Source Coding, Separation, & Feedback for MANETs

Introduction

What we know:

•Joint-source-network channel designs tailored to a specific to one application and a particular instantiation of a source/network probability distribution will have great performance.

•BUT they in general will *lack robustness and adaptability*

Why are These Problems Interesting?:

•Joint-source channel coding paradigm not completely well-defined

•Functional compression problem is not even completely characterized theoretically

•Common properties of provably good architectures not well understood

An ITMANET vision we aspire to:

•Developing robust architectures that are provably good across a broad class of source reconstruction metrics, and statistical properties of sources/channel/network topologies.

Source Coding, Separation, and Feedback for MANETs

Introduction (cont'd)

Numerous reconstruction demands/metrics

- **Near-lossless reconstruction of original sources**
- **Near-lossless reconstruction of *functions* of sources**
- **Lossy distortion metrics**
- ***Arbitrary* demand structures in line networks (beyond multicast/unicast)**

Robust architectures

- **Using successively refinable codes**
- **Modularized Graph Coloring/Slepian-Wolf Coding**

Various statistical source/channel/network topology scenarios

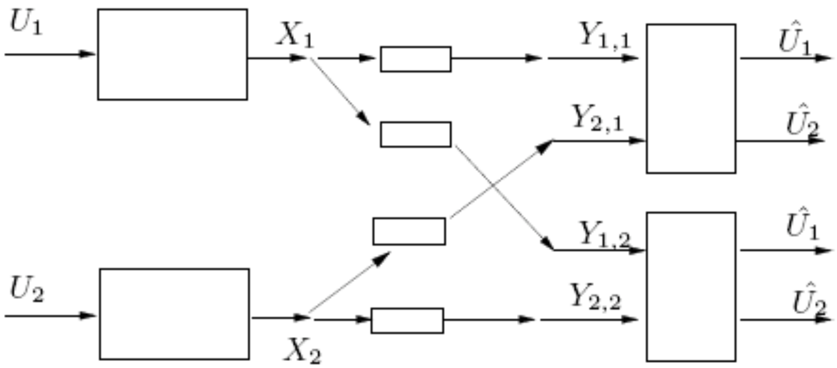
- **Communicating across *non-ergodic* channels**
- **Line networks**
- ***Random* network *topologies***

Source Coding, Separation, and Feedback for MANETs

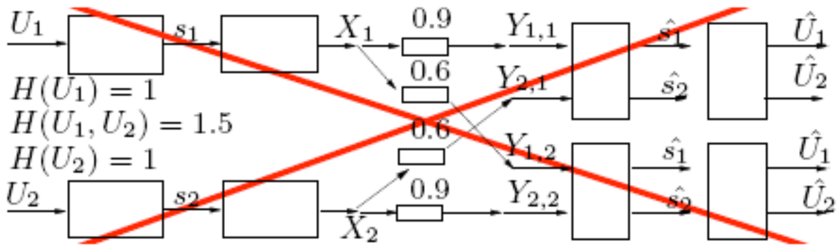
Future work in this arena

- Consider *non-iid sources* for lossless, functional, lossy reconstruction metrics
- Incorporate common aspects of sources into network designs
- *Feedback* provides possibilities for highly adaptive universal approaches in such scenarios. Fundamental question(s):
    - For sources with memory, joint coding and feedback, how should we balance *forward error correction* versus as *adaptive feedback-triggered error correction*?
    - Note (as we'll see with Ralf's work) we must look at this from *beyond a link-based feedback perspective*
    - Should we do mostly forward error correction or mostly adapt?
    - What is the right *balance* between the two and how is this *modulated by the memory of the sources?*
    - Understand this from *lossless* achievability, *error exponent*, *lossy* achievability, and *distortion exponent* perspectives

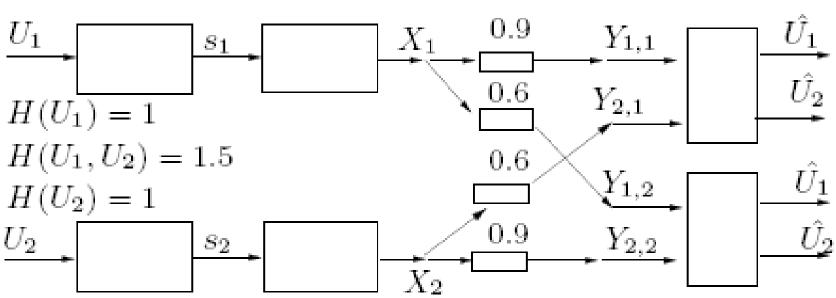
Qualification of definition of source-channel coding (Coleman et al)



• *General problem*: correlated sources, a network, each receiver wants to losslessly reconstruct them



• *Separation* at encoder *and* decoders *insufficient*

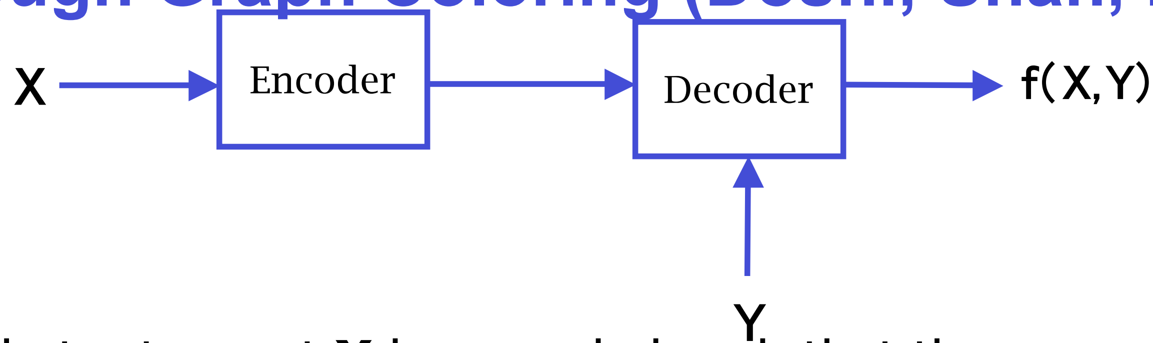


• *Separation* at *encoder* and *joint source-channel decoding* achieves whole capacity region

• A *robust*, *optimal* architecture

• There are *more degrees of freedom* in the separation vs. no separation question *than previously thought*

Distributed Functional Compression through Graph Coloring (Doshi, Shah, Medard)

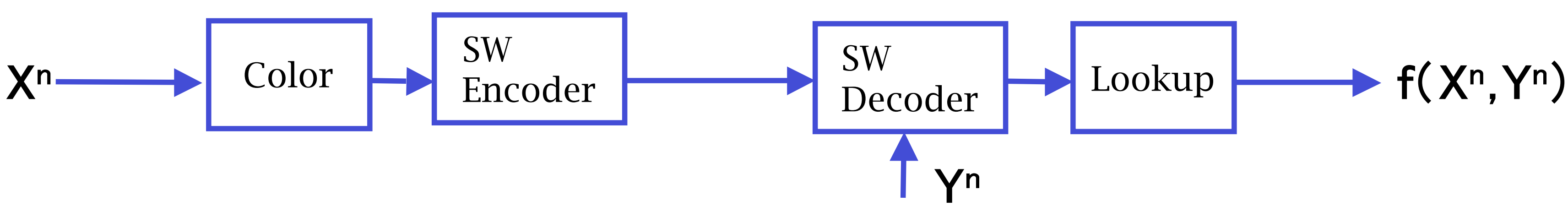


- At what rate must **X** be encoded such that the computation of f(**X**,**Y**) is possible at the receiver?
- Can we come up with viable coding schemes to achieve that rate?

- The best rate (Orlitsky. Roche): $$H_G(X|Y) = \min_{\substack{W - X - Y \\ X \in W \in \Gamma(G)}} I(W;X|Y)$$

  G is a graph defined by the function f(X,Y) and the distribution p(X,Y) called the characteristic graph.

- $H_G(X|Y) < H(X|Y)$, disparity determined by complexity of function f
- This rate can be achieved using graph colorings of powers of G.



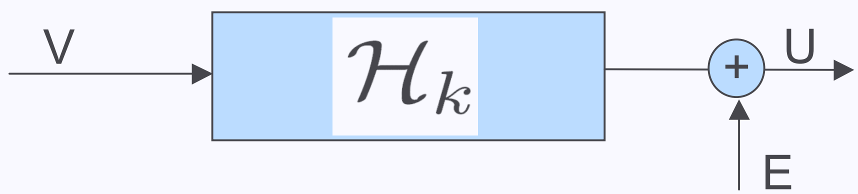
Network coding and network error correction (Koetter, Kschischang)

λ Random network coding is susceptible to modifications of packets (adversary, jamming, non-hostile, packet erasures)

• Error correction in combination with network coding was considered by Yeung et al., and Zhang, --- here the network topology plays a central role

•We consider a network as a modeled by a random linear operator reflecting the operation of ***random network coding*** on a network of **unknown** topology

Operator Channel: **Input** is a subspace V of ambient n-dimensional space W, H is a **random linear operator** mapping V to a k-dimensional subspace of V; E is an error space of dimension t(E)
Output is a subspace U of W



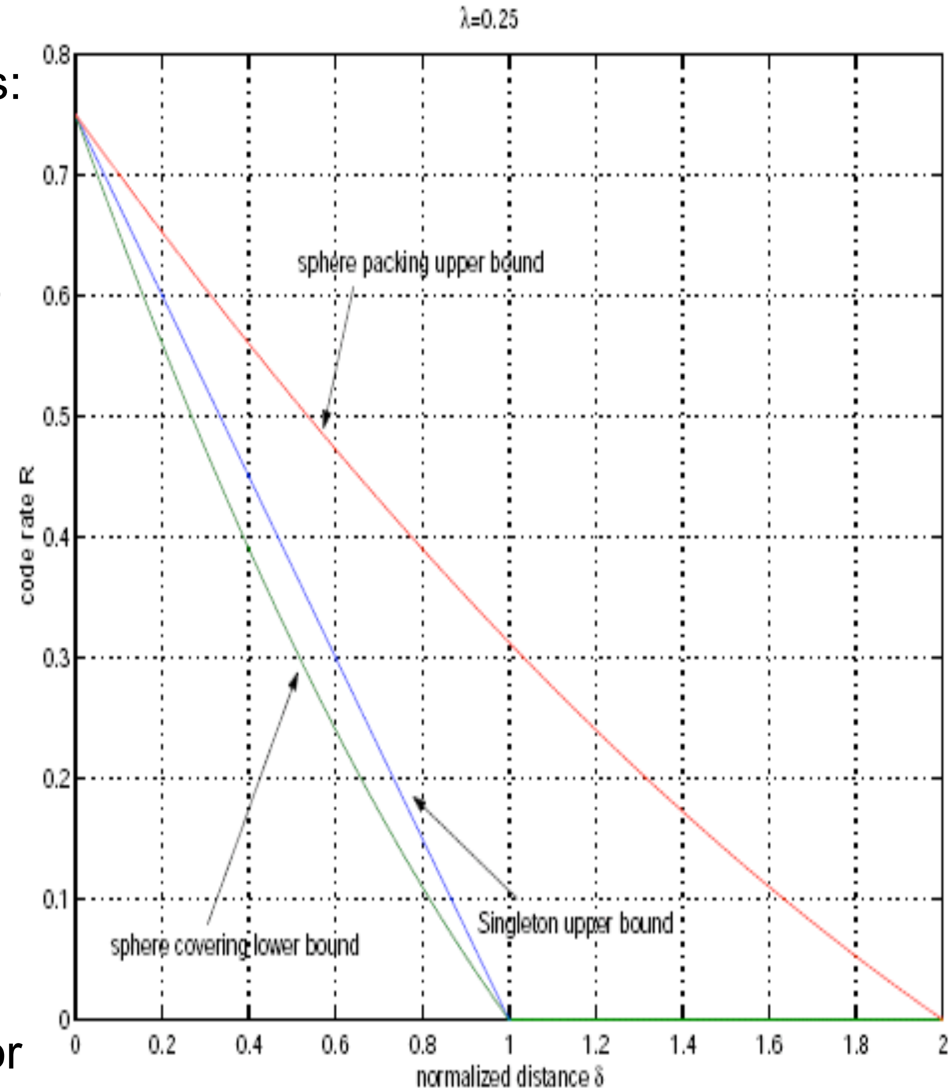
$$U = \mathcal{H}_k(V) \oplus E$$

Bounds and codes

- Already known (Lun et al) for erasures:

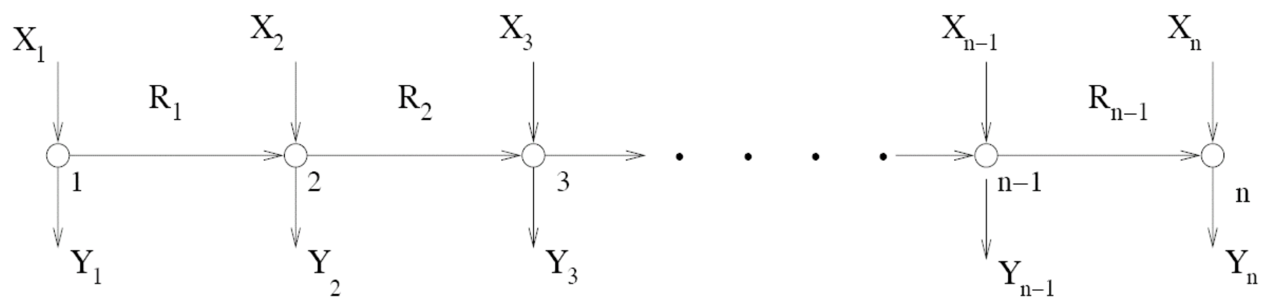
  - even if you allow feedback on a ***link by link basis***, network coding still beats out a protocol (feedback-based) mechanism

  - reason: forcing retransmissions on links still constrains encoding to be point-to-point, loss of diversity
- Here: when arbitrary errors are injected, network coding still wins
- Usually, cost for an error is ***twice*** cost for an erasure. Here, errors and erasures have the ***same*** cost
- A Singleton bound has been derived
- Codes meeting this bound can be constructed form Gabidulin's rank error correcting codes
- These codes come with fast encoding and decoding!



Network Coding of Correlated Sources in Line Networks (Koetter, Effros et al)

• Independent sources and a special class of dependent sources

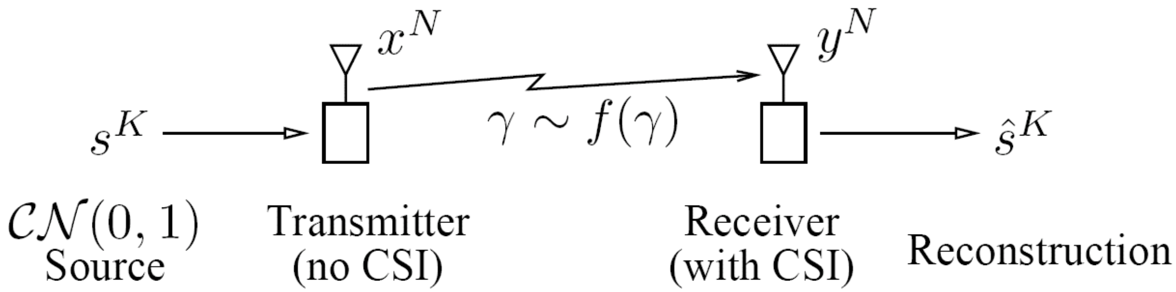


•Fully characterize the capacity region of line networks for *all possible demand structures* (e.g., multiple unicast, mixtures of unicasts and multicasts, etc.)

•Achievability bound is derived by decomposing a line network into components that have exactly one demand and adding the component rate regions to get rates for the parent network.

• For dependent sources, an achievability result is provided examples where the result is and is not tight.

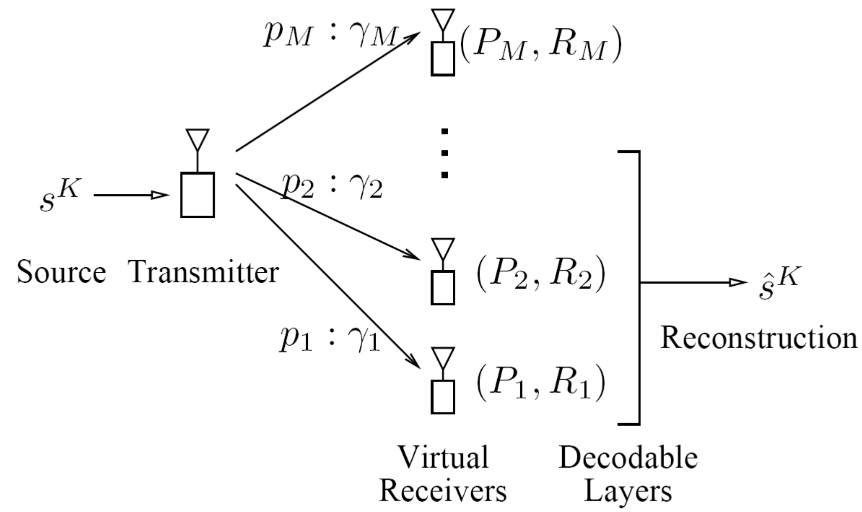
Joint Source-Channel Coding without CSI at the Transmitter (Goldsmith et al)



- Transmission of Gaussian source without CSIT.
  - Quasi-static block fading. Decoding is delay-limited.
  - Channel is non-ergodic: separation is suboptimal.
  - Transmitter knows the fading distribution.
- Minimize expected distortion $E_H[D]$ of reconstruction.
  - Power constraint P.
  - Bandwidth ratio: b source symbols per channel use.

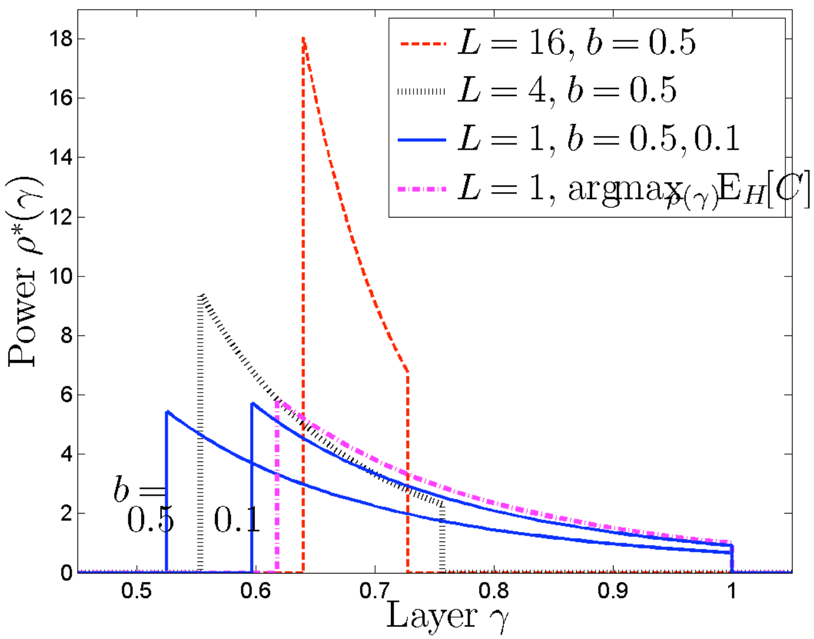
Layered Broadcast Coding with Successive Refinement

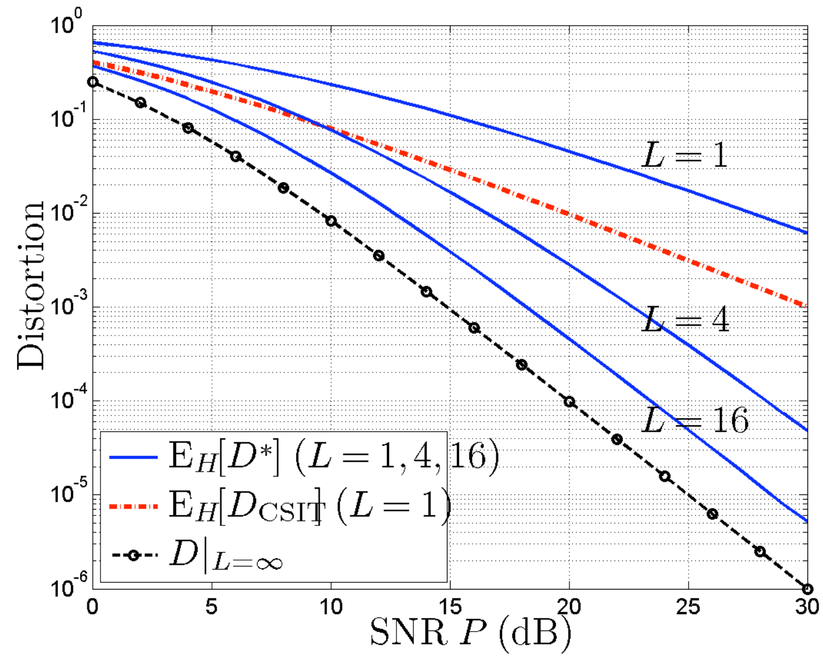
- Layered broadcast coding:
  - Superposition coding: one layer for each fading state.
  - Receiver decodes the layers supported by the channel realization.
  - Undecodable layers are treated as noise.
  - Successive decoding is capacity-achieving for single-antenna Gaussian broadcast channel.



- Gaussian source is successively refinable:
  - Each layer successively refines the description in the lower layer.

Optimized power allocation for minimum expected distortion





Two-layer power allocation:

- Allocate power to higher layer up to a power ceiling.

- Multiple layers:
  - Recursively apply two-layer optimization.
- Continuous fading distribution:
  - Solution given by a set of first-order linear differential equations
- Minimum expected distortion:
  - At high SNR, large benefits from diversity.