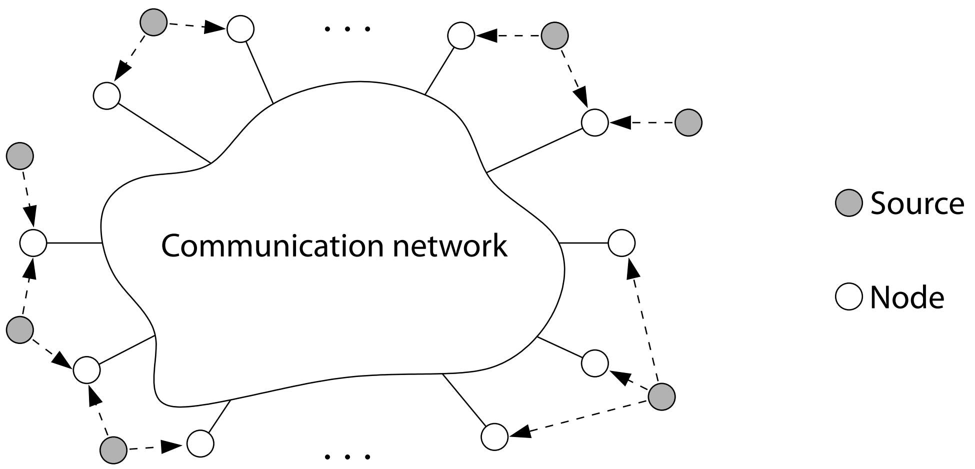
Lecture #1 Introduction

(Reading: NIT Preface, 1.1–1.4)

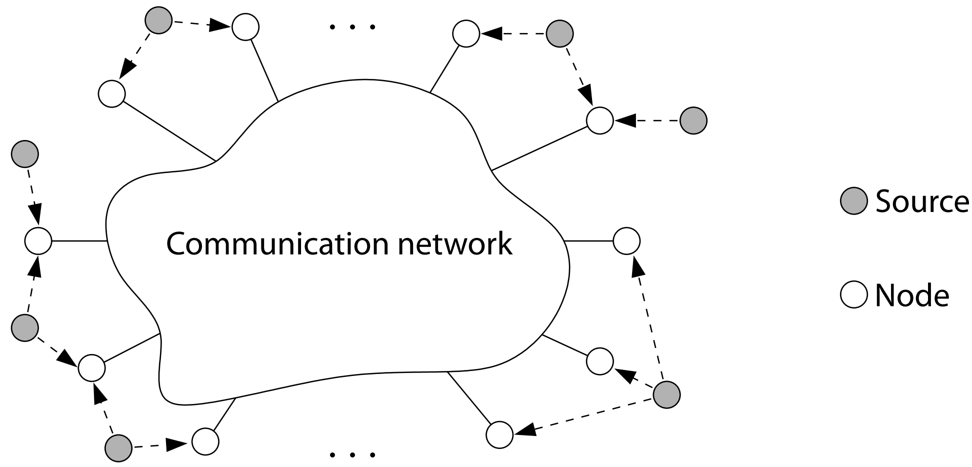
- Network information flow
- Graphical unicast networks
- Point-to-point information theory
- Network information theory
- Course overview

Networked information processing system



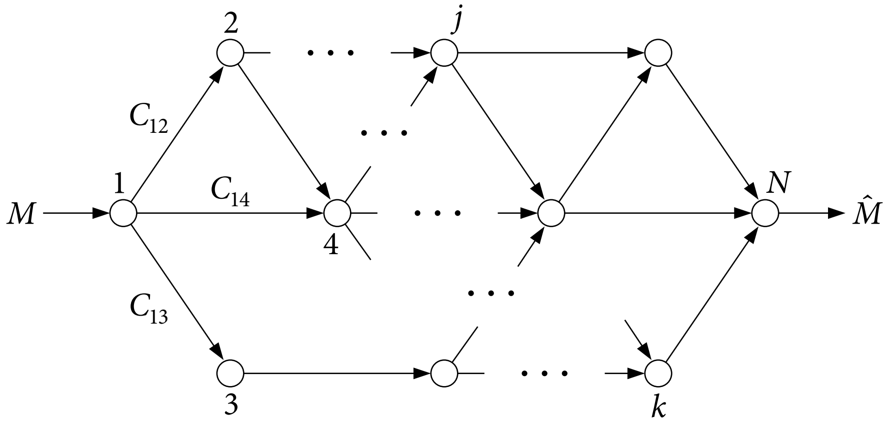
- System: Internet, peer-to-peer network, sensor network, …
- Sources: data, video, sensor measurement, biochemical signals, …
- Nodes: computers, handsets, sensor nodes, neurons, …
- Network: wired, wireless, or hybrid of the two
- Task: Communicate sources or make decision based on them

Network information flow questions



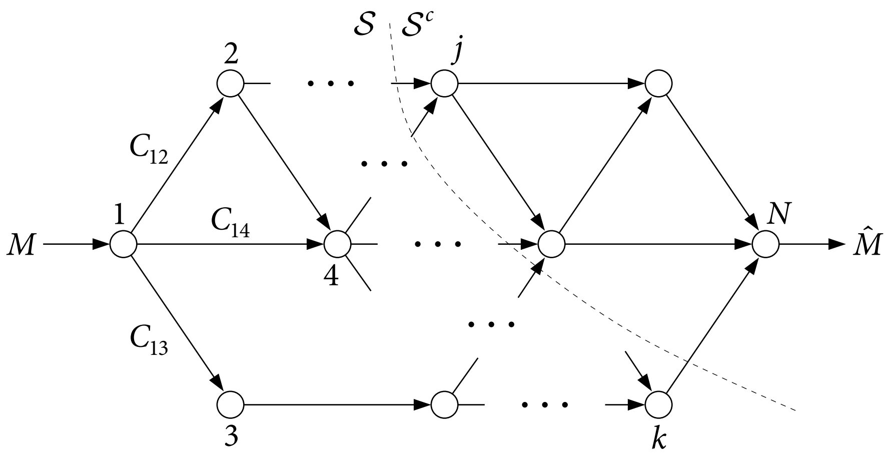
- What is the limit on the amount of communication needed?
- What are the coding schemes/techniques that achieve this limit?

Graphical unicast networks



- Model for wired networks (Internet, distributed storage, ...)
- Directed weighted graph $(\mathcal{N}, \mathcal{E})$ with link capacities C_{jk}
- Source node 1 wishes to send R-bit message M to destination node N
- What is the network capacity C (highest achievable R)?

Max-flow min-cut theorem (Ford–Fulkerson 1956)



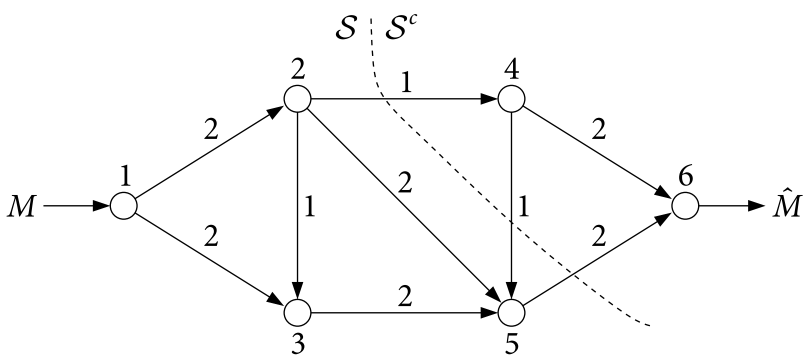
- Network capacity:

$$C = \min_{\mathcal{S} \subset \mathcal{N} : 1 \in \mathcal{S}, N \in \mathcal{S}^c} C(\mathcal{S})$$

  where $C(\mathcal{S}) = \sum_{j \in \mathcal{S}, k \in \mathcal{S}^c} C_{jk}$ is capacity of the cut $(\mathcal{S}, \mathcal{S}^c)$

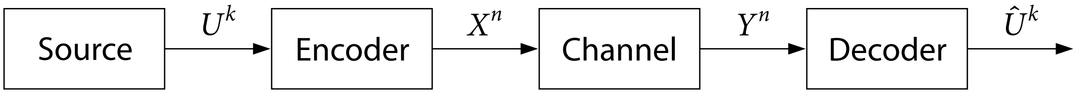
- Achieved error-free using simple forwarding (routing)
- Information treated as commodity flow

Example



- $C = 3$
- Minimum cut: $\mathcal{S} = \{1, 2, 3, 5\}$
- Achieved by routing 1 bit along $1 \to 2 \to 4 \to 6$ and 2 bits along $1 \to 3 \to 5 \to 6$

Point-to-point information theory (Shannon 1948, 1959)



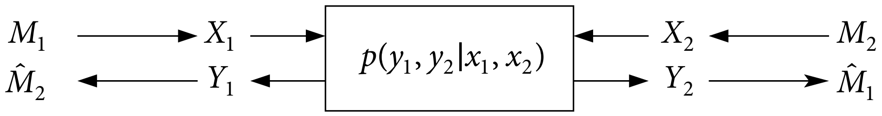
- Mathematical model for a communication system
- Probabilistic discrete memoryless models for source $p(u)$ and channel $p(y|x)$
- Block coding scheme
- Asymptotic approach to analyzing performance
- Four fundamental theorems in terms of entropy and mutual information
  - Lossless source coding: $R^* = H(U)$
  - Channel coding: $C = \max_{p(x)} I(X; Y)$
  - Lossy source coding: $R(D) = \min_{p(\hat{u}|u): \mathrm{E}(d(U,\hat{U})) \le D} I(U; \hat{U})$
  - Source–channel separation

Network information theory

- Multiple sources and destinations
- Function computation or collaborative decision making
- Wireless is shared broadcast medium
- Feedback and interactive communication
- Network security
- No source–channel separation
- Dynamic data arrival and network topology

Brief history

- First paper (Shannon 1961): "two-way communication channels"



- Significant research activities in 70s and early 80s, but
  - Many basic problems open
  - Little interest from practice

- Wireless communications and the Internet revived interest in mid 90s
  - Some progress on old open problems and many new problems
  - Very large number of papers in ISIT, T-IT, T-COM, T-WC, …
  - Results starting to have impact on real-world networks

About the course

- Provides broad coverage of key results, techniques, and open problems

- Emphasis is on coding schemes

- Proof techniques and some coding theorem proofs are presented in detail

- Other proofs are assigned as reading

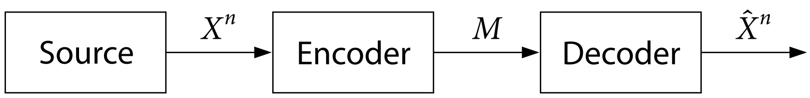
- This course is intended for:
  - Students interested in research in network information theory
  - Students interested in research in communication (wireless, wired) and multimedia
  - Students generally interested in information theory

About the course

- Text: El Gamal and Kim, Network Information Theory (NIT), Cambridge Univ. Press
- Course requirements:
  - 5 homework sets
  - ITA workshop report
  - Take-home midterm
  - Final projects: surveys of topics not covered, new research results, or new problems
- Make-up lectures on January 9, 16, 30, March 12 (Atkinson Hall 4010)

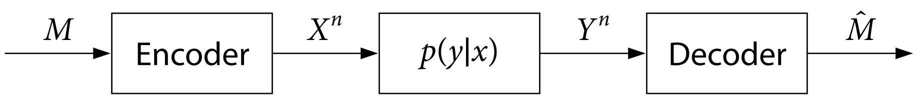
Basic information theory

- Lossless source coding (NIT 2.1, 2.4, 3.5):



Shannon's lossless source coding theorem (entropy, typicality)

- Channel coding (NIT 2.2, 2.3, 2.5, 3.1, 3.3, 3.4):

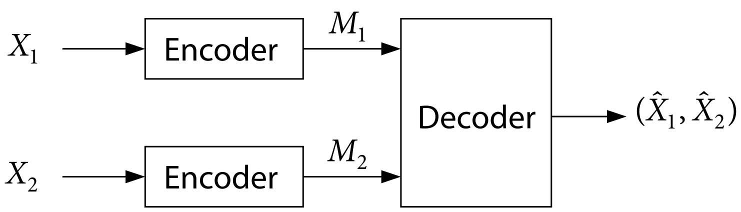


Shannon's channel coding theorem (mutual information, joint typicality)

Random coding; joint typicality decoding; from DMC to Gaussian

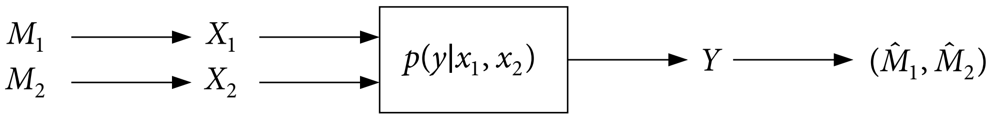
Single-hop networks

- Distributed lossless compression (NIT 10.1–10.3, 10.5):



Problem solved; Slepian–Wolf; Cover's random binning

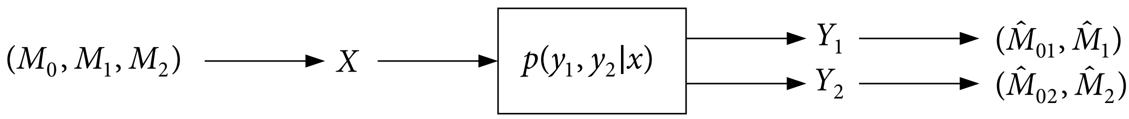
- Multiple access channels (NIT 3.2, 4.1, 4.2, 4.4, 4.5):



Problem solved; successive cancellation; simultaneous decoding; time sharing

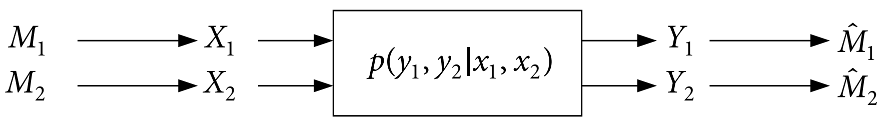
Single-hop networks

- Degraded broadcast channels (NIT 5.1–5.6):



Problem solved; superposition coding; simultaneous nonunique decoding

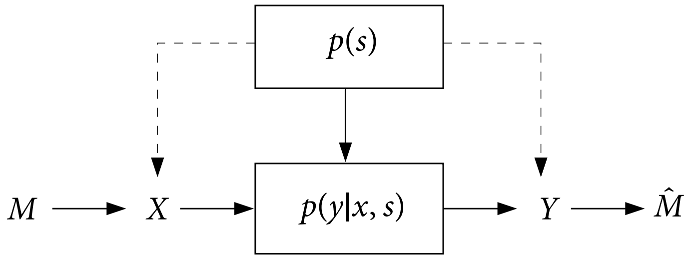
- Interference channels (NIT 6.1–6.7):



Problem open; strong interference; Han–Kobayashi

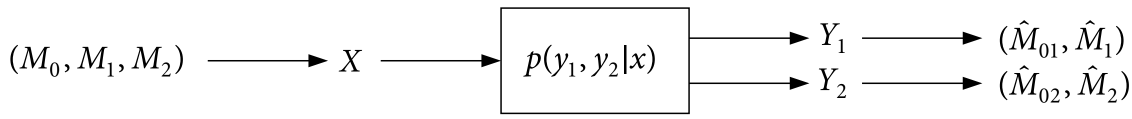
Single-hop networks

- Channels with state (NIT 3.7, 7.1, 7.2, 7.4–7.7):



Shannon strategy; Gelfand–Pinsker; multicoding; writing on dirty paper

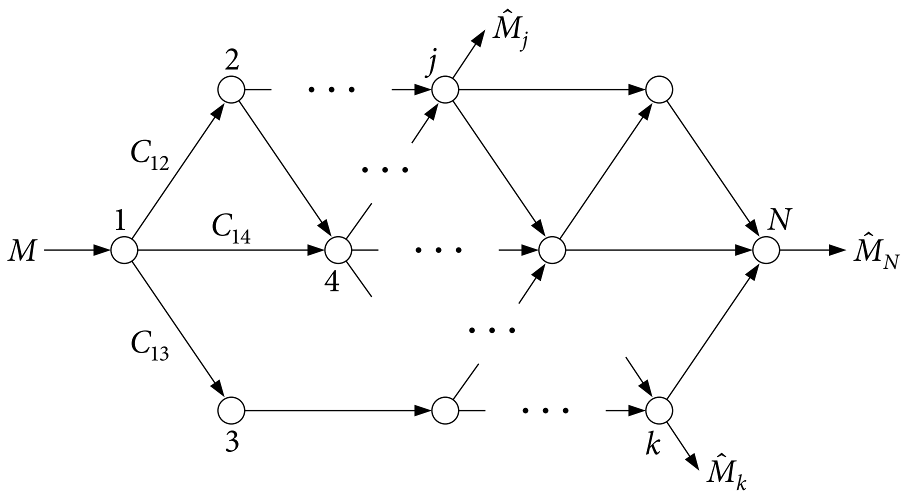
- General broadcast channels (NIT 8.1–8.5, 9.5, 9.6):



Problem open; degraded message sets; Marton coding; mutual covering;
Gaussian vector (MIMO) broadcast channel; vector writing on dirty paper

Multihop networks

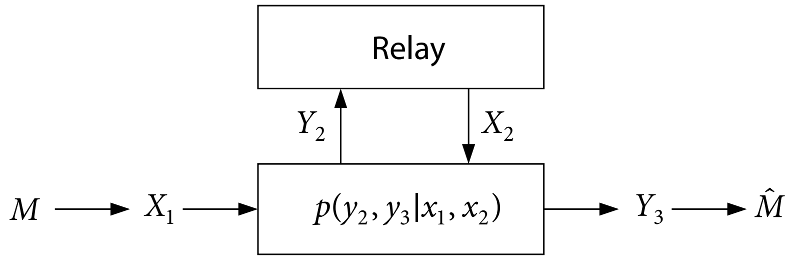
- Graphical networks (NIT 15.1–15.3):



Max-flow min-cut; network coding

Multihop networks

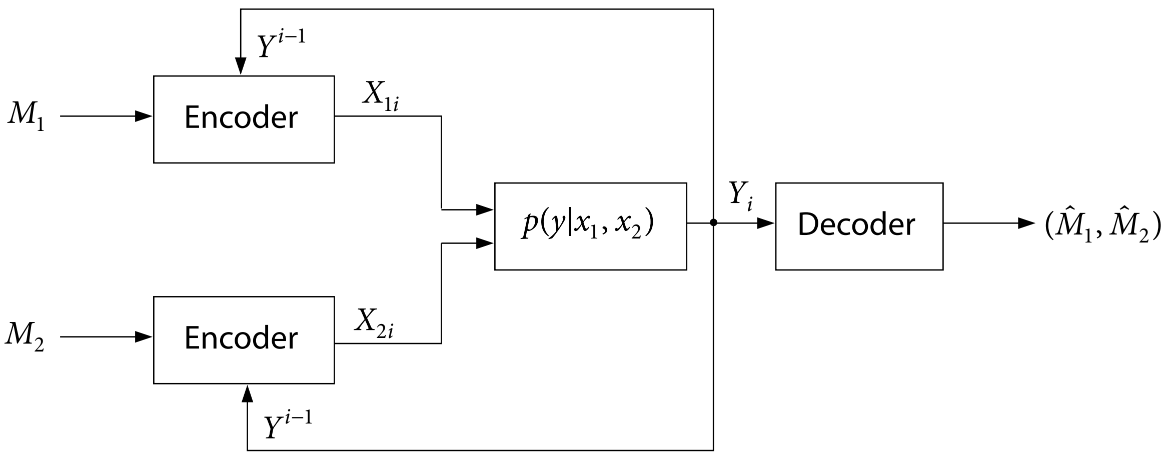
- Relay channels (NIT 16.1–16.7):



Problem open; cutset bound; decode–forward; compress–forward

Multihop networks

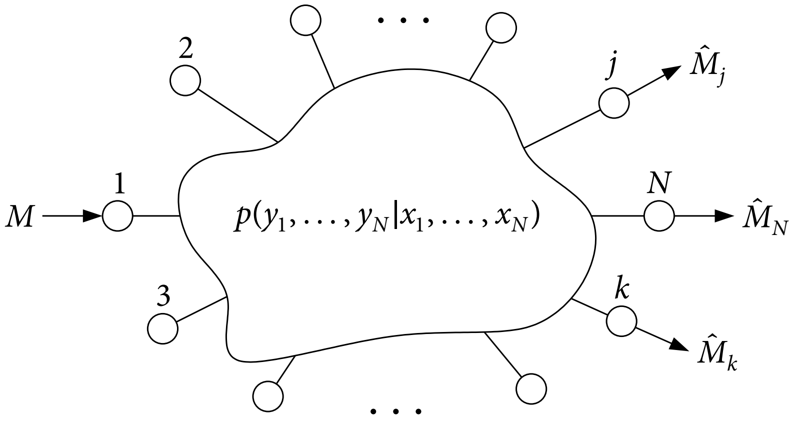
- Interactive communication (NIT 17.1–17.4):



Iterative refinement; feedback can increase capacity of multiuser channels

Multihop networks

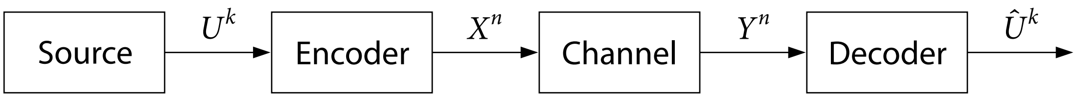
- Discrete memoryless and Gaussian networks (NIT 18.1–18.3, 19.1):



Cutset outer bound; network decode–forward; noisy network coding

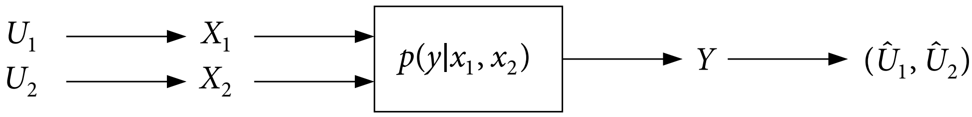
Joint source–channel coding

- Joint source–channel coding (NIT 3.9):



Shannon's source–channel separation theorem

- Correlated sources over a MAC (NIT 14.1):



Separation theorem does not hold in general for networks; common part

Course topics

- Not all material in sections listed is covered
- Lecture slides and reading assignments will clarify what is covered
- Topics not covered in the lectures:
  - Distributed lossy compression (NIT 3.6–8, 11, 12)
  - Multiple description coding (NIT 13)
  - Compression over graphical networks (NIT 20)
  - Communication for computing (NIT 21)
  - Information theoretic secrecy (NIT 22)
  - Wireless fading channels (NIT 23)
  - Networking and information theory (NIT 24)

Tentative course schedule

Jan 5	Introduction; Review of IT
Jan 7	Review of IT; HW1
(Jan 9)*	Review of IT
Jan 12	Distributed source coding
Jan 14	Multiple access channels; HW1 due; HW2
(Jan 16)	Multiple access channels
Jan 21	Degraded broadcast channels; project guidelines; HW2 due; HW3
Jan 26	Degraded broadcast channels; interference channels
Jan 28	Interference channels; HW3 due; HW4
(Jan 30)	Channels with states

* Make-up lectures: Time/location TBD

Tentative course schedule (contd.)

Feb 2–6	ITA workshop
Feb 9	Channels with state; ITA assignment & final project proposal due
Feb 11	General broadcast channel; HW4 due; HW5
Feb 18	Graphical networks; HW5 due; take-home midterm
Feb 23	Relay channels; midterm due
Feb 25	Relay channels; discrete memoryless networks
Mar 2	No lecture
Mar 4	No lecture
Mar 9	Discrete memoryless networks; Gaussian networks
Mar 11	Joint source–channel coding
(Mar 13)	Final project presentations

References

Ford, L. R., Jr. and Fulkerson, D. R. (1956). Maximal flow through a network. *Canad. J. Math.*, 8(3), 399–404.

Shannon, C. E. (1948). A mathematical theory of communication. *Bell Syst. Tech. J.*, 27(3), 379–423, 27(4), 623–656.

Shannon, C. E. (1959). Coding theorems for a discrete source with a fidelity criterion. In *IRE Int. Conv. Rec.*, vol. 7, part 4, pp. 142–163. Reprint with changes (1960). In R. E. Machol (ed.) *Information and Decision Processes*, pp. 93–126. McGraw-Hill, New York.

Shannon, C. E. (1961). Two-way communication channels. In *Proc. 4th Berkeley Symp. Math. Statist. Probab.*, vol. I, pp. 611–644. University of California Press, Berkeley.