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Embracing Wireless Interference: Analog Network Coding

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Please disregard the following:

❑ Strange statements:

- *“Traditionally, interference is considered harmful.....”*
- **Multiple user access channel ?**

❑ Curious assertions:

“Prior work, however, focuses on capacity bounds and does not provide an algorithm for delivering the resulting throughput benefits.”

[1] B. Rimoldi and R. Urbanke, “A rate splitting approach to the Gaussian multiple-access channel,” *IEEE Trans. on Inform. Theory*, 1996 ?

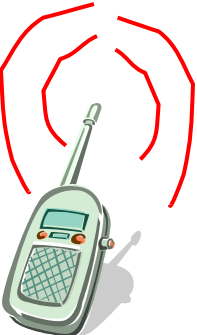
[2] Aline Roumy, David Declercq, and Eric Fabre, “Low Complexity Code Design for the 2-user Gaussian Multiple Access Channel”, ISIT 2004 ?

❑ Published at SIGCOMM

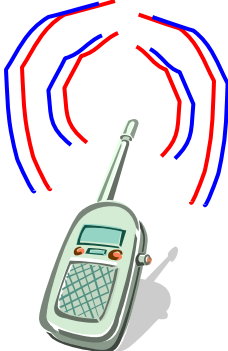
- Best venue for physical layer papers?

Motivation I

Without network coding



A



Relay



B

Time step: 2

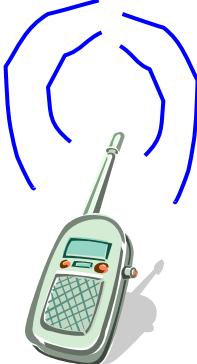
With “packet layer” network coding



A



Relay



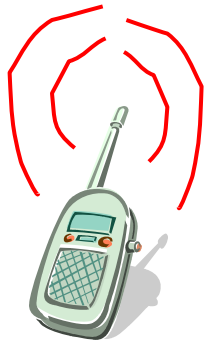
B

 XOR A, B

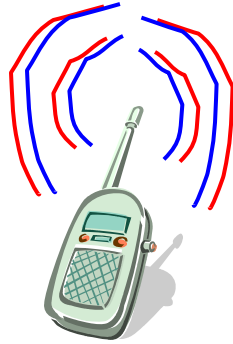
Time step: 3

Motivation II

“Physical layer” network coding



A



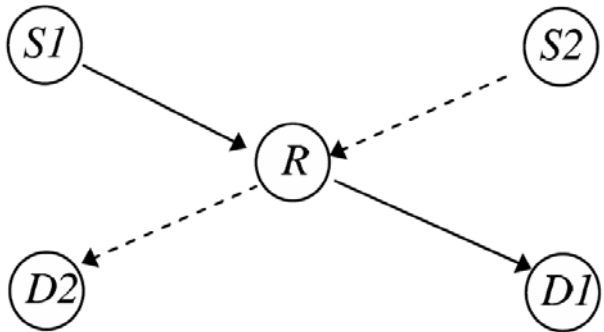
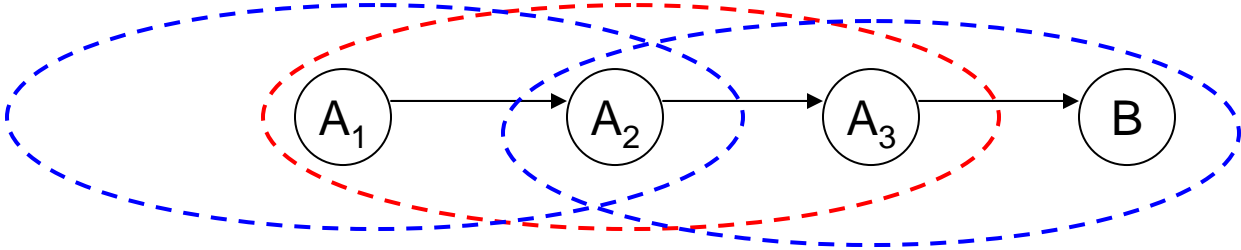
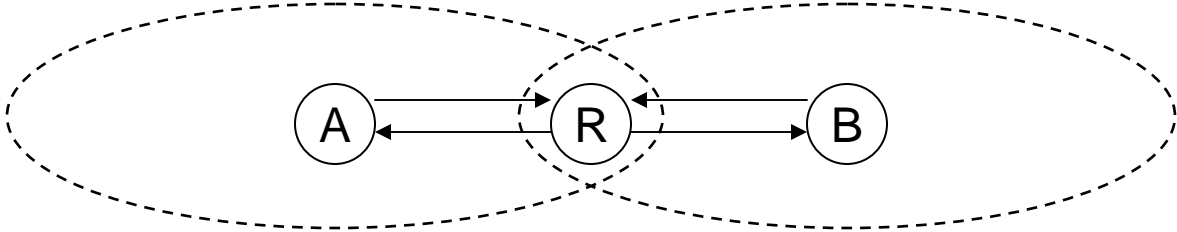
Relay



B

Time step: 2

Network scenarios



Unclear if claims carry over other scenarios

Constraints

- ❑ Minimum-shift keying modulation
 - Would also work with PSK?
- ❑ Topology
 - Restricted to certain 1-D, 2-D networks
- ❑ Received signal powers (R_A and R_B)
 - Experiments say

$$\frac{R_B}{2} \leq R_A \leq R_B \quad (\text{SIR} \in [0\text{dB}, -3\text{dB}])$$

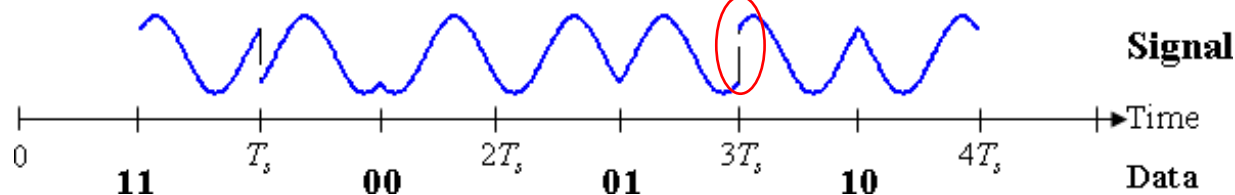
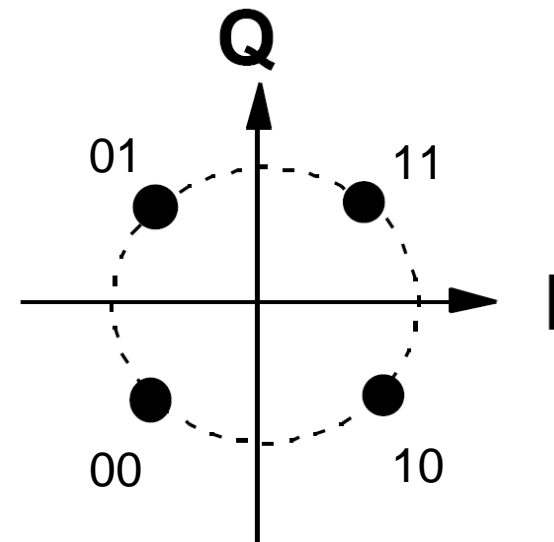
- Hard to believe it works with $R_A \ll R_B$
- ❑ Up to two simultaneous transmissions
- ❑ Relay can transmit with maximum power $\alpha(R_A + R_B)$
- ❑ Flat-fading

Nice properties

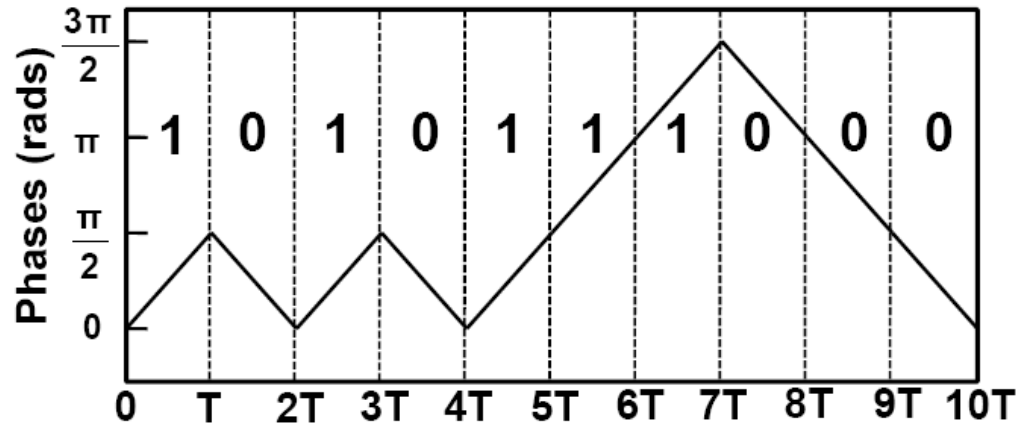
- ❑ Asynchronous transmissions
- ❑ No channel allocation protocol (RTS/CTS)
 - From network constraint
- ❑ Simple implementation (?)
- ❑

MSK (Minimum-phase keying)

- Encode bits changing carrier phase
- $\pi/2$ phase shifts
- Fixed amplitude
- Similar to OQPSK
 - But no abrupt variations in amplitude



Paper's MSK



□ One bit / phase shift

○ $\pi/2$ = zero

○ $-\pi/2$ = one

□ Computed by finding the angle of r

$$r = \frac{h A_s e^{i(\theta_s[n+1]+\gamma)}}{h A_s e^{i(\theta_s[n]+\gamma)}} = e^{i(\theta_s[n+1]-\theta_s[n])}$$

Relay

Very simple

- Receives signal
- Transmits same signal
 - ⇒ Amplified by α
 - ✧ Reasonable to assume $\alpha = (P_A + P_B) / (R_A + R_B)$?
 - ⇒ Does not model amplified background noise
 - ✧ Assumes high SNR

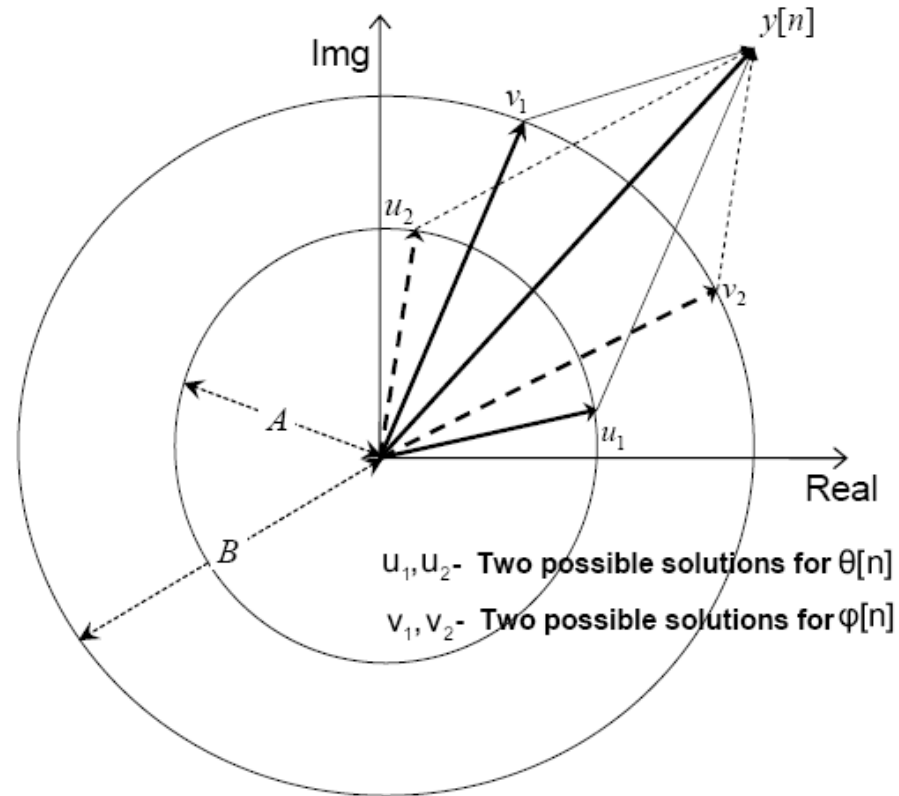
Receiver

- Upon receiving signal

$$y[n] = Ae^{i\theta[n]} + Be^{i\phi[n]}$$

- Find amplitudes A and B
 - Gives two possible values for $\theta[n]$ and $\phi[n]$

Two possible values for $\theta[n]$ and $\phi[n]$



For each value of n !

Obtaining amplitudes A and B

□ First equation

$$E[|y[n]|^2] = E[A^2 + B^2 + 2AB \cos(\theta[n] - \phi[n])]$$

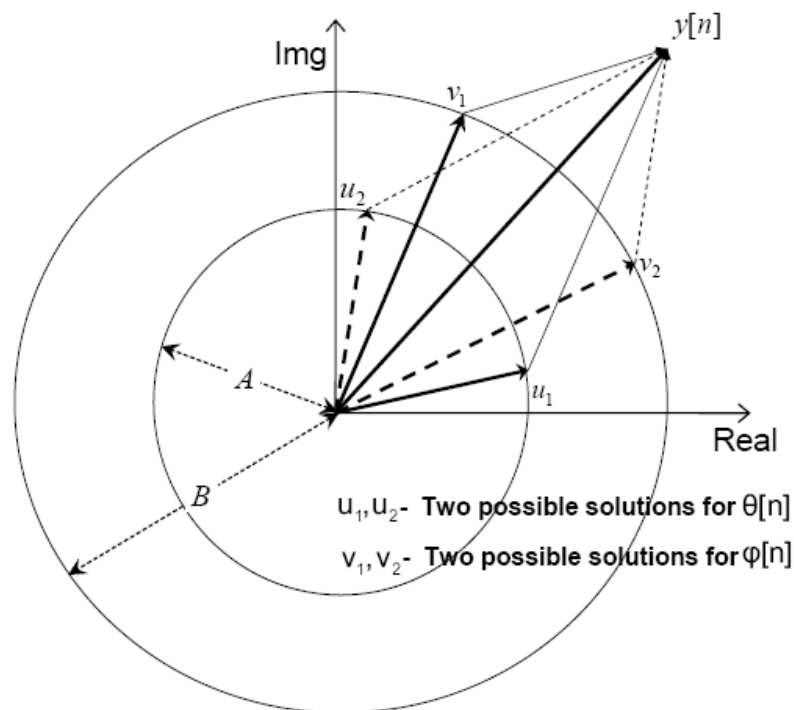
If bits are random $E[\cos(\theta[n] - \phi[n])] \approx 0$

$$E[|y[n]|^2] = \mu = A^2 + B^2$$

□ Second equation

$$\sigma = \frac{2}{N} \sum_{|y[n]|^2 > \mu} |y[n]|^2 \quad \Rightarrow \quad \sigma = A^2 + B^2 + 4AB/\pi$$

Two possible values for $\theta[n]$ and $\phi[n]$



Gives four phase difference pairs

$$\Delta\phi_{xy}[n] = \phi_x[n+1] - \phi_y[n]$$
$$\Delta\theta_{xy}[n] = \theta_x[n+1] - \theta_y[n] \quad \forall x, y \in \{1, 2\}$$

“Physical XOR” part I

- Known $\Delta\theta_s[n]$

- For each n :

$$\min |\Delta\theta_{xy}[n] - \Delta\theta_s[n]|$$

defines xy

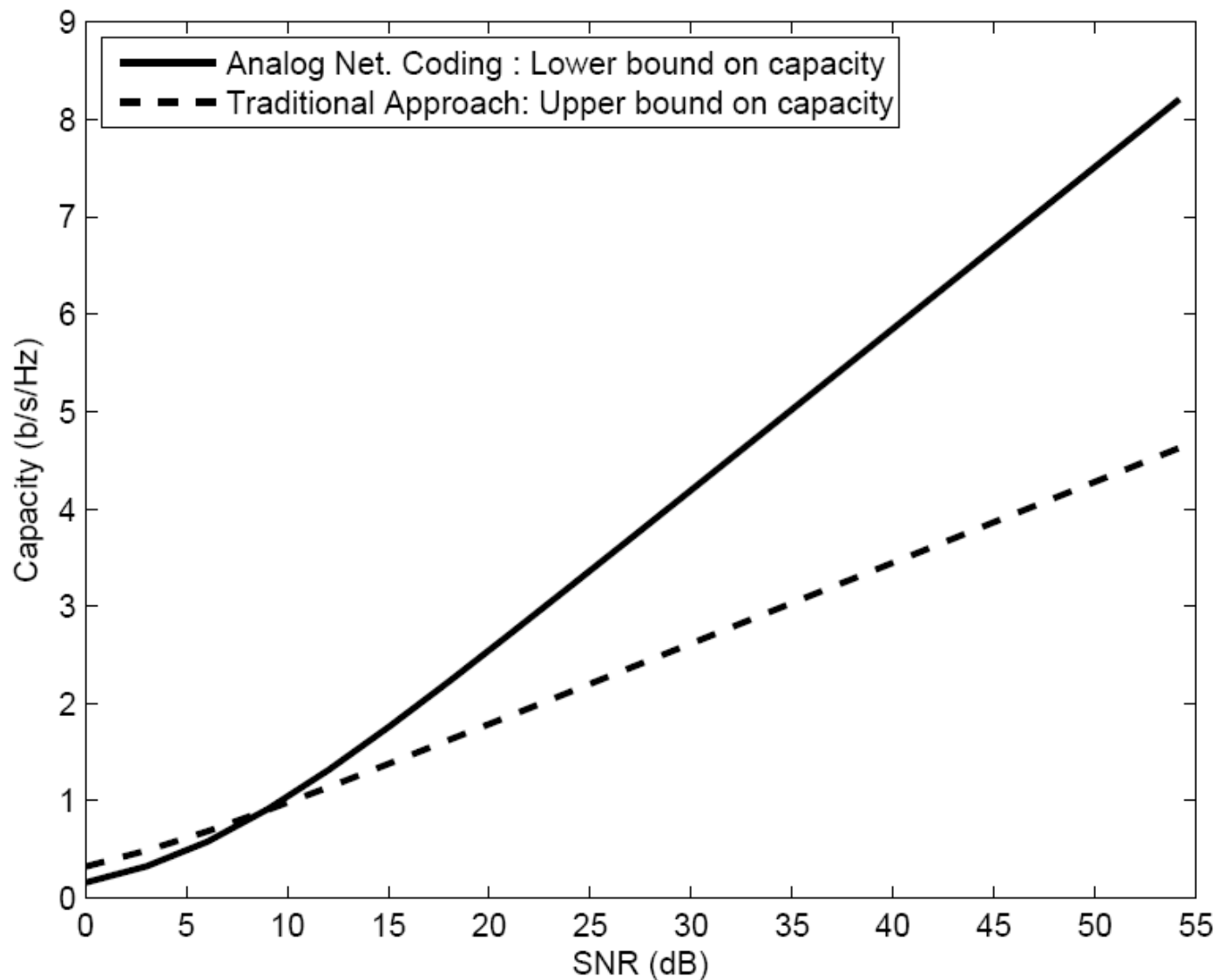
- Knowing xy we can choose $\Delta\phi_{xy}[n]$

“Physical XOR” part II

- Obtaining the message

if $\Delta\phi[n] \geq 0$, the n^{th} bit is “1”, else it is “0”

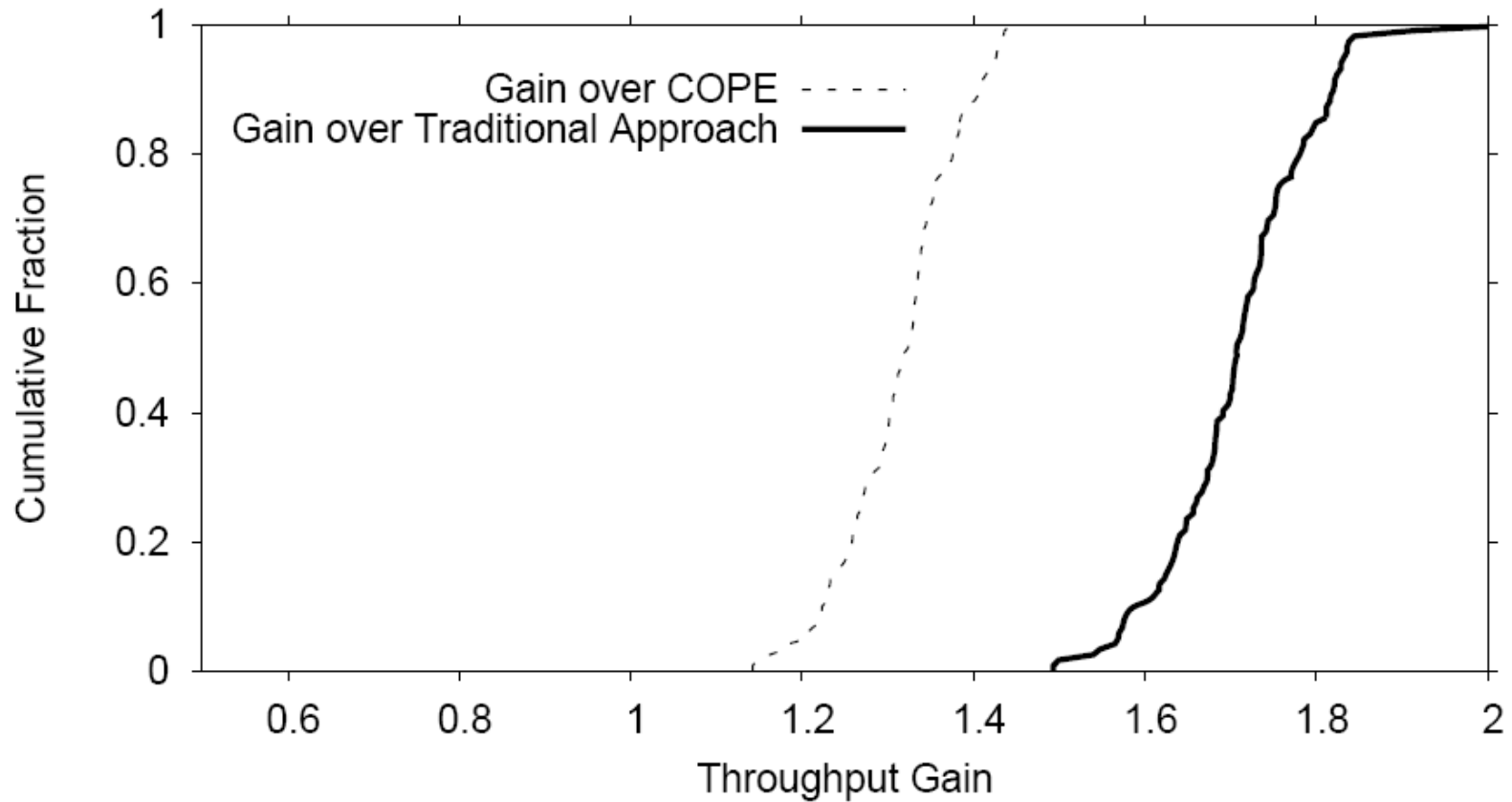
Capacity bounds



Emulation

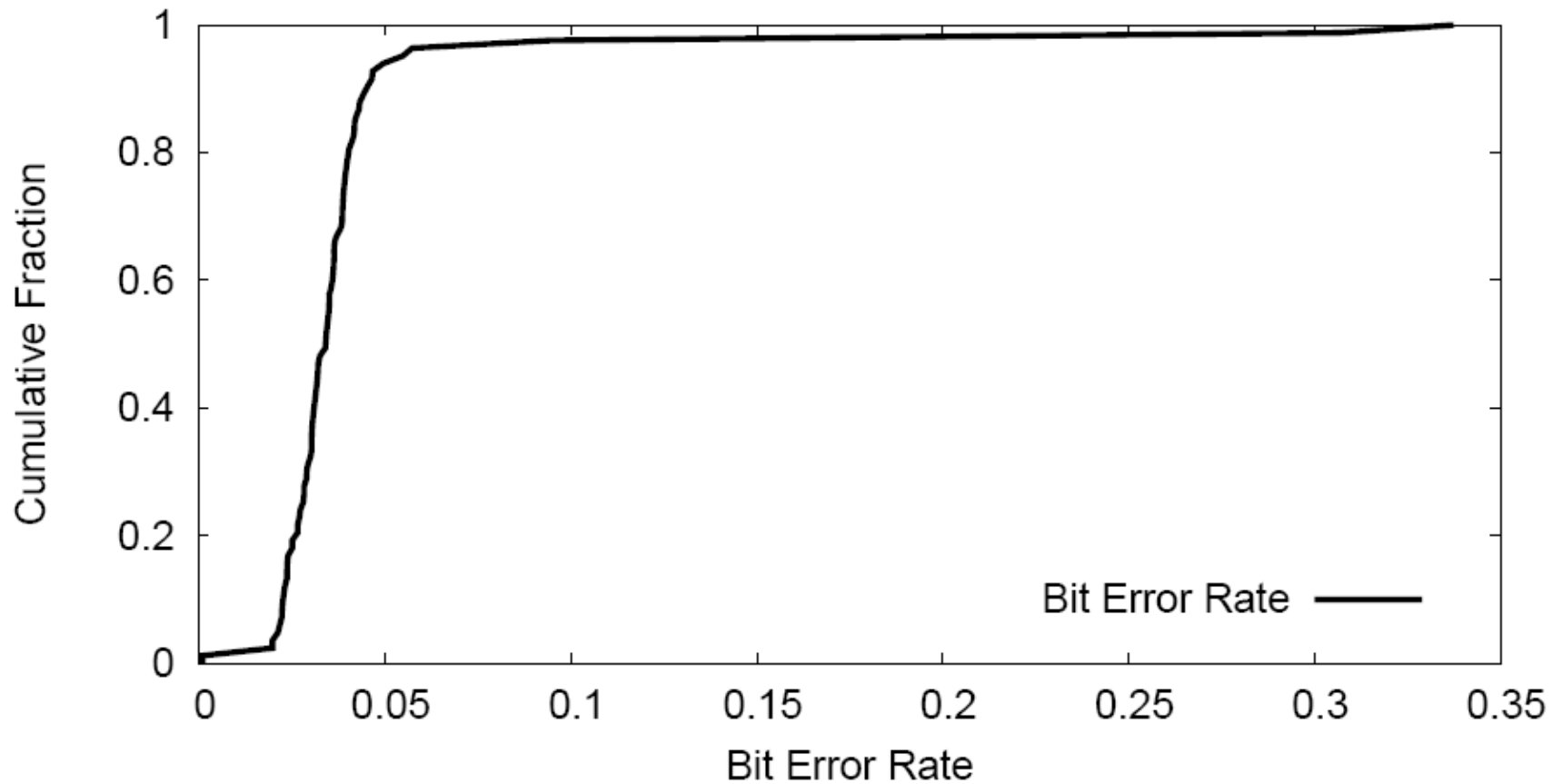
- ❑ Rate = 500Kbps
 - GNURadio is reported to achieve 1-2Mbps
- ❑ Topology 1-D, 1 relay, 2 senders
- ❑ Conclusions
 - Better than pure MSK
 - Needs 8% more FEC
- ❑ Graphs...

Results



(a) CDF of throughputs for Alice-Bob topology

Results II



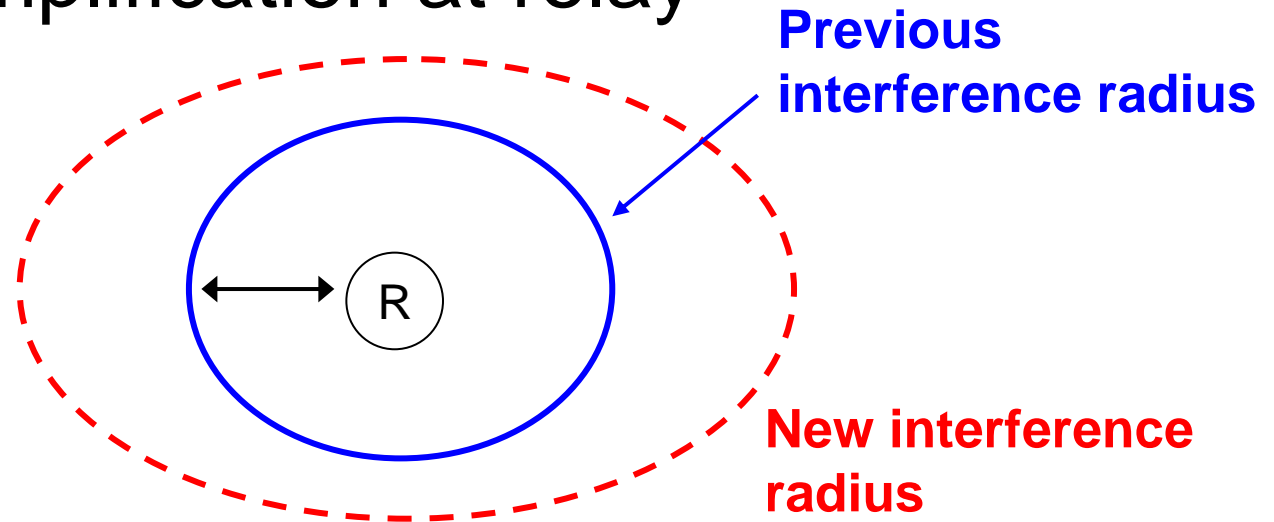
(b) CDF of BERs for Alice-Bob topology

Overview (before discussion)

- ❑ Interesting first step
 - Still a lot to be done
- ❑ Many unanswered questions (discussion..)

Discussion II

- ❑ Topology too naïve
- ❑ Signal amplification at relay

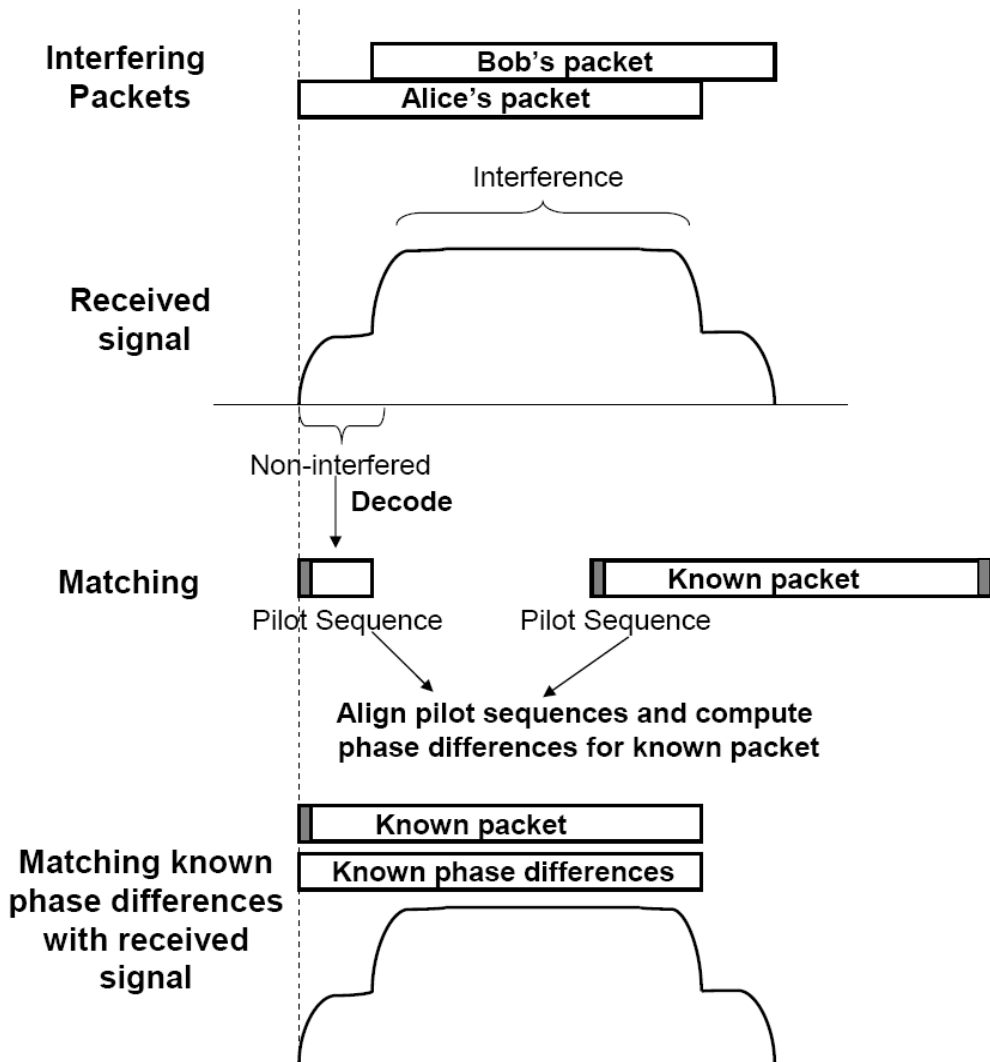


Increased network capacity?

Backup slides

Practical issues

How does node A detect interference?



- ❑ Random transmission times to avoid pilot signal interference
- ❑ Pilot signal helps align signals
 - Also helps reduce uncertainty
 - ✧ Frequency offsets
 - ✧ Channel distortion
- ❑ After pilot, encoded Src, Dest, packet ID