Multiuser Information Theory and Wireless Communications

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Where and When?

Good News

- No homework.
- No exam.

Credits:1-2

- One credit: submit a report on one of the topics covered in the course.
- Two credits: (extra work) either give a presentation or write a conference paper on a topic related to the course.

Course Webpage

- http://people.cornell.edu/pages/jc353/newcourse.htm

What is Information Theory?

An Example

- Channel: $p(y|x)$.

- Channel capacity (an operational definition): R is achievable if $\forall \epsilon, \delta > 0$, $\exists N$, $\forall n > N$, there exists an encoding function $f^{(n)} : \mathcal{W} = \{1, 2, \cdots, M = \lfloor 2^{n(R-\delta)} \rfloor\} \to \mathcal{X}^n$ and a decoding function $g^{(n)} : \mathcal{X}^n \to \{1, 2, \cdots, \lfloor 2^{n(R-\delta)} \rfloor\}$ such that $\frac{1}{M} \sum_{w=1}^{M} P(\widehat{W} \neq W | W = w) \leq \epsilon$, where $\widehat{W} = g^{(n)}(Y^n)$. C is the supremum of all achievable rates R.

- Shannon's channel coding theorem:

$$C = \max_{p(x)} I(X; Y).$$

An Observation

- Shannon's theorem reduces a high (actually infinite) dimensional optimization problem into a low dimensional optimization problem.

$$C = \max_{p(x)} I(X;Y).$$

Information Theory $\approx$ Optimization Theory

- $C = \max_{p(x)} I(X;Y)$.

- $\max_{p(x)} I(X;Y) = ?$ — ECE 562 homework problem.

- Binary symmetric channel: $Y = X + N \mod 2$, $P_{N=0} = p, P_{N=1} = 1 - p$.

$$C = \max_{p(x)} I(X;Y) = 1 - H(p).$$

- AWGN Channel: $Y = X + N$, $N \sim \mathcal{N}(0, \sigma_N^2)$, $\mathbb{E}X^2 \leq P$.

$$C = \max_{\mathbb{E}X^2 \leq P} I(X;Y) = \frac{1}{2}\log(1 + \frac{P}{\sigma_N^2})$$

$\max_{p(x)} I(X;Y)$ — Homework Problem?

- From scalar to vector: $Y = X + N \rightarrow \mathbf{Y} = \mathbf{X} + \mathbf{N}$.

- From AWGN channel to fading channel:

$$\mathbf{Y} = \mathbf{X} + \mathbf{N} \rightarrow \mathbf{Y} = H\mathbf{X} + \mathbf{N} \rightarrow \mathbf{Y} = \mathbf{H}\mathbf{X} + \mathbf{N}.$$

- $\mathbf{H}$ is unknown. $\mathbf{H}$ is known only at receiver. $\mathbf{H}$ is known at both transmitter and receiver.

- People won best paper award by solving this type of problems (Telatar, Zheng, Tse ...).

- It usually requires non-information theoretic techniques.

What is Multiuser Information Theory?

- Multiaccess channels: $\mathbf{Y} = \sum_{i=1}^{L} \mathbf{H}_i \mathbf{X}_i + \mathbf{N}$.

- Broadcast channels: $\mathbf{Y}_i = \mathbf{H}_i \mathbf{X} + \mathbf{N}_i$, $i = 1, 2, \cdots, L$.

Multiuser Information Theory is Hard!?

- Yes. It takes a whole semester to prove the channel coding theorem and the source coding theorem for the single-user scenario.

- Yes. There are more open problems than solved problems.

- No. It is easy to learn multiuser information theory since all the problems that have been solved are “easy”.

How to Learn Multiuser Information Theory?

- Understand basic building blocks.
- Explore similarities.

Why is Information Theory useful?

- Establish the fundamental performance limit.
- Construct the optimal scheme to achieve this limit.
- Suggest the structure of optimal systems.

General Description

This is a graduate level course on multiuser information theory and wireless communications. Besides covering the fundamental results in networok information theory, we will emphasize the connections between source cooding and channel coding, and the application of information theory in wireless communications.

Minimum Syllabus

- Review channel coding theory and rate distortion theory.

- Capacity analysis of MIMO systems.

- Multiaccess channles.

- Distributed source coding: Slepian-Wolf, Wyner-Ziv, Berger-Tung.

- Gelfand-Pinsker theorem and Costa's dirty paper coding.

- Broadcast channels: Marton's region and dirty paper precoding.

Minimum Syllabus (Cont'd)

- Multiple descriptions.

- Resource allocation in multiaccess communication systems and distributed compression systems.

- Rate splitting and source splitting.

- Duality between multiaccess channels and broadcast channels.

Optional Topics

- Diversity-multiplexing tradeoff in MIMO channels.
- Noncoherent MIMO channles.
- Network coding.

References

- T. M. Cover and J. A. Thomas, Elements of Information Theory. New York: Wiley, 1991.
- R. Gallager, Information Theory and Reliable Communication, John Wiley and Sons, Inc., 1968.
- R. Yeung, A First Course in Information Theory, Kluwer Academic/ Plenum Publishers, 2002.
- D. Tse and P. Viswanath, Fundamentals of Wireless Communication, to be published by Cambridge University Press. Online: http://degas.eecs.berkeley.edu/dtse
- T. Berger, "Multiterminal source coding," in The Information Theory Approach to Communications (G. Longo, ed.), vol. 229 of CISM Courses and Lectures, pp. 171-231, Springer-Verlag, Vienna/New York, 1978.