The Diagonal Vector Gaussian Finite State MAC with Cooperative Encoders and Delayed CSI

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November, 2012

Outline

- Motivation

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- Conferencing channel model

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- Common message channel model

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- Common message main result

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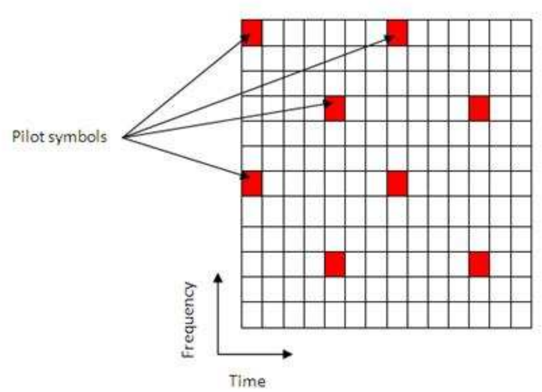
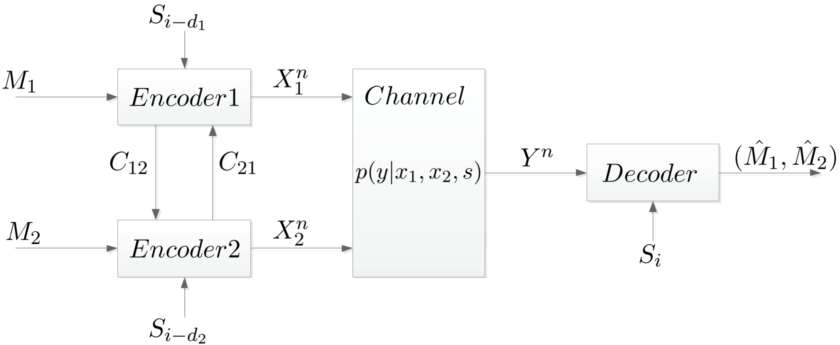
- Channel state information (CSI) needs to be estimated.
- In LTE uplink standard, pilot signal are sent by the users in



FSM-MAC with Conferencing and Delayed CSI



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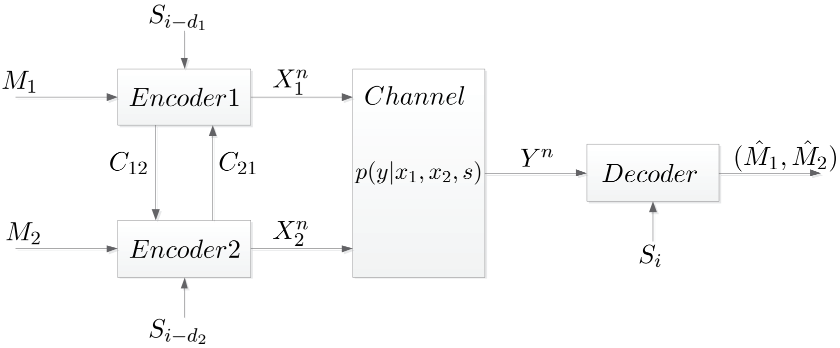

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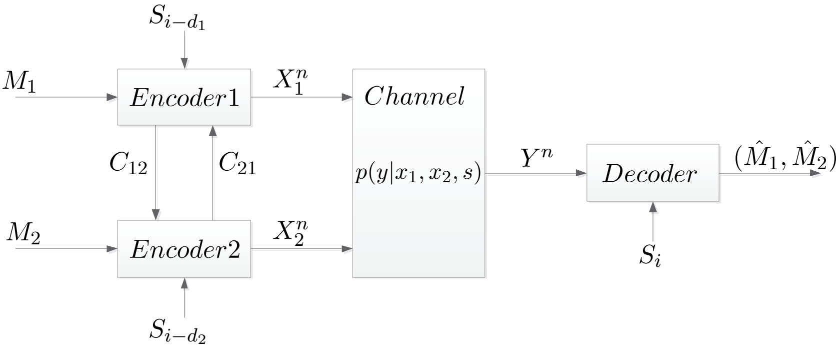

- CSI known to the Decoder and delayed CSI known to the Encoders.
- Conferencing between the Encoders is possible through limited links.

Channel Model and Notation

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- Finite number of states $|\mathcal{S}| < \infty$.
- Channel state is a stationary Markov process independent of the messages.
- The random variables S_i S_{i-d} denote the channel state at time i, and $i-d$, respectively.
- The (S_i, S_{i-d}) joint distribution is stationary and is given by

$$P(S_i = s_l, S_{i-d} = s_j) = \pi(s_j)K^d(s_l, s_j).$$

Channel Model - Partial Cooperation [Willems82]

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- The state process is independent of the conference communications.
- The conference is held using two communication links with finite capacities C_{12} and C_{21}.

Capacity Proof Chronology

Define Conferencing Model

Capacity Proof Chronology

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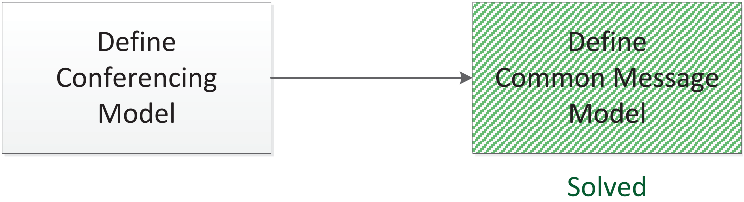

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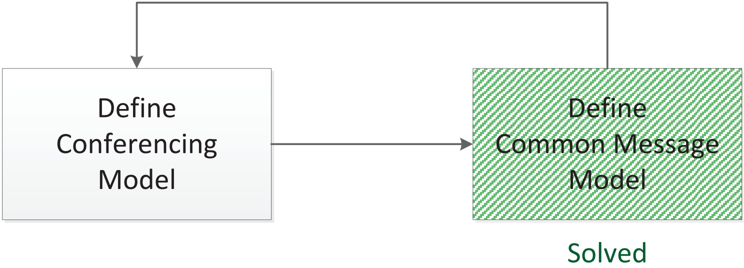

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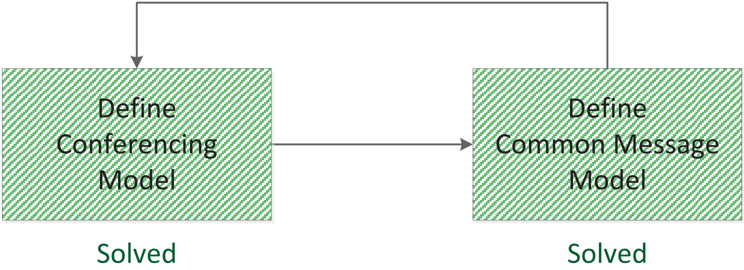
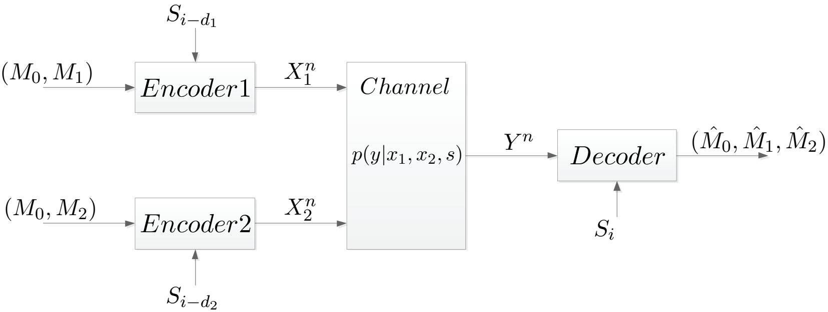


Common Message Model



Main Results Common Message with Delayed CSI ($d_1 \geq d_2$)

Theorem

The capacity region of FSM-MAC with a common message, CSI at the decoder and delayed CSI at the encoders with delays d_1 and d_2, is

$$\begin{aligned} R_1 &< I(X_1;Y|X_2,U,S,\widetilde{S}_1,\widetilde{S}_2), \\ R_2 &< I(X_2;Y|X_1,U,S,\widetilde{S}_1,\widetilde{S}_2), \\ R_1+R_2 &< I(X_1,X_2;Y|U,S,\widetilde{S}_1,\widetilde{S}_2), \\ R_0+R_1+R_2 &< I(X_1,X_2;Y|S,\widetilde{S}_1,\widetilde{S}_2), \end{aligned}$$

for some joint distribution of the form:

$$P(u|\tilde{s}_1)P(x_1|\tilde{s}_1,u)P(x_2|\tilde{s}_1,\tilde{s}_2,u).$$

The joint distribution $(S,\widetilde{S}_1,\widetilde{S}_2)$ is the same joint distribution as $(S_i,S_{i-d_1},S_{i-d_2})$.

Achievability - Ideas and Discussion

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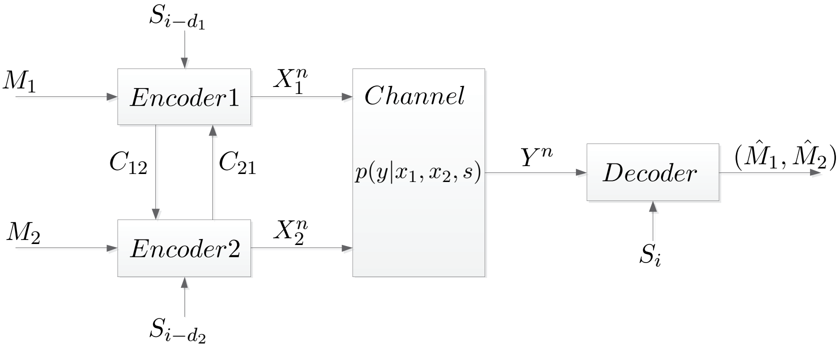
- Coding scheme: Encode using MUX, decode simultaneously using joint-typicality.
  - Achieves every possible point in the region.
  - Can be easily extended to multiple users.
- Generalizes the result for the FSM-MAC with delayed CSI and no common message [Basher/Shirazy/P.11].

MAC with Conferencing and Delayed CSI



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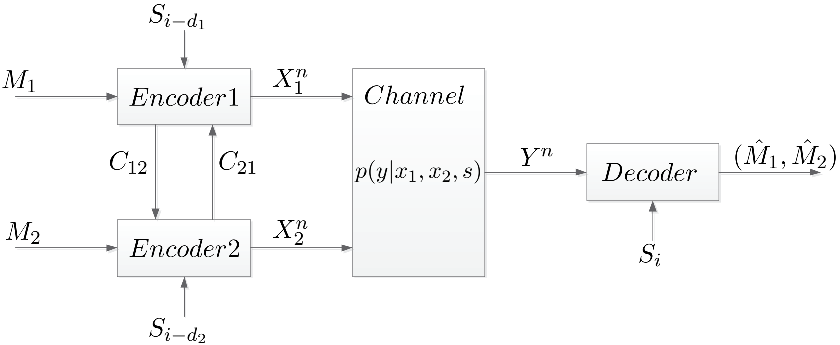
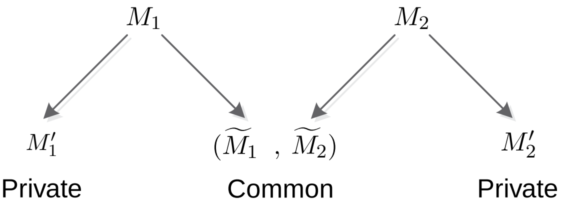


Share as much as possible of the massages through the conferencing links.

Conferencing Setting - Achievability Outline

- Split the original messages (M_1, M_2) into private messages (M_1', M_2') and a common message $(\widetilde{M}_1, \widetilde{M}_2)$.



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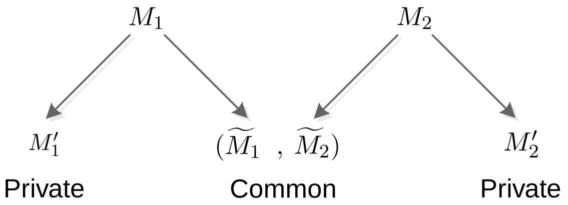

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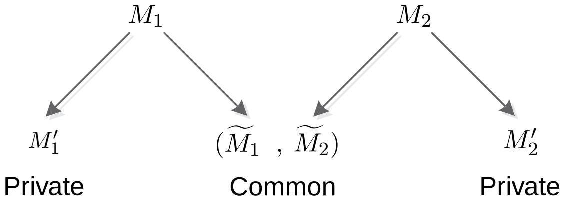

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Message	Rate
$M_0' = (\widetilde{M}_1, \widetilde{M}_2)$	$C_{12} + C_{21}$
M_1'	$R_1 - C_{12}$
M_2'	$R_2 - C_{21}$

Conferencing Setting - Achievability Outline

Using common message result:

Conferencing Setting - Achievability Outline

Using common message result:

$$(R_1 - C_{12}) \leq I(X_1; Y|X_2, U, S, \tilde{S}_1, \tilde{S}_2),$$
$$(R_2 - C_{21}) \leq I(X_2; Y|X_1, U, S, \tilde{S}_1, \tilde{S}_2),$$
$$(R_1 - C_{12}) + (R_2 - C_{21}) \leq I(X_1, X_2; Y|U, S, \tilde{S}_1, \tilde{S}_2),$$
$$(C_{12} + C_{21}) + (R_1 - C_{12}) + (R_2 - C_{21}) \leq I(X_1, X_2; Y|S, \tilde{S}_1, \tilde{S}_2).$$

Main Results with Conferencing and Delayed CSI $(d_1 \geq d_2)$

Theorem

The capacity region of FSM-MAC with partially cooperative encoders, CSI at the decoder and CSI at the encoders with delays d_1 and d_2, is

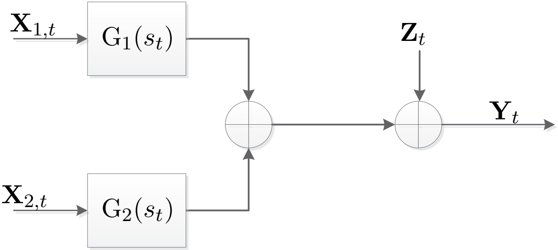
$$\begin{aligned} R_1 &< I(X_1;Y|X_2,U,S,\tilde{S}_1,\tilde{S}_2) + C_{12}, \\ R_2 &< I(X_2;Y|X_1,U,S,\tilde{S}_1,\tilde{S}_2) + C_{21}, \\ R_1 + R_2 &< \min\left\{ \begin{array}{c} I(X_1,X_2;Y|U,S,\tilde{S}_1,\tilde{S}_2) + C_{12} + C_{21}, \\ I(X_1,X_2;Y|S,\tilde{S}_1,\tilde{S}_2) \end{array} \right\}, \end{aligned}$$

for some joint distribution of the form:

$$P(u|\tilde{s}_1)P(x_1|\tilde{s}_1,u)P(x_2|\tilde{s}_1,\tilde{s}_2,u).$$

Vector Diagonal Gaussian FSM-MAC - Channel Model

The vector diagonal additive Gaussian noise (AGN) FSM-MAC with partially cooperative encoders and delayed CSI,



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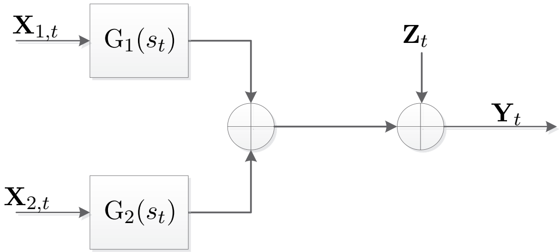

The channel model,

$$\mathbf{Y}_t = \mathrm{G}_1(s_t)\mathbf{X}_{1,t} + \mathrm{G}_2(s_t)\mathbf{X}_{2,t} + \mathbf{Z}_t,$$

Vector Diagonal Gaussian FSM-MAC - Channel Model

- $\left\{\mathrm{G}_1(s)\right\}_{s\in\mathcal{S}}$ and $\left\{\mathrm{G}_2(s)\right\}_{s\in\mathcal{S}}$ are real diagonal channel transition matrices of dimension $N \times N$.

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- $\mathbf{Z}$ is independent of $\mathbf{X}_1$ and $\mathbf{X}_2$.
- All vectors are real and of dimension $N \times 1$.
- The inputs are bounded by the following power constraints,

$$\mathrm{tr}\left(\Sigma_{X_1 X_1}\right) \leq \mathcal{P}_1 \;\; ; \;\; \mathrm{tr}\left(\Sigma_{X_2 X_2}\right) \leq \mathcal{P}_2 .$$

Vector Diagonal Gaussian FSM-MAC - Proof Outline

- The main difficulty is to that a Gaussian triplet $(\mathbf{X}_1, \mathbf{U}, \mathbf{X}_2)$ satisfying

$$\mathbf{U} - \widetilde{S}_1 - (S, \widetilde{S}_2),$$
$$\mathbf{X}_1 - (\mathbf{U}, \widetilde{S}_1) - (S, \widetilde{S}_2),$$
$$\mathbf{X}_2 - (\mathbf{U}, \widetilde{S}_1, \widetilde{S}_2) - (\mathbf{X}_1, S),$$

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\end{aligned}$$

  is optimal.
- Use an extension of the idea of [Lapidoth/Bross/Wigger08] and [Lapidoth/Venkatesan07].

Vector Diagonal Gaussian FSM-MAC - Main Result

$$R_1 < \frac{1}{2}\sum_{\tilde{s}_1}\pi(\tilde{s}_1)\sum_{\tilde{s}_2}K^{d_1-d_2}(\tilde{s}_2,\tilde{s}_1)\sum_{s}K^{d_2}(s,\tilde{s}_2)\sum_{i=1}^{N}\log\left(1+\left(g_1^i(s)\right)^2\gamma_1^i(\tilde{s}_1)\right)+C_{12},$$

$$R_2 < \frac{1}{2}\sum_{\tilde{s}_1}\pi(\tilde{s}_1)\sum_{\tilde{s}_2}K^{d_1-d_2}(\tilde{s}_2,\tilde{s}_1)\sum_{s}K^{d_2}(s,\tilde{s}_2)\sum_{i=1}^{N}\log\left(1+\left(g_2^i(s)\right)^2\gamma_2^i(\tilde{s}_1,\tilde{s}_2)\right)+C_{21},$$

$$R_1+R_2 < \frac{1}{2}\sum_{\tilde{s}_1}\pi(\tilde{s}_1)\sum_{\tilde{s}_2}K^{d_1-d_2}(\tilde{s}_2,\tilde{s}_1)\sum_{s}K^{d_2}(s,\tilde{s}_2)\sum_{i=1}^{N}\log\Big(1+\left(g_1^i(s)\right)^2\gamma_1^i(\tilde{s}_1) + \left(g_2^i(s)\right)^2\gamma_2^i(\tilde{s}_1,\tilde{s}_2)\Big)+C_{12}+C_{21},$$

$$R_1+R_2 < \frac{1}{2}\sum_{\tilde{s}_1}\pi(\tilde{s}_1)\sum_{\tilde{s}_2}K^{d_1-d_2}(\tilde{s}_2,\tilde{s}_1)\sum_{s}K^{d_2}(s,\tilde{s}_2)\sum_{i=1}^{N}\log\Big(1+\left(g_1^i(s)\right)^2P_1^i(\tilde{s}_1) + \left(g_2^i(s)\right)^2P_2^i(\tilde{s}_1,\tilde{s}_2)+2g_1^i(s)g_2^i(s)\sqrt{\left(P_1^i(\tilde{s}_1)-\gamma_1^i(\tilde{s}_1)\right)\left(P_2^i(\tilde{s}_1,\tilde{s}_2)-\gamma_2^i(\tilde{s}_1,\tilde{s}_2)\right)}\Big),$$

subject to the constraints,

$$\sum_{\tilde{s}_1}\pi(\tilde{s}_1)\sum_{i=1}^{N}P_1^i(\tilde{s}_1)\le\mathcal{P}_1, \quad ; \quad \sum_{\tilde{s}_1}\pi(\tilde{s}_1)\sum_{\tilde{s}_2}K^{d_1-d_2}(\tilde{s}_2,\tilde{s}_1)\sum_{i=1}^{N}P_2^i(\tilde{s}_1,\tilde{s}_2)\le\mathcal{P}_2,$$

$$0\le\gamma_1^i(\tilde{s}_1)\le P_1^i(\tilde{s}_1), \forall\, i\in\{1,\dots,N\}, \tilde{s}_1\in\mathcal{S},$$

$$0\le\gamma_2^i(\tilde{s}_1,\tilde{s}_2)\le P_2^i(\tilde{s}_1,\tilde{s}_2), \forall\, i\in\{1,\dots,N\}, (\tilde{s}_1,\tilde{s}_2)\in\mathcal{S}^2.$$

Example: Gilbert-Elliot Gaussian MAC

- At any given time t the channel is in one of two possible states, $Good$ or Bad.
- $g_1(G) > g_1(B)$ and $g_2(G) > g_2(B)$.

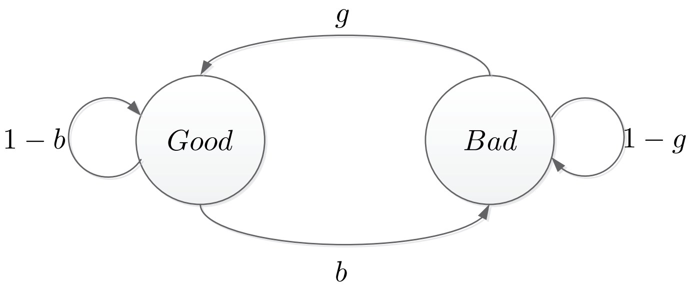
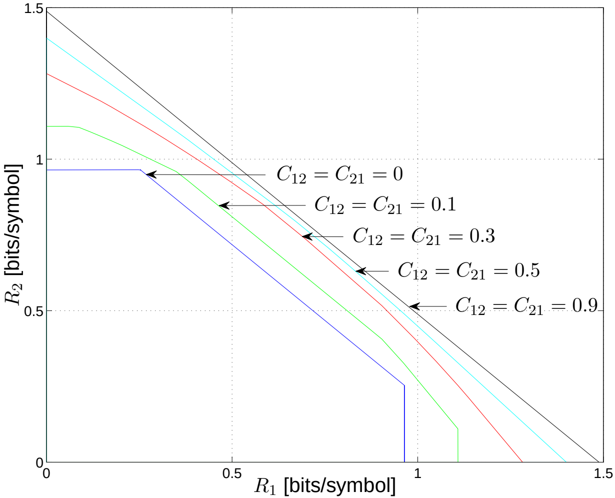


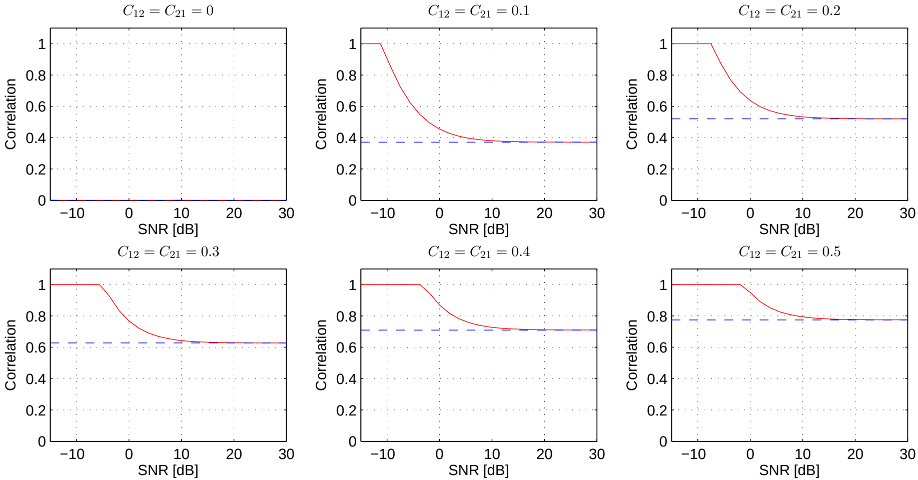
Figure : Two-state AGN channel.

Capacity region of Two-State AGN MAC Example

Fixed delays $d_1 = d_2 = 2$ and symmetrical con. $C_{12} = C_{21}$



Correlation versus SNR



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Thank you!

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- Channel encoder,

$$X_{1,i} = \left\{ \begin{array}{cc} f_{1,i}(M_1, V_2^{\ell}), & 1 \leq i \leq d_1 \\ f_{1,i}(M_1, V_2^{\ell}, S^{i-d_1}), & d_1 + 1 \leq i \leq n \end{array} \right\},$$

$$X_{2,i} = \left\{ \begin{array}{cc} f_{2,i}(M_2, V_1^{\ell}), & 1 \leq i \leq d_2 \\ f_{2,i}(M_2, V_1^{\ell}, S^{i-d_2}), & d_2 + 1 \leq i \leq n \end{array} \right\}.$$

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- The inequalities are reduced using induction and the Fourier-Motzkin elimination.

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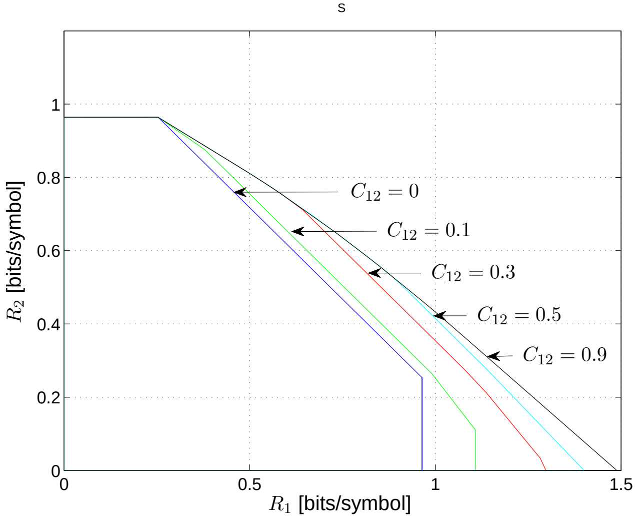
- Identification of the auxiliary random variable U as the common knowledge of the two encoders, $U_i = (M_0, S^{i-d_1-1})$.

Capacity region of Two-State AGN MAC Example

Fixed delays $d_1 = d_2 = 2$ and asymmetrical con. $C_{12} \geq C_{21} = 0$



Capacity region of Two-State AGN MAC Example

Fixed delays $d_1 = d_2 = 2$ and infinite con. $C_{12} \le C_{21} = \infty$