What is Wireless Resource?

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Wireless Foundations

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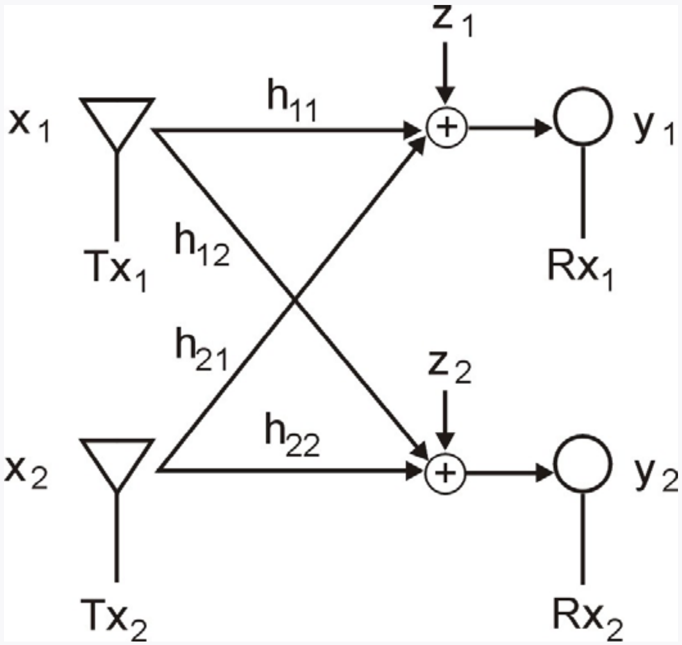
Interference

- Interference is a central phenomenon in wireless communication.
- Multiple wireless links compete for resource via interference.
- But what exactly is the resource being competed for?

The Interference Scenario

message m_1 — want m_1



message m_2 — want m_2

Bad news:

Capacity of the Gaussian interference channel is open for 30 years.

Good news:

Recent approximation results sufficient to identify what the resource is.

Basic Questions

1) How to quantify the resource being shared?

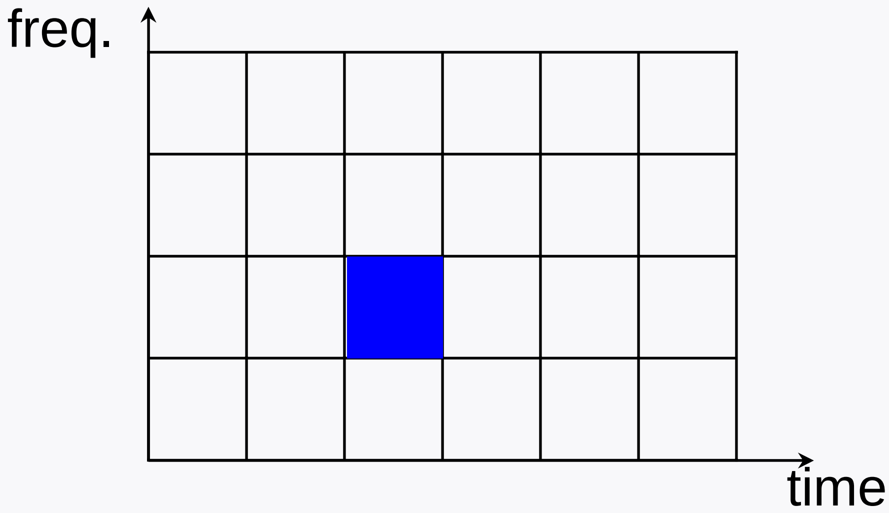
2) How to optimally share the resource?

3) How does feedback and cooperation improve resource utilization?

3) How do the insights translate into design of actual schemes?

Resource: Traditional View

time-frequency grid as a common ether.



Each transmission costs one time-frequency slot.

If a tree falls in a forest and no one is around to hear it, does it make a sound?

Resource is at the Receivers

- The action is at the receivers.

- No common ether: each Rx has its own resource.

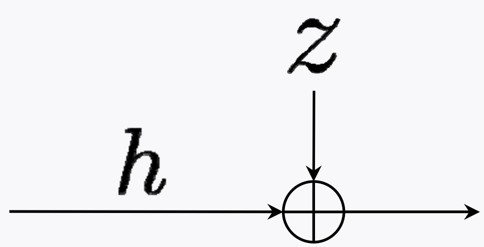
- Signal strengths have to come into picture.

- A new resource model is needed.

Signal Strength to Bits

Transmit a real number

$$x = 0.b_1 b_2 b_3 b_4 b_5$$



$$b_1 b_2 \cdots b_n . b_{n+1} \cdots$$

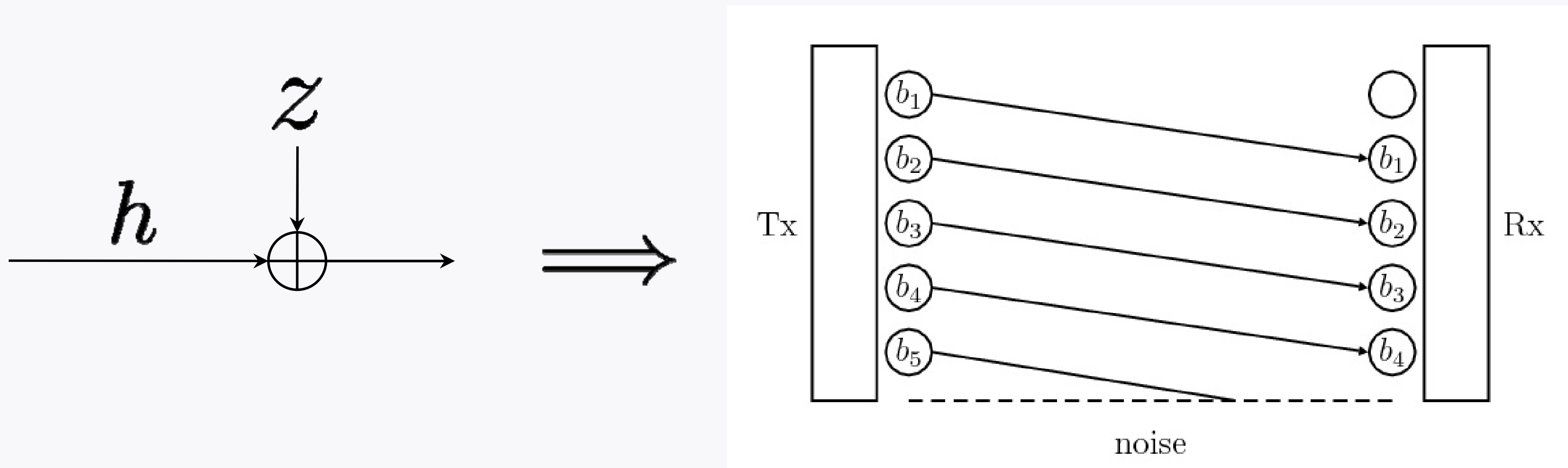
Least significant bits are truncated at noise level.

$$n \leftrightarrow \log_2 \mathsf{SNR}$$

Matches approx:

$$C_{\mathsf{awgn}}(\mathsf{SNR}) = \log(1 + \mathsf{SNR})$$

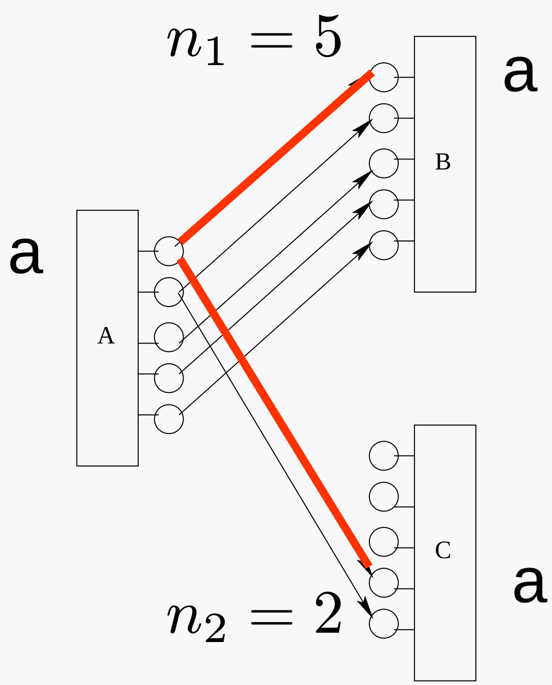
A Deterministic Model



(Avestimehr,Diggavi & T. 07)

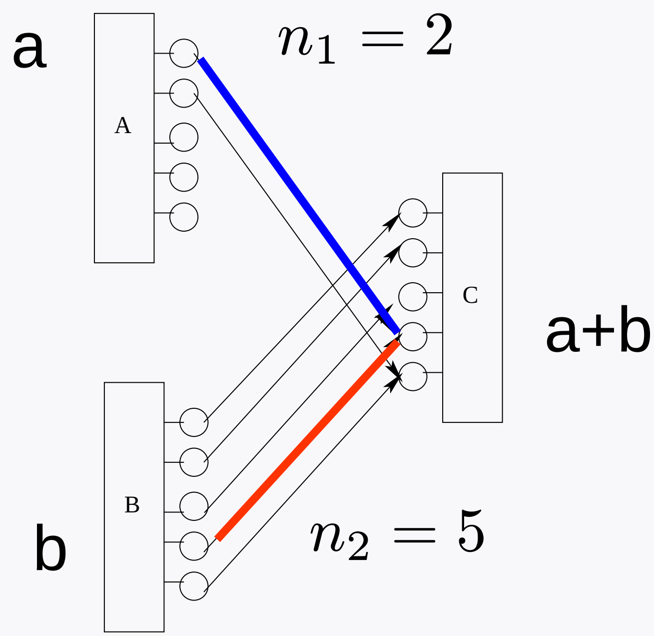
Broadcast and Superposition

Broadcast



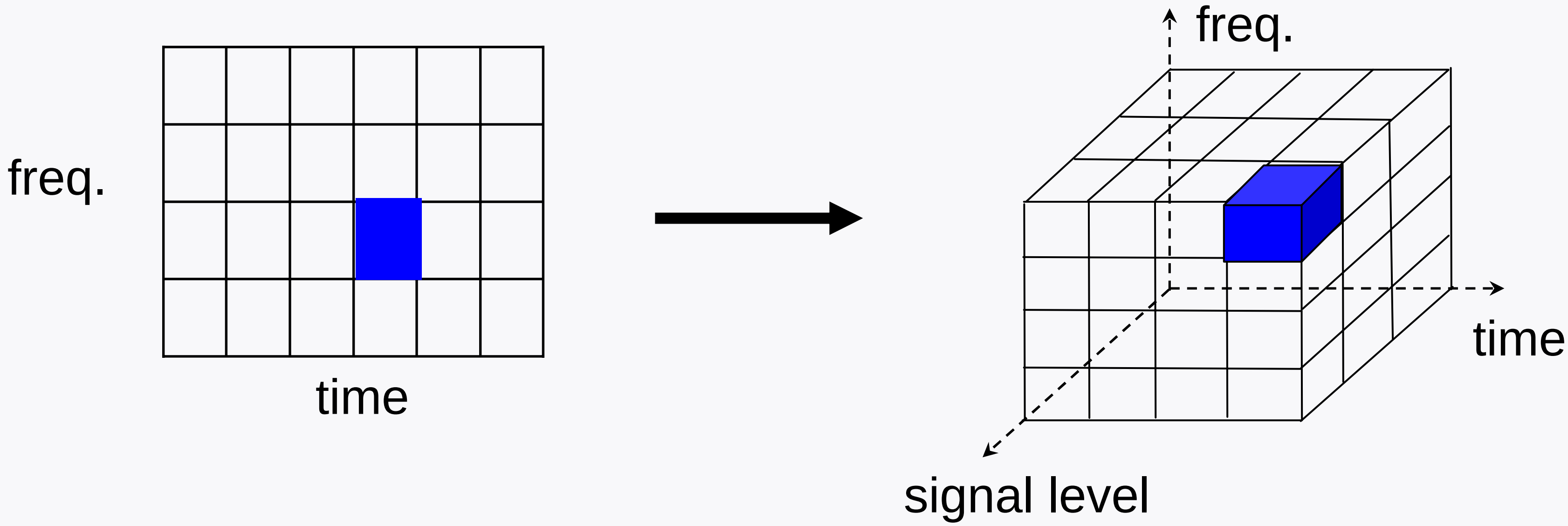
$n_i \propto \text{SNR}_i \ (\text{dB})$

Superposition



MSB's of weak users compete with LSB's of strong user.

A New Dimension

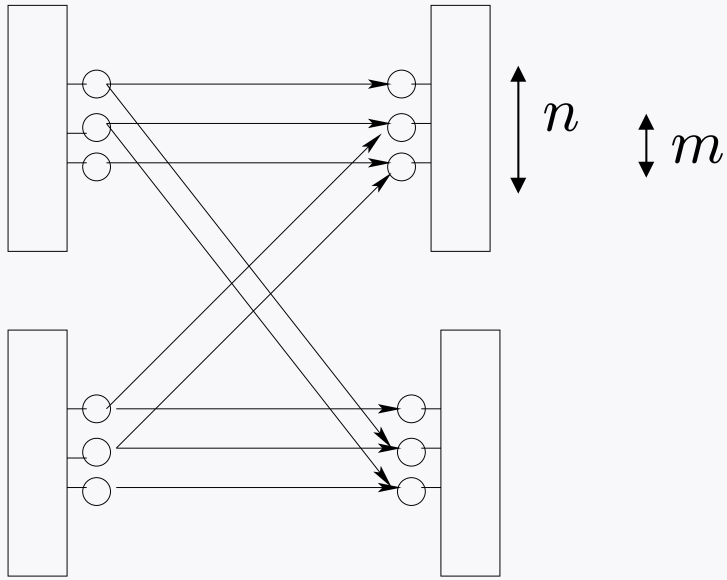


Resource at a receiver:

# of resolvable bits per sample $\times$ bandwidth $\times$ time

$$\log_2 \mathrm{SNR} \qquad\qquad W \qquad\qquad T$$

Interference Channel



$$n \propto \mathsf{SNR}\ (\mathrm{dB}), \quad m \propto \mathsf{INR}\ (\mathrm{dB})$$

INR = interference-to-noise ratio

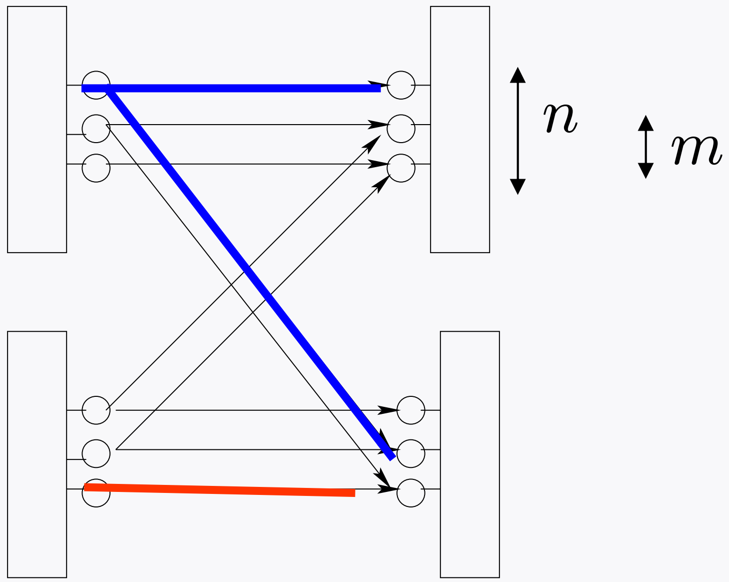
Key coupling parameter:

$$\alpha := \frac{m}{n} = \frac{\log \mathsf{INR}}{\log \mathsf{SNR}}$$

Resource and Cost

Resource available at each Rx

= max(m,n) signal levels ($)

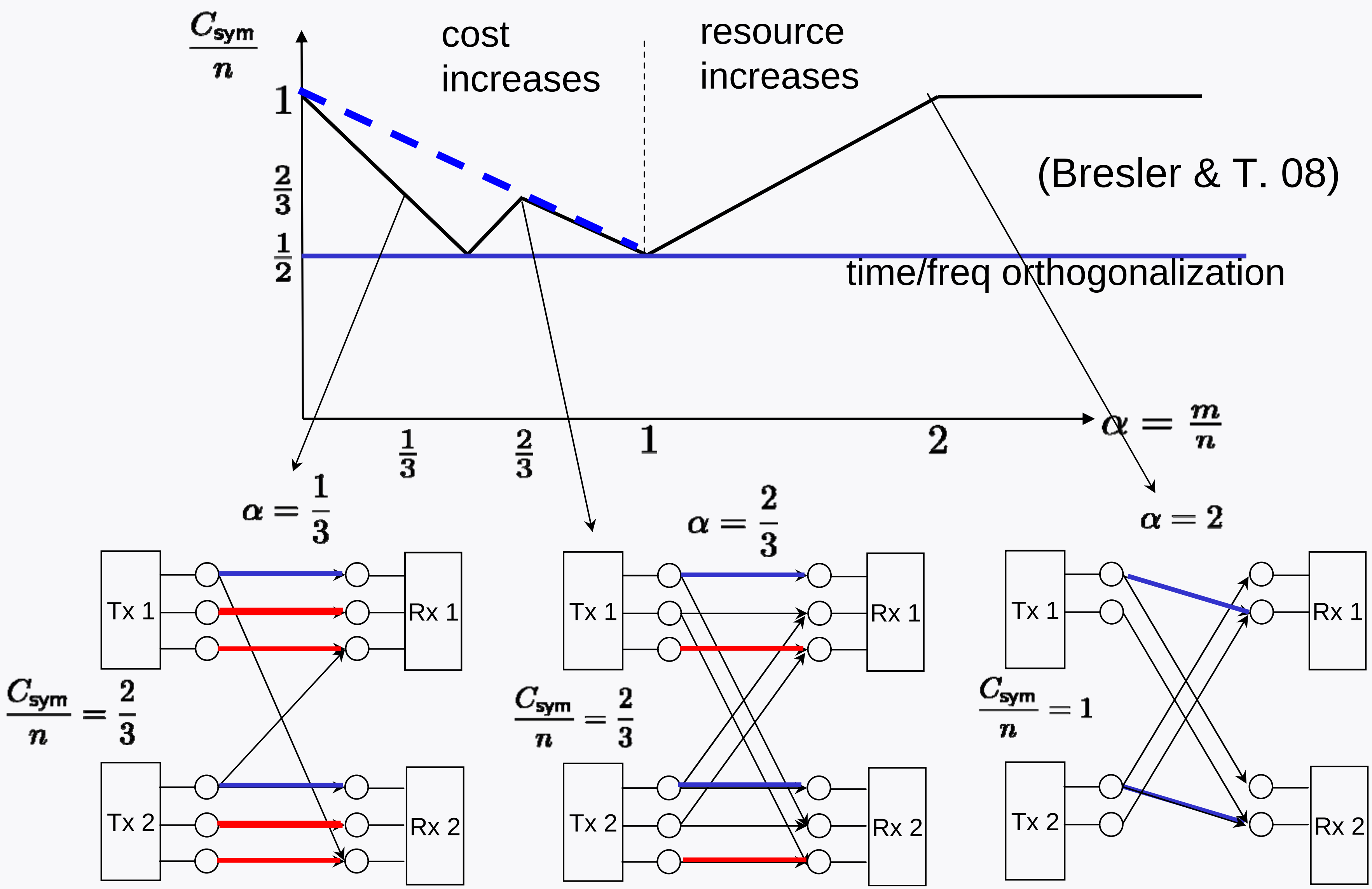


Cost to transmit 1 bit:

= $2 if visible to both Rx.

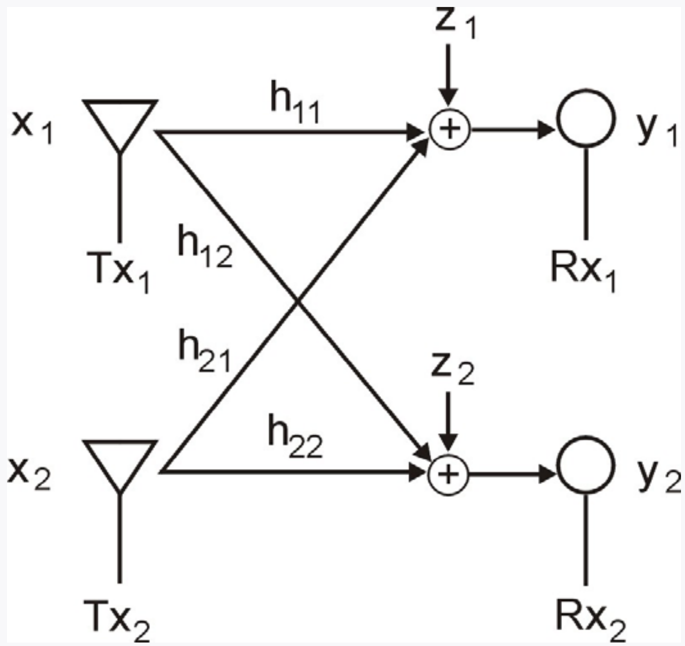
= $1 if visible to only own Rx.

Symmetric Capacity



Sanity Check

Similar behavior in the Gaussian interference channel?



Three Capacity Theorems

Strong Interference (Sato 82, Han & Kobayashi 82)

Capacity is achieved by sending public information only.

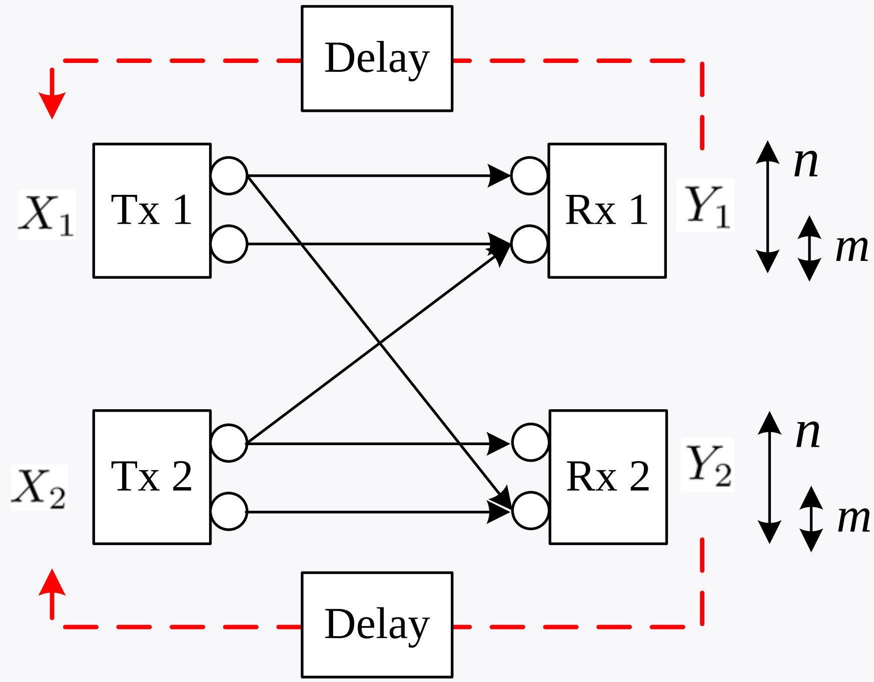
General Case (Etkin, T. & Wang 06)

Capacity is achieved within 1 bit/s/Hz by sending public and private info., with private received at noise level at the other receiver.

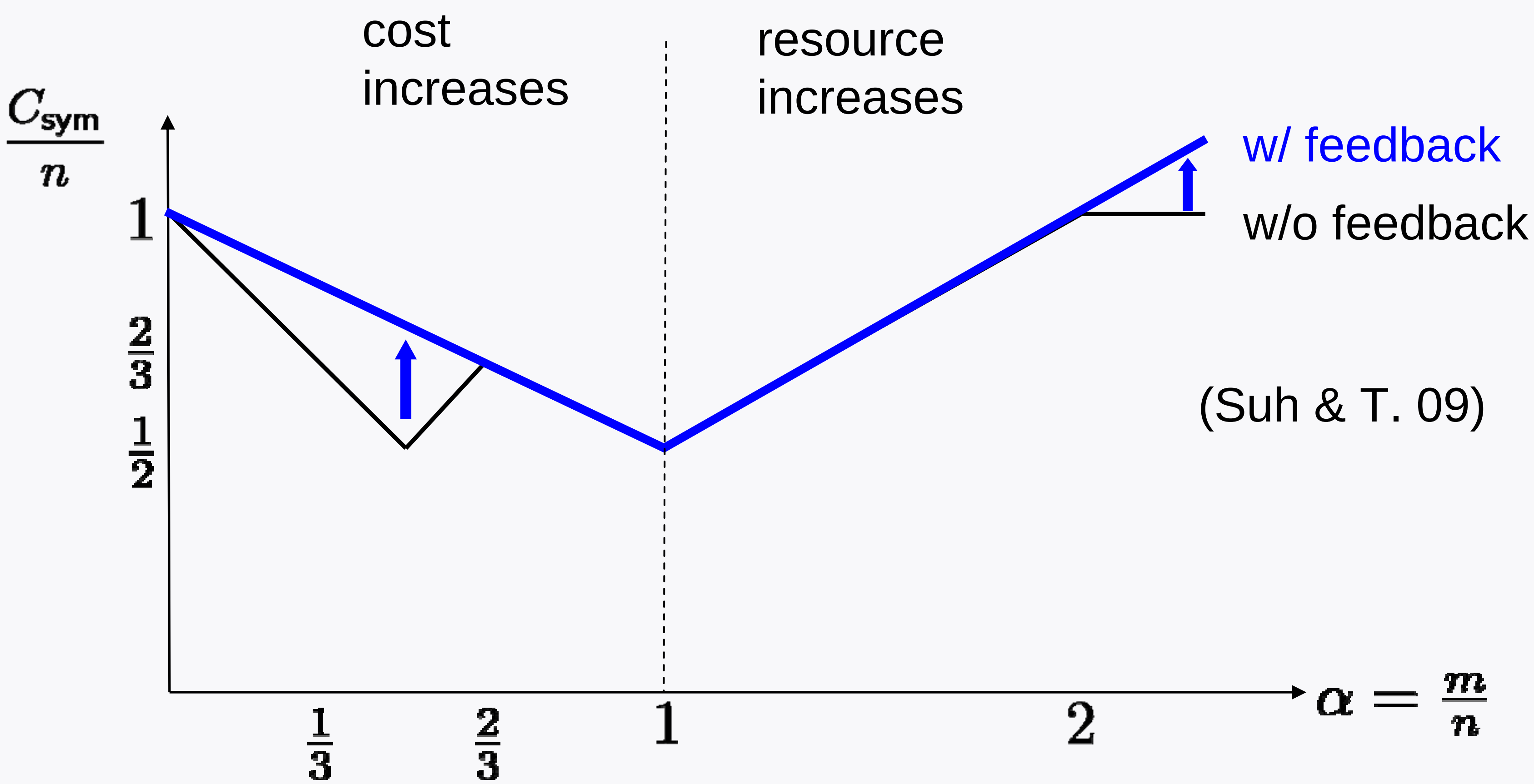
Very Weak Interference $\alpha < 1/3$ (Shang et al 07,Annaprueddy & Veeravalli08, Motahari & Khandani07)

Sum capacity is achieved by treating interference as noise.

Feedback

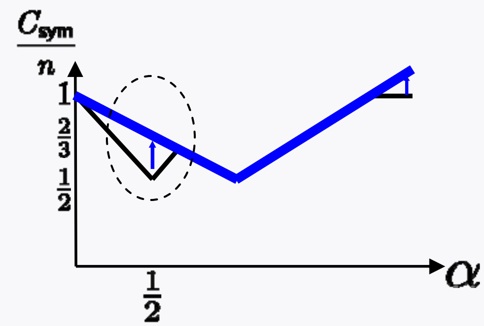


Can Feedback Help?

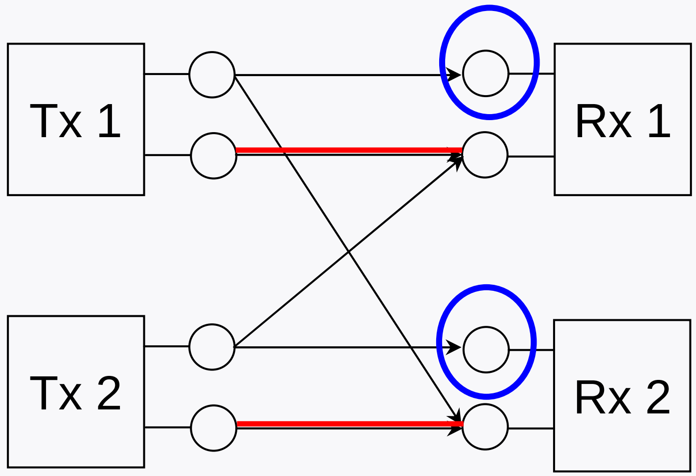


Feedback does not reduce cost, but it maximizes resource utilization.

Example: α = 0.5



w/o feedback

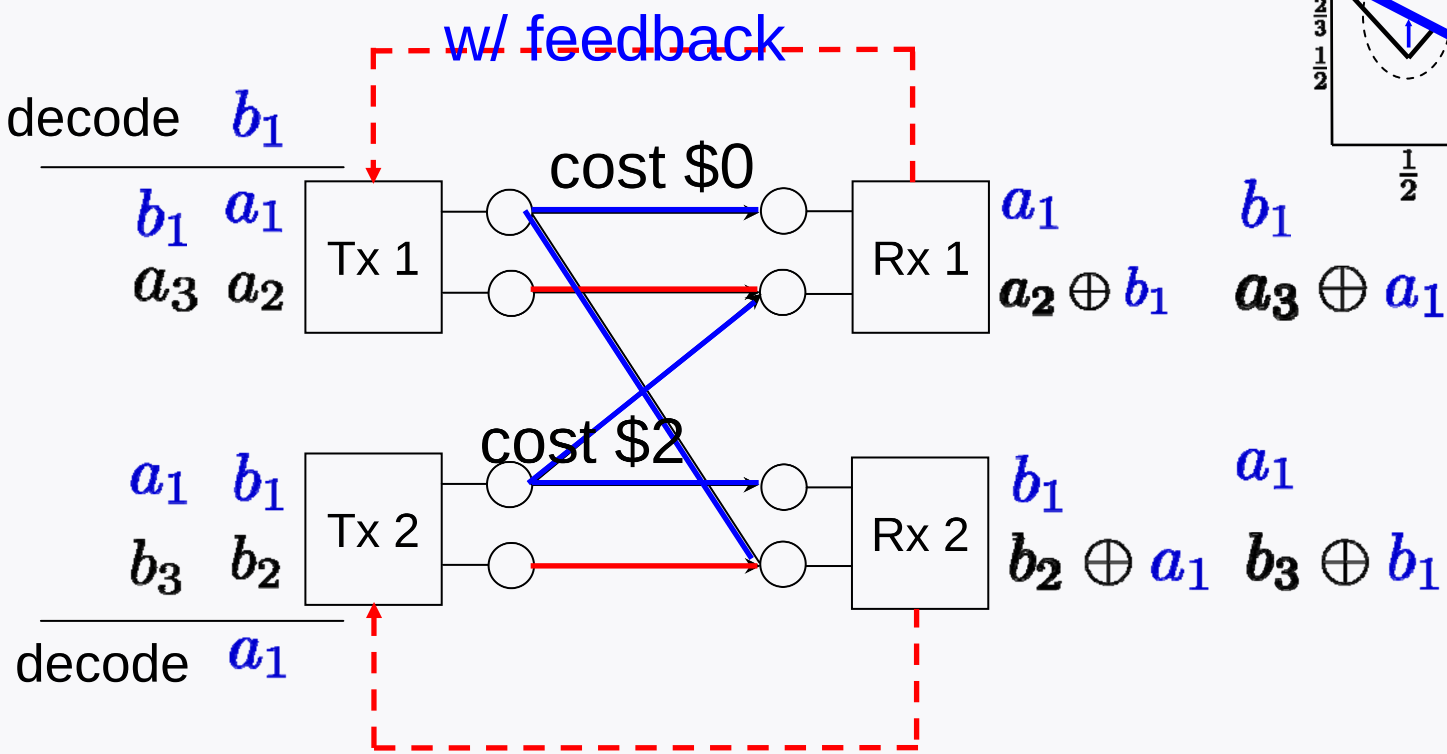


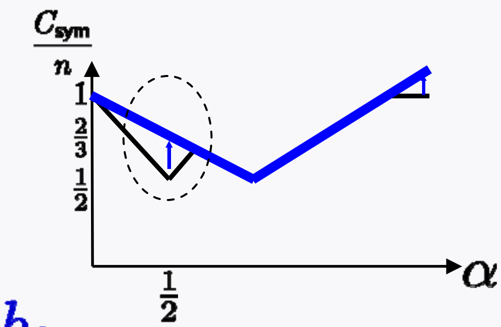
consumption: 2 levels

resource: 4 levels

Potential to squeeze 1 more bit in with feedback

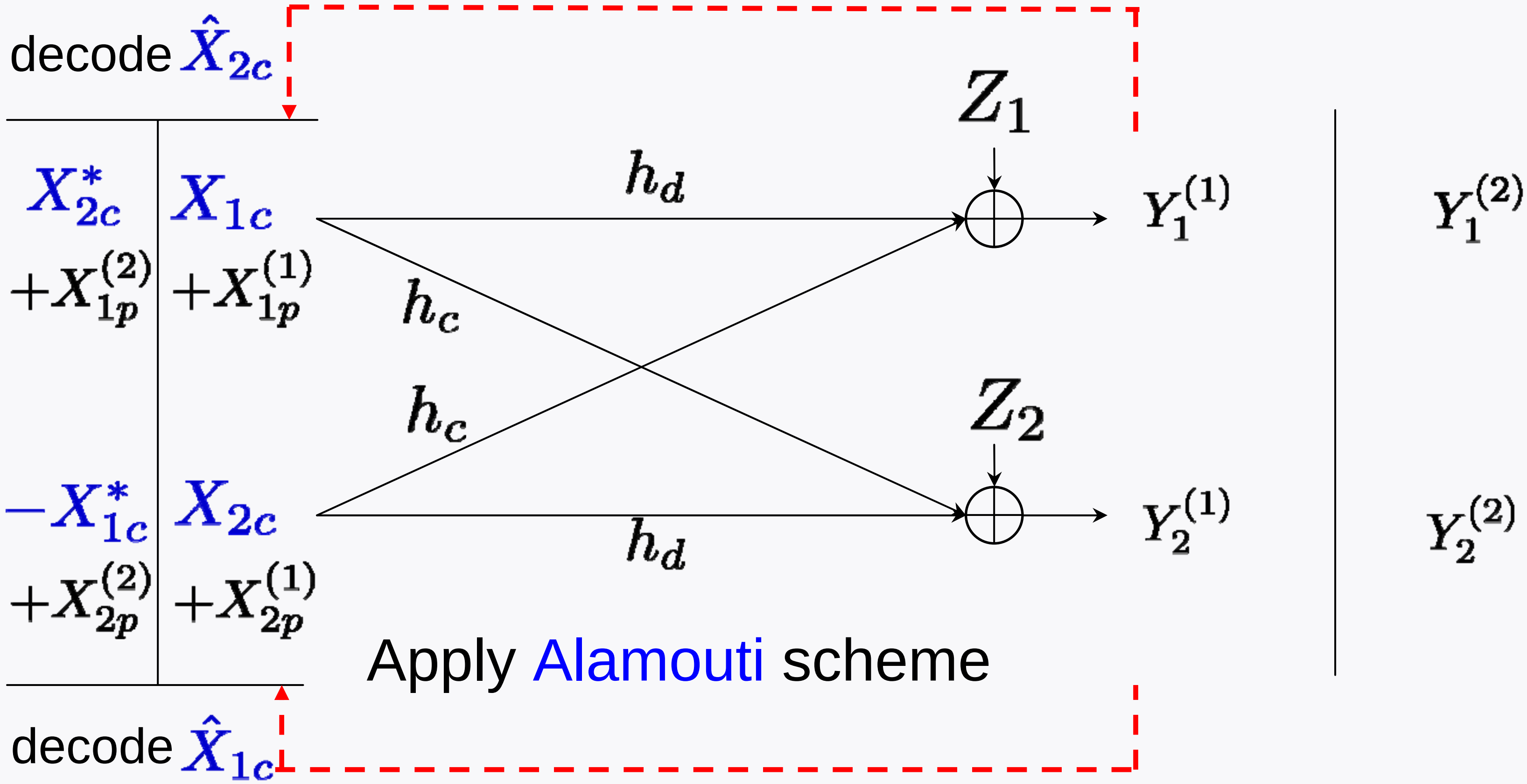
Example: α = 0.5





Tx 1 sending b1 helps Rx 1 to recover a1 without causing interference to Rx 2.

Gaussian Case



Apply Alamouti scheme

Gaussian Feedback Capacity Theorem

Theorem (Suh & T. 09)

The symmetric feedback capacity of the Gaussian interference channel is characterized to within 1 bit/s/Hz

Symmetric Feedback Capacity to Within 1 Bit

Theorem (Suh & T. 09)

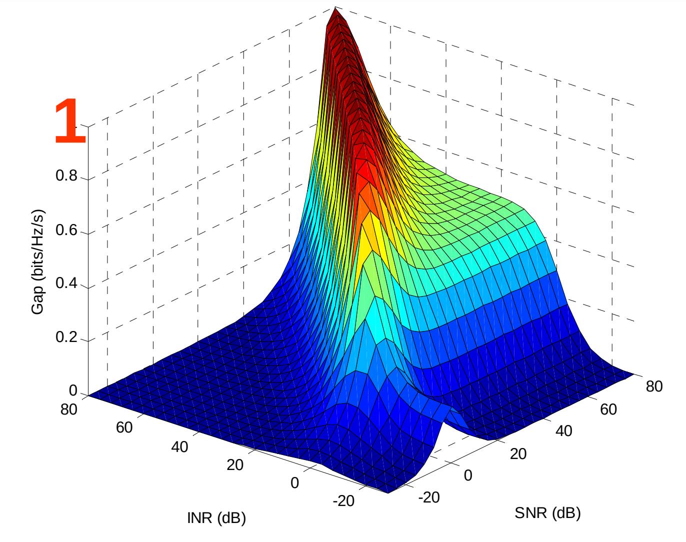
We can achieve a symmetric rate per user

$$R_{\mathsf{sym}} = \max\left\{ \frac{1}{2}\log\left(1+\mathsf{INR}\right), \frac{1}{2}\log\left(\frac{(1+\mathsf{SNR}+\mathsf{INR})^2 - \frac{\mathsf{SNR}}{1+\mathsf{INR}}}{1+2\mathsf{INR}} \right) \right\}.$$

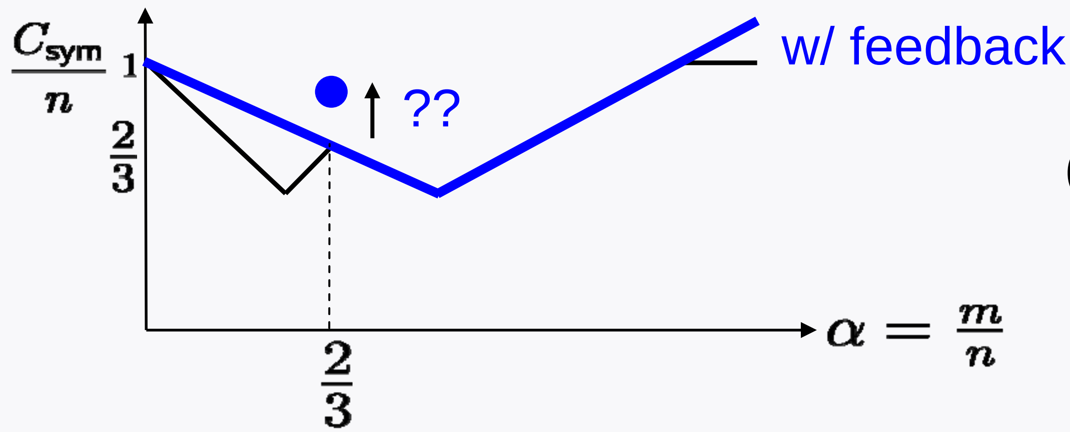
The symmetric capacity is upper-bounded by

$$C_{\mathsf{sym}} \le \frac{1}{2} \sup_{0\le\rho\le 1} \left[\log\left(1 + \frac{(1-\rho^2)\mathsf{SNR}}{1+(1-\rho^2)\mathsf{INR}}\right) + \log\left(1+\mathsf{SNR}+\mathsf{INR}+2\rho\sqrt{\mathsf{SNR}\cdot\mathsf{INR}}\right) \right].$$

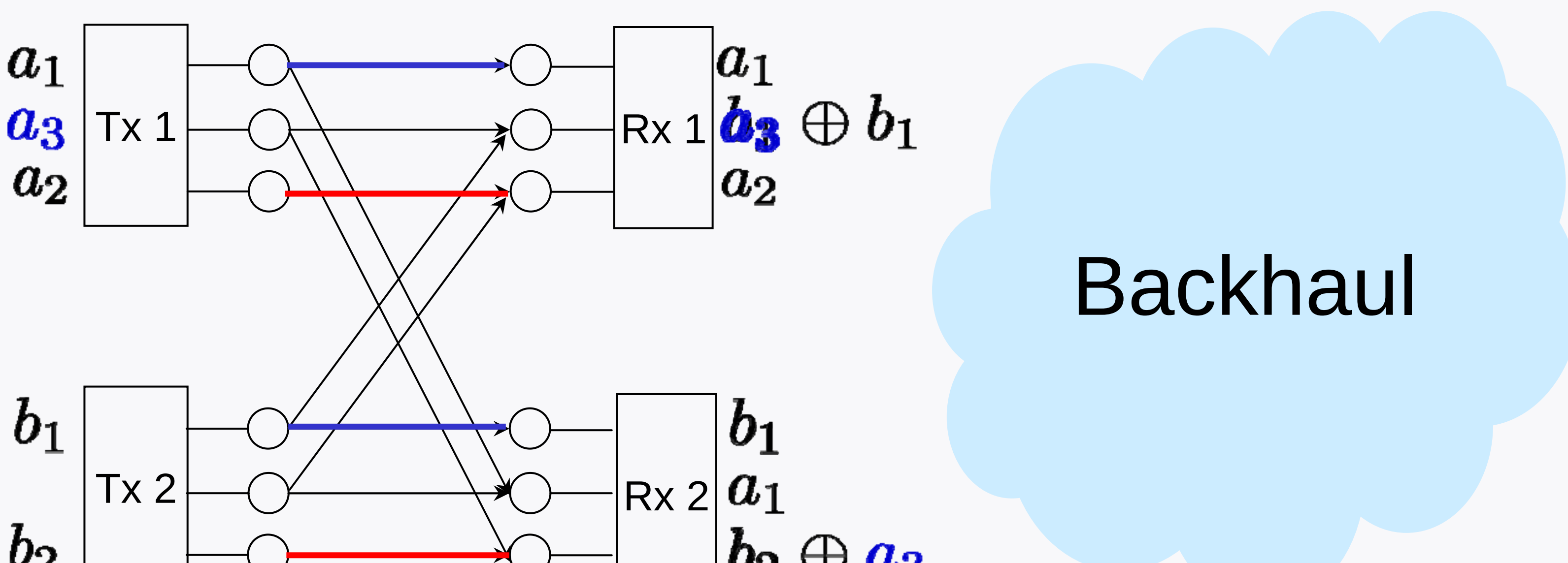
The gap is at most 1 bit for all SNR and INR.



Can We Do Better than the V-curve?



(Wang & T. 09)



Cooperation reduces cost.

Conclusions

- A resource sharing view on interference.
- Identify a new dimension of resource: signal level
- Can this view be extended to the spatial dimension and when there are more than 2 users?