Coding Perspective to the Wireless Multiple Access Relay Networks

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Abstract

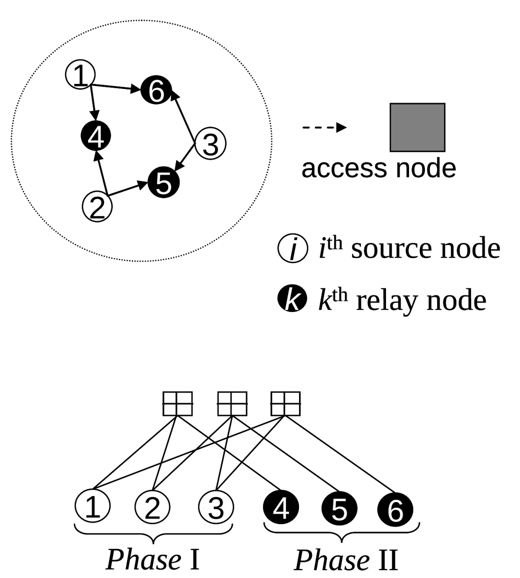
Wireless multiple access networks are the basis for current and future wireless communication networks. The performance of multiple access networks could be very limited due to the noisy and fading characteristics of wireless channels. Techniques that efficiently use the scarce resources such as spectrum and power are demanded.

In this work, we study the wireless multiple access relay networks in which source nodes cooperate with relay nodes. Relay nodes are configured to transmit the *parity check* of their incoming messages. Thus, a linear systematic *network code* is formed across the spatial domain. We study the performance of this network code in several ways.

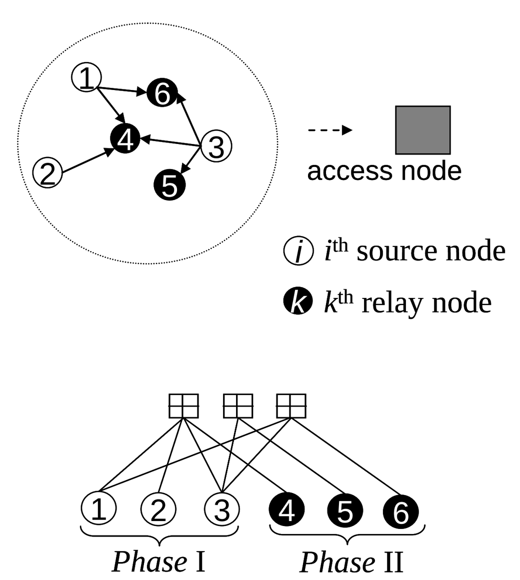
- **First**, we provide the asymptotic performance of the network codes under sum-product and majority-rule based iterative decoding algorithms.
- **Second**, we obtain *distance spectrum* of the network code. The distance spectrum analysis can help us understand the performance of network codes under maximum likelihood decoder.
- **Third**, we consider the more advanced scenario that the source nodes send their information over time-domain coding using low-density parity-check code. The resulting issue for the diversity benefits of coding in time-domain versus coding in spatial-domain is discussed.
- **In addition**, relay nodes may be deployed in an open area and hence vulnerable to malicious attacks. By utilizing the *built-in* parity check functions of network codes, we show detection of attacks can be achieved.

The network codes not only provide an enhanced error-performance for the WMAR networks, but also provide a way to verify the fidelity of the messages from relay nodes.

Examples of network topologies and corresponding network codes

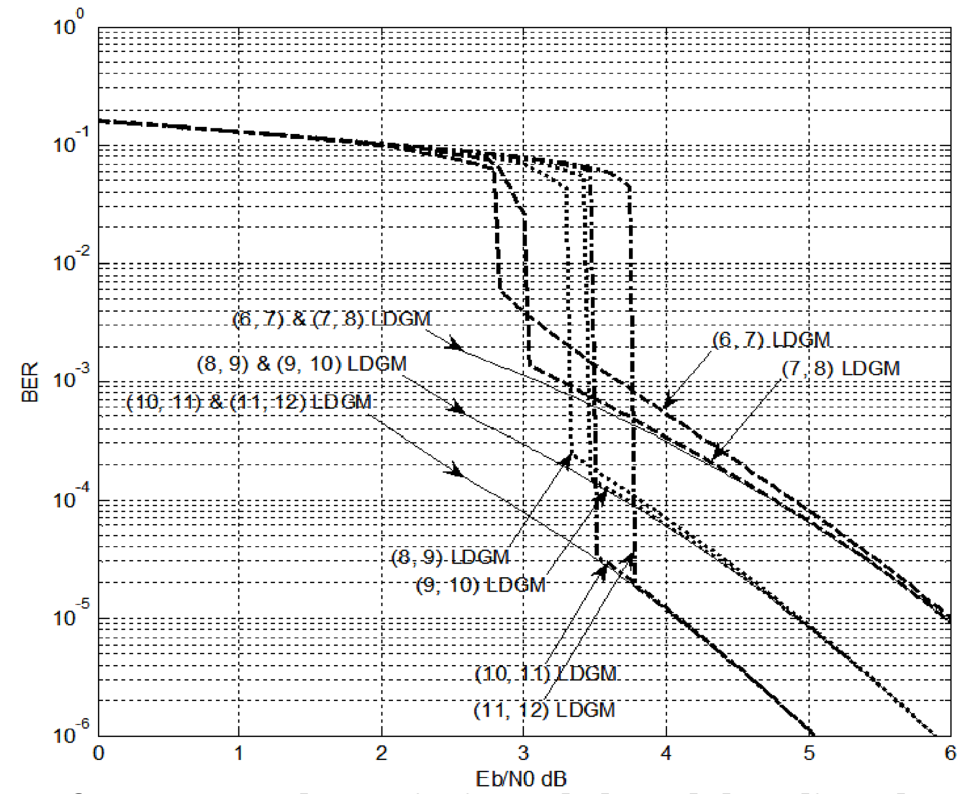


Regular LDGM codes



Irregular LDGM codes

Asymptotic performance of regular LDGM codes



Performance under majority-rule based decoding algorithm [2]

(a) dashed curves: obtained from the recusion expression with dynamic optimized weight *m*

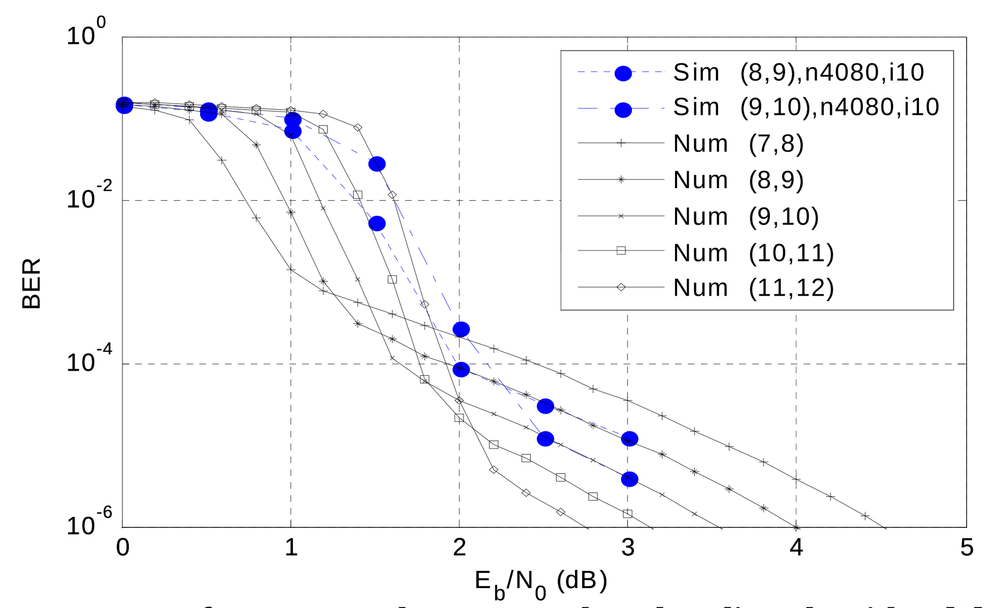
$$P_{l+1} = P_0\left(1 - f(m, P_l)\right) + (1 - P_0)\left(g(m, P_l)\right)$$

$$f(m,x) = \sum_{l=m}^{d_v-1}\binom{d_v-1}{l}\left(\frac{1+(1-2P_0)(1-2x)^{d_c-2}}{2}\right)^{l} \times \left(\frac{1-(1-2P_0)(1-2x)^{d_c-2}}{2}\right)^{d_v-1-l}$$

$$g(m,x) = \sum_{l=m}^{d_v-1}\binom{d_v-1}{l}\left(\frac{1-(1-2P_0)(1-2x)^{d_c-2}}{2}\right)^{l} \times \left(\frac{1+(1-2P_0)(1-2x)^{d_c-2}}{2}\right)^{d_v-1-l}.$$

(b) solid curves: obtained by the non-recursive lower-bound expression

$$P_{EF} = P_0\left(1 - \sum_{l=m^*}^{d_v}\binom{d_v}{l}(1-P_0)^l (P_0)^{d_v-l}\right) + (1-P_0)\left(\sum_{l=m^*}^{d_v}\binom{d_v}{l}(P_0)^l (1-P_0)^{d_v-l}\right)$$



Performance under sum-product decoding algorithm [3]

The Sim curves are obtained from Monte Carlo computer simulation with 10 iterations. The Num curves are obtained from the MGADE method (which is a simple density evolution method).

Reference

[1] X. Bao, and J. Li, "Matching code-on-graph with network-on-graph: adaptive network coding for wireless relamy networks," *Proc. Allerton Conf. on Commun., Control and Computing*, Urbana Champaign, IL, Sept. 2005.

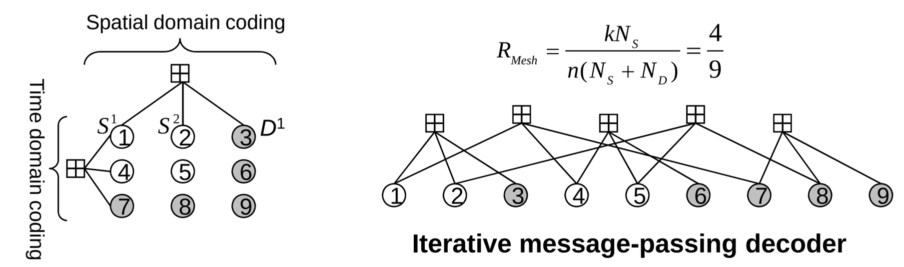
[2] C.-C. Chang, and Heung-No Lee, "Performance analysis of regular low-density generator matrix codes under majority-rule based iterative decoding algorithm," in *Proc. of IEEE Global Comm. Conf.* (GLOBECOM), Washington DC. USA, Nov. 2007.

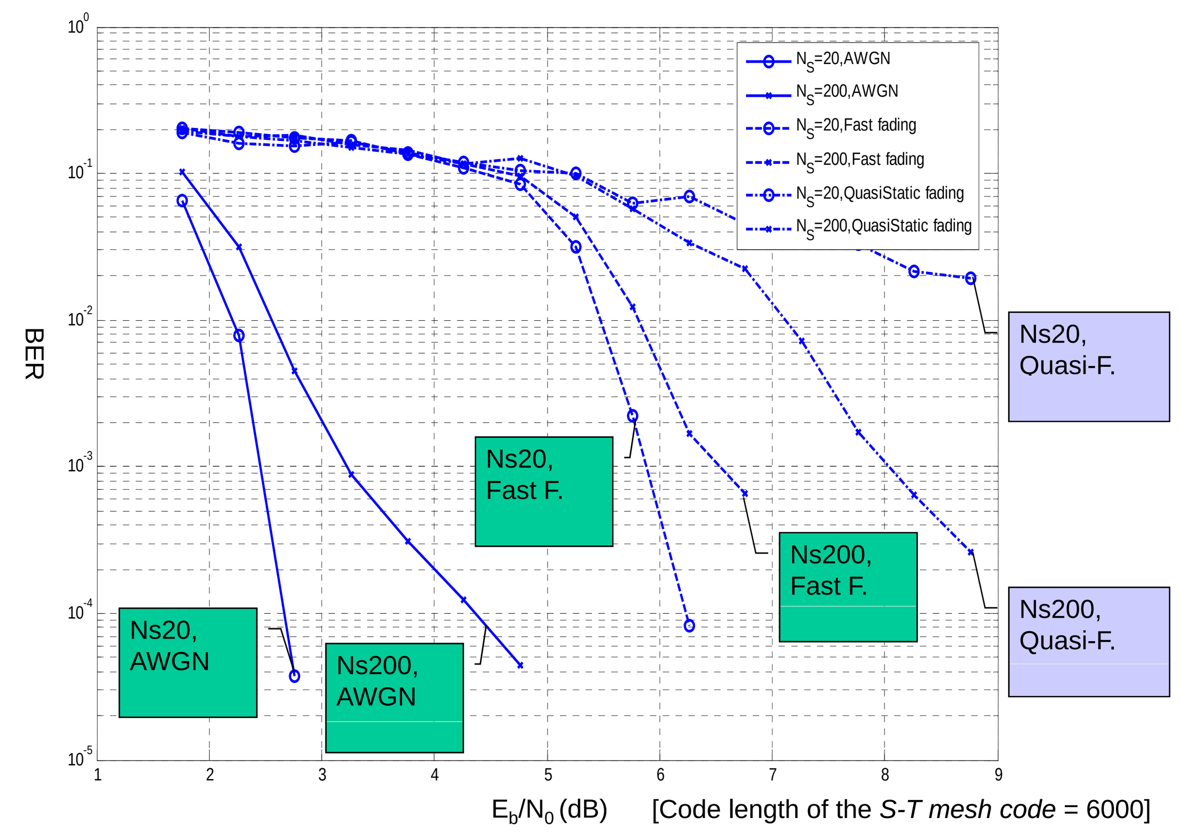
[3] C.-C. Chang, and Heung-No Lee, "simple density evolution for low-density generator- matrix codes," submitted to *Research Letters in Communications*, in reviewing since Feb. 2008.

[4] C.-C. Chang, and Heung-No Lee, "Space-time mesh codes for the multiple-access relay network: space v.s. time diversity benefits," in *Proc. Inform. Theory and Applications Workshop*, San Diego, USA, Jan. 2007.

[5] C.-C. Chang, and Heung-No Lee, "Attack Resilient Network Channel Code for the Wireless Multiple Access Relay Network," in *Proc. of Military Comm. Conf.* (MILCOM), Orlando, Florida USA, Oct. 2007.

The space-time mesh code

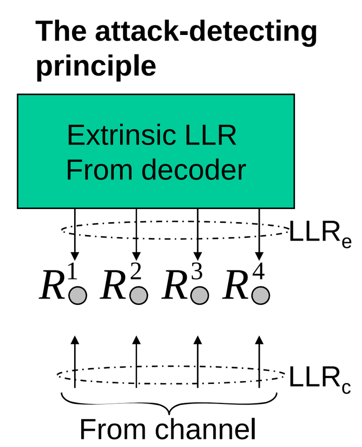




Performance for different network settings over fast fading, quasi-static fading, and AWGN channels [4]

Attack-resilient mechanism

- Attack model
  - Relay nodes are deployed in open area
    - vulnerable to physical tempering
  - The binary message out of the attacked relay nodes can be flipped by the adversary



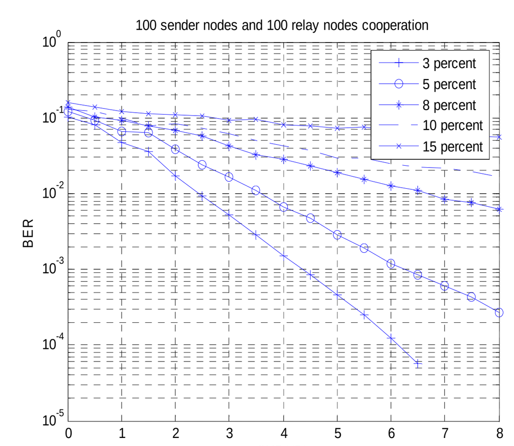
Attack-detection algorithm:

***I.* For j^{th} spatial-domain code:**

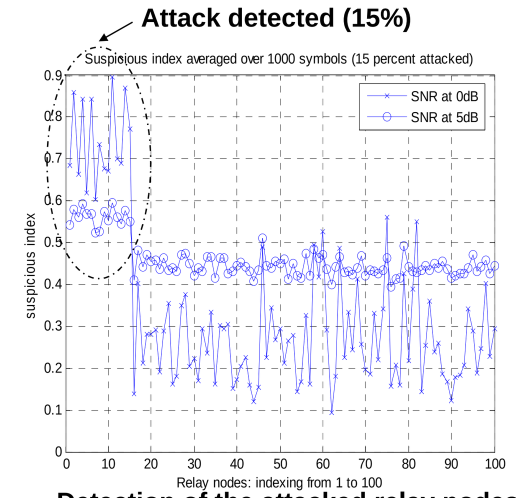
1. Make a hard-decision on the LLRc of i^{th} relay nodes for all i, i.e.,
$$LLRc_j^H(i) = \begin{cases} 0, & \text{if } LLRc_j(i) < 0 \\ 1, & \text{if } LLRc_j(i) > 0 \end{cases}, \forall i$$
2. Make a hard-decision on the *LLRe* of i^{th} relay nodes for all i, i.e.,
$$LLRe_j^H(i) = \begin{cases} 0, & \text{if } LLRe_j(i) < 0 \\ 1, & \text{if } LLRe_j(i) > 0 \end{cases}, \forall i$$
3. Find the (*instant*) *suspicion index, ISI,* for all relay nodes i by
$$ISI_j(i) = LLRc_j^H(i) \oplus LLRe_j^H(i), \forall i$$

***II.* Obtain the *averaged suspicion index, ASI,* by averaging over the *suspicion index, ISI*:**

$$ASI(i) = \frac{\sum_{j=1}^{N} ISI_j(i)}{N}, \forall i$$



BER performance of the network under different density of attack



Detection of the attacked relay nodes by using the attack-detection algorithm [5]