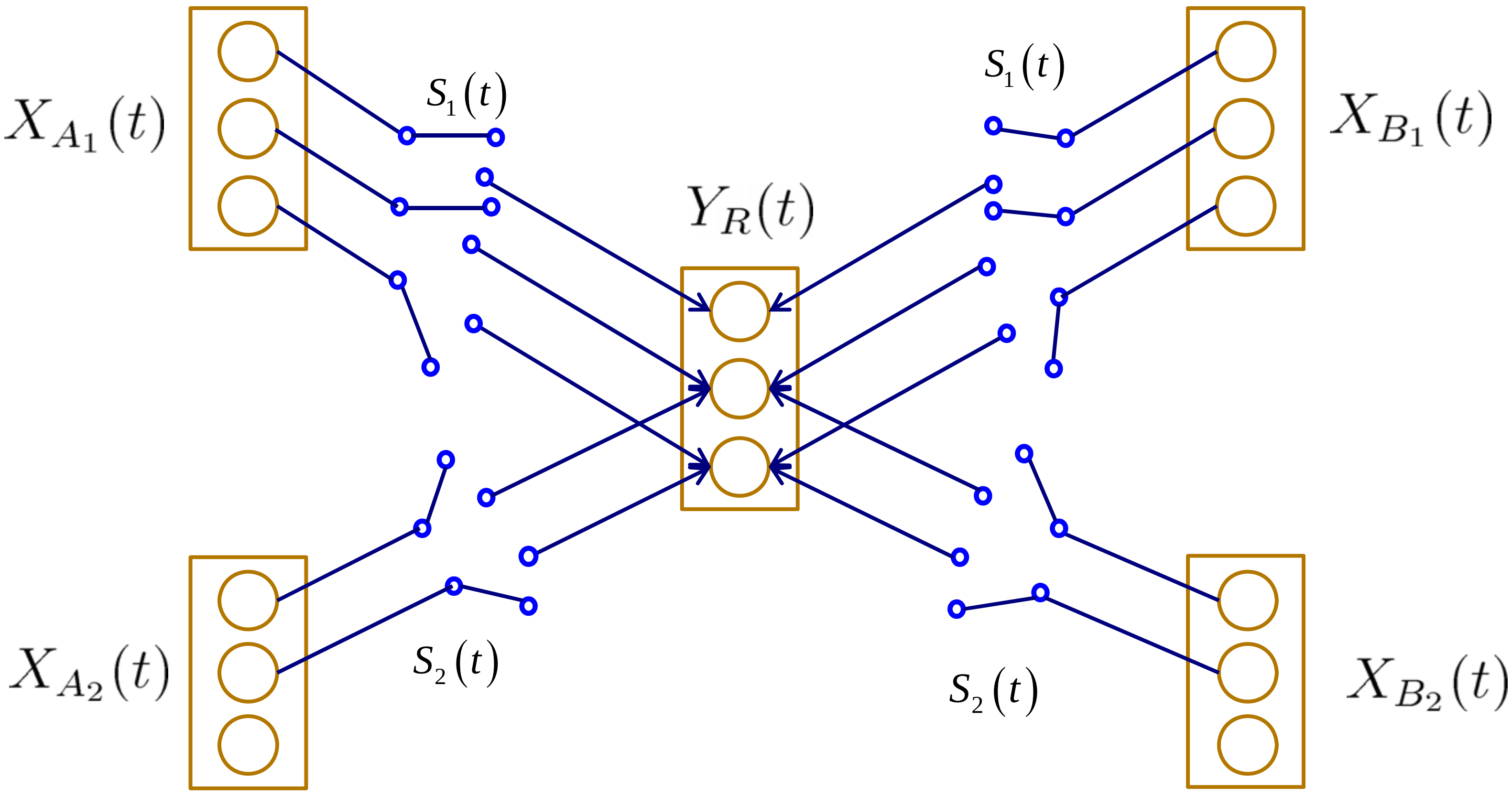
Union

$\cap$

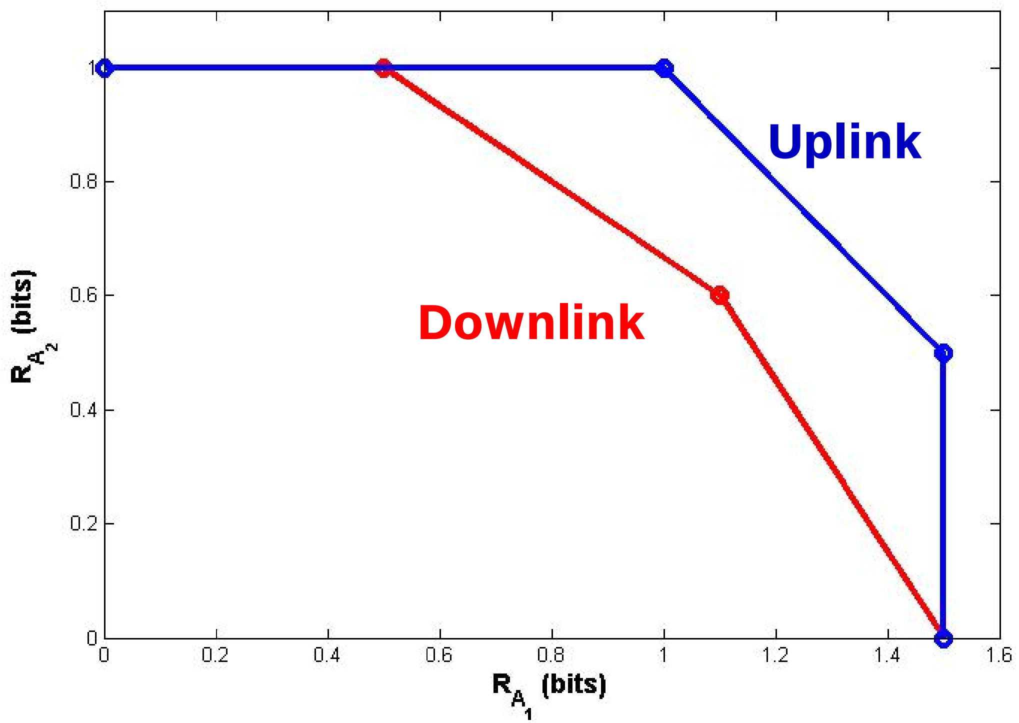


$p = 0.5$

Binary expansion model

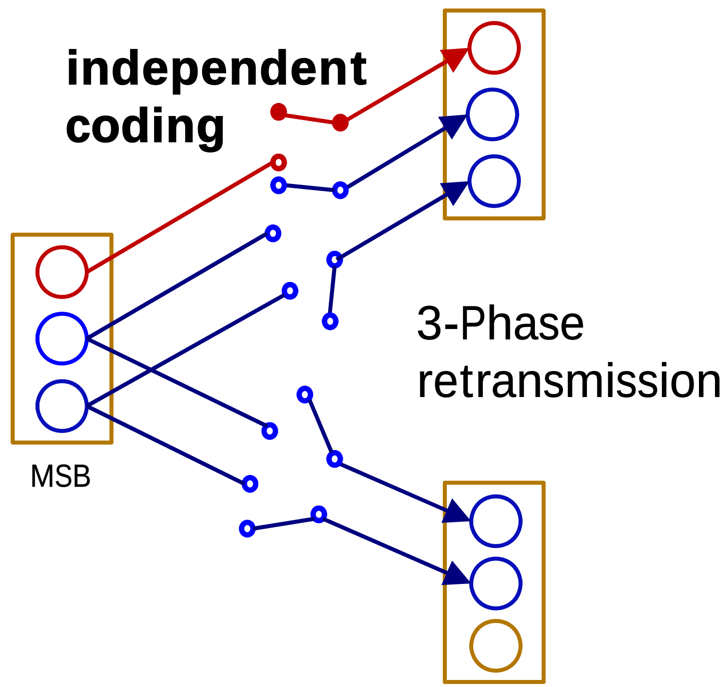


Capacity region (Symmetric)

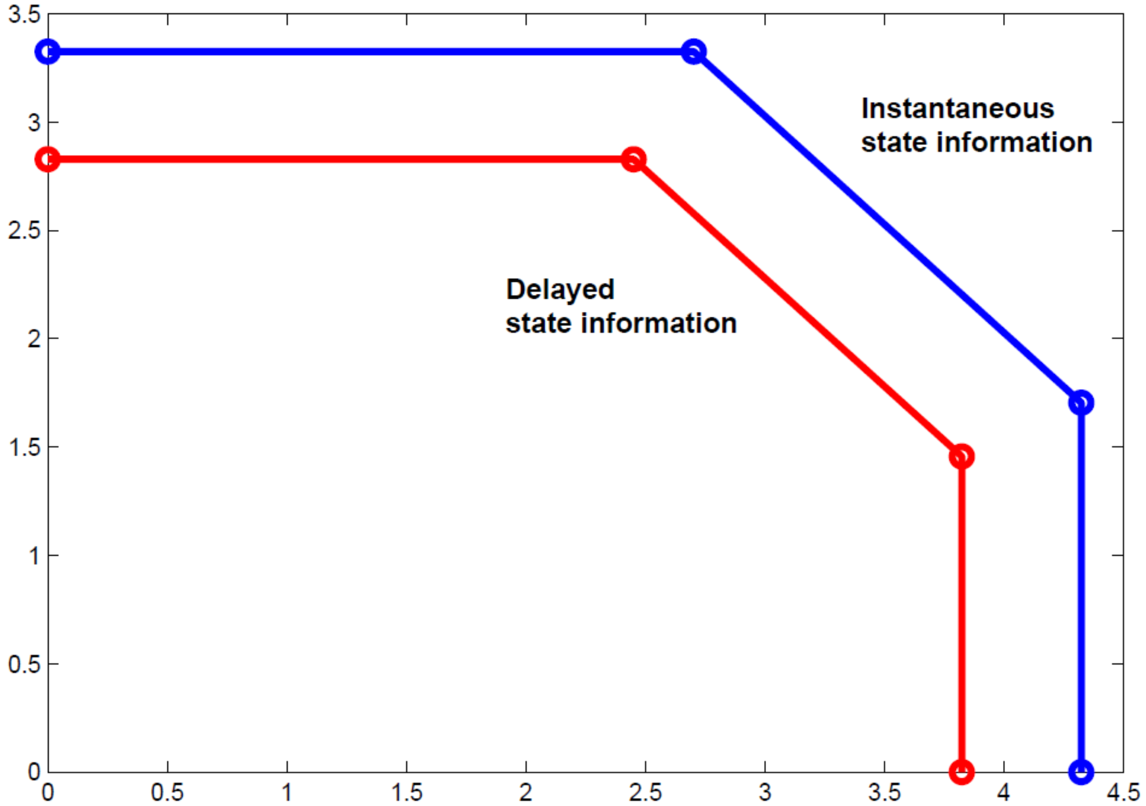


Delayed, $(n_{A1}, n_{A2})=(n_{B1}, n_{B2})=(3,2)$

- Uplink :
  Relay decodes
  independent XOR of each layer
- Downlink :

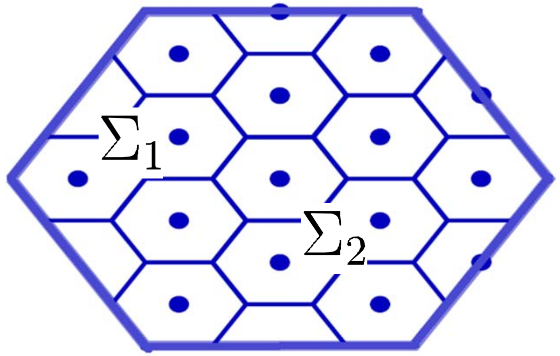


Gaussian uplink : bounded gap schemes



$|h_{R1}|=2$, $|h_{R2}|=1$, Tx SNR=10dB

- Compute and forward with **jointly lattice decoding**

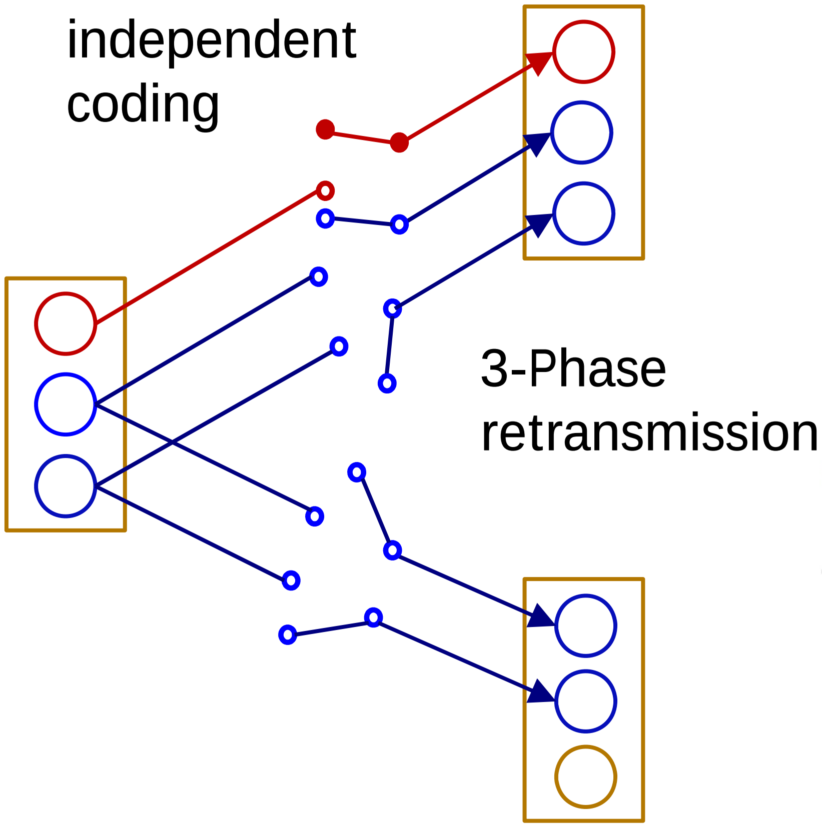


Relay

[c.f. **SIC** in Sezgin TIT 12]

  – Instantaneous state information : on/off power allocation

Downlink : from binary to Gaussian



- 3-Phase retransmission:

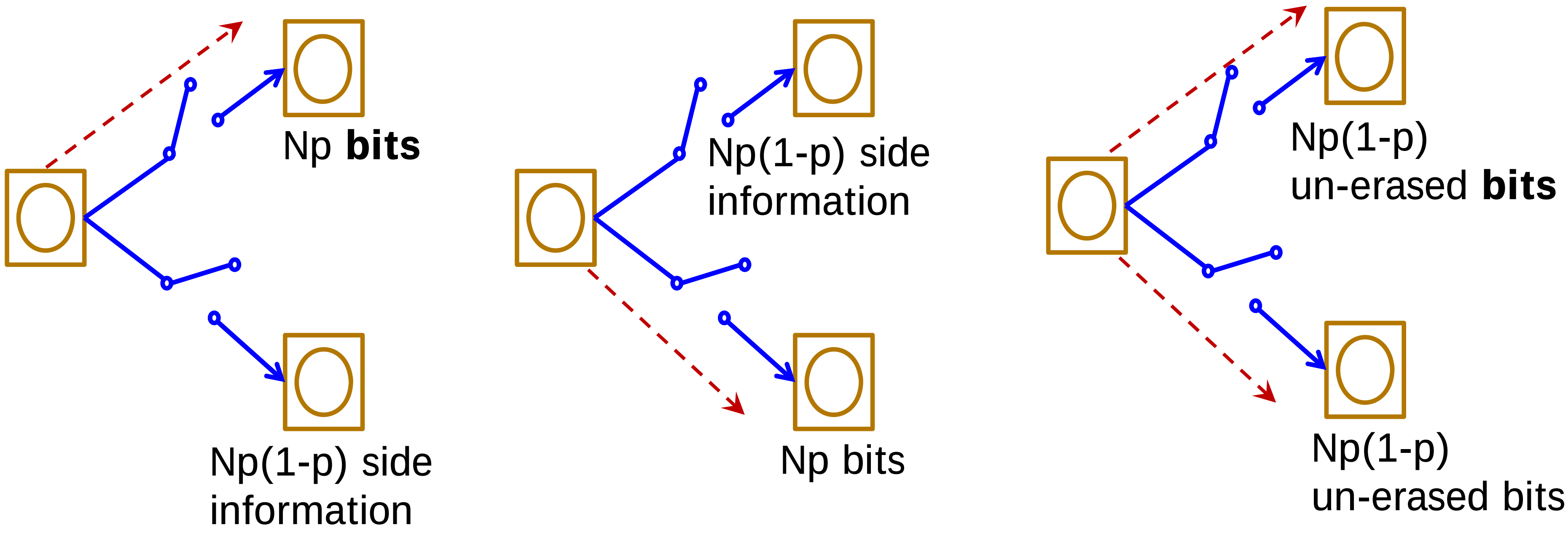
Σ_1	Σ_2	erased $\Sigma_1 \oplus \Sigma_2$

  – How to re-transmit erased **bits** in Gaussian channel?

  – How to incorporate superposition coding?

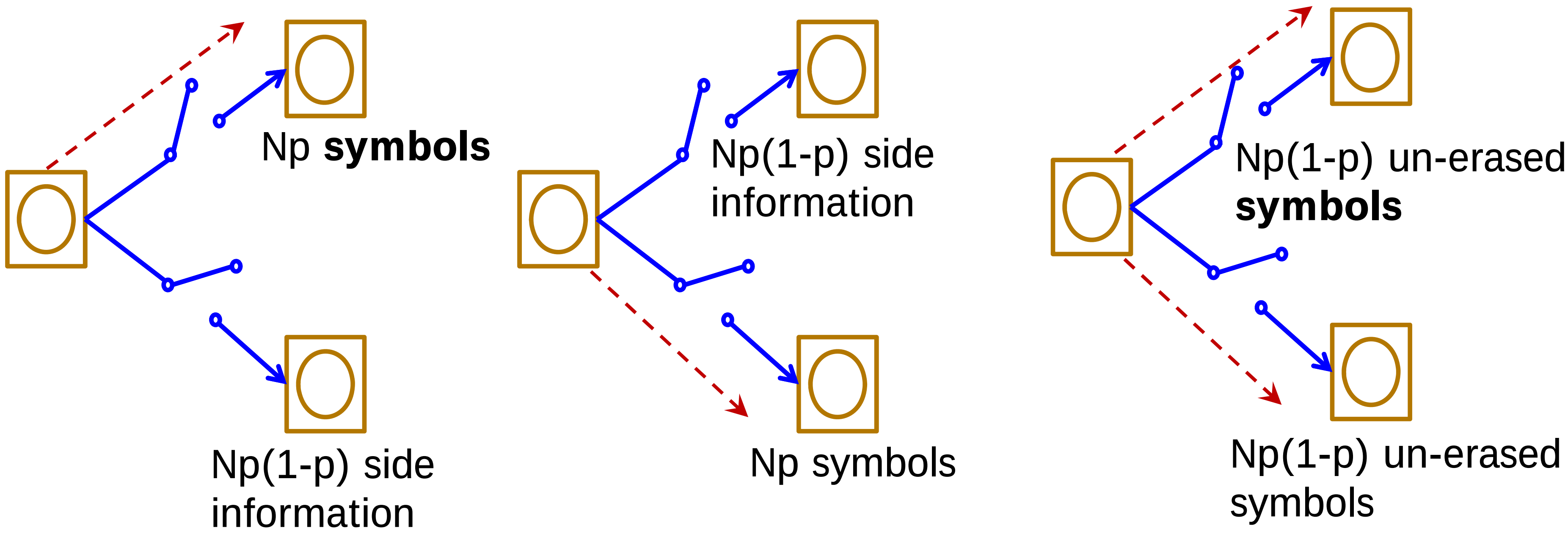
Binary 3-Phase retransmission scheme

Length: N	N	N(1-p)
Σ_1	Σ_2	erased $\Sigma_1 \oplus \Sigma_2$



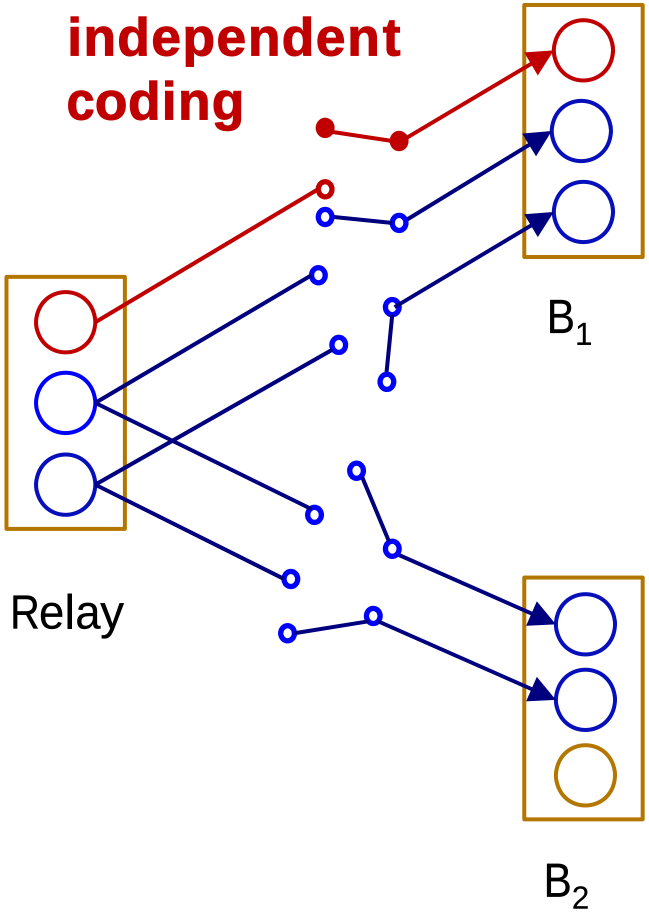
Retransmission in Gaussian model

- Phase 3 : Send **erased symbols** (2-Rx joint source-channel coding problem)



- Node B_1 decodes Σ_1 by total Np+Np(1-p) symbols

Superposition with delayed state information



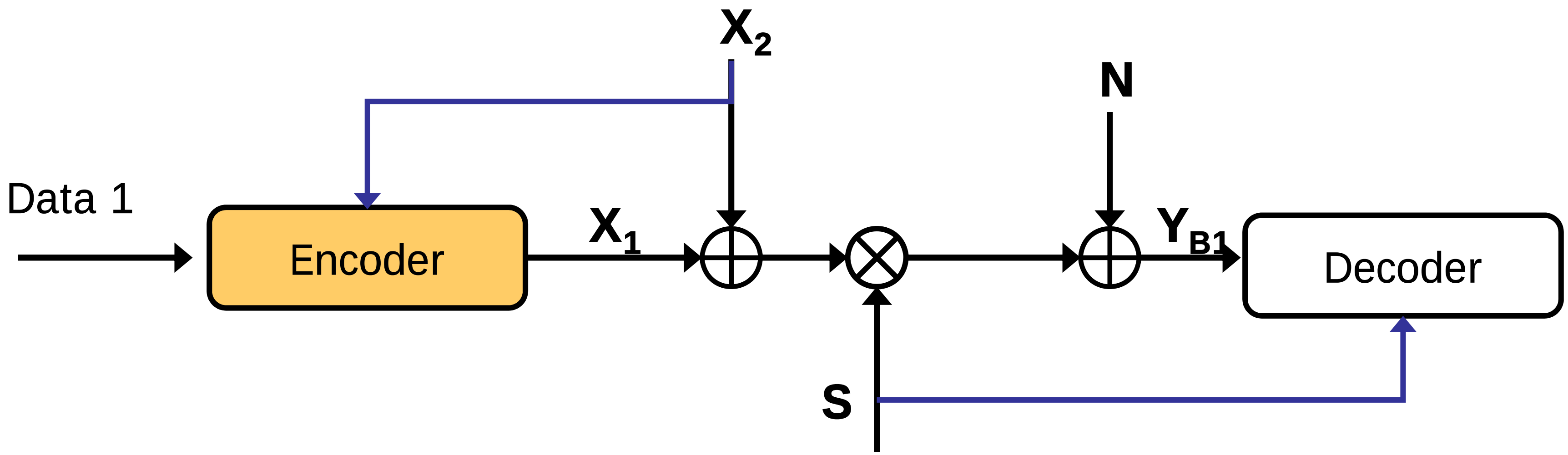
- 3-Phase retransmission in Gaussian model

Σ_1	Σ_2	Erased symbols

  - Phase 1 : transmit Σ_1
  - Phase 2 : transmit Σ_2 and Σ_1
  - Phase 3 : B_1 has better reconstruction

Superposition with delayed state information

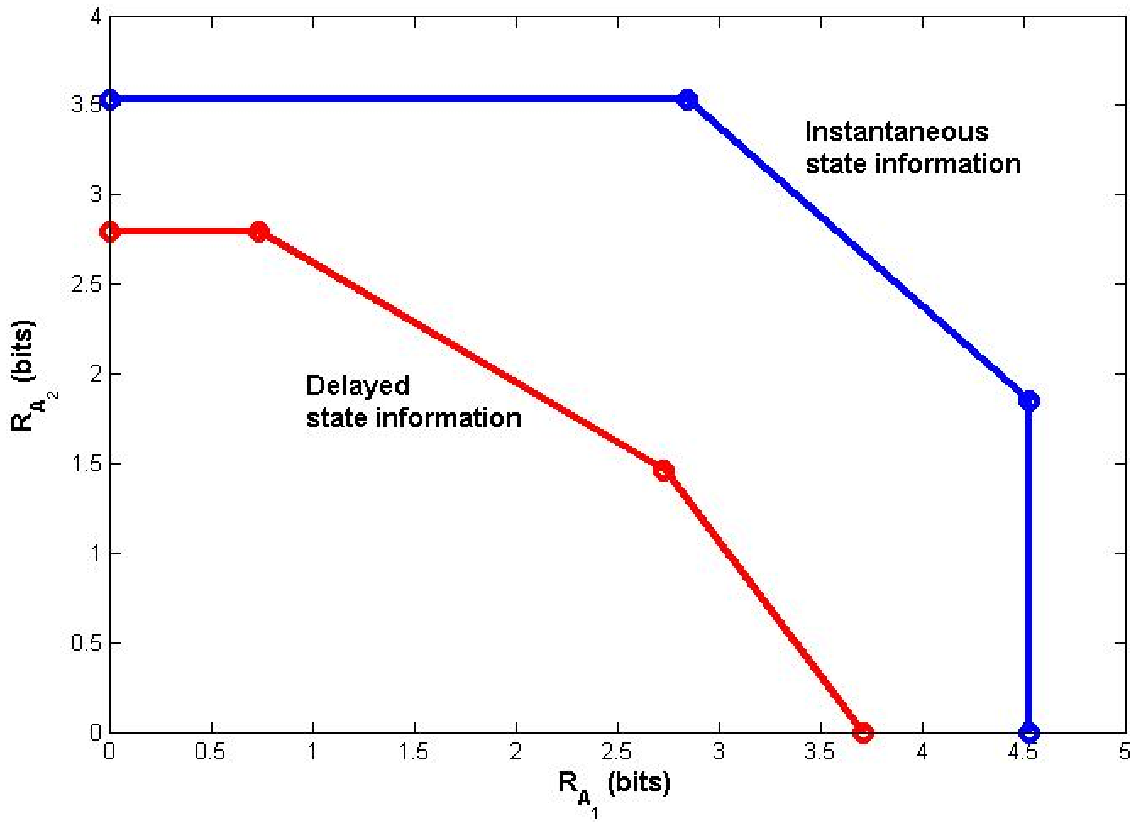
- Phase 2 : To superimpose x_1 and x_2



Solved by Lattice strategies

- Phase 3 : Compressing by successive refinement

Gaussian downlink : bounded gap schemes



$|h_{R1}| = 2$, $|h_{R2}| = 1$, Tx SNR=10dB

- Delayed : Proposed scheme has bounded gap to outer bounds

- Instantaneous : conventional superposition coding +on/off power allocation

Extensions

- Different burstness state $(S_1^{ul}(t), S_1^{dl}(t))$ at uplink and downlink
- More than two user pairs
- Different state for each user $(S_1(t), S_2(t), S_3(t), S_4(t))$: Shadowing

Conclusion

- Bursty interference is a more general and practical model for future communication system

- Capacity region to within a bounded gap in a bursty two-pair two-way relay channel in symmetric setting was identified

Thank you!