Habilitation Exam

Communication, Compression, and Coordination over Networks: Benefits of Cooperation and Side-Information

Michèle Wigger

Telecom ParisTech

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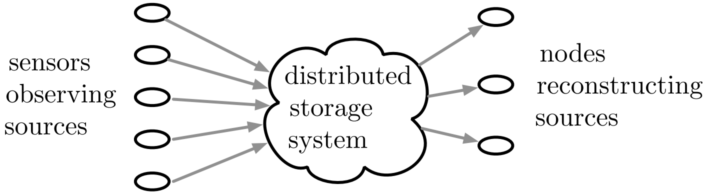
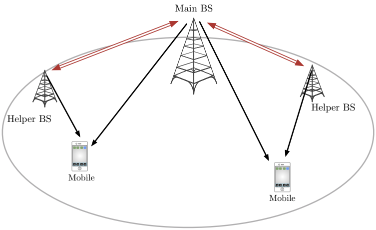
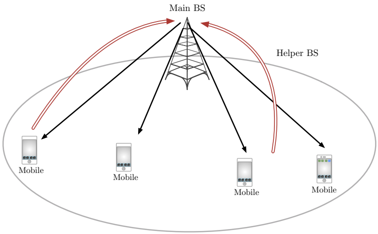
Distributed compression (source coding) with side-information



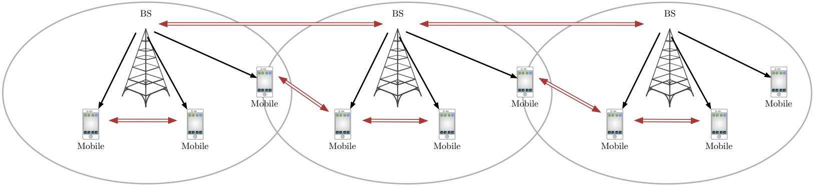
Communication networks with cooperating basestations or mobiles



BS-BS cooperation inside a cell

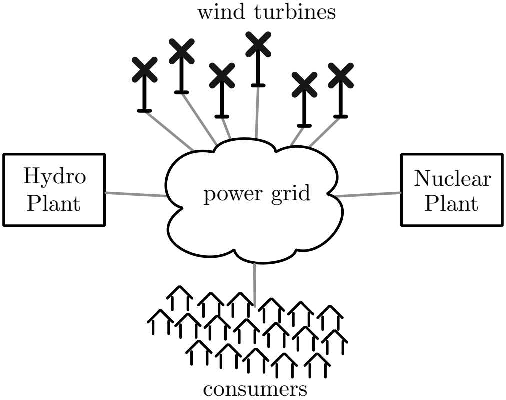


Mobile-BS cooperation inside a cell



BS-BS or mobile-mobile cooperation across cells

Coordinating partially-informed agents



- Here: Coordinate hydro- and nuclear-plant to stabilize system and minimize productions
- General cyber-physical system for transportation, rescue, health care, etc.

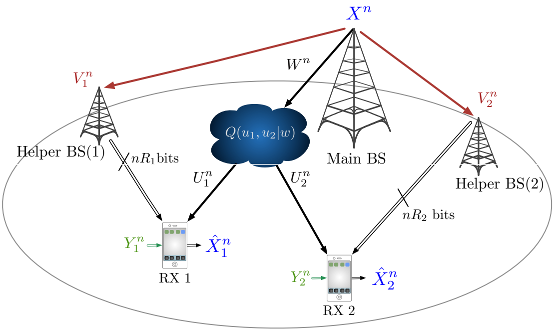
Information-theoretic setups

Asymptotically vanishing probability of error

- Distributed compression systems: how many bits to describe outcome of a source?
- Communication networks: how many bits can one transmit?
- Coordination of distributed agents: which actions-tuples are implementable?

Communication networks with cooperating users

BS-to-BS cooperation inside a cell: downlink



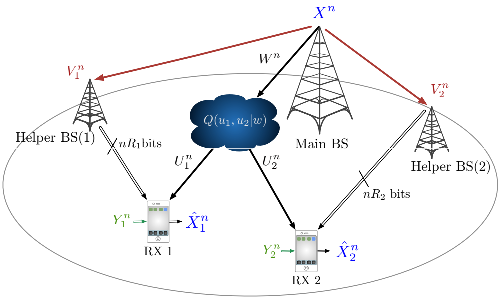
(Almost) lossless joint source-channel coding

Reliable communications for rates (R_1, R_2) possible, if $\exists$ encodings and decodings s.t.

$$\mathbb{P}\left[\left\{\hat{X}_1^n \neq X^n\right\} \cup \left\{\hat{X}_2^n \neq X^n\right\}\right] \longrightarrow 0$$

[1] R. Timo and M. Wigger, "Slepian-Wolf coding for broadcasting with cooperative basestations," *IEEE Trans. Communications*, 2015.

Two scenarios for helper side-informations V_1^n and V_2^n



Scenario 1 : Scalar quantisation

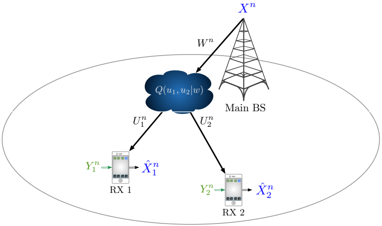
$$V_{k,t} = \phi_k(W_t)$$

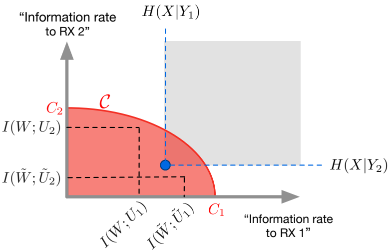
Scenario 2 : Correlated sources

$$X^n, Y_1^n, Y_2^n, V_1^n, V_2^n \text{ i.i.d.} \sim P_{XY_1Y_2V_1V_2}$$

[2] D. Gunduz, E. Erkip, A. Goldsmith, and H. V. Poor, "Reliable joint source-channel cooperative transmission over relay networks," *IEEE Trans. Inform. Theory*, 2013.

Background: No helper basestations, $R_1 = R_2 = 0$





Theorem [3]:

Reliable communications possible iff $\exists W \sim P_W$ s.t.

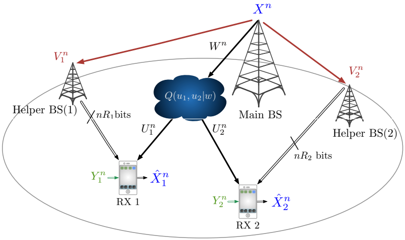
$$H(X|Y_1) \leq I(W;U_1)$$

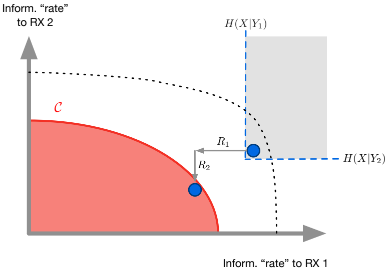
and

$$H(X|Y_2) \leq I(W;U_2)$$

[3] E. Tuncel, "Slepian-Wolf coding over broadcast channels," *IEEE Trans. Inform. Theory*, 2006.

Result for Scenario 1: $V_{k,t} = \phi_k(W_t)$





Theorem:

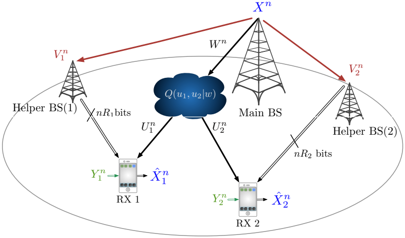
Reliable communications possible with helper rates (R_1, R_2) iff $\exists W \sim P_W$ s.t.

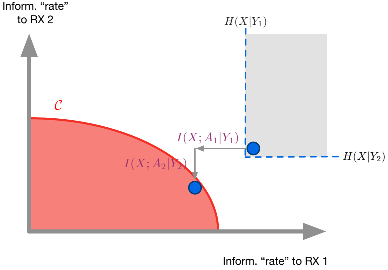
$$H(X|Y_1) \leq I(W;U_1) + \min\left\{R_1,\ I(W;V_1|U_1)\right\}$$

$$H(X|Y_2) \leq I(W;U_2) + \min\left\{R_2,\ I(W;V_2|U_2)\right\}$$

- Helper BS k randomly hashes V_k^n as in deterministic relay channels

Result for Scenario 2: $(X^n, Y_1^n, Y_2^n, V_1^n, V_2^n)$ i.i.d. $\sim P_{XY_1Y_2V_1V_2}$





Theorem:

Reliable communication possible with helper rates (R_1, R_2) iff $\exists W, A_1, A_2$ s.t.

$$H(X|Y_1, A_1) \le I(W; U_1) \qquad R_1 \ge I(V_1; A_1|Y_1) \ge I(X; A_1|Y_1)$$
$$H(X|Y_2, A_2) \le I(W; U_2) \qquad R_2 \ge I(V_2; A_2|Y_2) \ge I(X; A_2|Y_2)$$

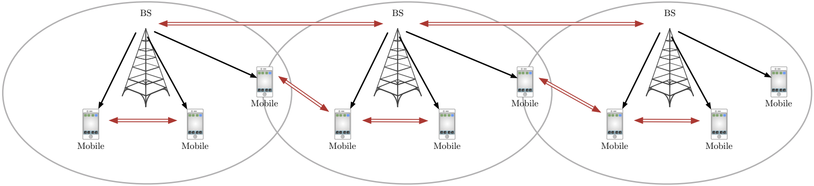
and $(X, Y_1) \to V_1 \to A_1$ and $(X, Y_2) \to V_2 \to A_2$

- Helper BS k uses Wyner's helper source-code to compress V_k^n into A_k^n

Summary on: BS-to-BS cooperation inside a cell

- Capacity for two-scenarios of BSs-cooperation models
- Modularity/Duality of optimal solutions
- same operations at main BS
- Helper BSs: use Wyner's helper source code or random hashing as for det. relay channels
- receiving mobiles: Tuncel's decoding *with improved*
  - channel outputs (Scenario 1); or
  - source side-information (Scenario 2)

BS-to-BS or mobile-to-mobile cooperation across cells

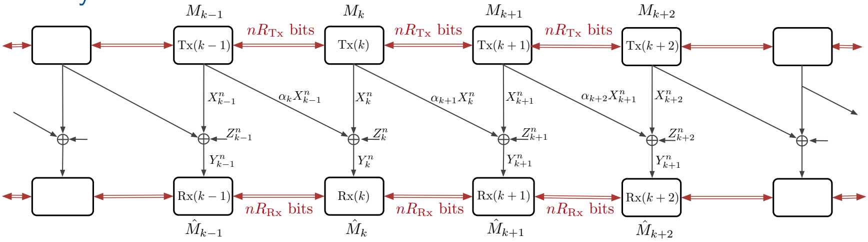


- Cooperation over digital links of given capacities

# of conferencing rounds limited due to latency or complexity constraints

[4] R. Timo, S. Shamai, M. Wigger, "Conferencing in Wyner's asymmetric interference network: effect of number of rounds," in *Proc. of ITW*, 2015.

Wyner's Asymmetric Soft-Handoff Model

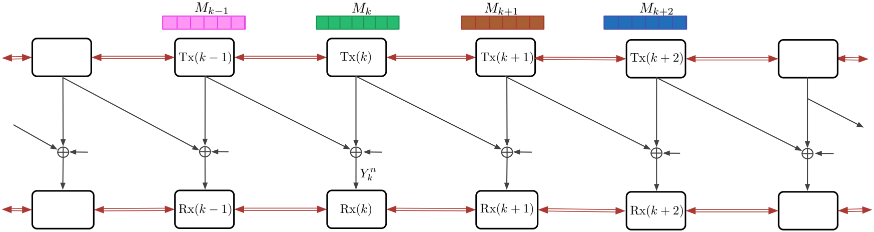


- K transmitter/receiver pairs
- Channel gains $\{\alpha_k\}$ fixed, constant, non-zero
- Memoryless Gaussian noises of variance σ^2 and equal power constraints P

Goal

Determine message rates $R_1, \ldots, R_K$ s.t. $\forall k \colon \Pr(\hat{M}_k \neq M_k) \to 0$ as $n \to \infty$

Communication takes place in 4 phases



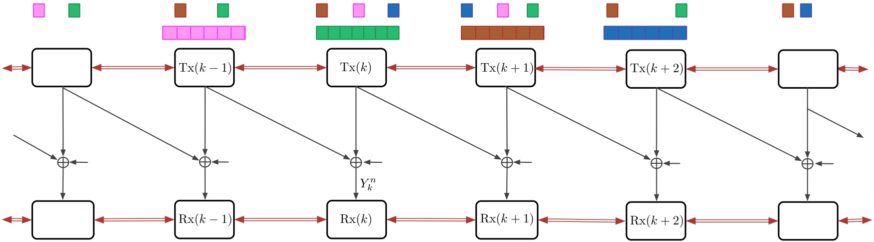
- Conferencing over κ rounds (here $\kappa = 2$):

  $\rightarrow$ Messages spread over κ transmitters to left & right

  $\rightarrow$ Output signals spread over κ receivers to left & right

Communication takes place in 4 phases

Phase 1: Transmitter-conferencing



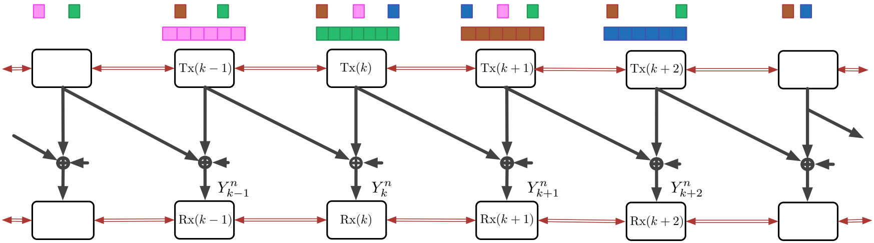
- Conferencing over κ rounds (here $\kappa = 2$):

  $\rightarrow$ Messages spread over κ transmitters to left & right

  $\rightarrow$ Output signals spread over κ receivers to left & right

Communication takes place in 4 phases

Phase 2: Cooperative communication over network



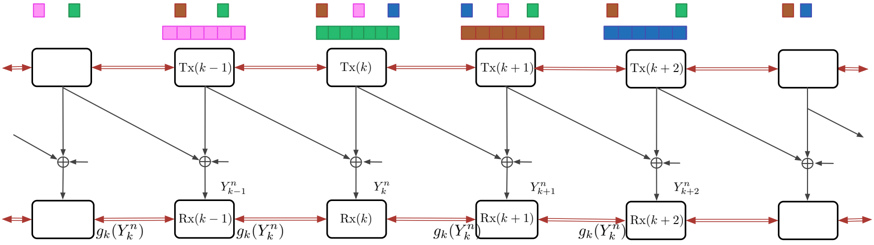
- Conferencing over κ rounds (here $\kappa = 2$):

  $\rightarrow$ Messages spread over κ transmitters to left & right

  $\rightarrow$ Output signals spread over κ receivers to left & right

Communication takes place in 4 phases

Phase 3: Receiver-conferencing



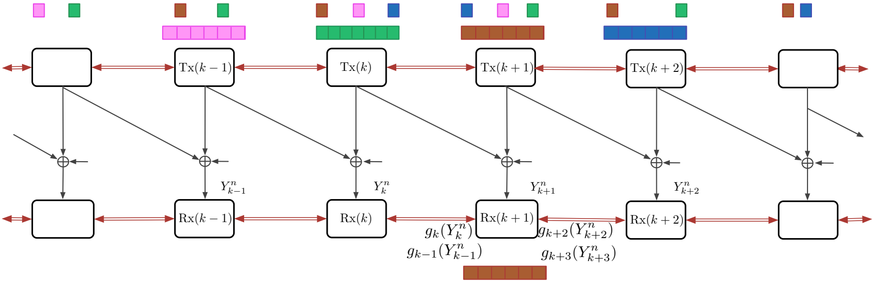
- Conferencing over κ rounds (here $\kappa = 2$):

  $\rightarrow$ Messages spread over κ transmitters to left & right

  $\rightarrow$ Output signals spread over κ receivers to left & right

Communication takes place in 4 phases

Phase 4: Clustered decoding



- Conferencing over κ rounds (here $\kappa = 2$):

  $\rightarrow$ Messages spread over κ transmitters to left & right

  $\rightarrow$ Output signals spread over κ receivers to left & right

High-SNR Performance: Multiplexing-Gain Per User

- Sum-capacity: C_Σ maximum sum of rates $R_1 + R_2 + \cdots + R_K$ s.t. $p(error) \to 0$

- Asymptotic multiplexing gain per user $\mathcal{S}$:

$$\text{Sum-capacity: } C_\Sigma \approx \mathcal{S} \cdot \frac{K}{2} \log(1 + P/\sigma^2), \qquad P\sigma^2 \gg 1$$

- Conferencing prelogs μ_{Tx} and μ_{Rx}:

$$R_{\mathrm{Tx}} = \mu_{\text{Tx}} \cdot \frac{1}{2} \log(1+P/\sigma^2) \qquad \text{and} \qquad R_{\mathrm{Rx}} = \mu_{\text{Rx}} \cdot \frac{1}{2} \log(1+P/\sigma^2)$$

Results:

Theorem (Achievability when number of conferencing rounds $\kappa < \infty$)

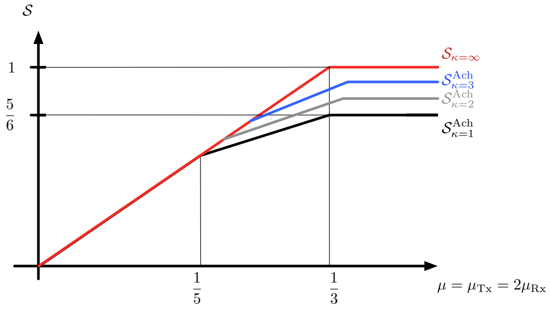
$$\mathcal{S} \geq \begin{cases} \frac{1+2\mu_{\mathsf{Tx}}+2\mu_{\mathsf{Rx}}}{2} & 2\mu_{\mathsf{Tx}} + 2\mu_{\mathsf{Rx}} + \frac{2\max\{\mu_{\mathsf{Tx}},\mu_{\mathsf{Rx}}\}}{\kappa} < 1 \\ \frac{1+2\kappa+\max\{2\mu_{\mathsf{Tx}},2\mu_{\mathsf{Rx}}\}}{2\kappa+2} & \text{otherwise} \\ \frac{4\kappa+1}{4\kappa+2} & \min\{\mu_{\mathsf{Tx}}, \mu_{\mathsf{Rx}}\} > \frac{\kappa}{4\kappa+2} \end{cases}$$

Converse tight when $\kappa = 1$ and at the same time $\mu_{\mathsf{Tx}} = 0$ or $\mu_{\mathsf{Rx}} = 0$.

Theorem (Number of conferencing rounds $\kappa = \infty$)

$$\mathcal{S}_{\kappa=\infty} = \min\left\{1, \frac{1+2\mu_{\mathsf{Tx}}+2\mu_{\mathsf{Rx}}}{2}\right\}$$

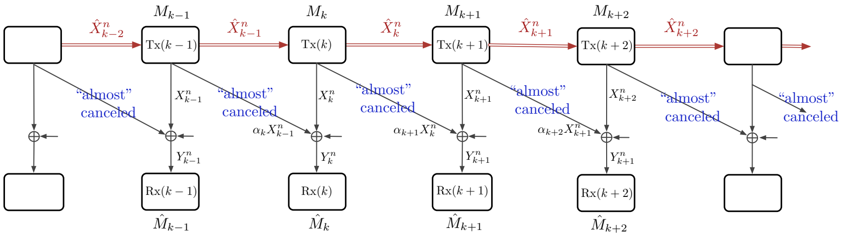
Comparison



- For small conferencing prelogs $\kappa = 1$ suffices!
- For finite κ, multiplexing gain per user saturates below 1
- Duality between transmitter-cooperation and receiver-cooperation

Coding scheme for $\kappa = \infty$

- $\mu_{\mathsf{Tx}} = \mu_{\mathsf{Rx}} = 1/2 \implies \mathcal{S}_{\kappa=\infty} = 1$



- Tx-conferencing: $\hat{X}_k = f_k(M_1, \ldots, M_k)$

- Rx-conferencing: $\hat{M}_k = g_k(Y_1^n, \ldots, Y_k^n)$

[5] V. Ntranos, M.A. Maddah-Ali and G. Caire, "Cellular interference alignment," *IEEE Trans. Inform. Theory*, Mar. 2015

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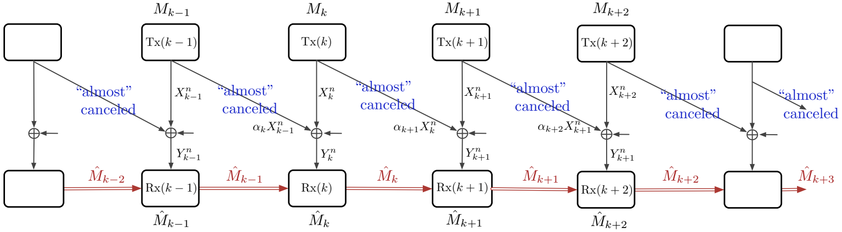

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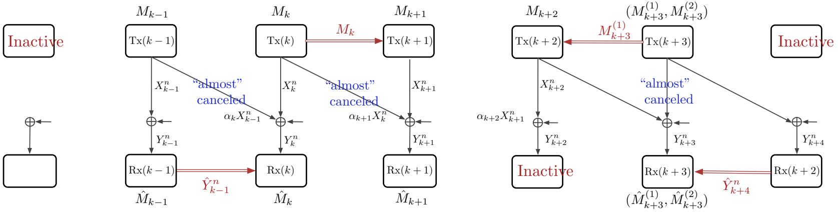
[5] V. Ntranos, M.A. Maddah-Ali and G. Caire, "Cellular interference alignment," *IEEE Trans. Inform. Theory*, Mar. 2015

Coding Scheme for $\kappa = 1$

- $\mu_{\mathrm{Tx}} = \mu_{\mathrm{Rx}} = 1/2 \implies \mathcal{S}_{\kappa=\infty} = 5/6$



- Tx-conferencing: M_k

- Rx-conferencing: $\hat{Y}^n_k = g_k(Y^n_k)$

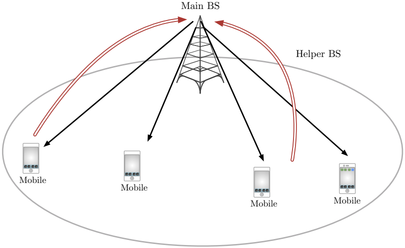
Generally, interference mitigation causes interference to propagate

$\rightarrow$ for finite κ need to switch off txs!

Summary and Outlook on: Cooperation across cells

- For small conferencing prelogs $\kappa = 1$ suffices!
- For finite κ, multiplexing gain per user saturates below 1
- Duality between transmitter-cooperation and receiver-cooperation
- In future: analyze different cooperation constraints
  - oblivious codebooks
  - more accurate latency and complexity constraints? (mobiles!)

Mobiles-to-BS cooperation in a cell using feedback



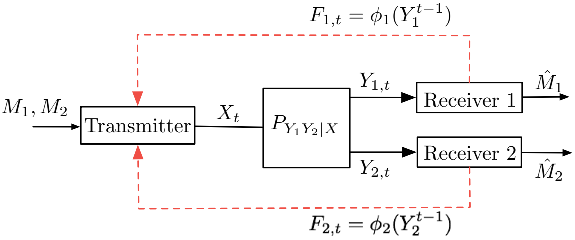
- How and how much does feedback help on a memoryless BC
- Duality to the MAC

[6] O. Shayevitz and M. Wigger, "On the capacity of the discrete memoryless broadcast channel with feedback," *IEEE Trans. Inform. Theory*, Mar. 2013

[7] Y. Wu and M. Wigger, "Coding schemes with rate-limited feedback that improve over the nofeedback capacity for a large class of broadcast channels," submitted to *IEEE Trans. on Inform. Theory*, July 2014

[8] S. Belhadj Amor, Y. Steinberg, and M. Wigger, "MAC-BC duality with linear-feedback schemes," submitted to *IEEE Trans. on Inform. Theory*, Apr. 2014

Rate-limited feedback on discrete memoryless BCs



- Feedback rate constraint: $|\mathcal{F}_{i,1}| \cdots |\mathcal{F}_{i,n}| \leq nR_{\text{fb},i}, \quad i = 1, 2$
- $X_t = f_t(M_1, M_2, F_1^{t-1}, F_2^{t-1})$

Dueck's example provides first intuition how feedback helps on the BC

$$X_t = \begin{pmatrix} B_{1,t} \\ B_{0,t} \\ B_{2,t} \end{pmatrix}, \quad Y_{1,t} = \begin{pmatrix} B_{1,t} + Z_{0,t} \\ B_{0,t} \end{pmatrix}, \quad Y_{2,t} = \begin{pmatrix} B_{2,t} + Z_{0,t} \\ B_{0,t} \end{pmatrix}, \quad Z_{0,t} \sim \mathcal{B}(1/2)$$

- Capacity without feedback: $0 \leq R_1 + R_2 \leq 1$
- Capacity with feedback: $0 \leq R_1 \leq 1$ and $0 \leq R_2 \leq 1$

  $\rightarrow$ send uncoded bits through $\{B_{1,t}\}$ and $\{B_{2,t}\}$ and send $B_{0,t} = Z_{0,t-1}$

Feedback allows identifying update inform. that will be useful to *both receivers*
$\rightarrow$ common update information allows to increase *both* private rates!

Subsequent schemes building on this idea

- Wang'09: $\rightarrow$ Erasure BC
- Tassiulas&Georgiadis'10: $\rightarrow$ Erasure BC
- Shayevitz&W'10: $\rightarrow$ General channels, generalized feedback
- Maddah-Ali&Tse'10: $\rightarrow$ Fading channels and deterministic models; state-feedback
- Chen&Elia'13, Yang/Kobayashi/Gesbert/Yi'13

Feedback-gain remains unknown for most BCs

(Strictly) Less-Noisy DMBCs

Strictly Less-Noisy DMBC $Y_2 \succ Y_1$

For every auxiliary $U \to X \to (Y_1, Y_2)$ with $I(U; Y_1) > 0$:

$$I(U; Y_2) > I(U; Y_1)$$

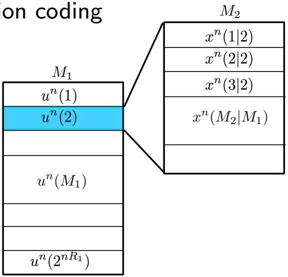
- Asymmetric Binary Symmetric BC
- Asymmetric Binary Erasure BC
- Binary Symmetric/Erasure BC for certain parameters

Capacity of Less-Noisy DMBCs, $Y_2 \succeq Y_1$, i.e. $I(U;Y_2) \geq I(U;Y_1)$

- Capacity: all rate pairs (R_1, R_2) where for some $U \to X \to (Y_1, Y_2)$

$$R_1 \leq I(U;Y_1)$$
$$R_2 \leq I(X;Y_2|U)$$

- Achieved by superposition coding

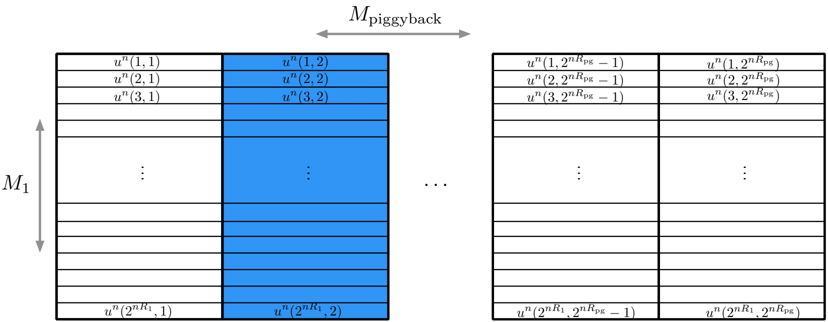


- If $I(U;Y_2) > I(U;Y_1)$, Rx 2 could even decode an extra message in cloud center

- Problem: Rx 1 cannot decode, unless it knows this extra message...

Piggyback-coding

- Receiver 1 knows extra message $M_{\text{piggyback}}$
- Product codebook for messages M_1 and $M_{\text{piggyback}}$

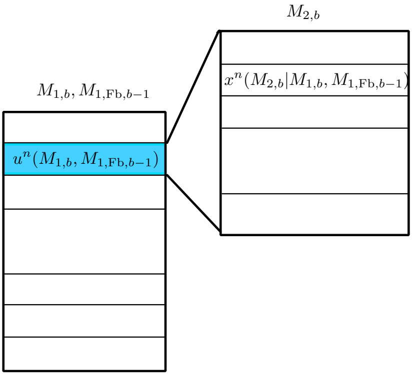


- Decoding possible if: $R_1 + R_{\text{pg}} < I(U;Y_2)$ and $R_1 < I(U;Y_1)$

$M_{\text{piggyback}}$ is not harming Receiver 1!

BC-scheme with feedback from the weaker Receiver 1

- Block-Markov coding with a piggyback superposition code in each block b:



- Choose $M_{1,\mathrm{Fb},b-1}$ as a Wyner-Ziv message to compress $Y^n_{1,b-1} \to \tilde{Y}^n_{1,b}$

- Rx 2 decodes $M_{2,b}$ based on $(\tilde{Y}^n_{1,b}, Y^n_{2,b})$

A Simpler Achievable Region

Theorem

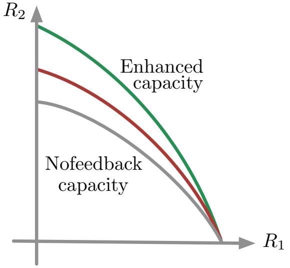
(R_1, R_2) achievable, if for some $P_U P_{X|U} P_{\hat{Y}_1|UY_1}$:

$$R_1 \leq I(U; Y_1)$$
$$R_2 \leq I(X; \tilde{Y}_1, Y_2|U) = I(X; Y_2|U) + I(X; \tilde{Y}_1|U, Y_2)$$

and $$I(\tilde{Y}_1; Y_1|U, Y_2) \leq \min\{R_{\mathrm{FB},1}, I(U; Y_2) - I(U; Y_1)\}.$$

- Sending $\tilde{Y}_1$ is purely beneficial: not bothering Rx 1 and helping Rx 2

If $R_{\mathrm{FB},1} > 0$, Feedback Increases Entire Capacity Region



Theorem: For Any DMBC $Y_2 \succ Y_1$, when $R_{\mathrm{FB},1} > 0$

Feedback improves all $(R_1 > 0, R_2 > 0)$ of the nofeedback capacity,

unless (R_1, R_2) lies on boundary of capacity of enhanced channel

- Ex.: Asymmetric Binary Symmetric, Binary Erasure, Gaussian BC

Extension to Two-Sided Feedback

- Marton-coding
- Send feedback messages $M_{\text{FB},1,b-1}$ and $M_{\text{FB},2,b-1}$ in cloud center of block b using double piggyback-coding
- Feedback messages compress outputs $Y_{1,b}^n$ or $Y_{2,b}^n$

$M_{\text{FB},1,b-1}$ "transparent" for Receiver 1, $M_{\text{FB},2,b-1}$ for Receiver 2
$\rightarrow$ like "double-booking" resources in cloud-center

Duality between Gaussian MIMO MAC and BC with feedback

Gaussian MIMO BC:

$$\mathbf{Y}_k = H_k \mathbf{X} + \mathbf{Z}_k, \qquad k = 1, \ldots, K$$

power constraint P

Gaussian MIMO MAC:

$$\mathbf{Y}_k = \sum_{k=1}^{K} H_k^T \mathbf{X}_k + \mathbf{Z}$$

sum-power const.
$P_1 + P_2 + \ldots + P_K = P$

perfect feedback

Theorem

Rates achievable with linear-feedback schemes for dual BC and MAC coincide!

[9] S. Vishwanath, N. Jindal, and A. Goldsmith, "Duality, achievable rates, and sum-rate capacity of Gaussian MIMO broadcast channels," *IEEE Trans. on Inf. Theory*, 2003

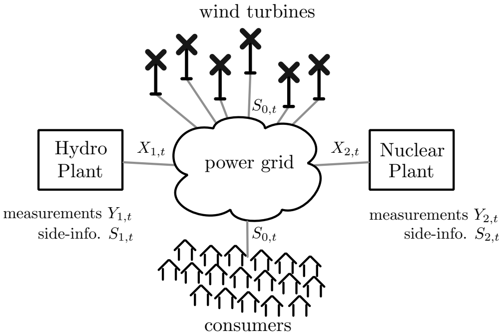
[10] S. Belhadj Amor, Y. Steinberg, M. Wigger, "MIMO MAC-BC duality with linear-feedback coding schemes," submitted to *IEEE Trans. on Inf. Theory*, Apr. 2014

Summary and outlook on: mobiles-to-BS cooperation using feedback

- Proposed two ways of exploiting feedback on memoryless BCs
- Even low-rate feedback increases capacity of large class of memoryless BCs
  $\rightarrow$ not only strictly less noisy!
- Memoryless Gaussian MAC-BC duality when restricting to linear-feedback schemes (perfect feedback)
- Explore MAC-BC duality with feedback for discrete memoryless case
  $\rightarrow$ BC-dual to the Cover-Leung scheme for MAC with feedback?

Coordinating partially-informed agents

Coordination over state-dependent networks: motivation



- Wish to coordinate inputs and state:

$$\frac{1}{T}\sum_{t=1}^{T} P_{S_{0,t}X_{1,t},X_{2,t}} \to \bar{Q} \quad \text{as } T \to \infty$$

[11] B. Larousse, S. Lasaulce, and M. Wigger, "Coordinating partially-informed agents over state-dependent networks," in *Proc. of ITW 2015*

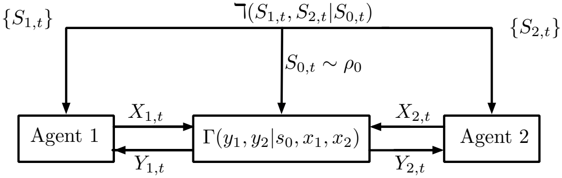
Game-Theoretic Motivation: Infinitively Repeated Games

- Agents' actions $X_{1,t}$ and $X_{2,t}$
- Payoff-functions $\omega_1(s_{0,t}, x_{1,t}, x_{2,t})$ and $\omega_2(s_{0,t}, x_{1,t}, x_{2,t})$
- Average expected payoff:

$$\overline{\omega}_k = \lim_{T\to\infty} \frac{1}{T} \sum_{t=1}^{T} \mathbb{E}\left[\omega_k(S_{0,t}, X_{1,t}, X_{2,t})\right]$$

$$= \sum_{(s_0,x_1,x_2)} \omega_k(s_0, x_1, x_2) \lim_{T\to\infty} \frac{1}{T} \sum_{t=1}^{T} P_{S_{0,t}X_{1,t}X_{2,t}}(s_0, x_1, x_2).$$

Setup and implementable distributions



- Causal or non-causal SI:

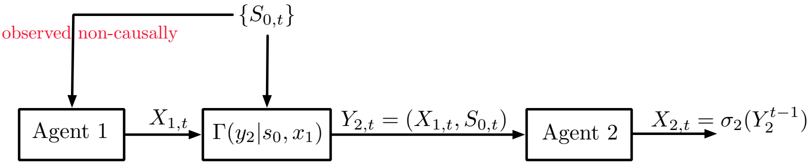
$$X_{k,t} = \sigma_{k,t}^{(c)}(S_k^t, Y_k^{t-1}) \qquad \text{or} \qquad X_{k,t} = \sigma_{k,t}^{(nc)}(S_k^T, Y_k^{t-1})$$

Implementable distributions $\overline{Q}$

$\forall \epsilon > 0$ there exist T and encodings, s.t.

$$\left| \frac{1}{T} \sum_{t=1}^{T} P_{S_{0,t}X_{1,t}X_{2,t}}(s_0, x_1, x_2) - \overline{Q}(s_0, x_1, x_2) \right| \leq \epsilon.$$

Early related model and result: Gossner et al. 2006



- $\{X_{1,t}\}$ communicates $\{S_{0,t}\}$ to Agent 2

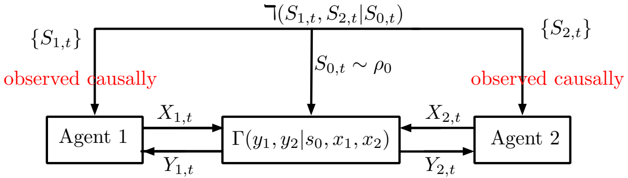
Theorem[12]

$\overline{Q}(s_0, x_1, x_2)$ implementable iff $\quad I(S_0; X_2) \leq H(X_1|S_0, X_2)$

[12] O. Gossner, P. Hernandez, and A. Neyman, "Optimal use of communication resources," Econometrica 2006.

[13] G. Kramer and S. Savari, "Communicating probability distributions," *IEEE Trans. on Inf. Theory*, 2007. (ISIT-version 2002)

New results under causal SI at both agents: $X_{k,t} = \sigma^{(c)}_{k,t}(S_k^t, Y_k^{t-1})$



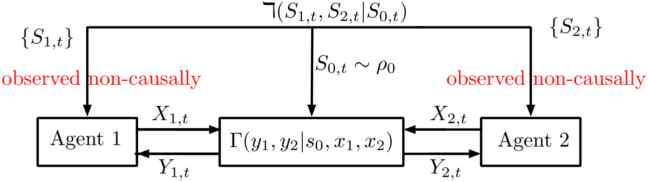
Theorem

$\overline{Q}$ implementable iff it factorizes as

$$\overline{Q}(s_0, x_1, x_2) = \sum_{u, s_1, s_2} \left[\rho_0(s_0) \daleth(s_1, s_2|s_0) P_U(u) \prod_{k=1}^{2} P_{X_k|US_k}(x_k|u, s_k) \right]$$

- No coding/communication required
- Extends to K agents

Non-causal state-info at both agents



Theorem: If $S_{2,t} = f(S_{1,t})$ or $\Gamma(y_1, y_2|s_0, x_1, x_2) = \tilde{\Gamma}(y_1, y_2|s_0, x_1)$

$\overline{Q}(s_0, x_1, x_2)$ implementable iff it is marginal of some

$$Q(s_0, s_1, s_2, u, v, x_1, x_2, y_2)$$
$$= \rho_0(s_0)\daleth(s_1, s_2|s_0)P_{UVX_1|S_1}(u, v, x_1|s_1)P_{X_2|US_2}(x_2|u, s_2)\Gamma(y_1, y_2|s_0, x_1, x_2)$$

satisfying

$$I(S_1; U|S_2) \leq I(V; Y_2, S_2|U) - I(V; S_1|U)$$

- Communication only in one direction: Agent 1 coordinates Agent 2

Summary and outlook on: coordinating partially-informed agents

- Proposed K-agent framework for coordination over state-dependent networks
- Only local coordination when state-information at agents local
- Implementable distributions under non-causal state-information when $K = 2$ and when communication only in one direction
- In future:
  - Distributed coordination, e.g., many-to-one
  - Benefits of coding strategies for real cyber-physical networks

More research plans

- Cache-aided communication networks (noisy channels!)
- Video streaming
- Interplays between information theory and statistics:
  - distributed hypothesis testing
  - distributed clustering (information bottleneck method)

Curriculum

- Master of Sciences ETH Zurich, March 2003
- PhD ETH Zurich, October 2008
- PostDoc University of California San Diego, May–November 2009
- Assistant Professor (Maître de Conférences) Telecom ParisTech, December 2009
- Visiting Professor at the Technion—Israel Institute of Technology June 2011
- Visiting Professor at ETH Zurich July/August 2010, August 2013, July/August 2015

Teaching

- Introduction to digital communications, Telecom ParisTech
- Information theory, Telecom ParisTech
- Iterative decoding methods, Telecom ParisTech
- Multi-user information theory, ETH Zurich
- Coding and cellular automata, ETH Zurich

Supervision of students

- Post Docs:
  - Roy Timo, November 2013–April 2014
  - Sadaf Salehkalaibar, February/March 2015
- PhD students:
  - Youlong Wu, November 2011–October 2014
  - Selma Belhadj Amor, October 2011–March 2015
- Master Thesis students:
  - Andreas Malär, June–December 2010
  - Thomas Laich, June–December 2012

Service to the society

- Associate Editor of IEEE Communication Letters, since December 2012

- TPC member of:
  - ISIT 2011, 2012, 2013, 2014, 2015, 2016
  - ITW 2015
  - IZS 2012, 2014, 2016
  - ISWCS 2011
  - PIMRC 2013, 2014, 2015

- Organization of conferences, workshops, and invited sessions:
  - Publicity chair ITW 2016, Cambridge, UK
  - Co-organizer of GdR ISIS workshop "Recent advances in information theory", April 2012, Paris, France
  - Organizer of invited sessions at ISWCS 2011 and IZS 2012

Awards and grants

- ETH Medal for excellent PhD Thesis (8%)
- ETH Medal for excellent Master Thesis (2.5%)
- Diploma of Master of Science with Distinction

- "Emergences" Starting-Grant from the city of Paris, October 2012–March 2015
- CEFIPRA Project *D2D*, starting May 2015. Collaborative project with Alcatel-Lucent, INRIA, and IIT Mumbay
- Technion scholarship for visiting professors, June 2011
- IDEA League scholarships for visiting professors Jul/Aug. 2010 and Aug. 2013
- Google scholarship for research visit of PhD student Youlong Wu at the Technion
- Swiss National Science Foundation fellowship for prospective researchers 2009

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The jury members:

Giuseppe Caire, Elza Erkip, Inbar Fialkow, Michael Gastpar, David Gesbert, Philippe Loubaton, Luc Vandendorpe