Multiple Access Channel Coding for Interference-Limited Communications

Robert M. Taylor Jr.

703-983-5211

rtaylor@mitre.org

MITRE Sponsored Research

Problem

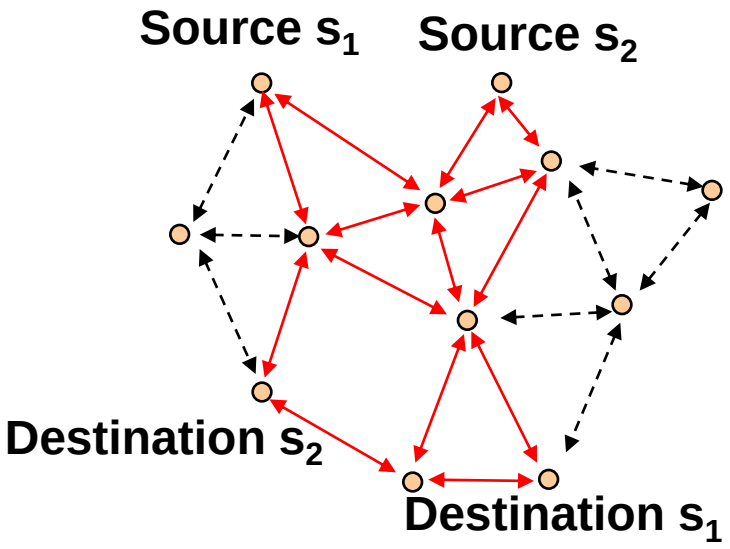
Current wireless network design is fundamentally flawed.

State of the Practice/Art		Truths from Network Information Theory
1. Design protocols to prevent packet collisions.	vs.	1. Multiple-access relay channel coding requires packets to collide.
2. Design routing algorithms at network layer.	vs.	2. Routing is suboptimal. Network coding is necessary.
3. Apply Shannon separation principle to design source and channel coders.	vs.	3. Shannon separation principle fails for networks and finite delay systems.

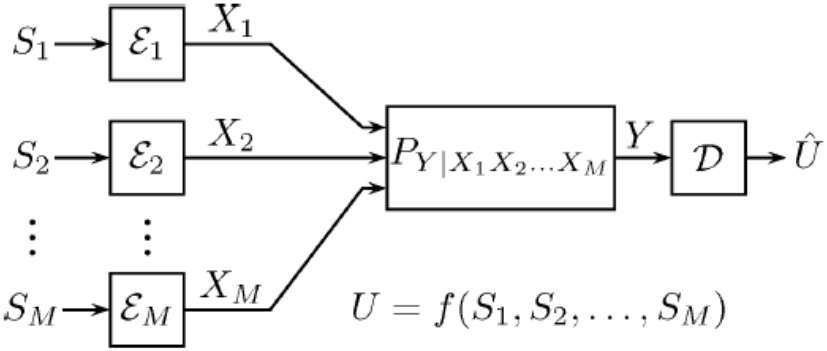
Background

"Interference" is our friend.

- **Network coding [Ahlswede] reveals that information does NOT flow like water through pipes but relies on *combining* packets at intermediate nodes.**
- **Broadcast nature of nodes ideally suited to create wireless *network information flow.***
- **Computation codes [Nazer, Gastpar] needed to "combine interference" at intermediate multiple access relay nodes to achieve multicast capacity.**



Communicate *function* of sources instead of sources themselves.



Objectives

To *achieve* Optimal Performance Theoretically Achievable (OPTA) a wireless communication network must employ:

1. **Joint source-channel-network codes**
2. **Unified receiver**

- **Objective 1. Design joint source-channel-network codes capable of correctly COMBINING the "interference" to approach multicast capacity using *computation codes*.**
- **Objective 2. Design unified multi-access receiver that simultaneously estimates transmitted symbols, channel impulse responses, carrier frequency offsets, and packet arrivals.**

Activities

- We identified a solution space for exploiting ad hoc network interference for multi-access nodes consistent with truths from network information theory.
- We demonstrated the optimality of joint source-channel coding for transmitting speech over Gaussian (extension of Goblick's Gaussian-over-Gaussian).
- We developed a joint source-channel-network computation code for application to wireless network coding.
- We experimented with hardware design by implementing a simple belief propagation receiver in VHDL and Xilinx System Generator.

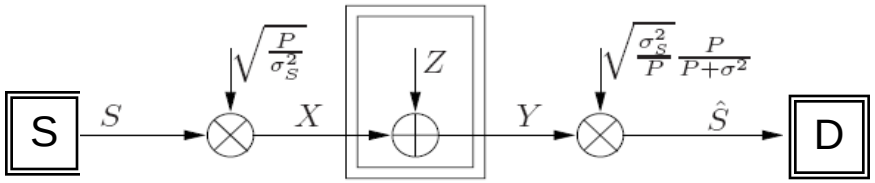
Highlight

Failure of the Shannon separation principle even for single-user coding

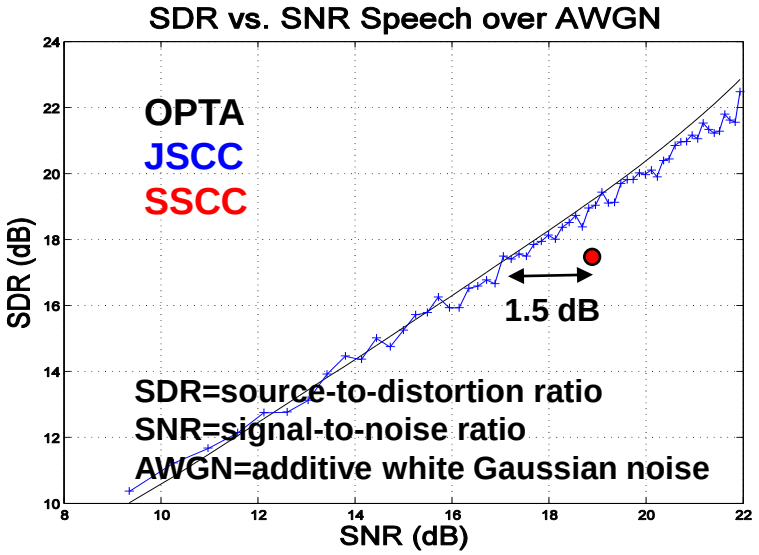
Near optimal Separate Source-Channel Coding (SSCC)

- **Apply optimal source code (achieves *rate-distortion bound*)**
- **Apply length=8000 non-binary (2,4) LDPC GF(16) (1.5 dB Eb/No capacity gap results [Declercq])**

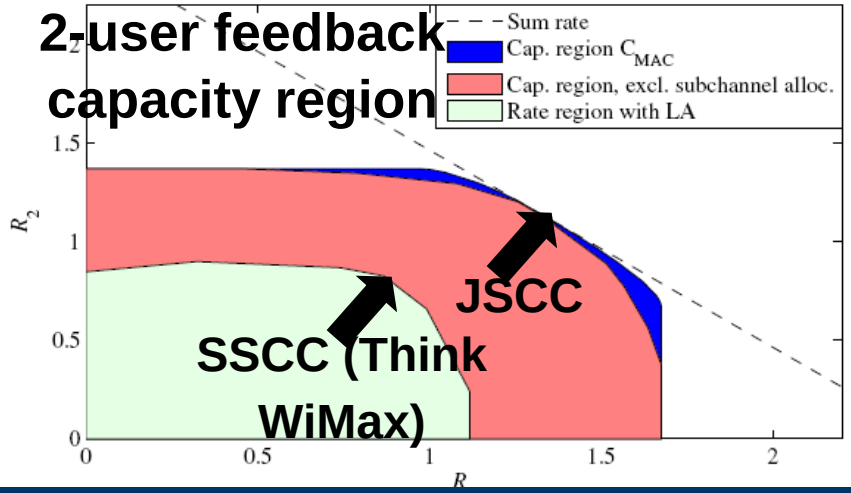
Compare to this zero-delay JSCC.



(Goblick's Guassian-over-Gaussian)



2-user feedback capacity region

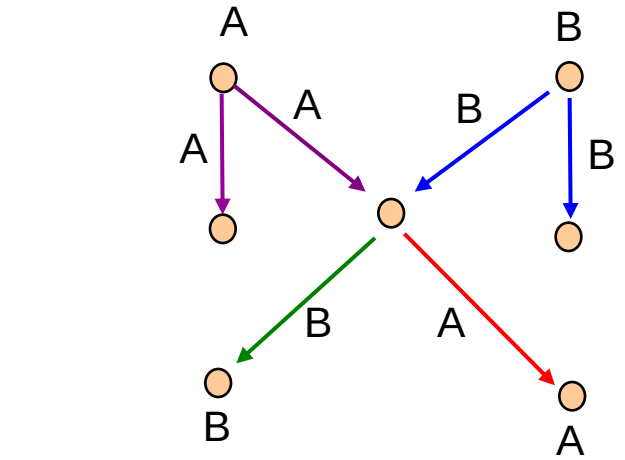


Joint source-channel code nearly optimal and with zero delay!

Demonstration

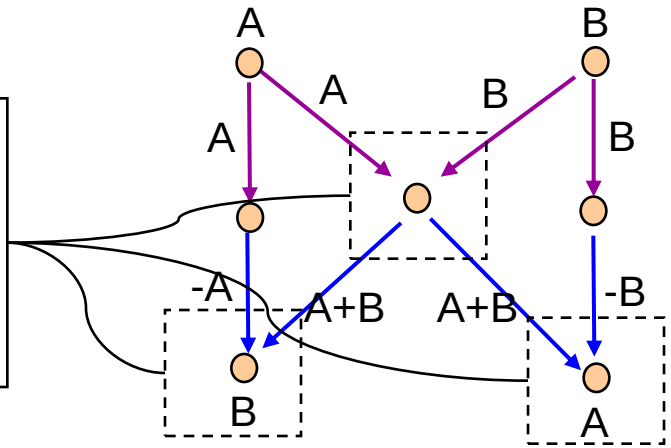
Failure of conventional routing to achieve multicast capacity

- Conventional routing takes four time slots for half duplex case.
- Wireless network coding needs only two time slots and achieves max-flow min-cut bound.



Legend: Step 1 Step 2 Step 3 Step 4

Computation coding applied to the multiple access nodes allows us to use the channel to compute the desired summation function.



Computation coding on the multiple access nodes are the building blocks necessary for wireless networks to achieve multicast capacity.

Impacts

- We demonstrated a revolutionary result—state-of-the-art separation-based coding schemes cannot compete with joint source-channel-network coding schemes. Results such as this affect every area of communications since all standardized schemes obey the Shannon separation principle.
- We are making a fundamental step towards realizing wireless network codes using computation codes.
- The closest immediate connection to government funded programs is DARPA ITMANET program and DARPA CBMANET program.

Future Plans

- Computation coding combines messages that are part of an intended information flow but does not separate unintended traffic.
- Interference alignment provides *K*/2 degrees of freedom for a *K*-user interference channel and could be used to separate packets that are part of a different information flow.
- Special techniques need to be developed to give each transmitter channel state information of its own outgoing channel and those of its neighbors.

Interference alignment on 3-user interference channel [Cadambe, Jafar]