EECS 290S: Network Information Flow

Anant Sahai
David Tse

Logistics

- Anant Sahai: 267 Cory (office hours in 258 Cory), sahai@eecs. Office hours: Mon 4-5pm and Tue 2:30-3:30pm.
- David Tse, 257 Cory (enter through 253 Cory), dtse@eecs. Office hours: Tue 10-11am, and Wed 9:30-10:30am.
- Prerequisite: some background in information theory, particularly for the second half of the course.
- Evaluations:
  - Two problem sets (10%)
  - Take-home midterm (15%)
  - In-class participation and a lecture (25%)
  - Term paper/project (50%)

Logistics

- Text:
  - Raymond Yeung, Information Theory and Network Coding, preprint available at http://iest2.ie.cuhk.edu.hk/~whyeung/post/main2.pdf.
  - Papers
- References
  - T. Cover and J. Thomas, Elements of Information Theory, 2nd edition.

Classical Information Theory

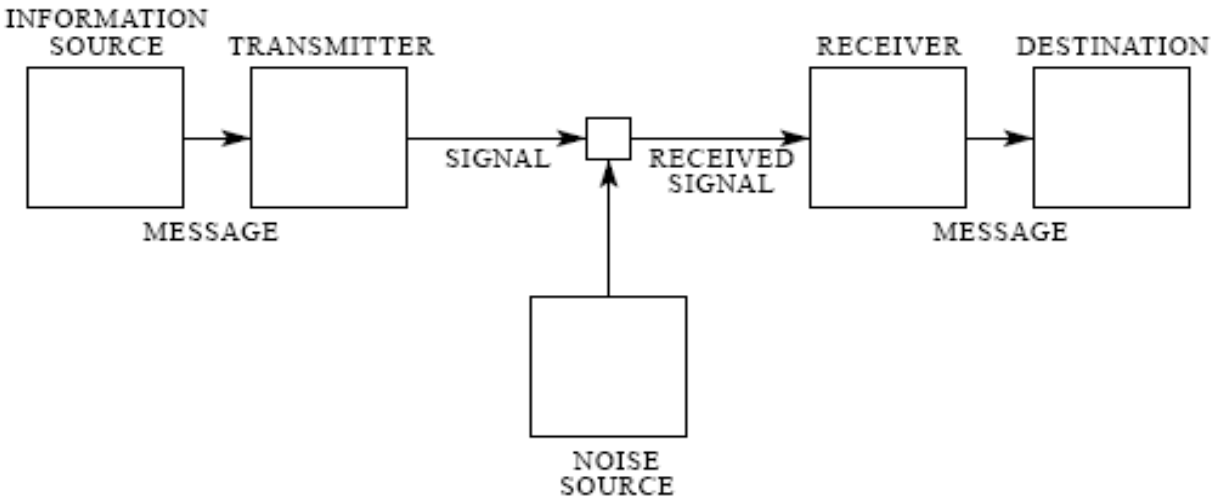
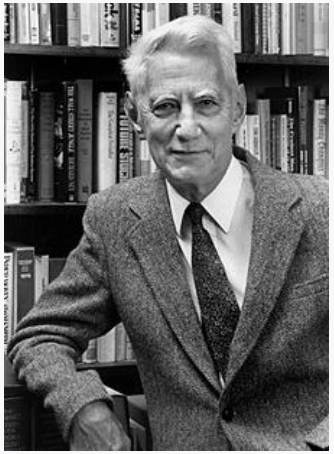


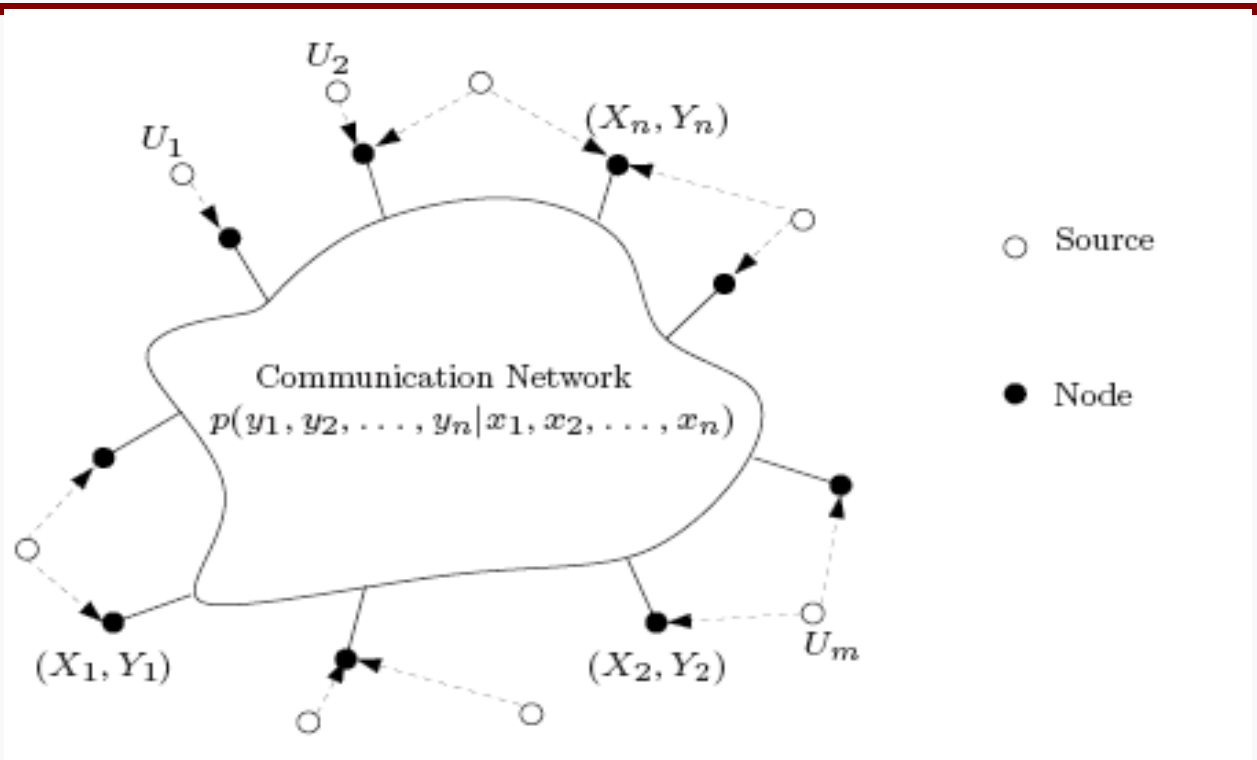
Fig. 1—Schematic diagram of a general communication system.



A Mathematical Theory of Communication
1948

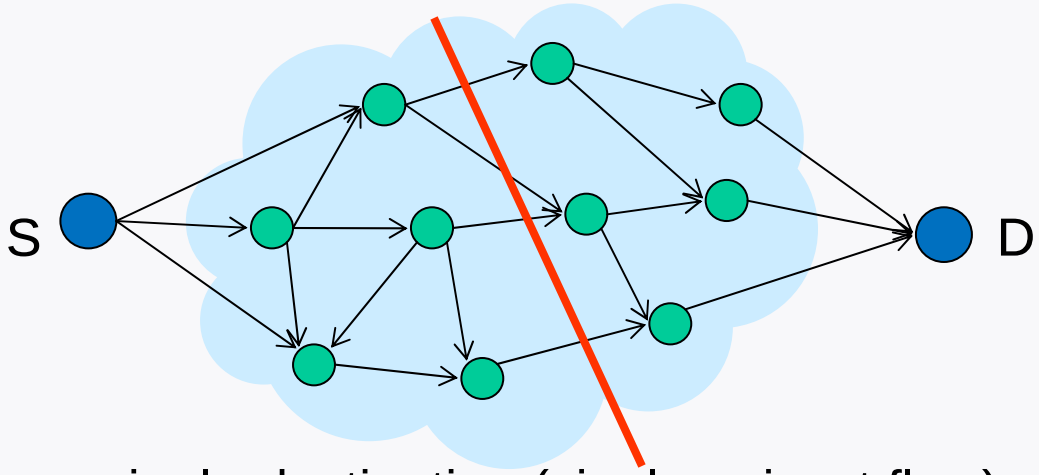
- Source has entropy rate H bits/sample.
- Channel has capacity C bits/sample.
- Reliable communication is possible iff H < C.
- Information is like fluid passing through a pipe.
- How about for networks?

General Problem



- Each source is observed by some nodes and needs to be sent to other nodes
- Question: Under what conditions can the sources be reliably sent to their intended nodes?

Simplest Case



- Single-source-single-destination (single unicast flow)
- All links are orthogonal and non-interfering (wireline)

$$C = \mathrm{mincut}(S;D)$$

(Ford-Fulkerson 1956)

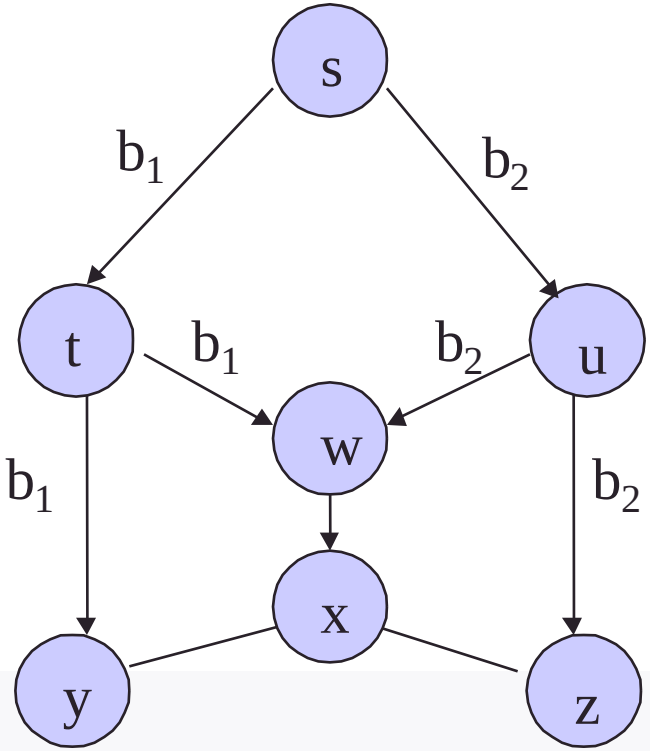
- Applies to commodities or information.
- Applies even if each link is noisy.
- Fluid through pipes analogy still holds.

Extensions

- More complex traffic patterns
- More complex signal interactions.

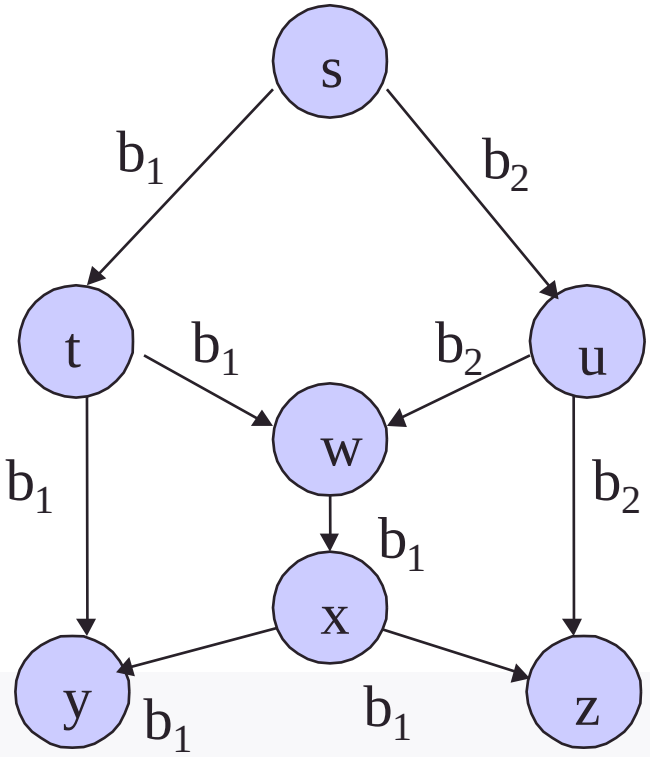
Multicast

- Single source needs to send the same information to multiple destinations.
- What choices can we make at node w?
- One slave cannot serve two masters.
- Or can it?



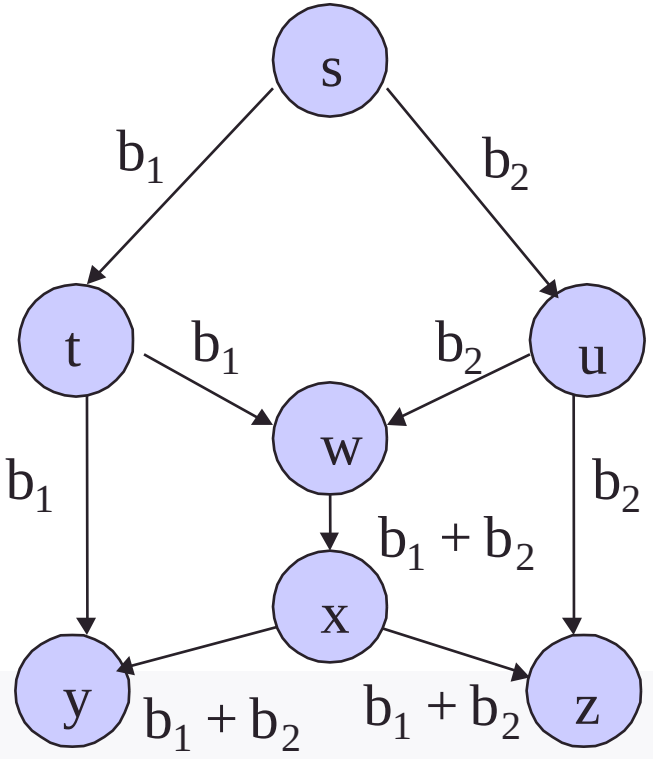
Multicast

- Picking a single bit does not achieve the min-cut of both destinations



Network coding

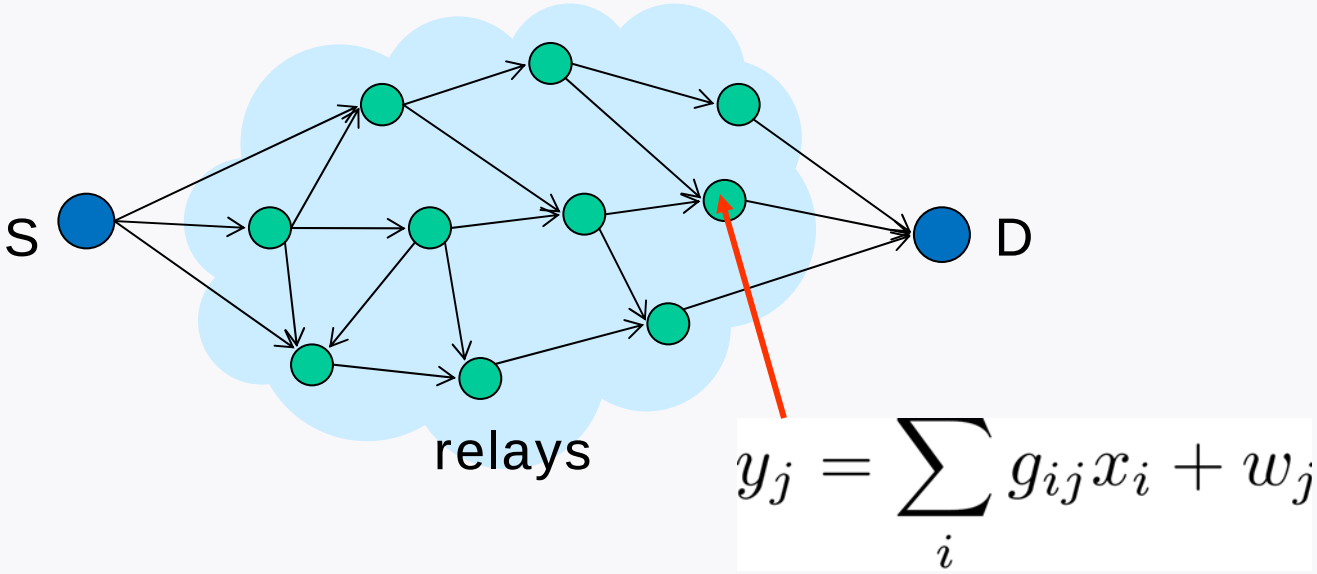
- Needs to combine the bits and forward equations.
- Each destination collects all the equations and solves for the unknown bits.
- Can achieve the min-cut bound simultaneously for both destinations.



Other traffic patterns

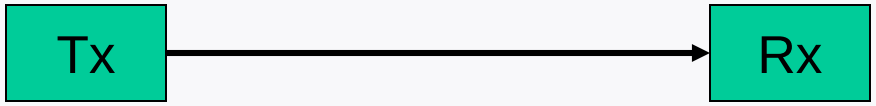
- Multiple sources send independent information to the same destination.
- Single source sending independent information to several destinations.
- Multiple sources each sending information to their respective destinations.
- The last two problems are not easy due to interference

Complex Signal Interactions: Wireless Networks



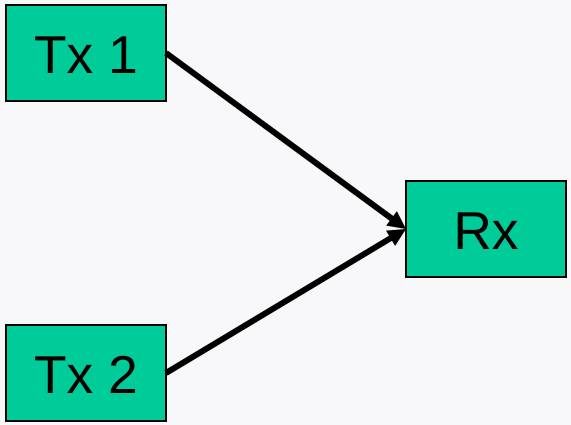
- Key properties of wireless medium: broadcast and superposition.
- Signals interact in a complex way.
- Standard physical-layer model: linear model with additive Gaussian noise.

Gaussian Network Capacity: Known Results

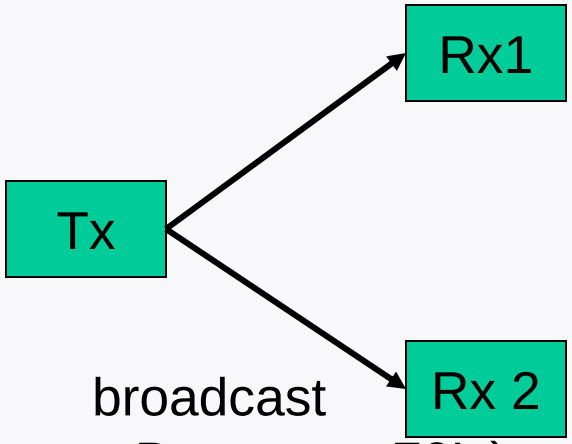


point-to-point (Shannon 48)

$$C = \log_2(1 + SNR)$$



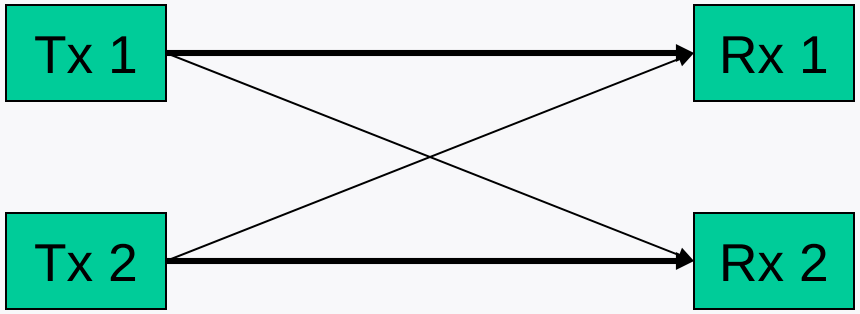
multiple-access
(Alshwede, Liao 70's)



broadcast
(Cover, Bergmans 70's)
(Weintgarten et al 05)

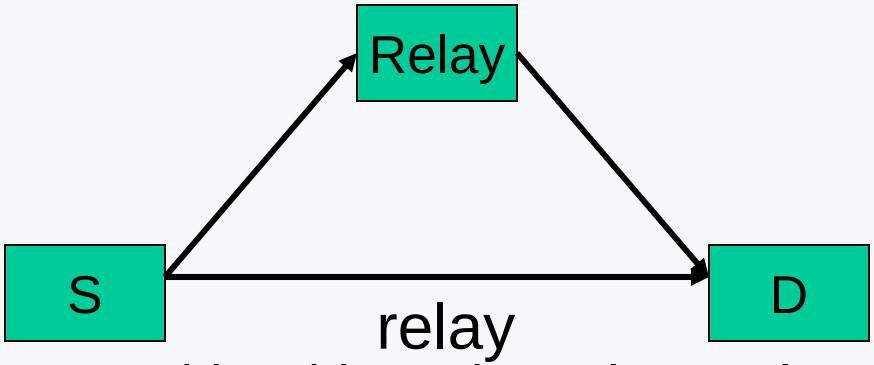
What We Don’t Know

Unfortunately we don’t know the capacity of most other Gaussian networks.



Interference

(Best known achievable region: Han & Kobayashi 81)



relay

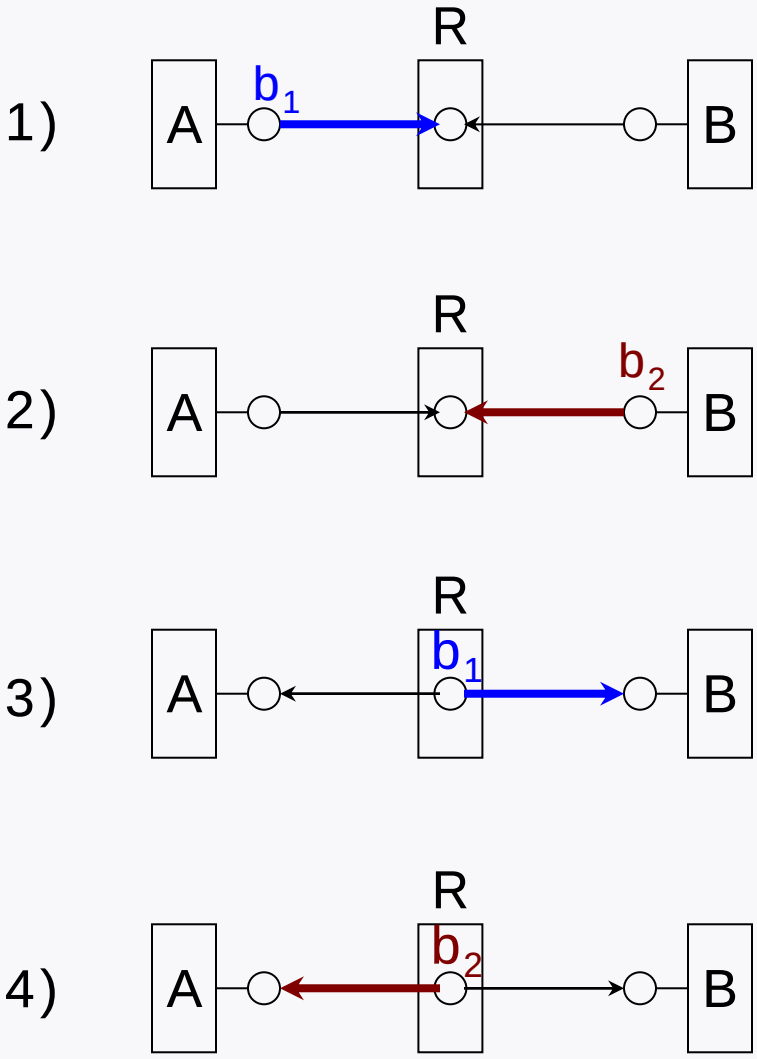
(Best known achievable region: El Gamal & Cover 79)

Bridging between Wireline and Wireless Models

- There is a huge gap between wireline and Gaussian channel models:
  - signal interactions
  - Noise

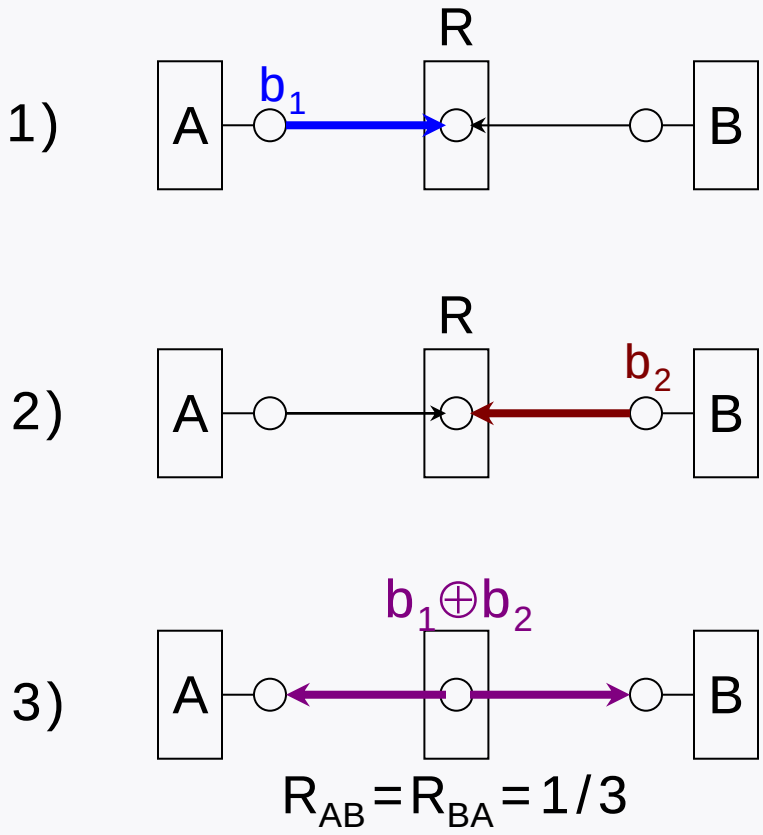
- Approach: deterministic channel models that bridge the gap by focusing on signal interactions and forgoing the noise.

Two-way relay example

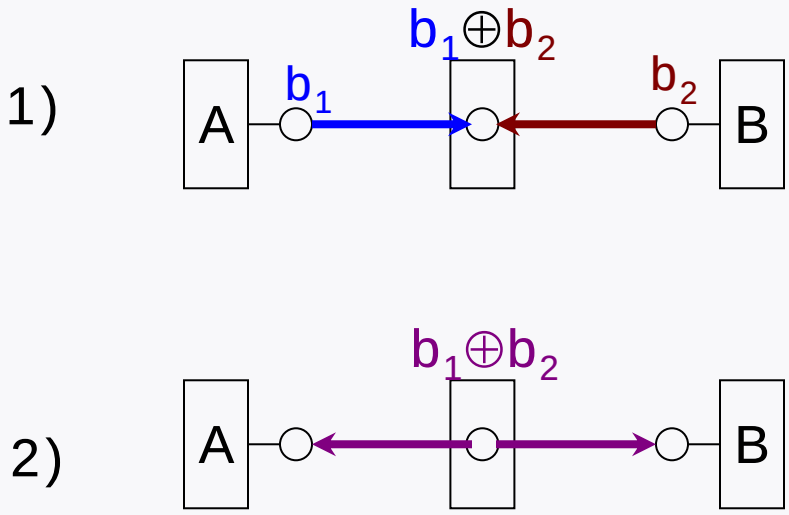


$$R_{AB} = R_{BA} = 1/4$$

Network coding exploits broadcast medium



Nature does the coding via superposition



$$R_{AB} = R_{BA} = 1/2$$

But what happens when the signal strengths of the two links are different?