Integrity of Relay Misbehavior Detection in Wireless Network Coding

Sang Wu Kim

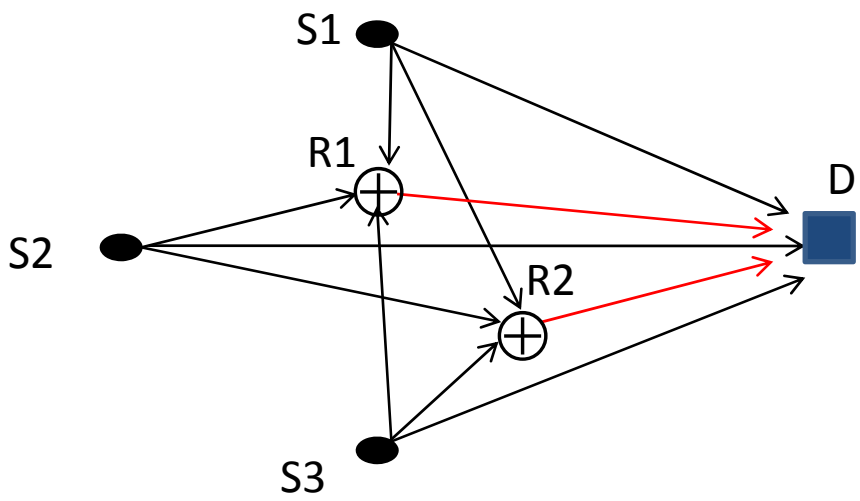
Dept of ECE

Iowa State University

Outline

- MAP approach to detect misbehaving relay that injects false data into the network encoder in multiple access relay networks
- MAP detection with the aid of tracing bits to enhance integrity of detection outcome
- Integrity of detection outcome as a function of information transmission rate and SNR

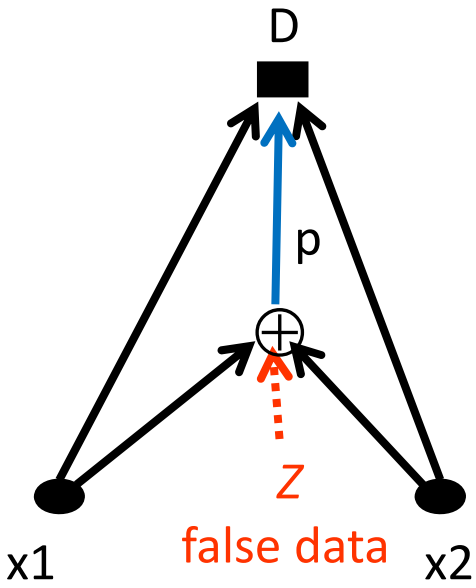
Multiple Access Relay Network



- Multiple sources, multiple relays, single destination
- Network coding: combine source packets at each relay
  - Increase throughput, robustness against packet failures

Relay Misbehavior

- Relay may receive x1, x2 incorrectly (unintentional error)
- Relay may insert false data z to prevent D from correct decoding (intentional error)

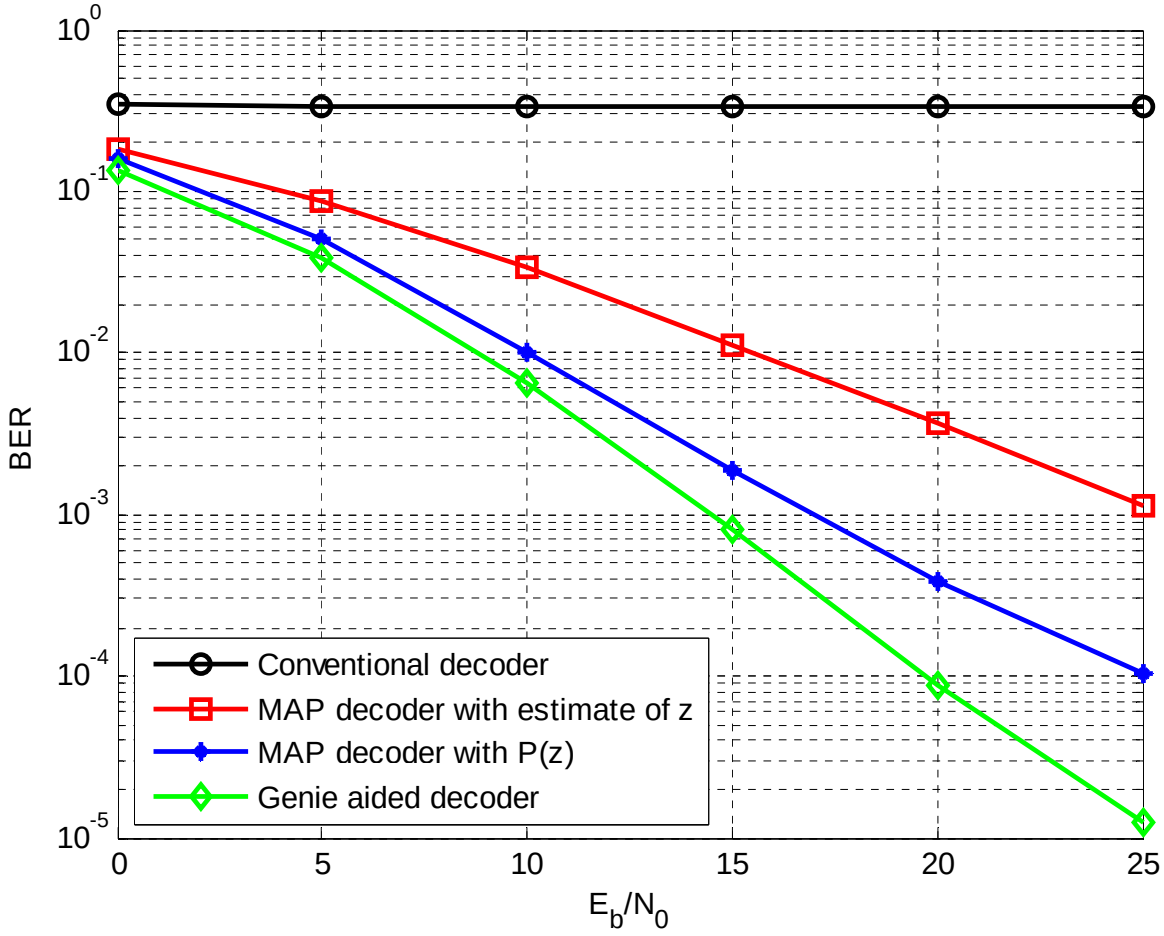


$$p = x_1 \oplus x_2 \oplus z$$

z : injected false data ($\neq 0$)

$$@\ D: \quad \hat{x}_1 = p \oplus x_2$$
$$= x_1 \oplus z$$
$$\neq x_1$$

Bit Error Probability



$P(z=1)=0.9$

Two sources, one relay

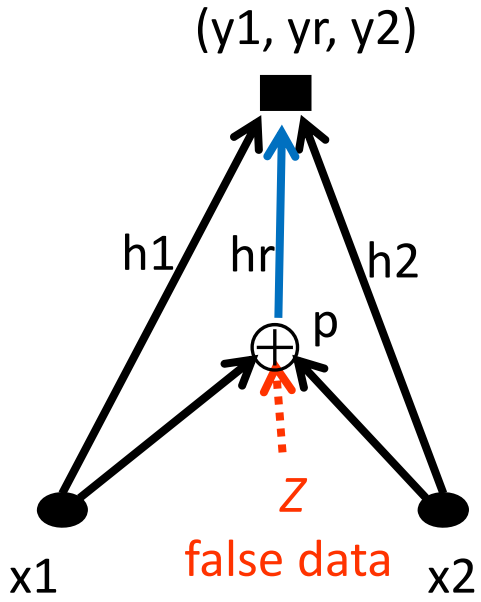
Rayleigh fading

Communication becomes completely unreliable regardless of SNR.

Detection of Relay Misbehavior - Prior Arts

- Significant efforts at the higher layer to detect misbehaving relay
  - Digital signatures, hash functions
- Overhead (computation, bandwidth) could be prohibitive for several applications in wireless networks
- Assumes the physical layer provides an error-free link
  - May not hold in practice due to various channel impairments

MAP Detection -- Proposed



MAP detection principle:

$$\mathrm{L}(z \mid \mathbf{h}, \mathbf{y}) = \log\left(\frac{P(z=0 \mid \mathbf{h}, \mathbf{y})}{P(z=1 \mid \mathbf{h}, \mathbf{y})}\right)$$

$$> 0\,?$$

If yes, $\hat{z} = 0$; otherwise, $\hat{z} = 1$.

$$\mathrm{p} = \mathrm{x1} \oplus \mathrm{x2} \oplus \mathrm{z}$$

$$\mathrm{yi} = \mathrm{hi} \times \mathrm{xi} + \mathrm{ni},\ \mathrm{i} = 1,2,\mathrm{r} : \mathrm{Rayleighfading} + \mathrm{AWGN}$$

$$\mathbf{h} = (\mathrm{h1},\mathrm{h2},\mathrm{hr}),\ \mathbf{y} = (\mathrm{y1},\mathrm{y2},\mathrm{yr})$$

MAP Detection (cont'd)

- Optimal detection
  - Minimizes the probability of incorrect detection (false alarm, misdetection)
- No transmission overhead
  - Increase throughput

MAP Detection

$$P(\hat{z} \neq z \mid \mathbf{h}, \mathbf{y}) = \frac{1}{1 + \exp(|\, L(z \mid \mathbf{h}, \mathbf{y}) \,|)}$$

where

$$|\, L(z \mid \mathbf{h}, \mathbf{y}) \,| = \min\{|\, L_1 \,|, \ \ldots, |\, L_K \,|, |\, L_r \,|\}$$

$$L_i = \mathrm{LLR}(x_i \mid \mathbf{h}, \mathbf{y})$$

- Probability of incorrect detection is determined by the least reliable link.

Probability of False Alarm and Misdetection

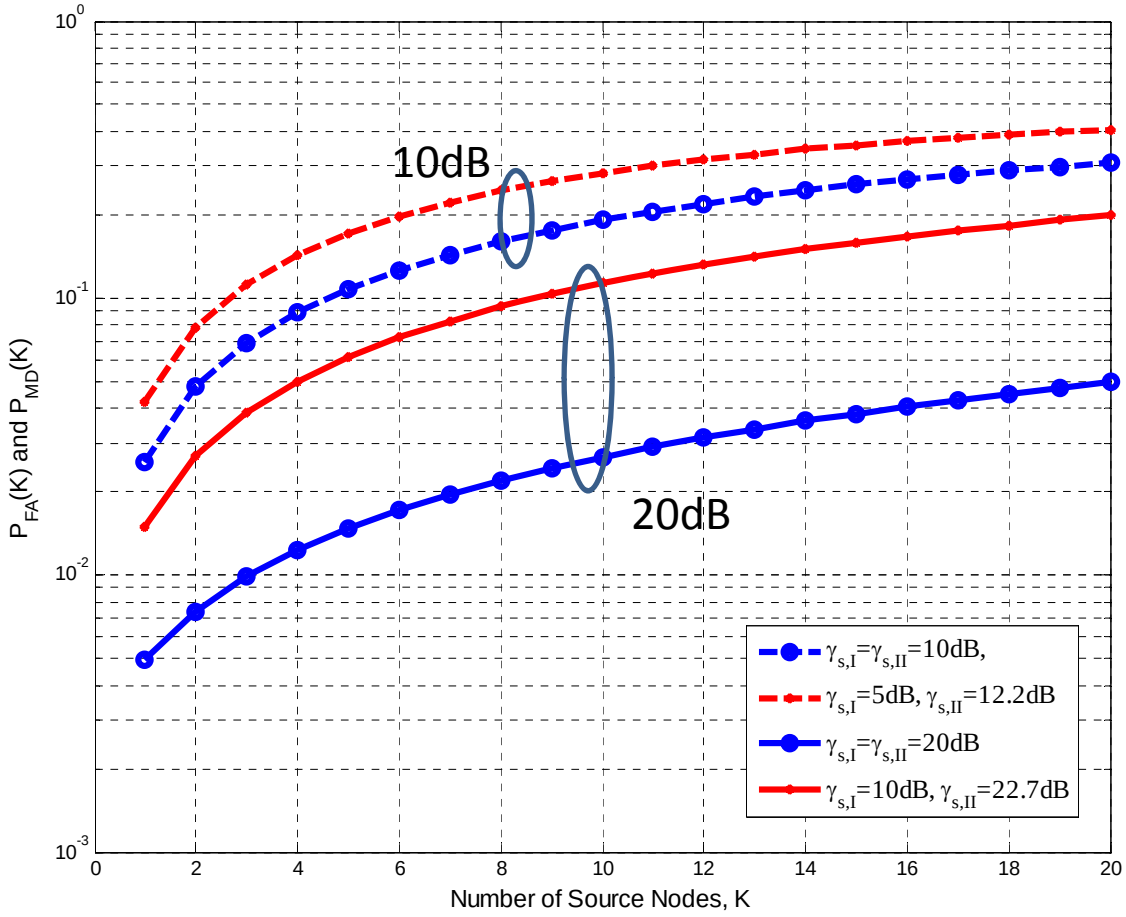
- False Alarm : $\hat{z} = 1$ given $z = 0$
- Misdetection : $\hat{z} = 0$ given $z = 1$

$$
\begin{aligned}
P_{FA}(K) &= P(L(z|\mathbf{h},\mathbf{y}) < 0 \mid z = 0) \\
&= \frac{1}{2}\left[1 - \left(\frac{\gamma_r}{1+\gamma_r}\right)^{\frac{1}{2}} \prod_{i=1}^{K} \left(\frac{\gamma_{s,i}}{1+\gamma_{s,i}}\right)^{\frac{1}{2}}\right] \\
&= P_{MD}(K)
\end{aligned}
$$

where γ_r= received SNR for coded bit

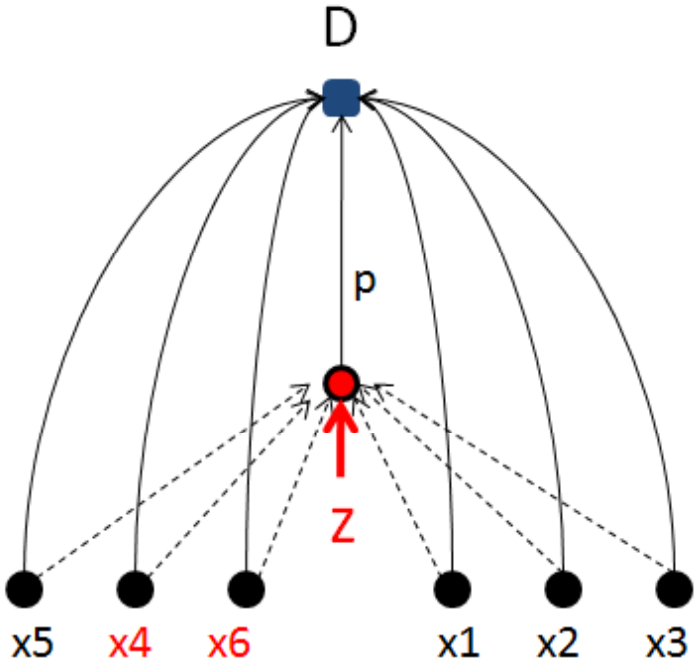
$\gamma_{s,i}$= received SNR for the i-th message bit

Probability of False Alarm and Misdetection



- More difficult to detect the misbehaving relays as more sources are combined at a relay and the channel is more noisy.
- Sensitive to the disparity of received SNRs of different source nodes.

MAP Detection with Tracing Bits

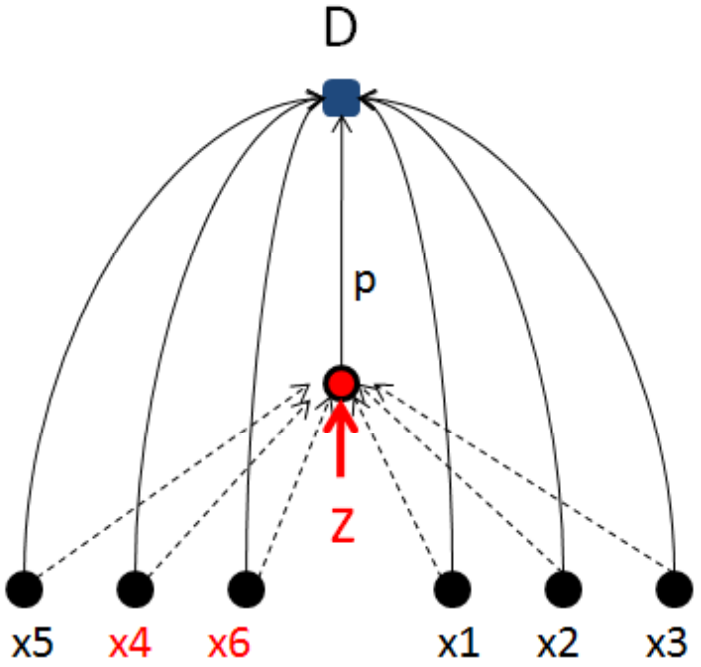


x4,x6 are tracing bits (known to D *a priori*).

T=2

- Tracing bits are reference bits that are known to the destination.

MAP Detection with Tracing Bits



x4,x6 are tracing bits (known to D *a priori*).

T=2

$$P(\hat{z} \neq z \,|\, \mathbf{h}, \mathbf{y}) = \frac{1}{1 + \exp(|\, L(z \,|\, \mathbf{h}, \mathbf{y}) \,|)}$$

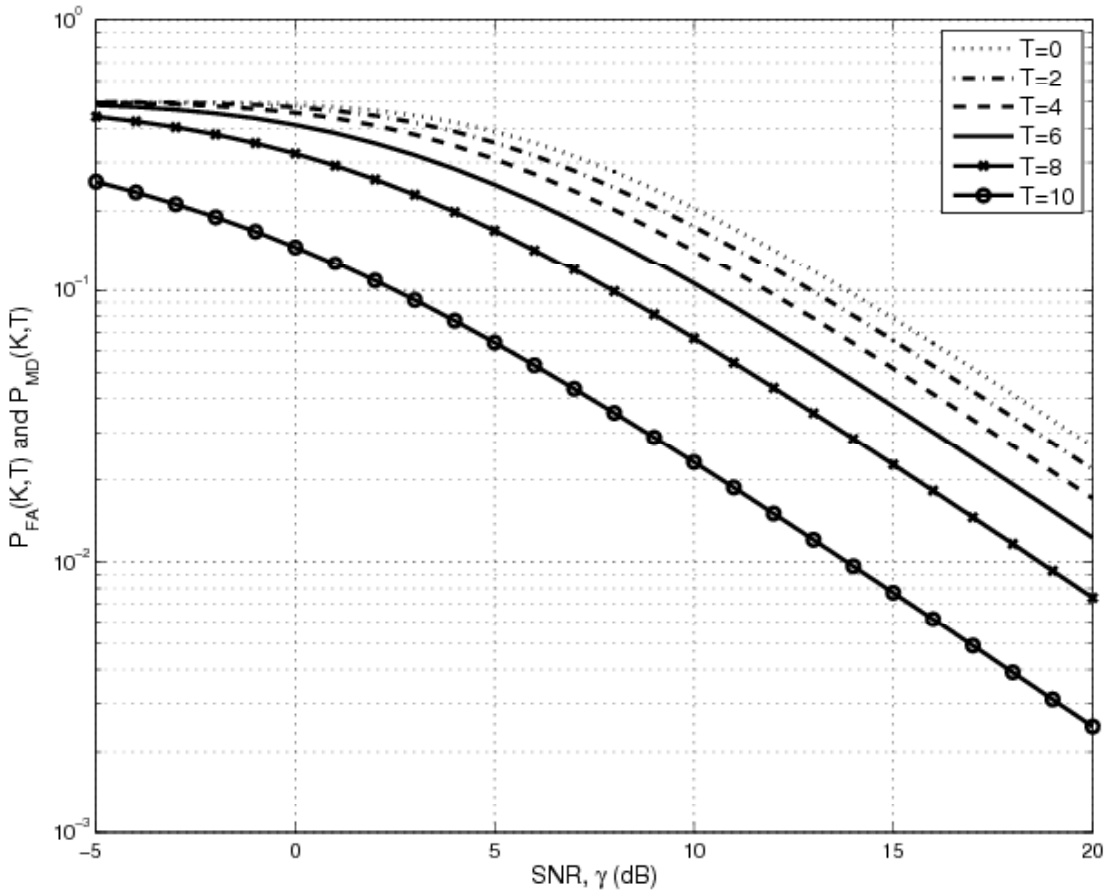
where

$$|\, L(z \,|\, \mathbf{h}, \mathbf{y}) \,| = \min\{|\, L_1 \,|, \ \ldots, |\, L_{K\text{-}T} \,|, |\, L_r \,|\}$$

$$L_i = \mathrm{LLR}(x_i \,|\, \mathbf{h}, \mathbf{y})$$

- Tracing bits are reference bits that are known to the destination.

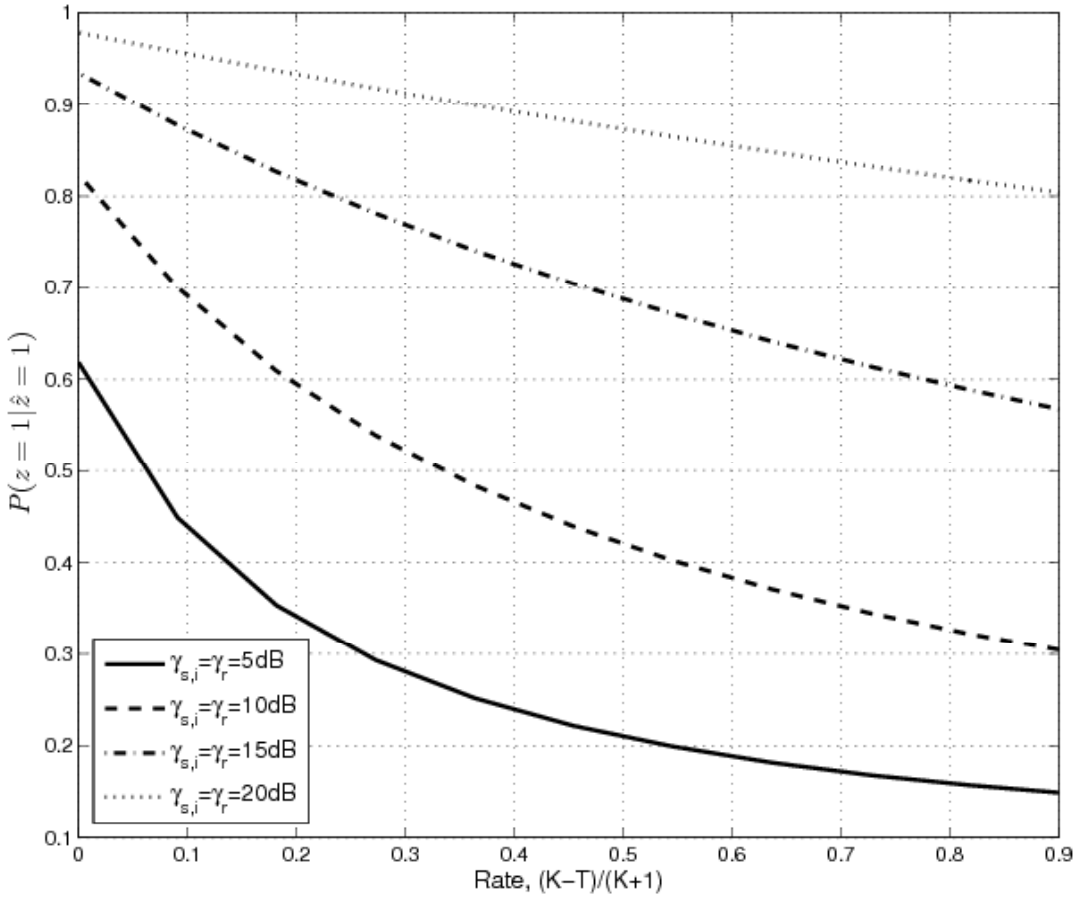
MAP with Tracing Bits



K=10

- $P_{FA}(K)$, $P_{MD}(K)$ decrease with increasing number of tracing bits T.

Integrity-Rate Tradeoff



P(z=1)=0.1
K=10

- The integrity of detection outcome decreases as the amount of transmitted information increases.

Conclusion

- Proposed the MAP approach in detecting the misbehaving relay that injects false data or adds channel error into the network encoder in noisy multi-access relay networks.
  - Optimal
  - No transmission overhead
- Analyzed probability of false alarm and miss detection
- Proposed MAP detection with the aid of tracing bits
  - Improvement of integrity as a function of overhead amount