Joint Network Channel Fountain Scheme for Reliable Communication in Wireless Networks

by Ahasanun Nessa, Michel Kadoch and Bo Rong

Presented by Prof. Michel Kadoch

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Outline

- Background
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- Methodology
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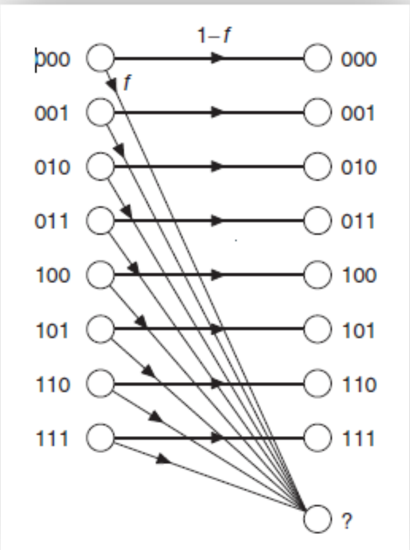
Erasure channels

from D.J.C. Mackay, “Fountain codes” IEE proc.-Comm. Vol 152, No6, dec 2005

- q-ary erasure channel has probability 1-p correct transmission and p probability of loss for all input alphabet 0 ...q-1.
- The size of the alphabet q is 2**ℓ, ℓ is the number of bits in a packet.



Erasure channels

from D.J.C. Mackay, "Fountain codes" IEE proc.-Comm. Vol 152, No6, dec 2005

- If the erasure probability p is high, the common feedback protocols are useless because regardless of whether there is a feedback channel or not, the forward channel capacity is (1-p) ℓ bits.
- A good forward error correcting code would improve the communication.

Gaussian Channel

- A discrete-time Gaussian channel is defined by

$$Y_i = X_i + Z_i;\; Z_i \sim \mathrm{N}(0, N).$$

The output Y_i is the sum of input X_i and noise Z_i. The noise Z is assumed to be independent of X.

- If the noise variance N is zero or the power of input X is not constrained, then the capacity of the channel is infinite.
- Send $\sqrt{P}$ and $-\sqrt{P}$ for bit 0 and bit 1 respectively.
- Decode $X_i = 0$ if $Y_i > 0$ and $X_i = 1$ if $Y_i \leq 0$

Gaussian Channel Cont..

- Assuming both levels are equally likely, the probability of decoding error is

$$P_e = 1 - \Phi\left(\sqrt{\frac{P}{N}}\right),$$

where $\Phi(x)$ is the cumulative normal function.

- The Channel Capacity with power constraint P is

$$C = \frac{1}{2}\log\left(1 + \frac{P}{N}\right)$$

Rayleigh Fading Channel

- Rayleigh Fading manifests in two mechanism:
  - Time Spreading due to mutipath (time dispersion).
  - Time Variant behavior of the channel due to the motion and subsequent changes in propagation paths.
- In Rayleigh fading the received signal at destination is

$$Y_i = H_i X_i + Z_i$$

where H_i is the fading coefficient follows the Rayleigh

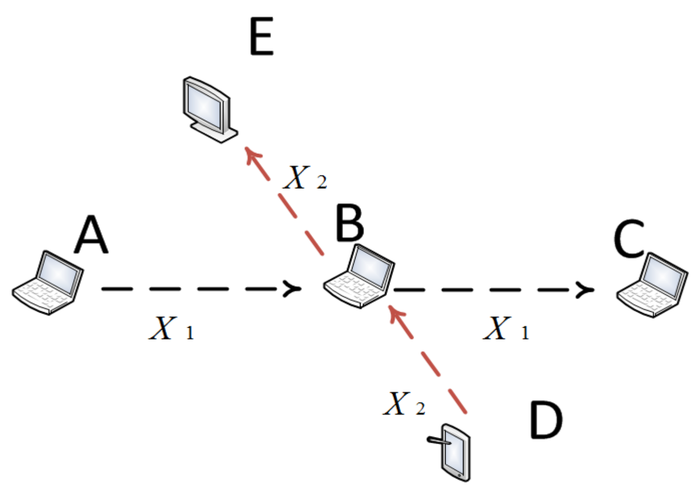
$$p(a) = \lambda e^{-\lambda a} \text{ where } (a = |H|^2)$$

Cooperative Communication:

- Improve the system performance in terms of: reduced **power consumption**, increased system **throughput** and greater **resilience**, and **coverage**.
- Combat the fading in wireless links and achieve diversity gains even though the node is equipped with single antenna.
- Achieved by sharing resources and possible for network with 3 or more nodes.
- Cooperation strategies with relay node
  - Decode and forward protocol
  - Estimate and forward
  - Amplify and forward

Cooperative Communication

- However, the resulting increase diversity comes at the cost of a loss of spectral efficiency.
- Node B in the network below is a “bottleneck”!
- How many time slot it need to forward traffic for two flows (A to C and D to E).?



Network Coding

- Traditionally, intermediate nodes in networks just forward data.
- Network coding deviates from this paradigm, in the sense that intermediate nodes are allowed to **process data before forwarding.**

A transmits X1 data to C. C is out of reach of A

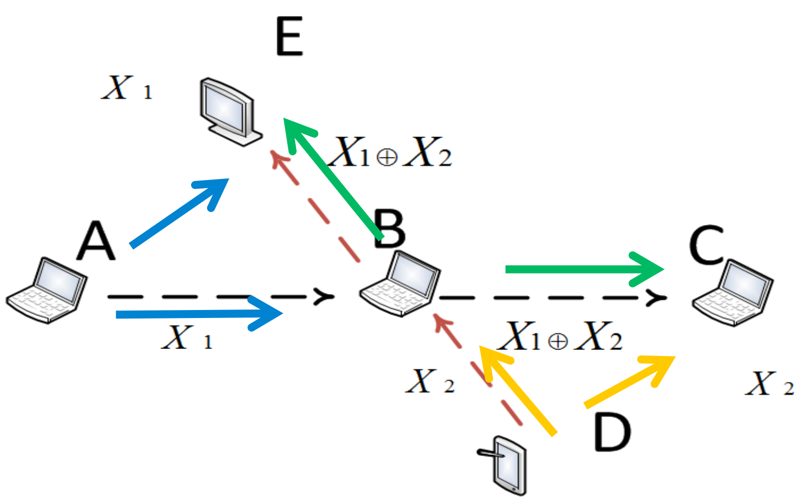
D transmits X2 data to E. E is out of reach of D

E receives X1 from A and C receives X2 from D.

B receives from both A and B and transmits the network code X1+X2 to E and C simultaneously.

E can then extract X2 from the X1+X2 received

C can then extract X1 from the X1+X2 received



Channel Coding

- To recover erroneous bits/symbols redundant bits/symbols appends with the packet.
- Some sophisticated channel coding: Reed-Solomon code, convolution code, Turbo code and low-density parity-check (LDPC) code.
- Have sound performance and approach the channel capacity of non-fading channels.
- However, in slow and deep fading, the performance of channel coding degrades dramatically and packet loss will occur.

Unified network and Channel Coding

- Unifying network coding with different coding schemes have gained much interest to combat the detrimental effects of wireless fading channel.
- The idea is to couple network and channel coding techniques simultaneously in the physical layer so that the redundancy in the network code should be used to support the channel code for better error protection.

Related Work

- C. Hausl et al. [1] proposed joint network and channel coding based on low-density parity-check (LDPC) code to obtain additional diversity gain in Multiple Access Relay Channel (MARC).
- Turbo codes based joint network-channel coding was applied to the two-way relay [2].
- Hausl uses decoding first and than Network Coding. If the code fails then packet is lost. Network coding is done at the network layer and cannot help the channel coding (Physical layer).

Related Work

- Using non-binary LDPC coding and linear network coding, Zheng et al. proposed non binary joint network-channel decoding(NB-JNCD) for large networks[3]. It has been shown that NB-JNCD outperforms binary LDPC JNCD.
- Zheng performs joint channel and Network decoding at the physical layer. Thus being more efficient. Redundancy of channel coding is helping network coding packet and vice versa.

Problem Statement

- To our knowledge, most research efforts till now have been limited in unifying fixed rate channel coding and network coding.
- In fixed rate coding the outage probability never reaches zero without the availability of precise Channel State Information (CSI) at the transmitter.

Methodology

- We propose joint network and fountain coding (JNFC) scheme for the cooperative diversity system of two sources and two relay nodes.
- JNFC seamlessly couples fountain coding and binary random linear network coding.

Why JNFC?

- In Separate Network Fountain Coding (SNFC), Channel decoding is performed for each received packet at destination.
- Then network decoder uses the error free packets to recover the packet which is not error free.
- As a result, the packets that fail the channel decoding are wasted.
- On the other hand in Joint decoding the redundancy in network coding and channel coding help each other to recover data.

Fountain codes [Byers99]

- With K **input symbols** (info.), the transmitter generates a series of unlimited **output symbols**.
- A receiver can decode any subset of K(1 + …) received output symbols.
- Application : multicast transmission

Fountain Code

- Naturally adapts its rate to the channel realization.
- The source unconscious of channel state information (CSI) generates as many encoding symbols as needed by simply performing modulo-2 operation among the source symbols.
- The receiver keeps accumulating incoming information until it is capable to decode source information successfully.

Fountain codes

from D.J.C. Mackay, "Fountain codes" IEE proc.-Comm. Vol 152, No6, dec 2005

- Michael Luby proposed an efficient method in 1998
- Suppose a source file of $K\ell$ bits, each transmitted packet has ℓ encoded bits.
- Receiver collects packets until he receives a little more than K. The original file should be recoverable.
- Fountain codes are rateless. Number of packets generated from the source message is limitless, and the number of packets generated can be readily determined.

Fountain codes

- When receivers, collecting bits, are satisfied to have recovered the message from these received bits, they acknowledge it to the transmitter.
- The method is not dependant on the rate of reception. If there is a large amount of loss in the transmission, it will require more time to the receiver to recover the information.

LT (Luby Transform) Code

- First class of universal and almost efficient Fountain Codes.
- The data of length N is partitioned into $k = N/l$ input symbols, i.e., each input symbol is of length l.
- Encoding Rule :
  - Randomly choose the degree d of the encoding symbol from a degree distribution.
  - Choose uniformly at random d distinct input symbols as neighbours of the encoding symbol.
  - The value of the encoding symbol is the exclusive-or of the d neighbour.

Encoding LT

from presentation of Krishna Chaitanya A Department of Electrical Engineering Indian Institute of Technology Madras

- Input symbol can be a bit (0 or 1) or a set of bits
- Encoding
  - Sample a degree d from a degree distribution (d), where d=0,1,2,…,k k is total number of input symbols.
  - Choose d number of input symbols from k input symbols.
  - XOR these d input symbols to get one output symbol
- Each symbol is generated independently
- Degree distribution (d) is the probability that degree d is chosen

Encoding LT : example

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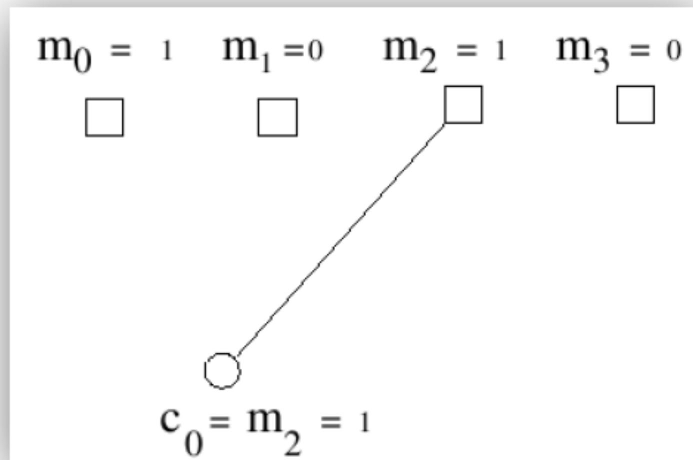
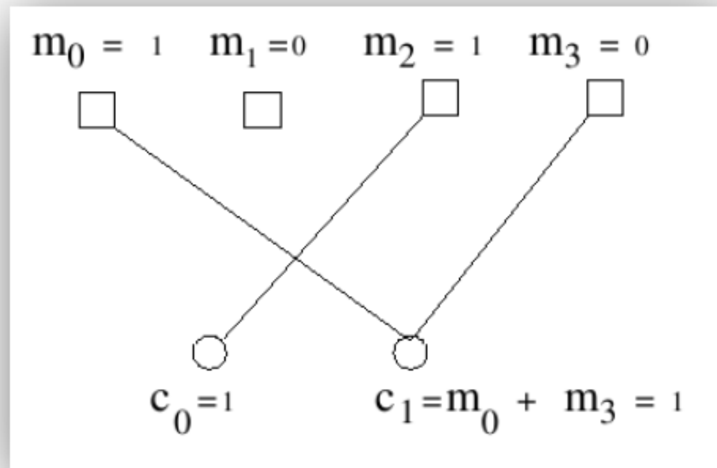
- Message length= 4 symbols, one bit per symbol and degree used are 1,2,3 (degree is important)
- Input symbols m: 1 0 1 0





Encoding LT: example

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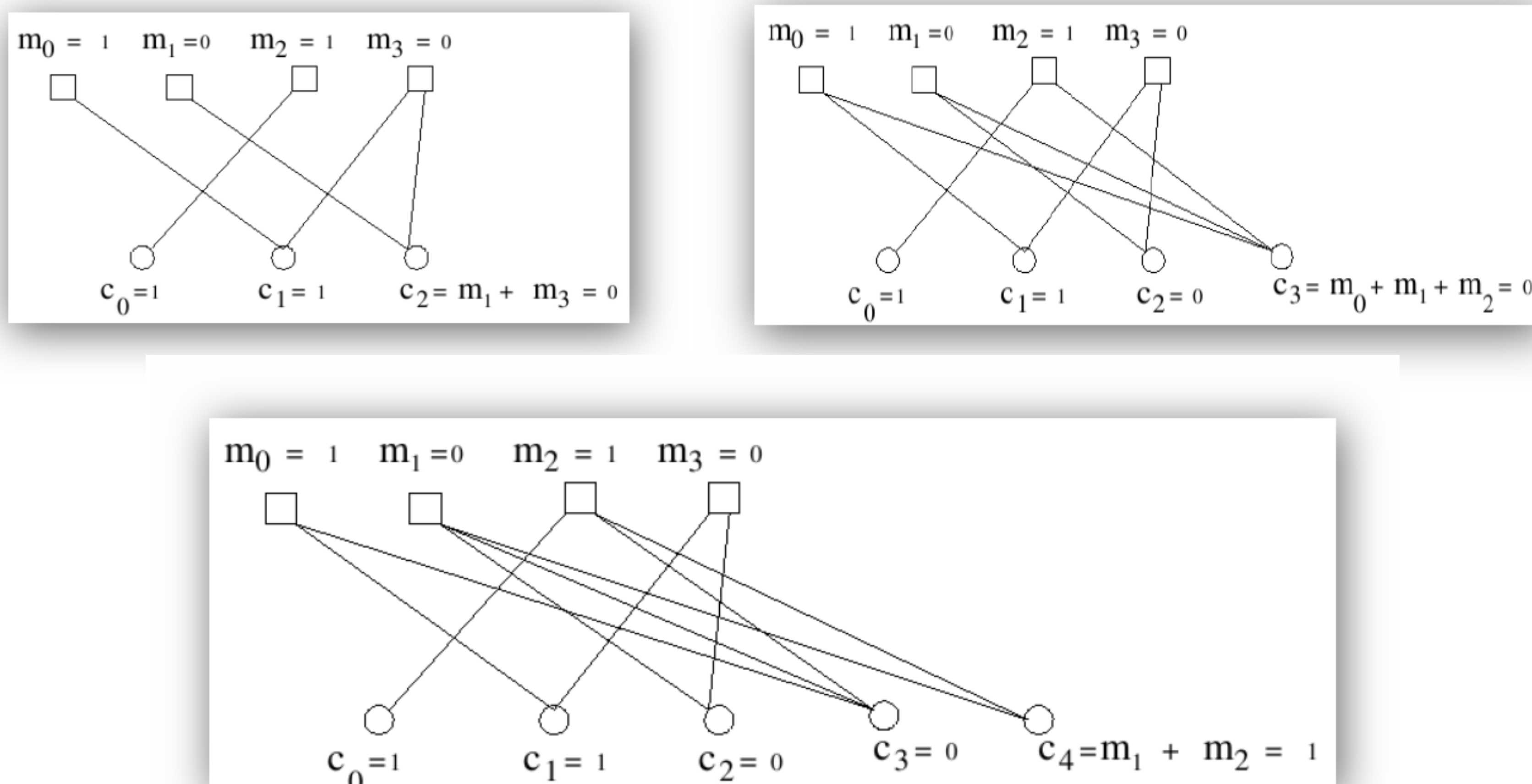

Output symbols c: 1 1 0 0 1

LT Code

- Decoding:
  - The decoder recover information symbols with the following three-step process, which is called LT process:
  - 1) (Release) All encoding symbols of degree one are released to cover their unique neighbor.
  - 2) (Cover) The released encoding symbols cover their unique neighbor information symbols. In this step, the covered but not processed input symbols are sent to ripple.
  - 3) (Process) One information symbol in the ripple is chosen to be processed: the edges connecting the information symbol to its neighbor encoding symbols are removed and the value of each encoding symbol changes according to the information symbol. The processed information symbol is removed from the ripple.

Decoding LT: example

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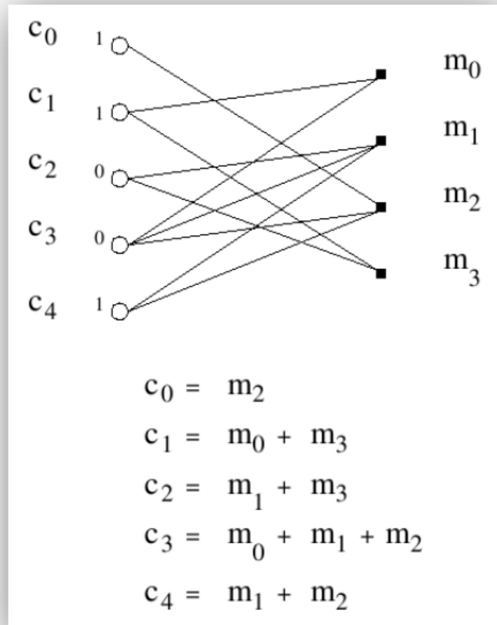

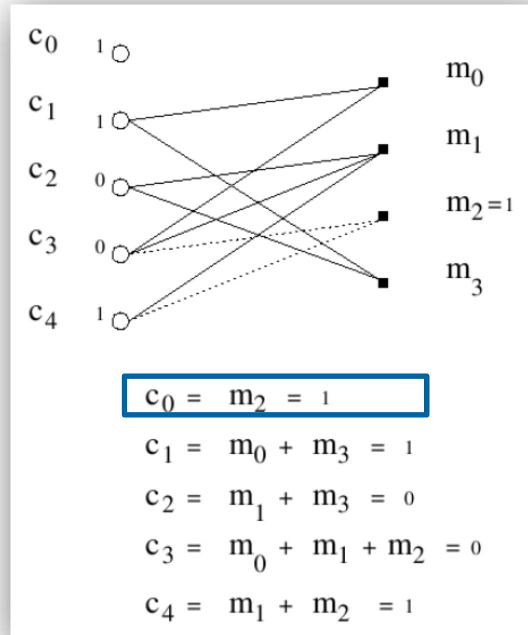

Decoding LT: example

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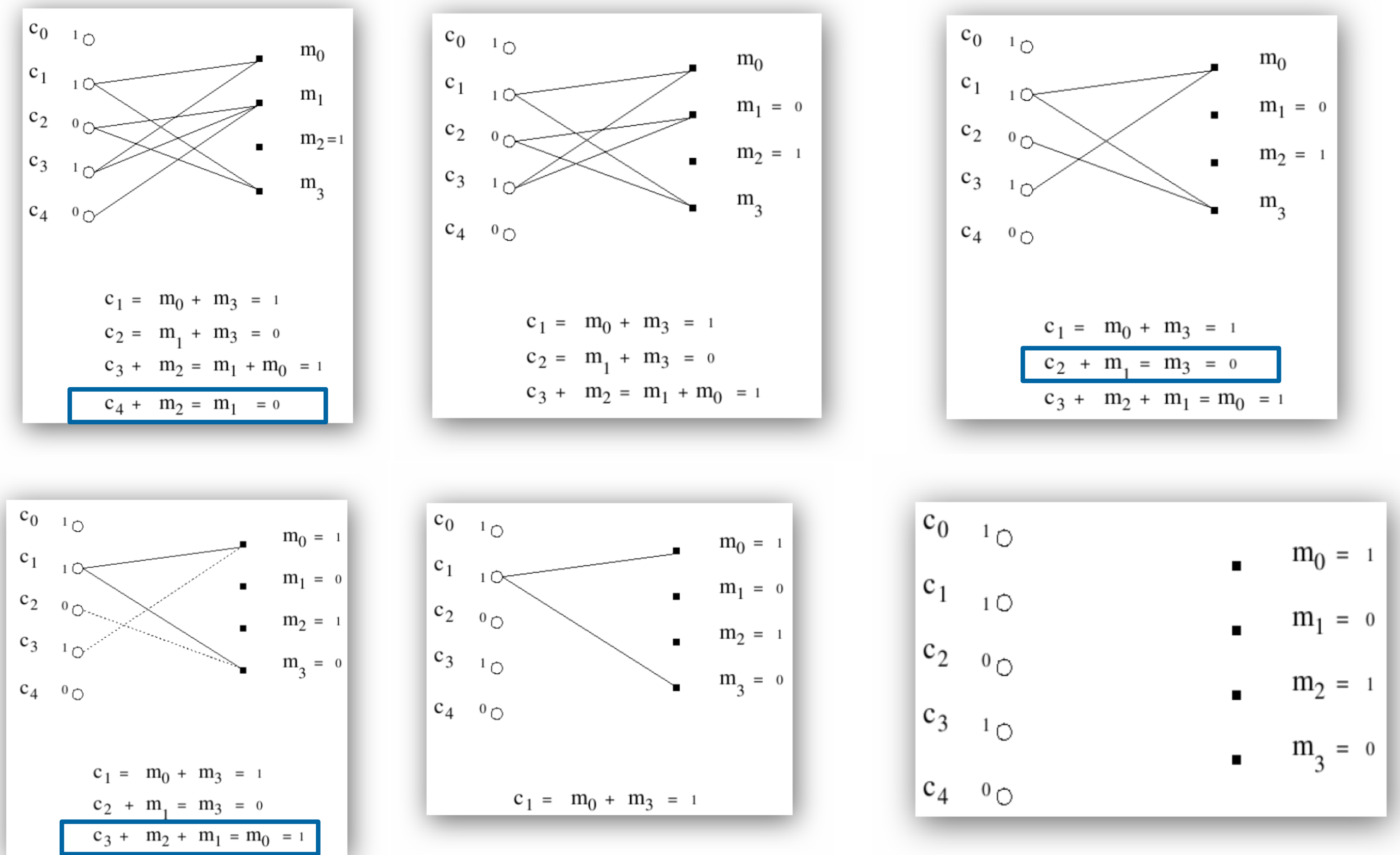
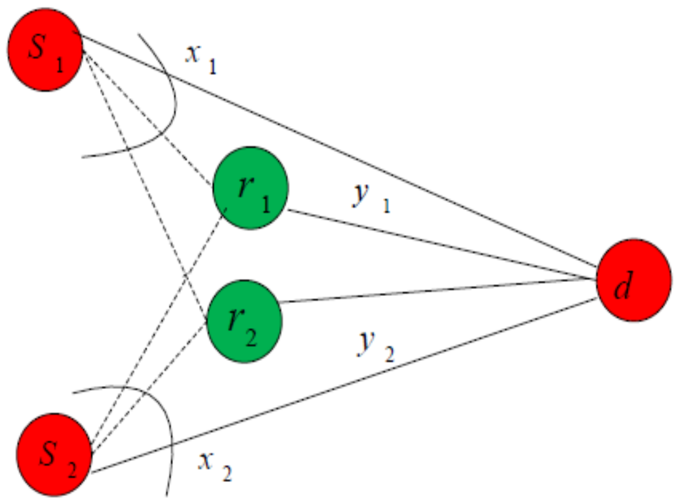
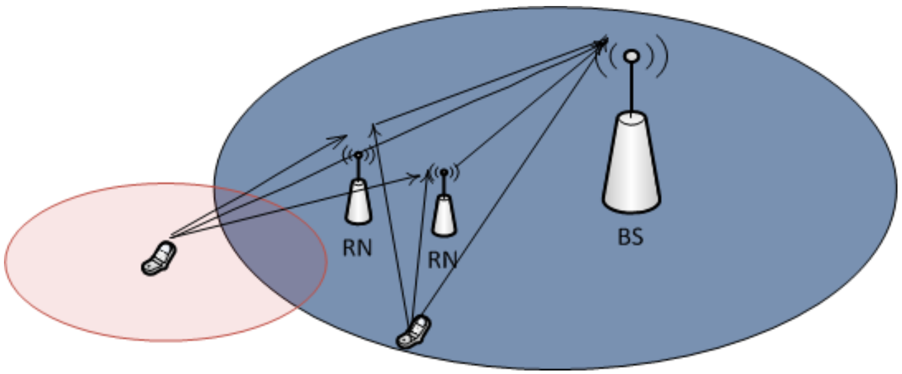


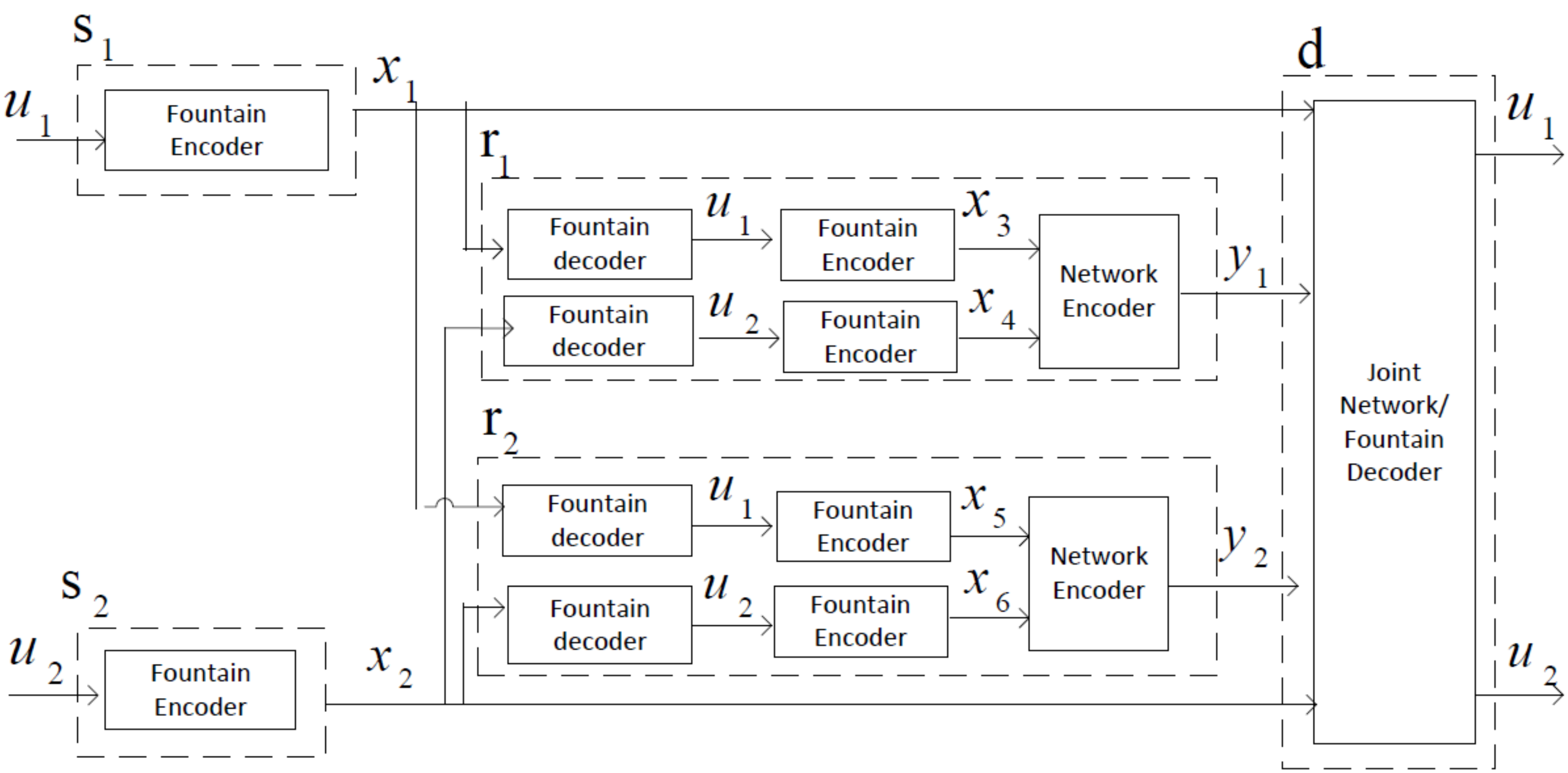
System Model





Application: Uplink cellular network where S_1 and S_2 are cell phones and d is base station.

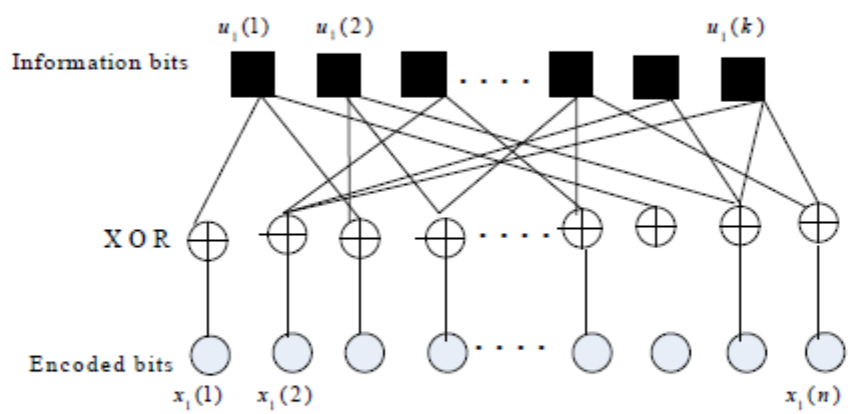
Block diagram of the system



Decode and Forward Protocol or cooperation

Code Construction

Using LT code, sources s_1 and s_2 generate a large number of encoded bit streams $x_1 = \{x_1(1), x_1(2), ...x_1(n)...\}$ and $x_2 = \{x_2(1), x_2(2), ...x_2(n)...\}$ from source packets u1 and u2 respectively. A factor graph representation of encoded packet is shown in the following figure that is truncated to length n.



Code Construction

At Sources s1 and s2, the encoded bit streams is given by

$$x_1 = u_1 \mathcal{G}_n^1,$$

$$x_2 = u_2 \mathcal{G}_n^2,$$

where, $\mathcal{G}_n^1$ and $\mathcal{G}_n^2$ are the generator matrix.

Relay Nodes obtains u1 and u2 and generates new packets, then performs network coding:

$$y_1 = \alpha_{11} u_1 . \mathcal{G}_n^3 \oplus \alpha_{12} u_2 . \mathcal{G}_n^4,$$

$$y_2 = \alpha_{21} u_1 . \mathcal{G}_n^5 \oplus \alpha_{22} u_2 . \mathcal{G}_n^6,$$

where, $\alpha_{ij}(i, j = 1, 2)$ are network coding coefficient and $\mathcal{G}_n^i (i = 3, 4, 5, 6)$ are the generator matrix.

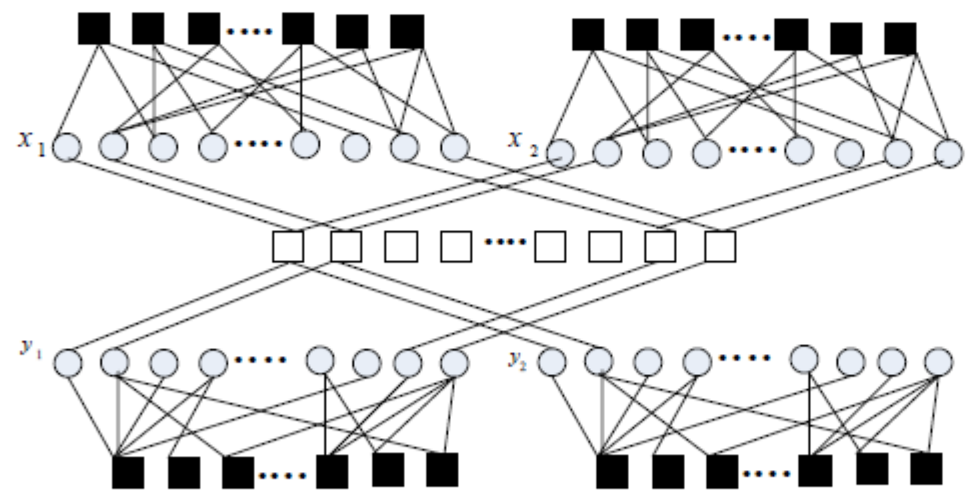


Fig. 4. Factor graph representation of the integrated code. Black box represents input bits and the shaded circle represent the output bits.

Joint Decoding

Four packets x_1, x_2, y_1 and y_2 are received at destination

The destination forms a longer codeword as follows

$$[x_1\ x_2\ y_1\ y_2] = [u_1\ u_2]\mathcal{G}'.$$

where, $$\mathcal{G}' = \begin{bmatrix} \mathcal{G}_n^1 & 0 & \alpha_{11}\mathcal{G}_n^3 & \alpha_{21}\mathcal{G}_n^5 \\ 0 & \mathcal{G}_n^2 & \alpha_{12}\mathcal{G}_n^4 & \alpha_{22}\mathcal{G}_n^6 \end{bmatrix}$$

with size k x 4n (k symbols by 4 length n)

- In noisy channels, the decoding of fountain code is accomplished using the standard Belief Propagation (BP) algorithm on generator $\mathcal{G}'$ matrix.
- A receiver tries to decode the codewords repeatedly with an iterative BP decoder until decoding is successful.

Benefit

- Benefit of this method in terms of delay:
  - Using two relays without network coding, 6 time slot needs to receive the packets at destination.

    Using two relays with network coding 4 time slot needs to receive the packets at destination.

Channel Model

- Propagation channel between nodes are considered independant and identically distributed Rayleigh fading with AWGN.
- BPSK modulation

Simulation Setup

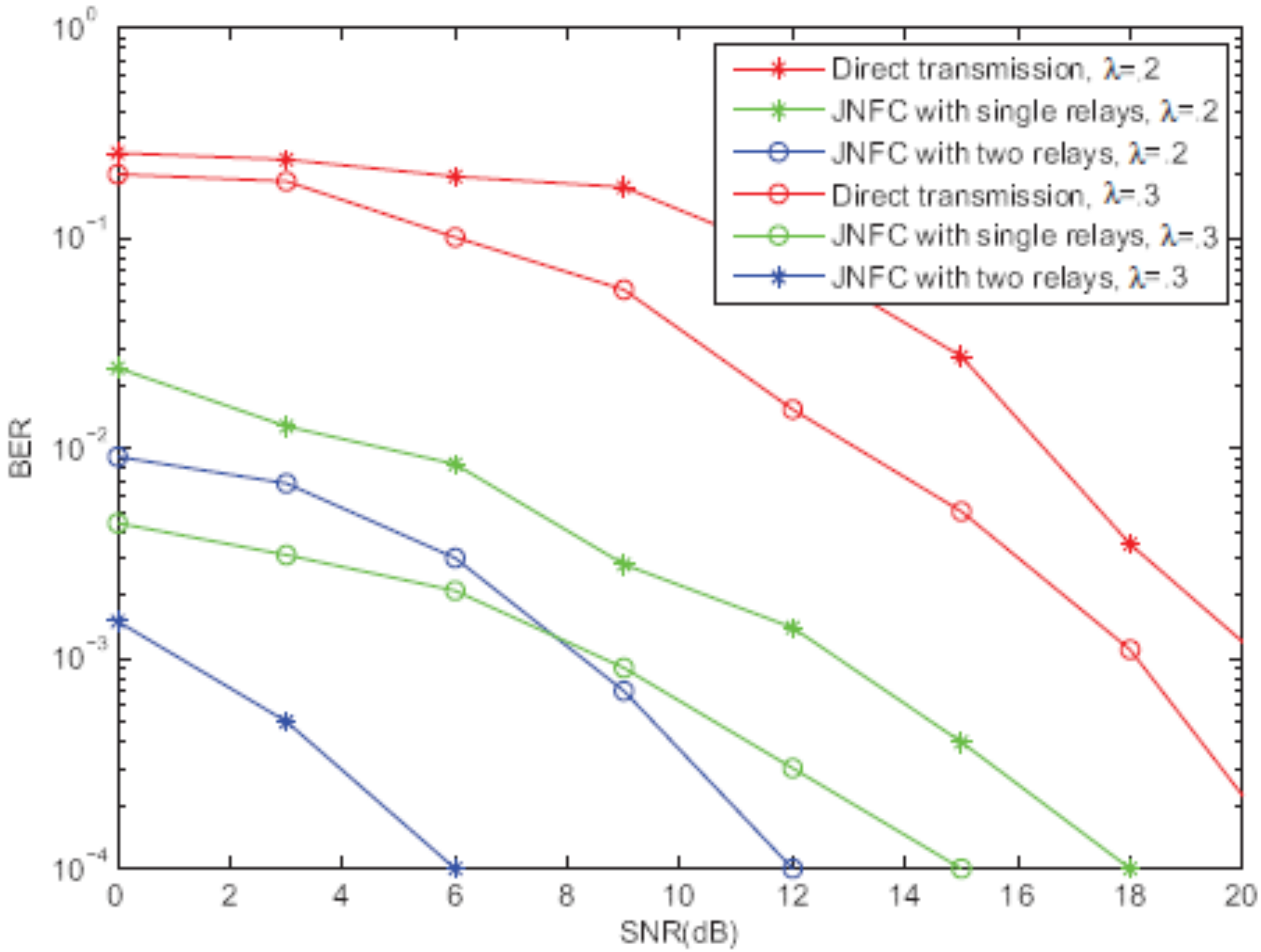
- The length of each packet generated by both source is k=1000 bits
- The SNR of each relay-destination link is given by

$$SNR_{r_i d} = SNR_{sd} + 10dB,$$

- where SNR_{sd} is the SNR of source-destination link.
- The decoding failure probability at the decoder, δ is considered as .5.

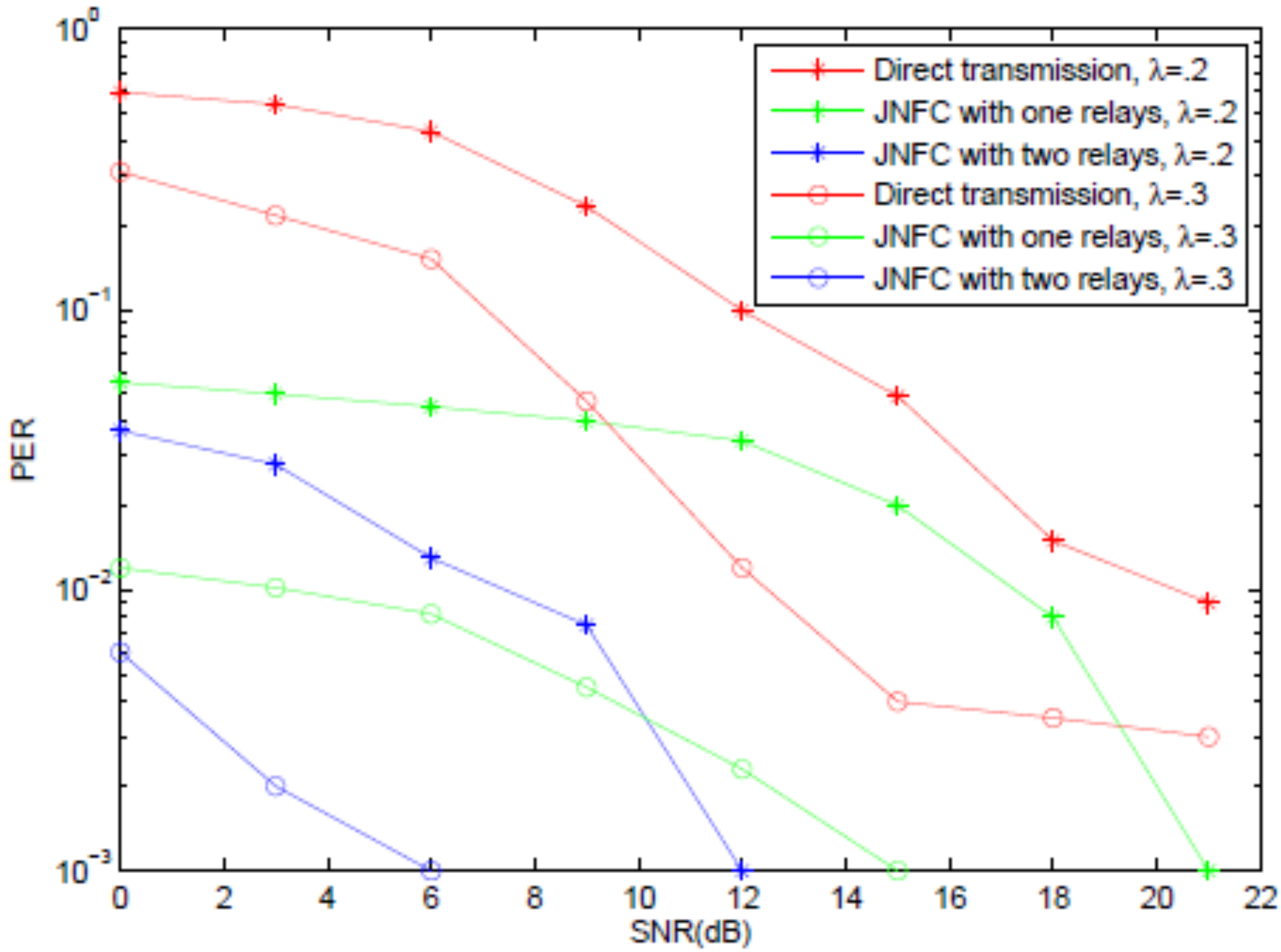
Simulation results

Bit Error rate vs SNR



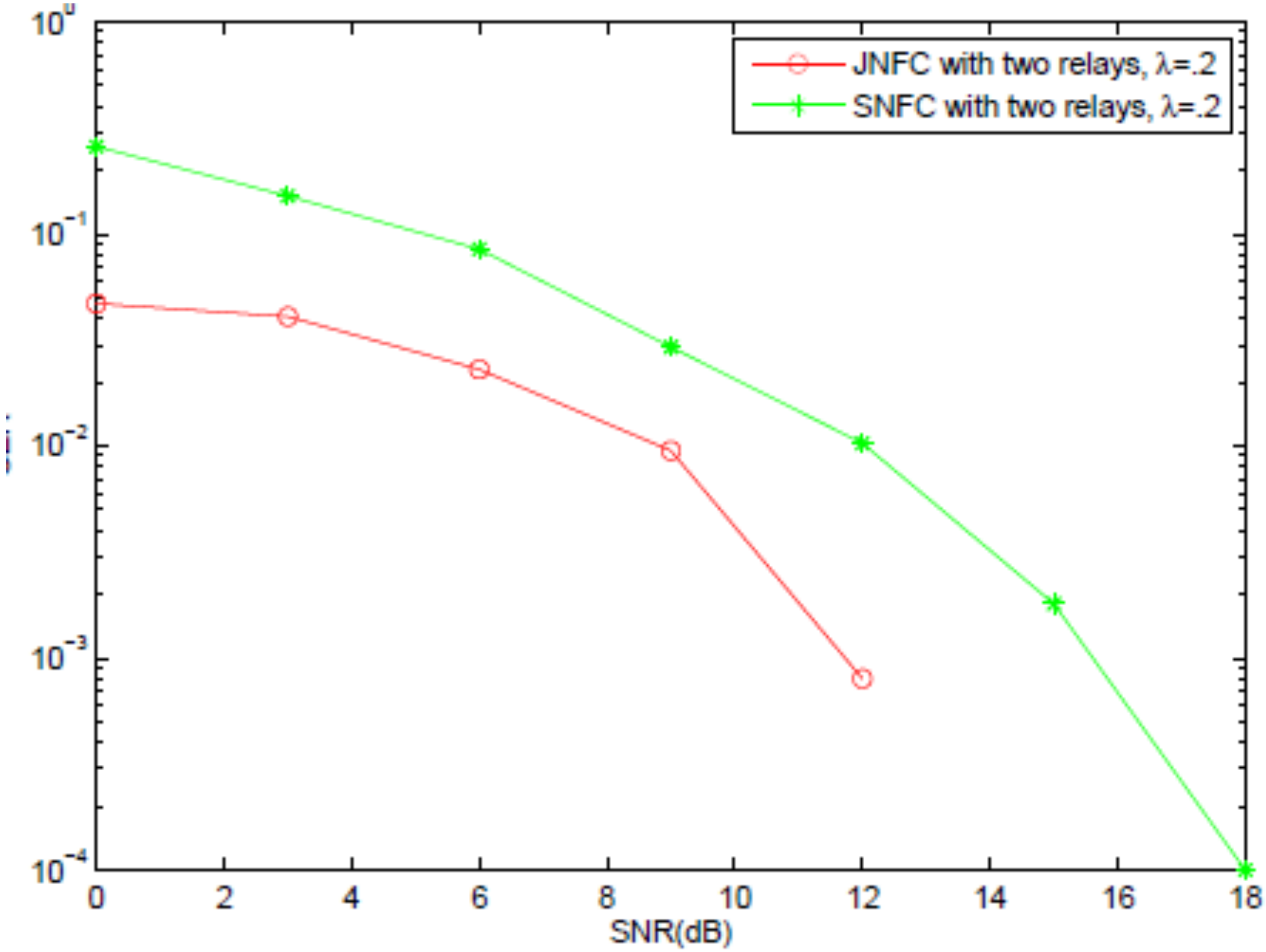
Simulation results

Packet error rate vs SNR



Simulation results

Generation Error(GER): At least one of the two packets can not be recovered at the destination correctly.



Conclusion

- A scheme of joint network fountain coding for reliable communication in wireless networks is proposed.
- The proposed JNFC seamless combines fountain and network coding techniques and thus makes use of the redundancy efficiently.
- Simulations results show that the proposed JNFC outperforms the direct transmission and SNFC in terms of BER, PER and GER performance regardless of the design parameters of LT code..

References

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