Enhancing Rates in Relay Channels

Carleton UNIVERSITY

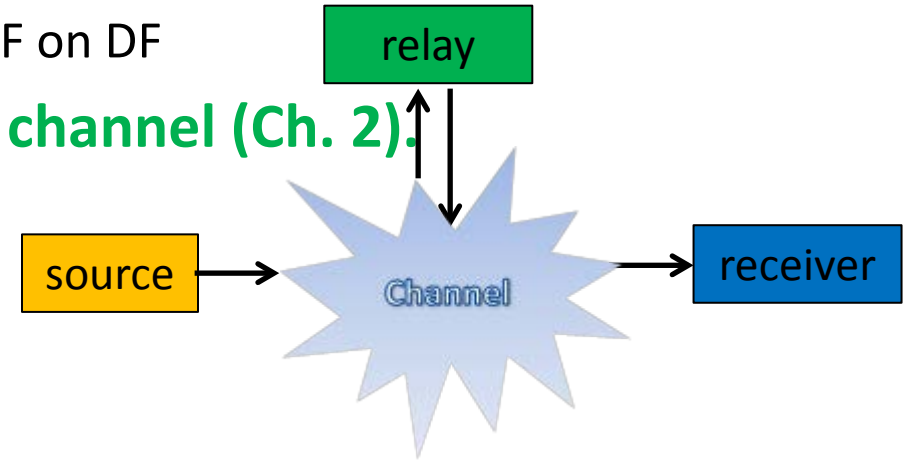
Wen (Kevin) Luo

Sept 2015

INTRODUCTION

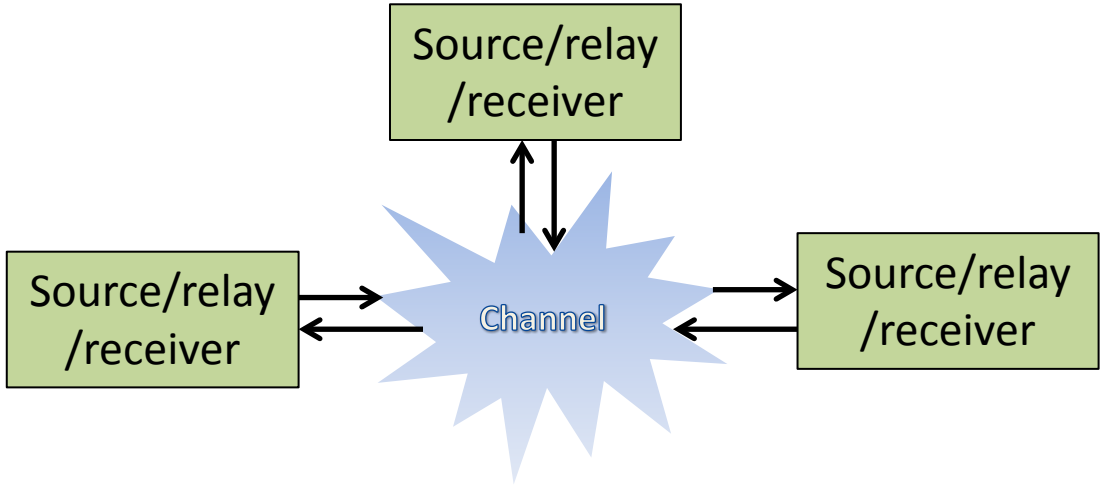
Introduction

- Landmark work
  - "Capacity theorem for the relay channel," [Cover and El Gamal, TIT, 1979].
  - Introduced two fundamental relaying schemes:
    - Decoding and Forward (DF) and Compress-and-Forward (CF).
  - Upper bound: cut-set bound.
    - Cut-set bound can be loose: modulo-sum relay channel (Aleksic and Yu, TIT, 2009).
- A generalized DF-CF: superimposes CF on DF
  - **We analyzed it in Gaussian channel (Ch. 2).**



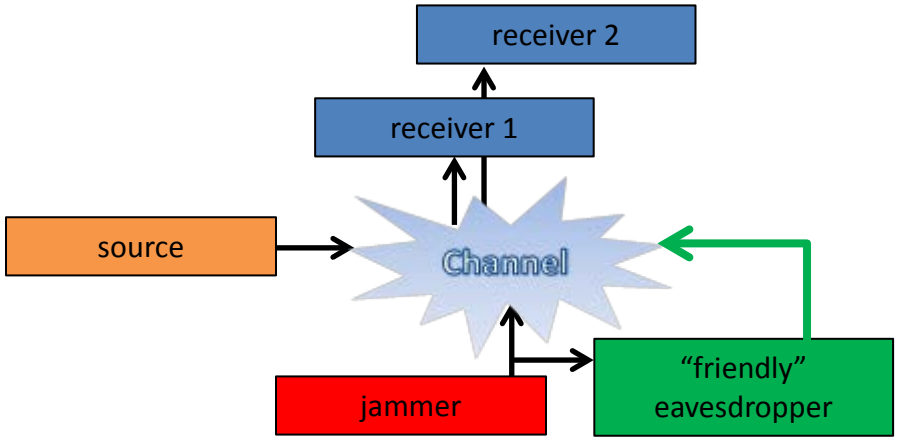
Introduction (cont'd)

- Recent progress
  - "Noisy network coding," [Lim, Kim, El. Gamal, Chung, TIT, 2011].
  - showed advantage over conventional CF in multimessage network.
  - **Based on the study of the relay codebook structure, we proposed a new decoding procedure (Ch. 3).**
  - **We analyzed the gain in certain networks (Ch. 4).**



Introduction (cont'd)

- Application in channel with jamming
  - "The Gaussian test channel with an intelligent jammer," [Basar, TIT, 1983].
  - **We introduced a "friendly" eavesdropper.**
  - **We analyzed its role as a CF relay. (Ch. 5)**

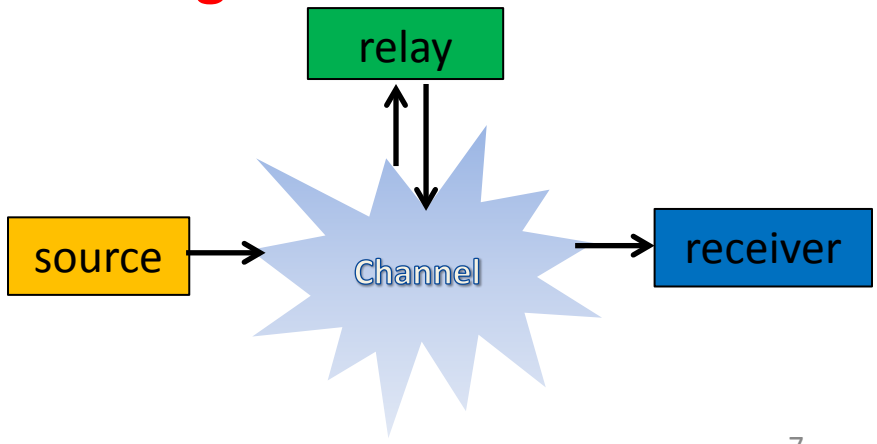


TOPIC I

GENERALIZED DF-CF

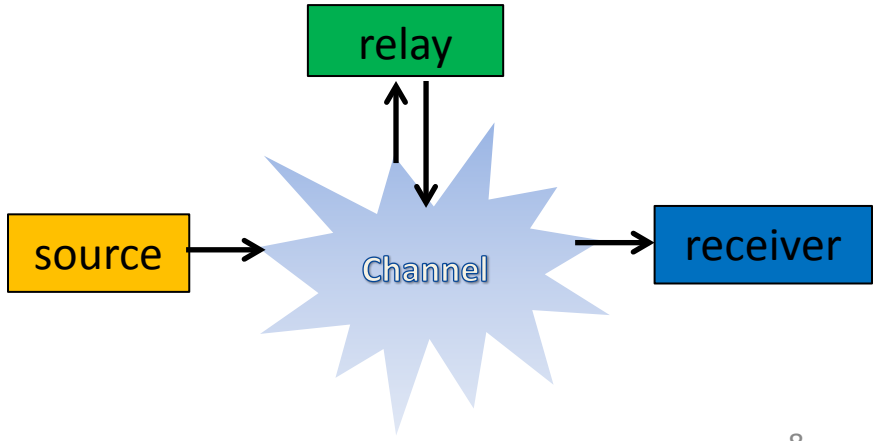
Analysis on Generalized DF-CF

- Related work
  - "Capacity theorem of relay channels," [Theorem 7] [Cover, El. Gamal, TIT, 1979].
  - "On Achievable Rates for the General Relay Channel," [Chong, Motani, TIT, 2011].
  - "Combined decode-forward and layered noisy network coding schemes for relay channels," [Zhong, Vu, ISIT, 2012].
- **Question: Does it provide guaranteed gain?**



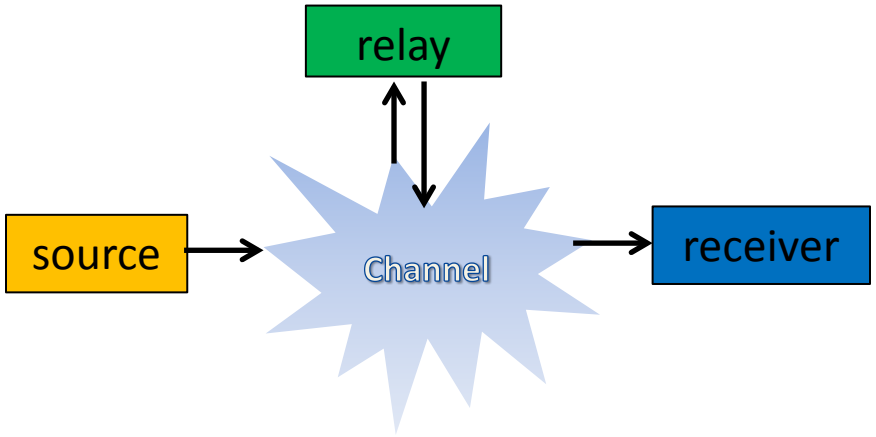
Analysis on Generalized DF-CF

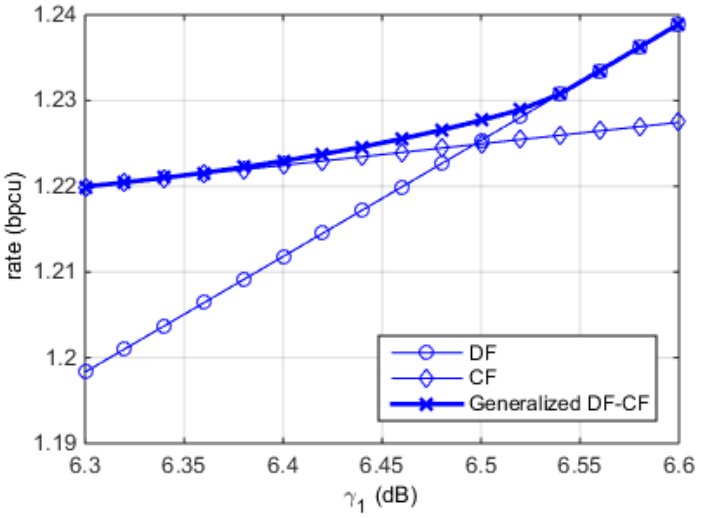
- We particularized the abstract channel and codebooks to Gaussian channel and Gaussian codebooks with average power constraint.
- We considered Signal-to-Noise Ratio (SNR) in different regions.
- Using KKT, we analyzed the optimality of this Generalized DF-CF scheme in each SNR region.



Analysis on Generalized DF-CF

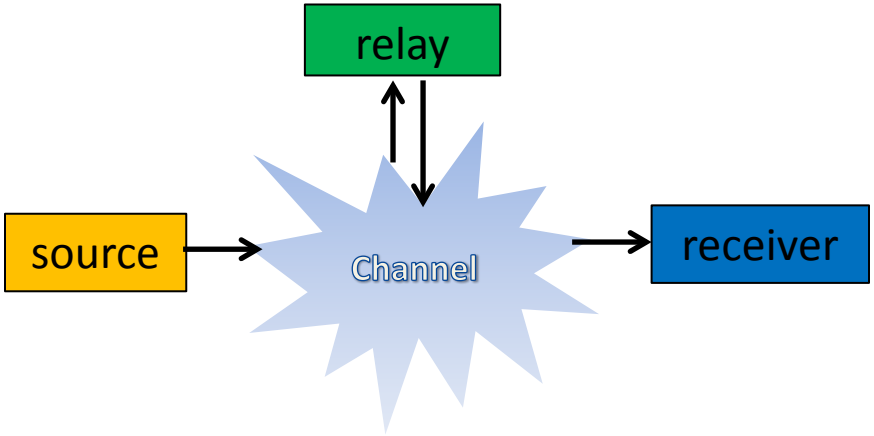
- We showed that in certain SNR regions, the generalized DF-CF reduces to its underlying DF or CF.
- We proved that there exist SNR regions in which generalized DF-CF is guaranteed to provide a gain over both DF and CF.
- However, this gain was shown to be upper bounded by 0.5 bits per channel use (bpcu).

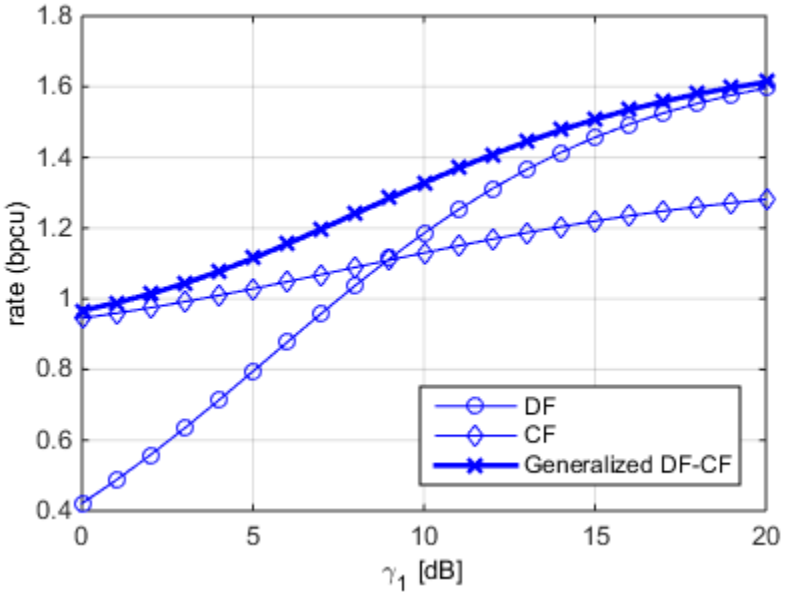




Analysis on Generalized DF-CF

- Gaining this insight, we proposed that DF-CF switching can provide substantial rate gain over fixed DF or CF.
- Simulation using quasi-static Rayleigh fading channel confirms the gain.



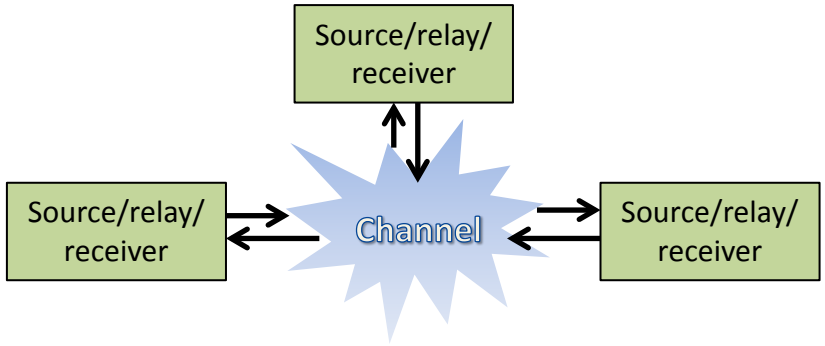


TOPIC II

EXPLOITING THE N-TO-1 MAPPING IN CF

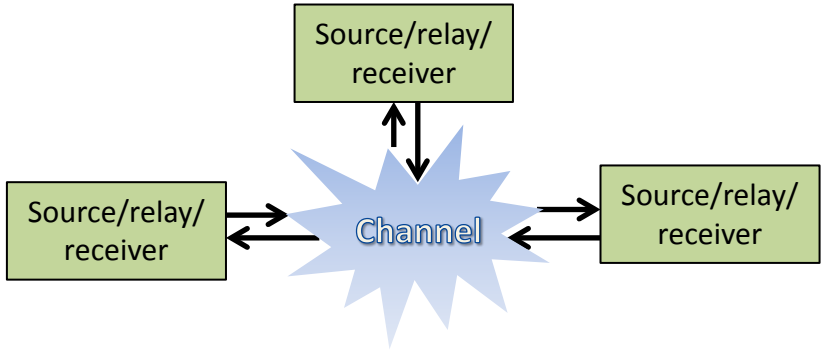
Exploiting the N-to-1 Mapping in CF

- Related work
  - "Noisy network coding," [Lim, Kim, Gamal, Chung, TIT 2011] (NNC).
  - "Slepian-Wolf coding over cooperative relay networks," [Yassaee, Aref, TIT, 2011].
  - "Short message noisy network coding for multiple sources," [Hou, Kramer, ISIT, 2012] (SNNC).



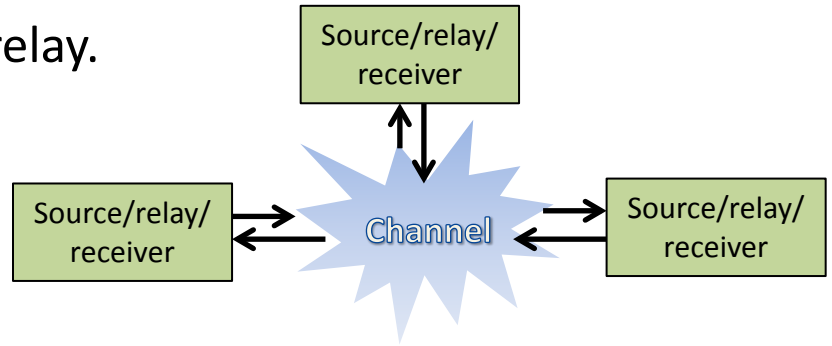
Exploiting the N-to-1 Mapping in CF

- Insight into NNC/SNNC
  - Both NNC and SNNC use 1-to-1 mapping as opposed to the N-to-1 mapping inherited in Wyner-Ziv binning in the conventional CF.
  - This implicitly imposes a rate constraint on the relay transmission rate.
  - Rate gain can be obtained in the considered multimessage network.
- **Is 1-to-1 mapping necessary?**
- **Does the general N-to-1 mapping provide gain?**



Exploiting the N-to-1 Mapping in CF

- The framework of our approach
  - Conventional CF codebook structure (N-to-1 mapping).
  - Short message encoding.
  - Sliding window forward decoding.
  - Layered decoding structure.
    - Only the codebooks in which unique codewords are found in the joint typicality set at one layer will be considered at the next layer.
- Result
  - Achieves the same rates as NNC/SNNC in the multimessage network.
  - Relaxes the rate constraint on the relay.

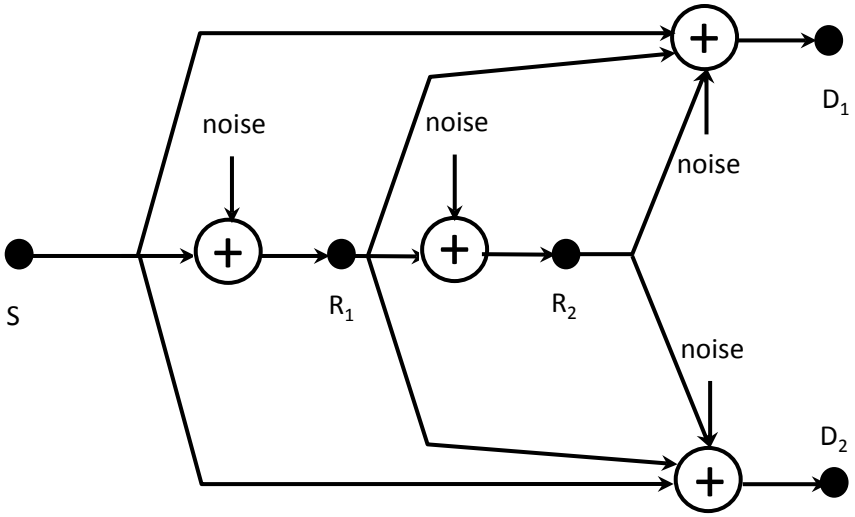


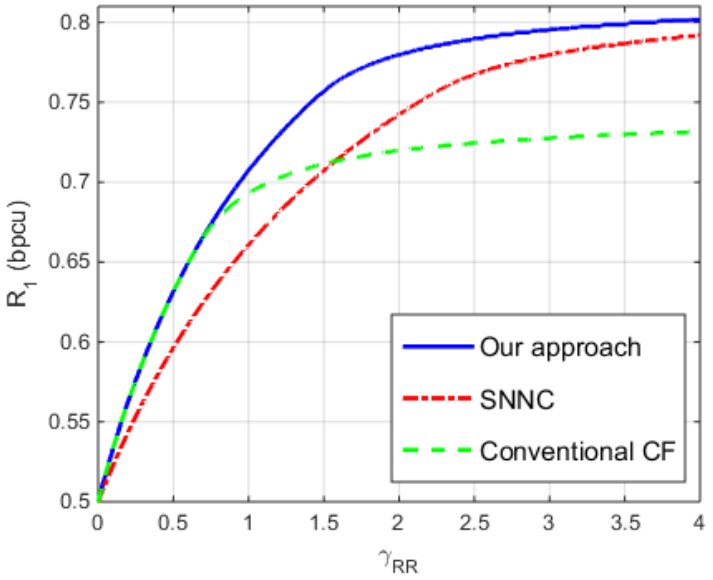
Exploiting the N-to-1 Mapping in CF

- Achieving rate gain by the new decoding procedure
  - We consider two networks:
    - DF-CF relay chain network.
    - Partially cooperative network.
  - In both networks, side information is only available to a subset of the receiving nodes in the network.
  - Lower relay transmission rate in these cases provides advantages.

Exploiting the N-to-1 Mapping in CF

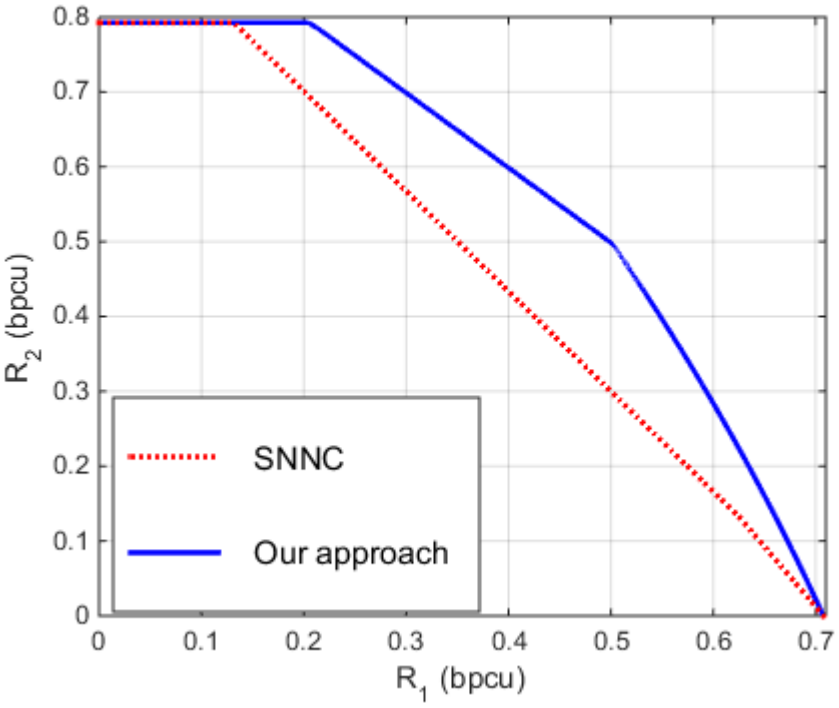
- DF-CF broadcast relay (BR) chain network:
  - A BR channel with common message and two receivers.
  - A CF relay followed by a DF relay.
    - This setup is similar, to some extent, to a case of the DF-DF relay chain in "Parity forwarding for multiple-relay networks," [Razaghi and Yu, TIT, 2009].
  - DF does not have direct link from the source.

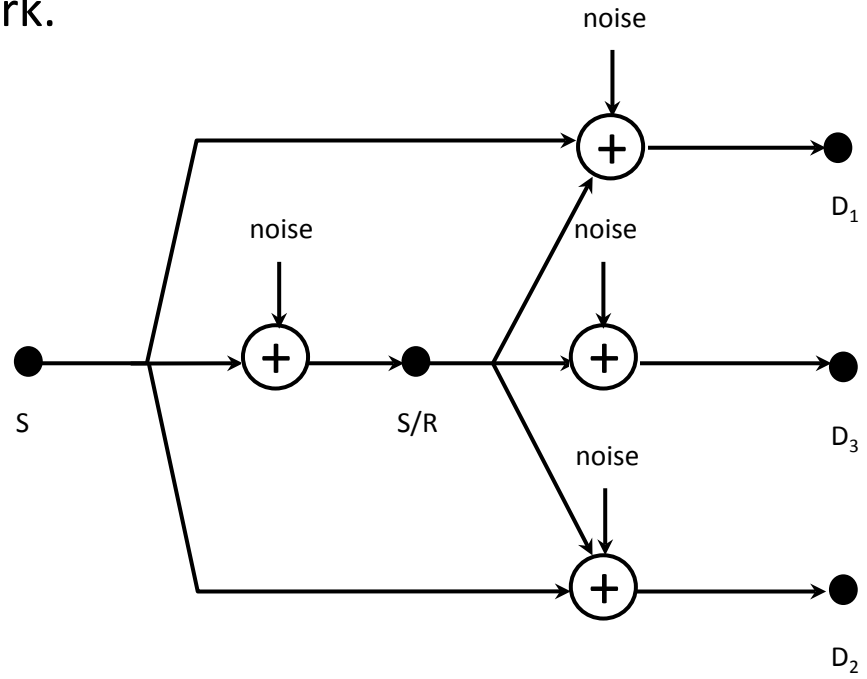




Exploiting the N-to-1 Mapping in CF

- Partially cooperative multimessage network:
  - A BR channel with common message and two receivers.
  - A CF relay also has its own receiver, which does not have direct link from other nodes in the network.





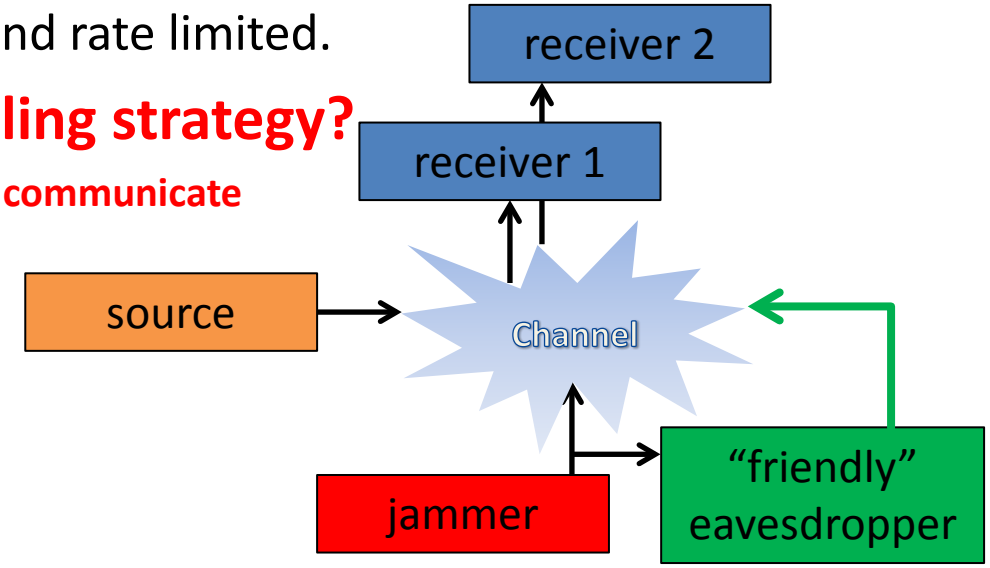
TOPIC III

APPLICATION IN COMMUNICATION WITH JAMMING

Friendly Eavesdropper Combatting a Gaussian Jammer

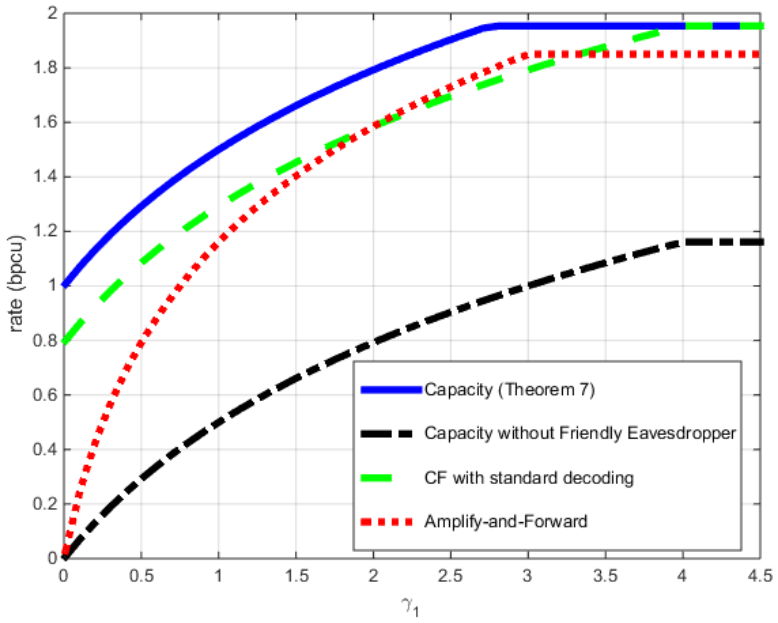
- We considered a communication network with a Gaussian jammer.
- We introduced a "friendly" eavesdropper:
  - Picks a jammer's signal.
  - Assists the communication.
  - Average power constraint and rate limited.
- **What is the optimal signaling strategy?**

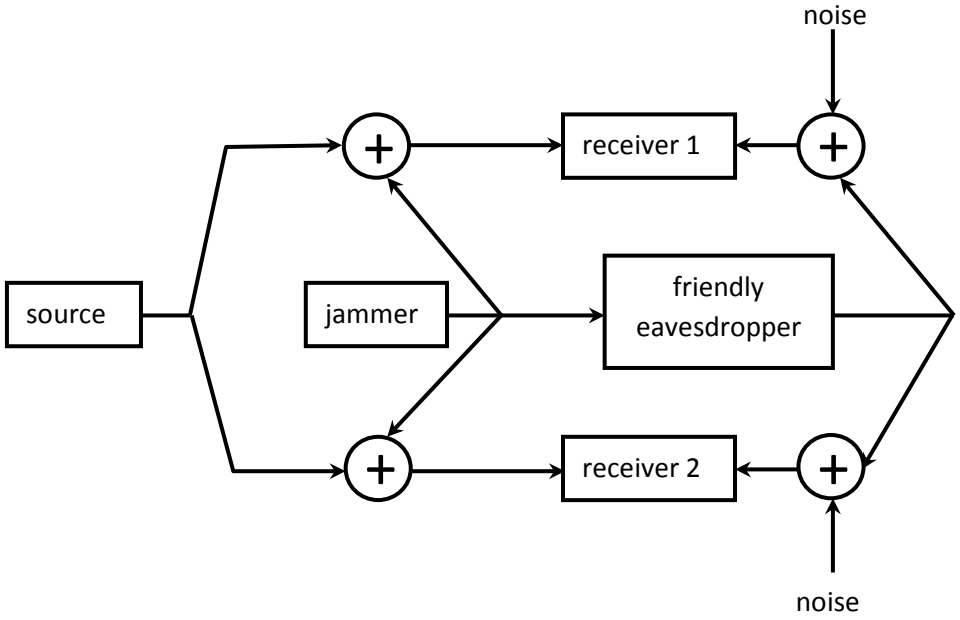
  (the max. rate the source can reliably communicate to the receivers)



Friendly Eavesdropper Combatting a Gaussian Jammer

- We analyzed the following signaling strategy:
  - Gaussian codebook.
  - Using CF relaying scheme with our decoding procedure.
- Result: capacity achieving.





CONCLUSION

Summary of Contributions

- Generalized DF-CF
  - Showed SNR conditions under which the generalization reduces to its underlying DF or CF.
  - Proved the existence of the SNR regions in which generalized DF-CF is guaranteed to provide rate gain over DF and CF.
  - The gain is proved to be upper bounded by 0.5 bpcu.
  - Showed that switching between DF and CF yields substantial gain.
- Exploiting the N-to-1 mapping in CF
  - Generalized the conventional CF.
  - Relaxed relay transmission rate constraint for conventional CF.
  - Showed that in two networks, when side information is only available to a subset of the receiving nodes, the new procedure is able to provide rate gain.

Summary of Contributions

- Communication in the presence of Gaussian jamming
  - Introduced the concept of friendly eavesdropper.
  - Analyzed its role as a CF relay.
  - Showed that Gaussian codebook and CF with our decoding procedure achieve the capacity.

Future Work

- Multimessage network:
  - How can decoding nodes use the information to help other receivers?
- Communication in jamming:
  - Consider generalized DF-CF.
  - Consider channel state information.

Publications

- Journal papers
  - Kevin Luo, et al., “Analysis of the generalized DF-CF for Gaussian relay channels: decode or compress?” IEEE TCOM, May 2013
  - Kevin Luo, et al., “Exploiting the N-to-1 Mapping in compress-and-forward relaying,” IEEE TIT, revision submitted: July 2015.
- Conference papers
  - Kevin Luo, et al., “On the generalization of decode-and-forward and compress-and-forward for Gaussian relay channel,” IEEE ITW, Oct. 2011.
  - Kevin Luo, et al., “A decoding procedure for compress-and-forward and quantize-and-forward relaying,” IEEE Allerton, Oct. 2012.
  - Kevin Luo, et al., “The capacity of a broadcast channel with Gaussian jamming and a friendly eavesdropper,” IEEE ITW, Oct. 2015

THANK YOU