

Distributed Protocols for Signal-Scale Cooperation

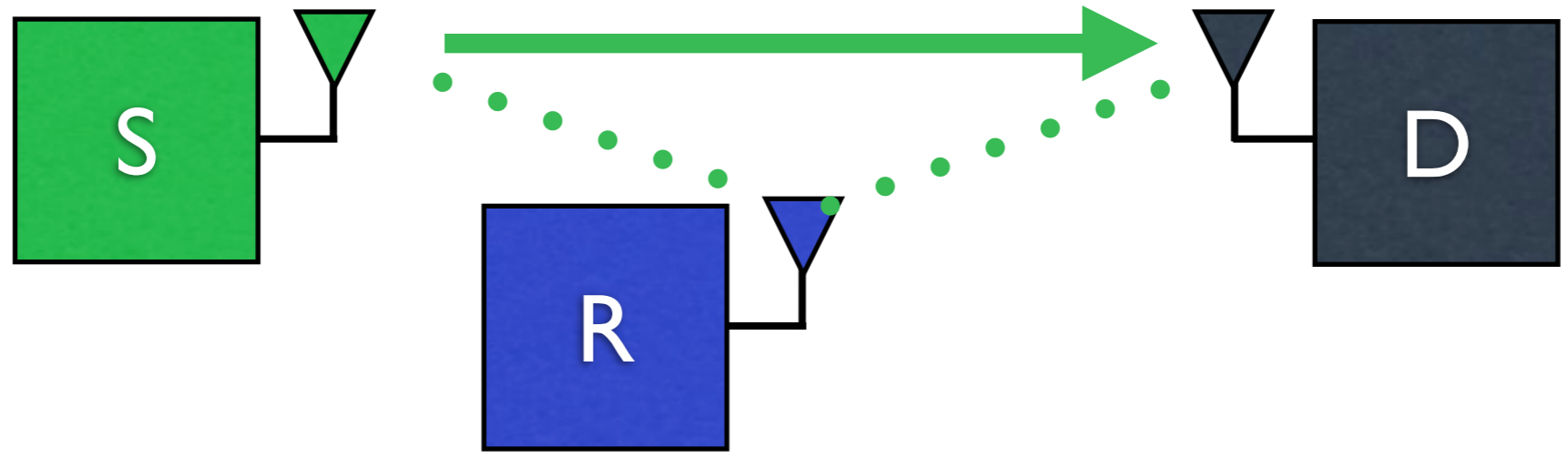
Christopher Hunter

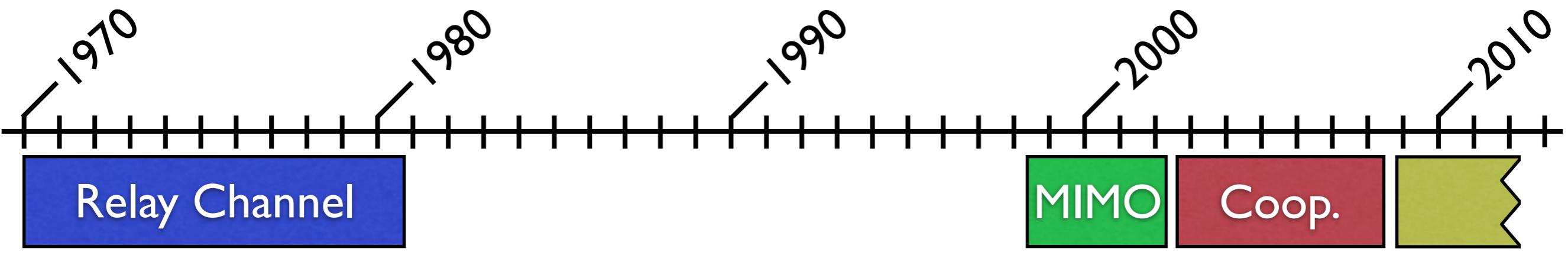
PhD Defense
April 11, 2012

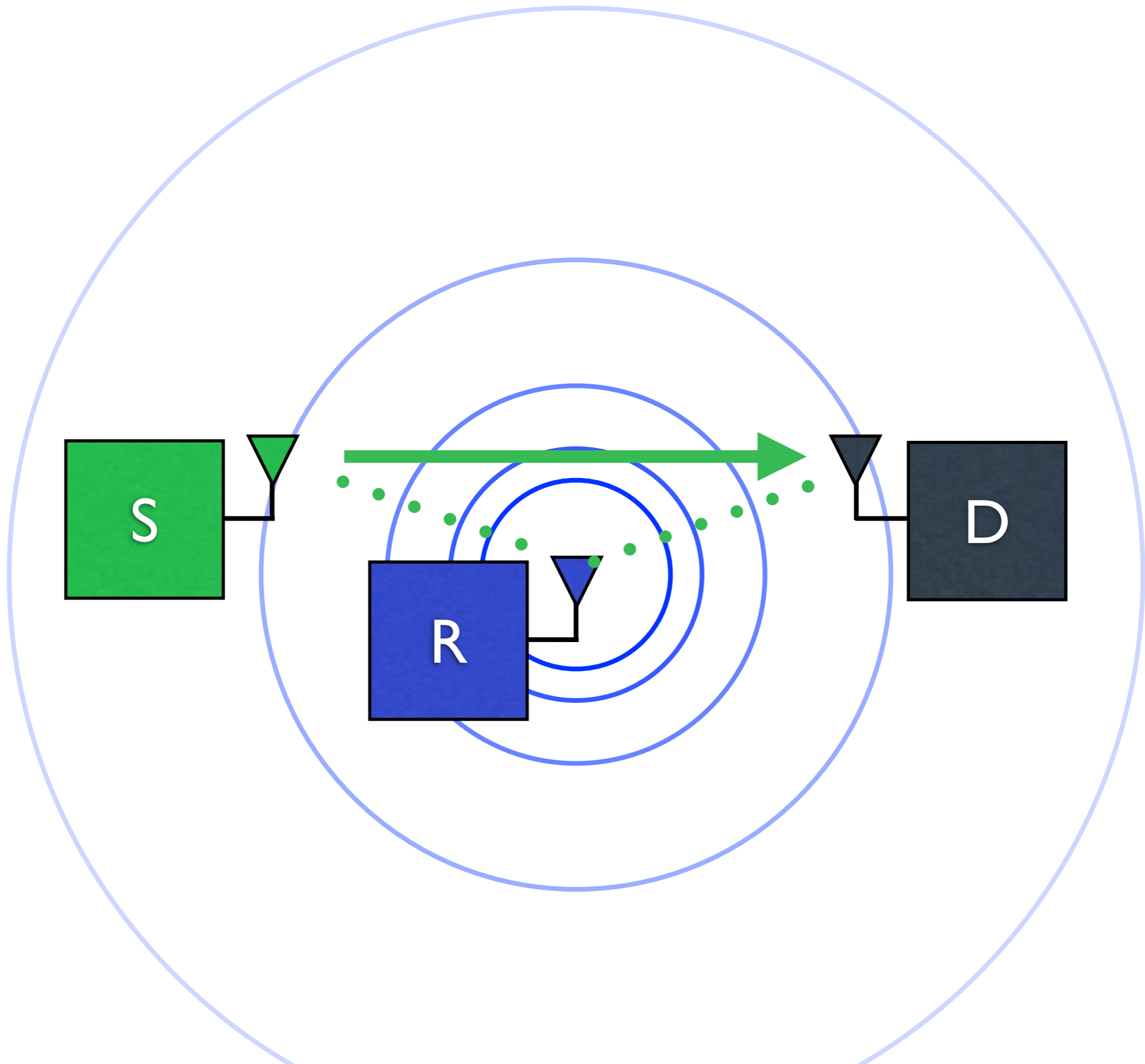
Wireless is broadcast by nature



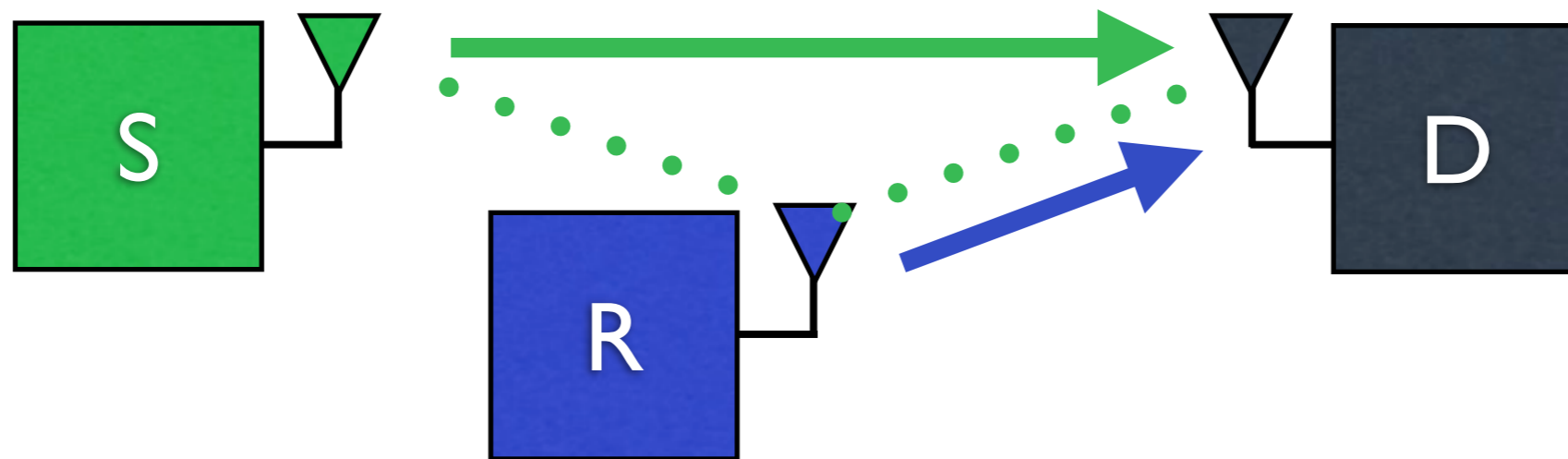
Spatial Diversity







What if costs outweigh benefits?



Talk Outline

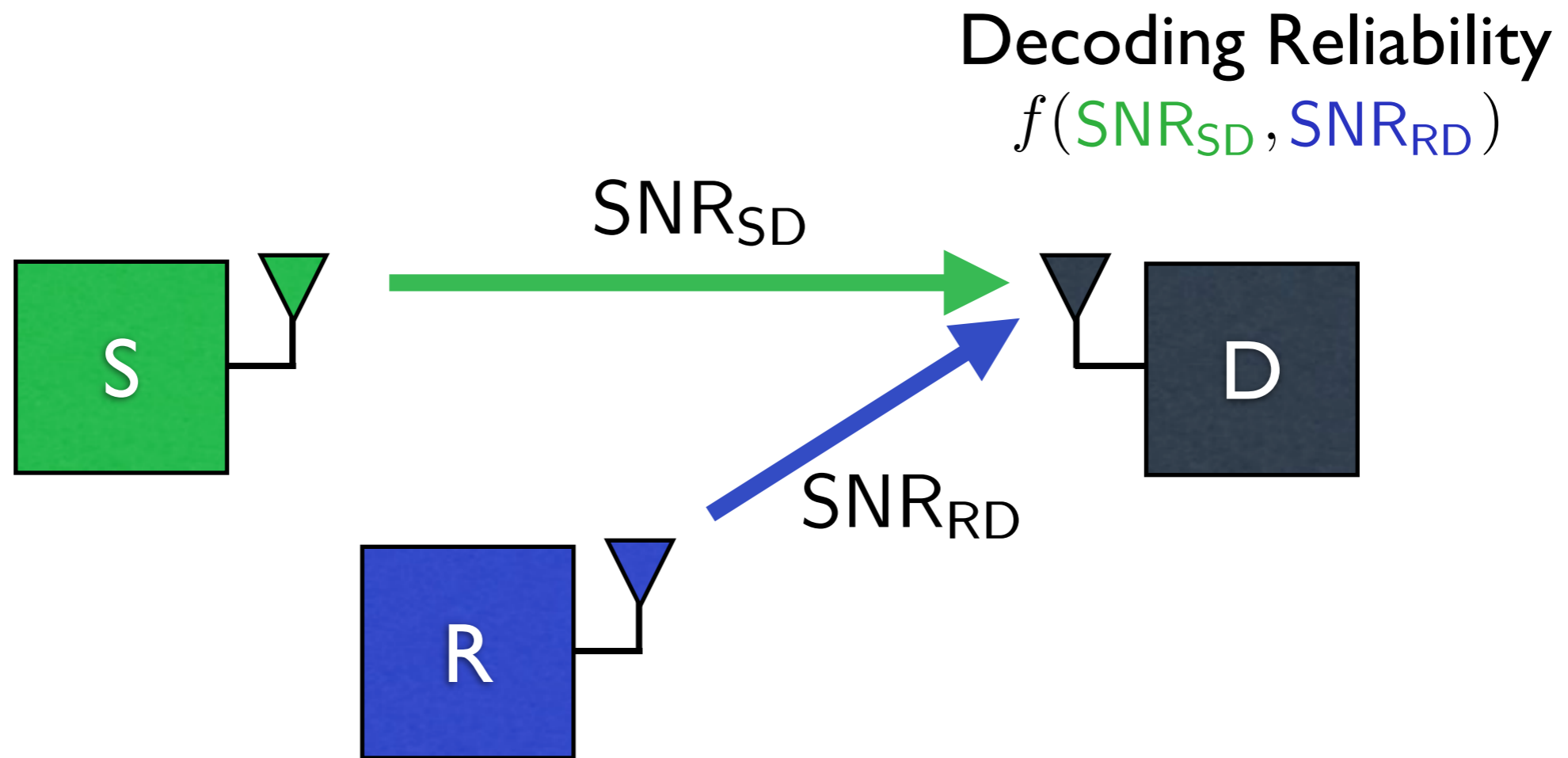
- Making cooperation “cheap”
 - Distributed On-demand Cooperation (DOC)
 - Power-controlled DOC (PDOCC)
- Adapting cooperative effort according to benefits and costs of cooperation
 - Distributed Energy-Conserving Cooperation (DECC)

Protocol Design Goals

Make relays smart by teaching them about the network around them

knowing when they can't help

helping, when they can,
with *just* enough power



Adjust relay transmission power

$$T_{\text{R}} = f(\text{SNR}_{\text{SD}}, \text{SNR}_{\text{RD}})$$

$T_R > T_{\max}$ don't bother

$T_{\max} - T_R$ “saved” power

(relative to max)

Adjust relay transmission power

$$T_R = f(\text{SNR}_{SD}, \text{SNR}_{RD})$$

$T_R > T_{\max}$ don't bother

How can the relay actually learn this information?

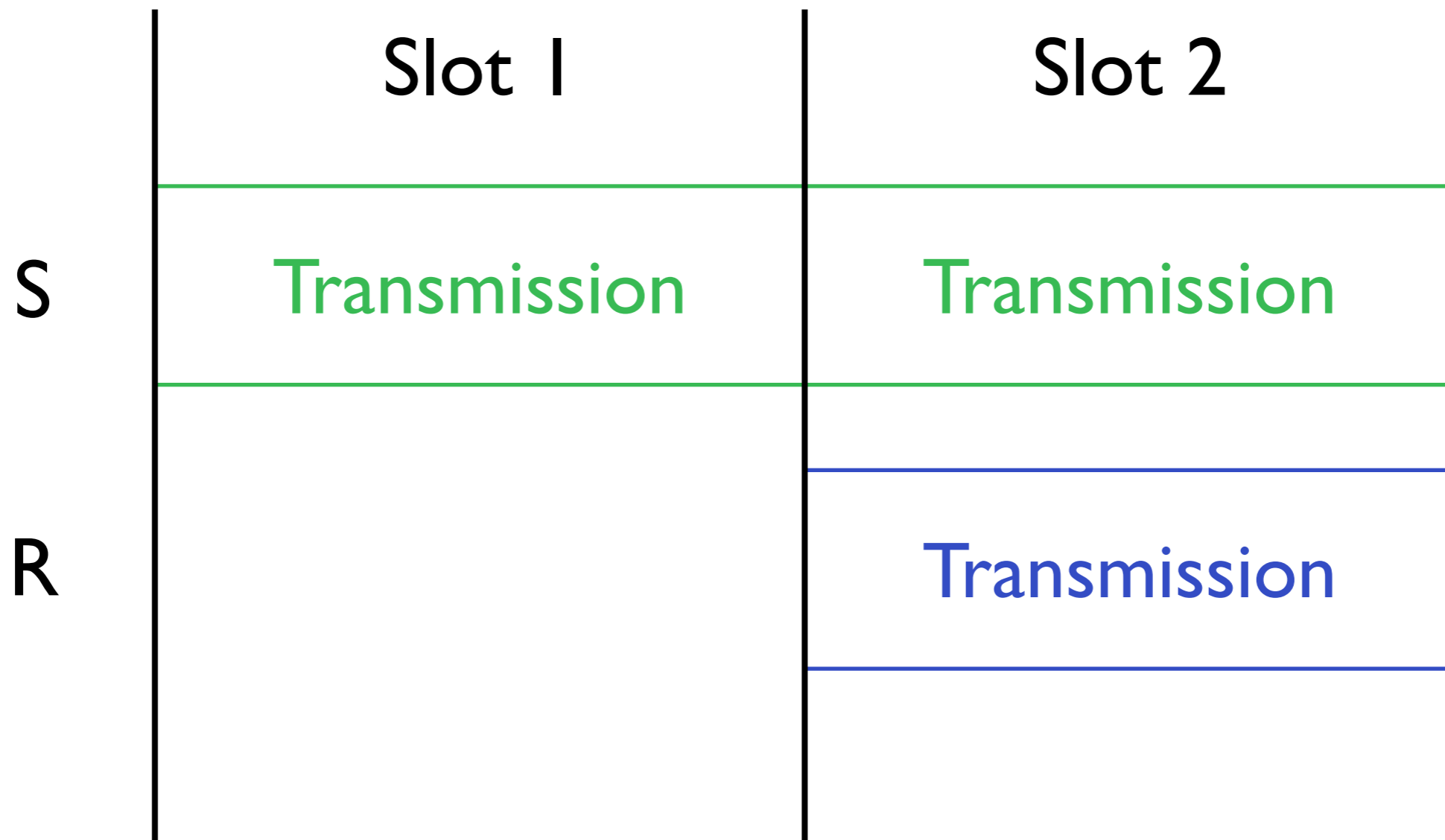
$T_{\max} - T_R$ “saved” power

(relative to max)

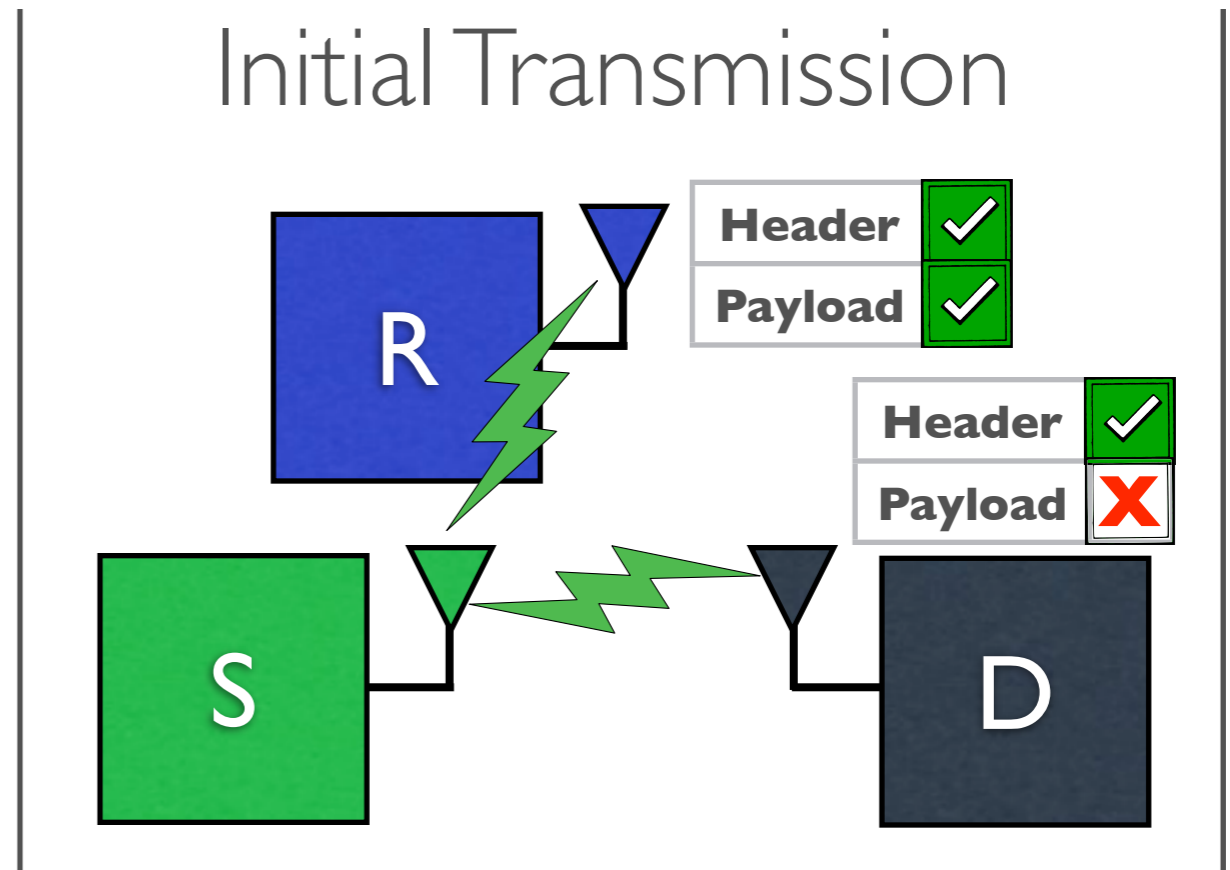
Adjust relay transmission power

$$T_R = f(\text{SNR}_{SD}, \text{SNR}_{RD})$$

Distributed On-demand Cooperation (DOC)

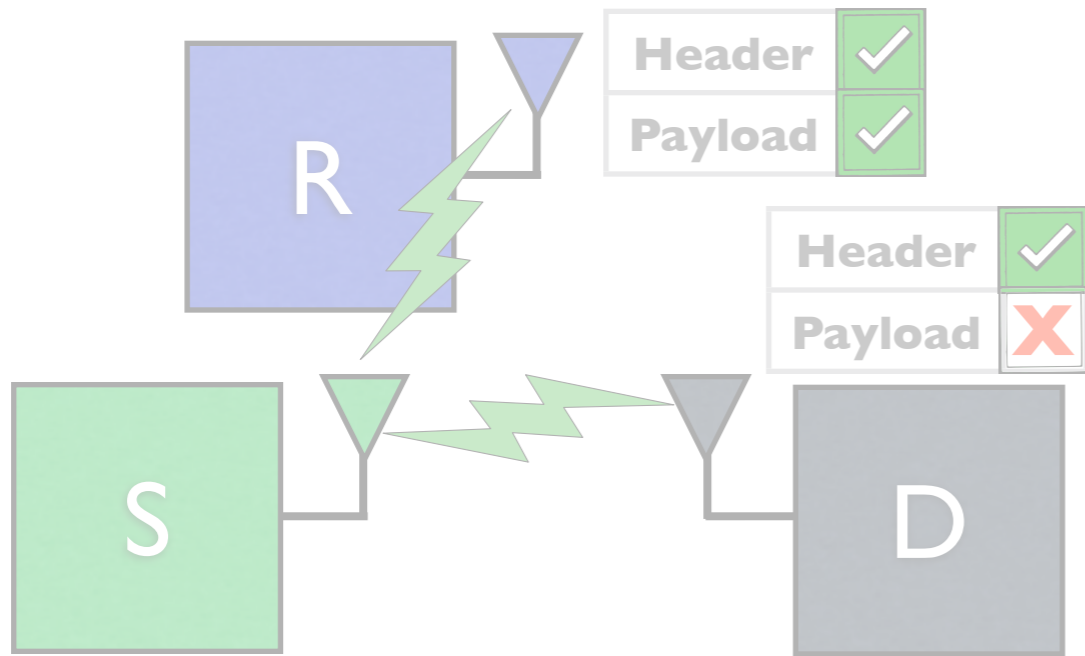


Distributed On-demand Cooperation (DOC)

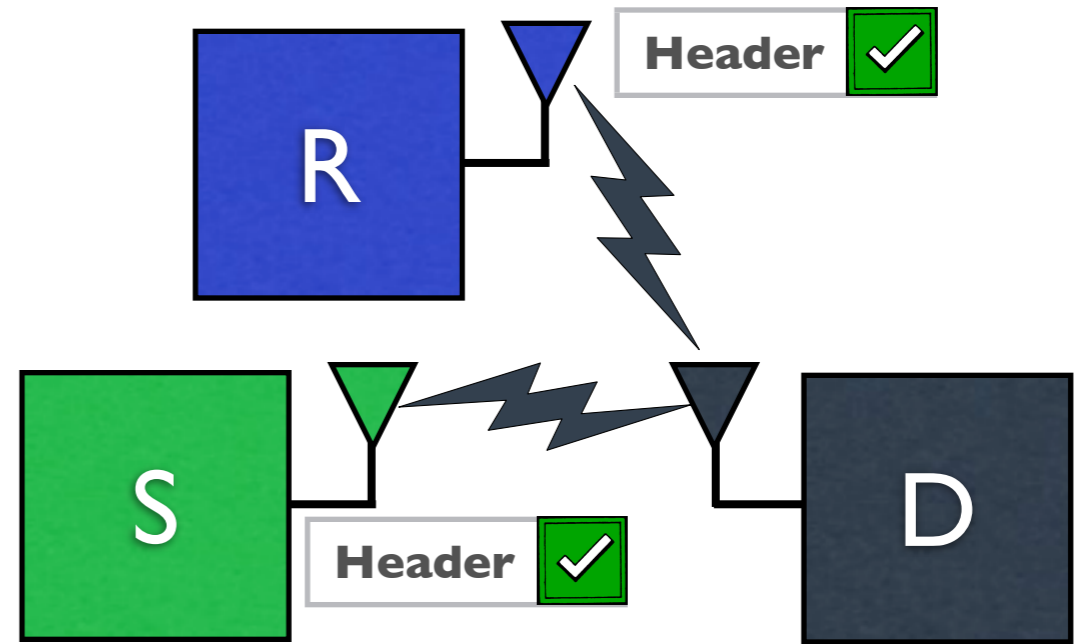


Distributed On-demand Cooperation (DOC)

Initial Transmission

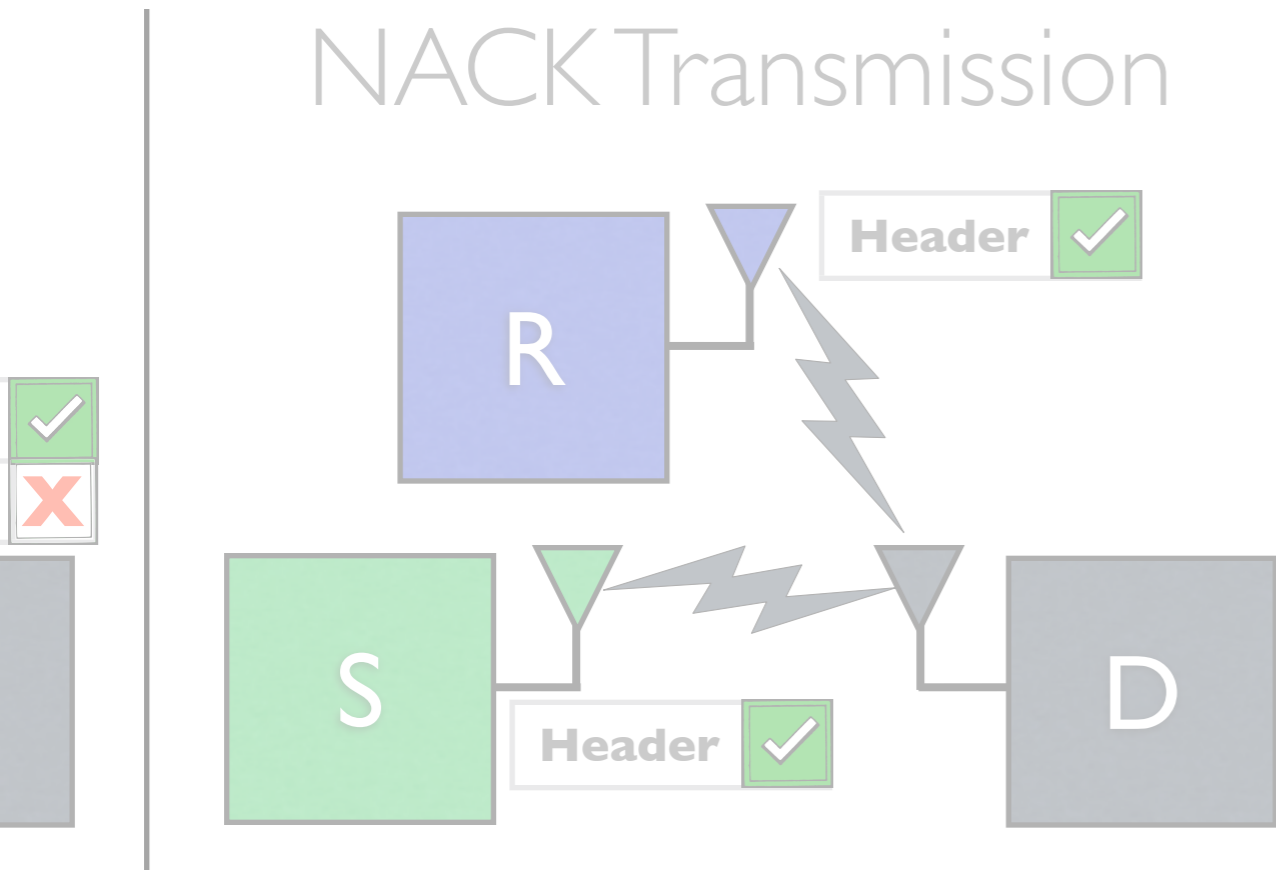


NACK Transmission

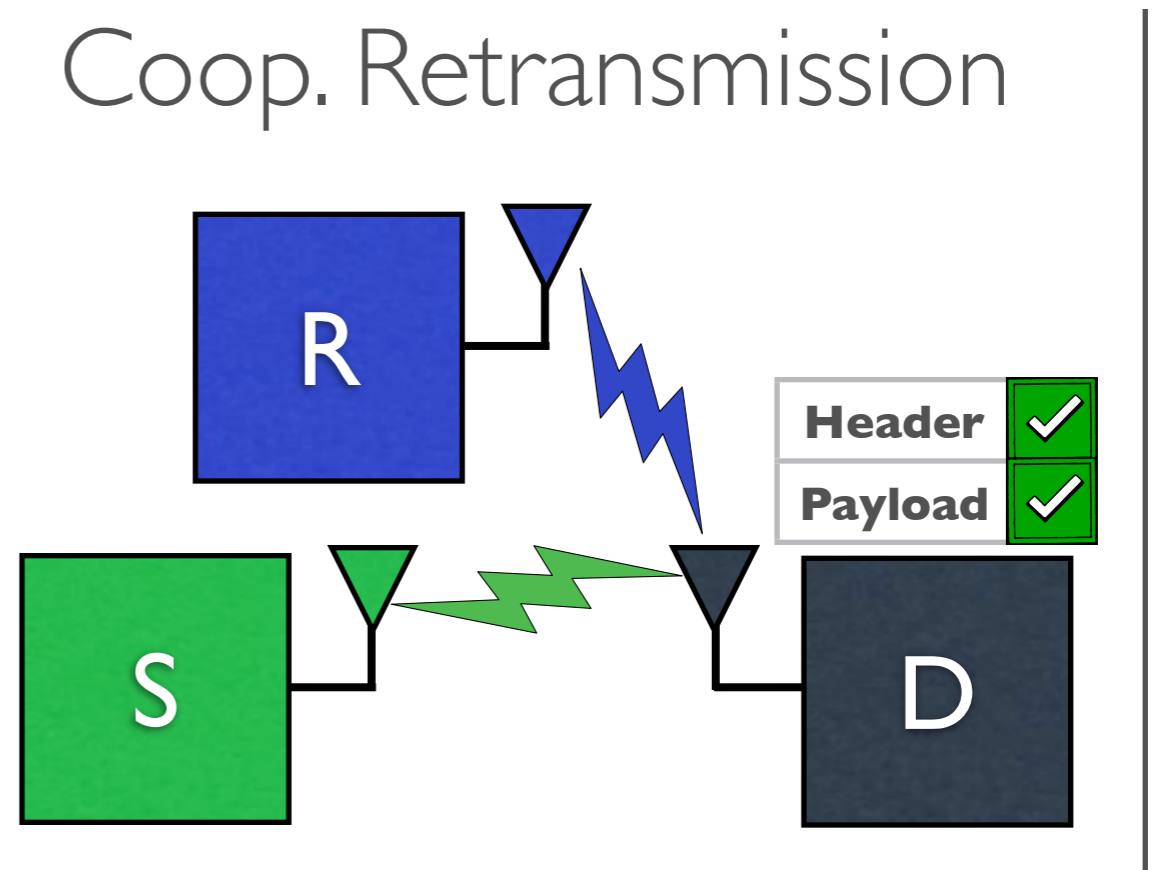


Distributed On-demand Cooperation (DOC)

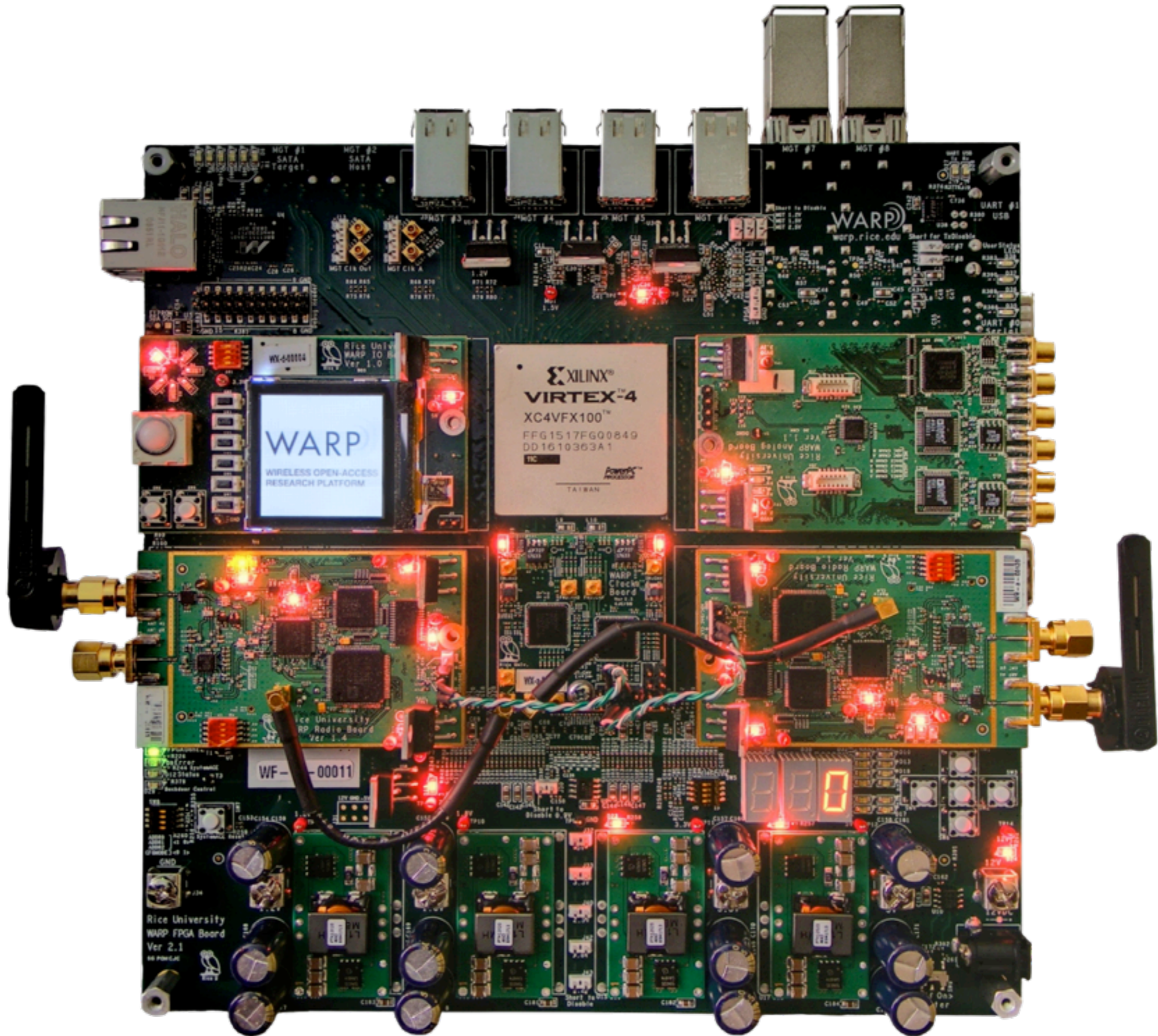
NACK Transmission

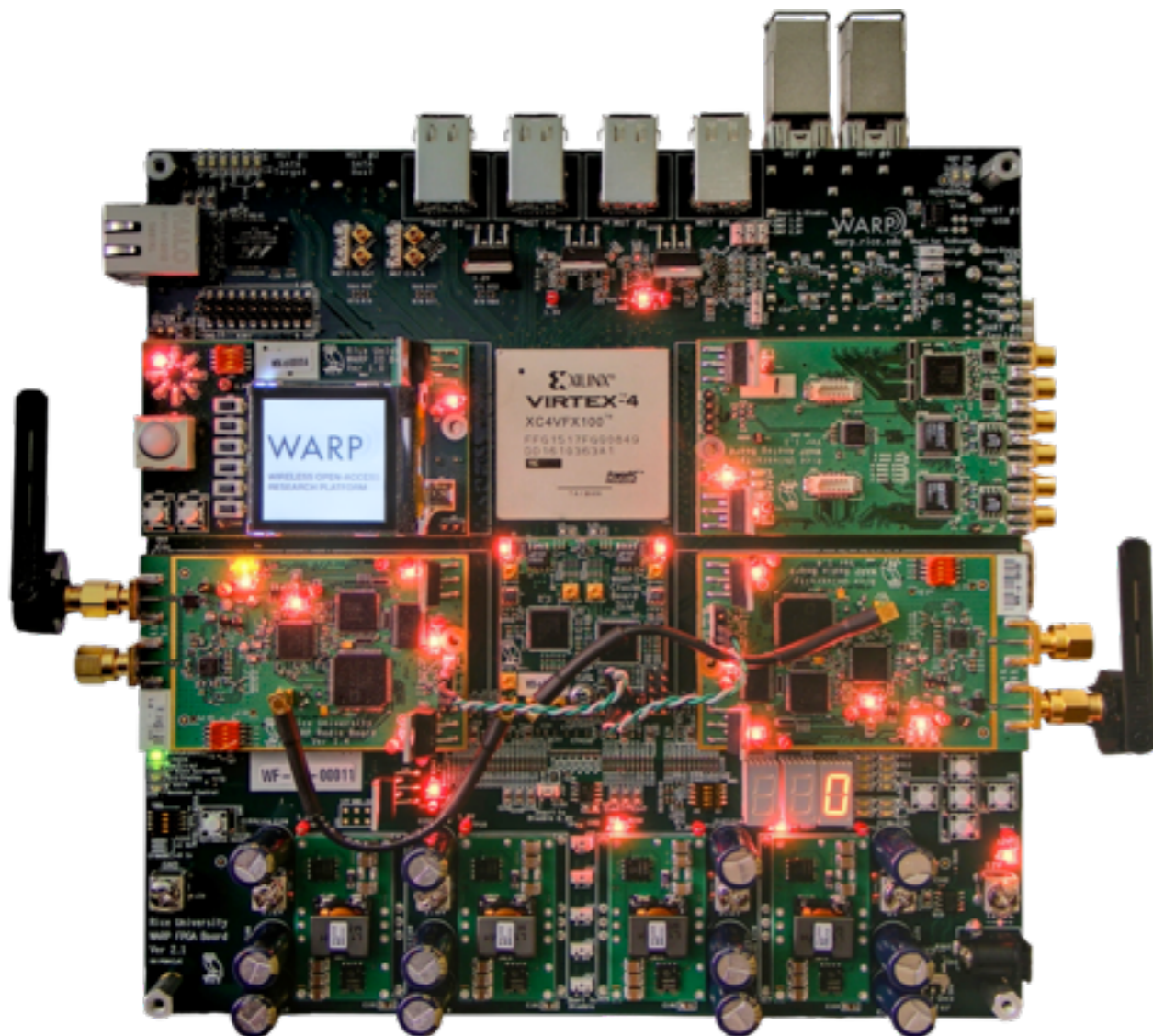


Coop. Retransmission



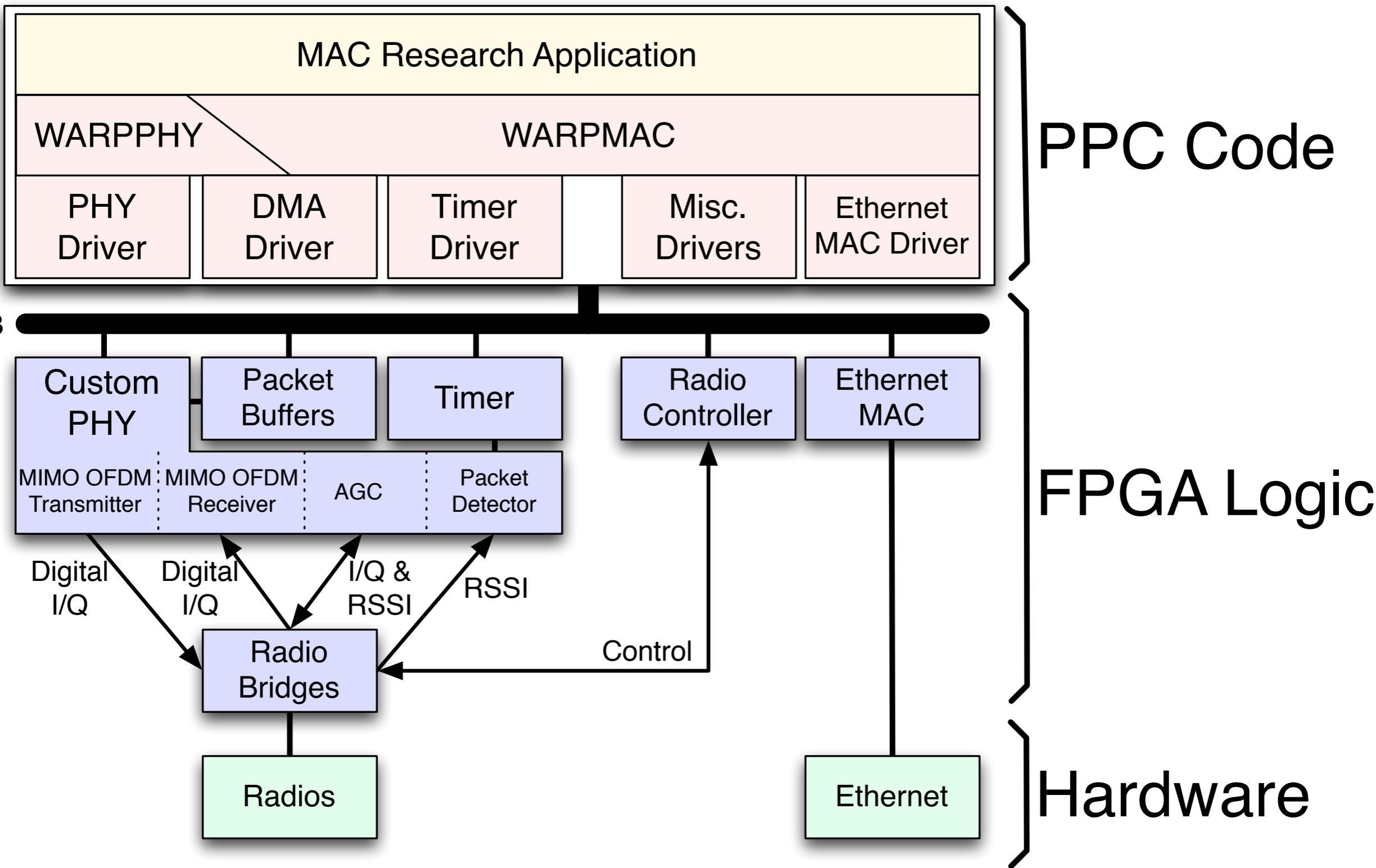
- Only cooperates when retransmissions would be needed anyway
- NACKs are a frame of reference for synchronization



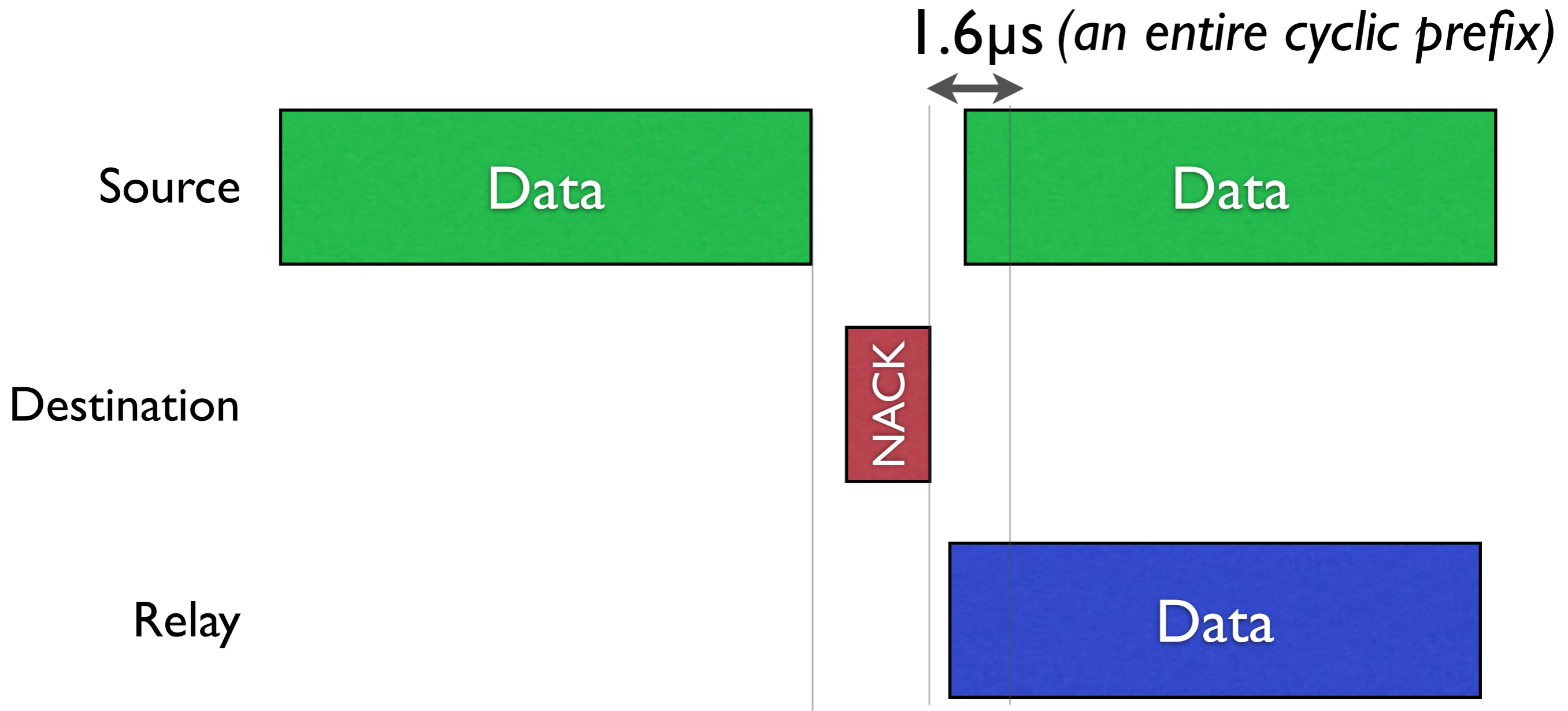


- OFDM Cooperative PHY
 - 10MHz of BW
 - Distributed STBC
 - Decode-and-Forward

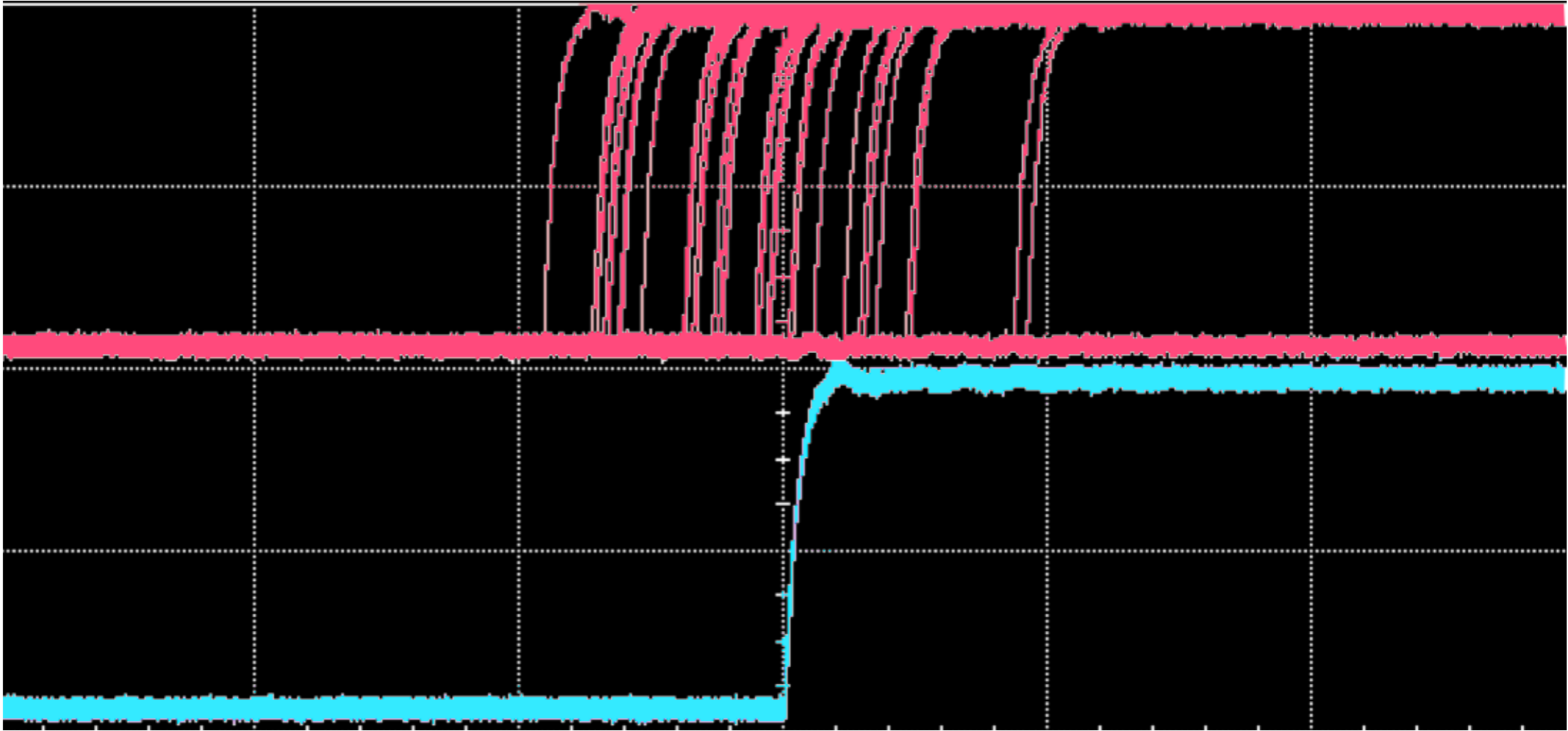
P. Murphy, C. Hunter, A. Sabharwal, "Design of a Cooperative OFDM Transceiver," Proc. Asilomar 2009



Solution: Harden packet responses to fabric



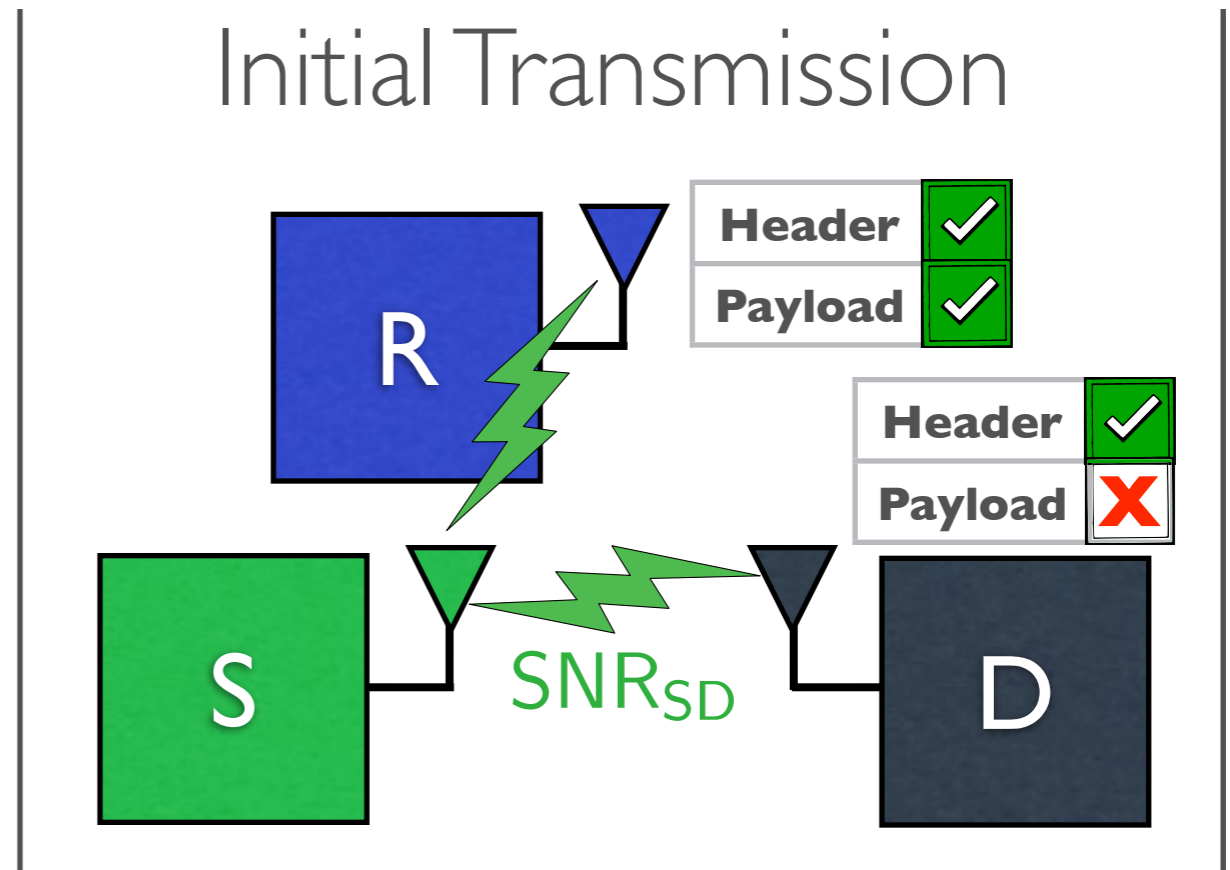
Source Tx:



Relay Tx:

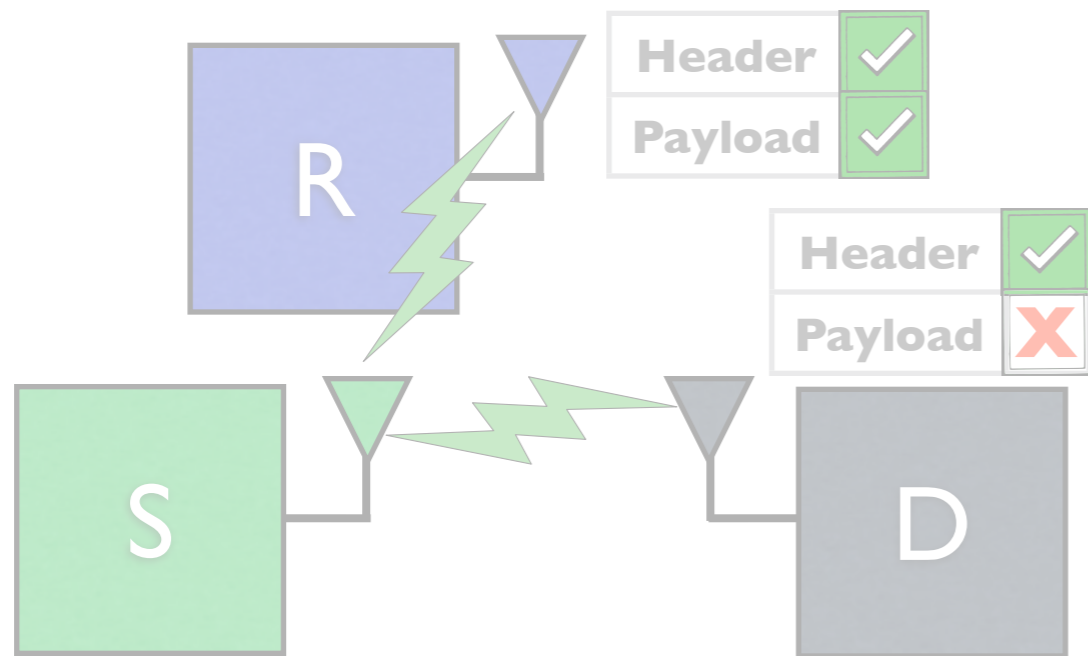
200ns

Power-controlled DOC (PDOOC)

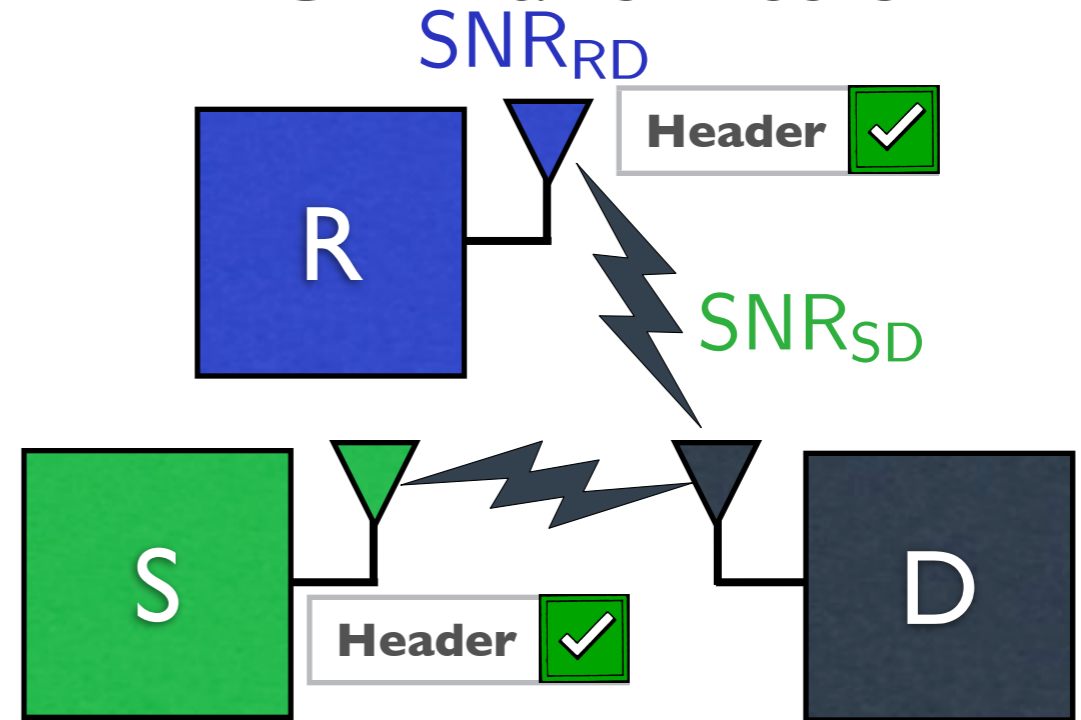


Power-controlled DOC (PDOC)

Initial Transmission

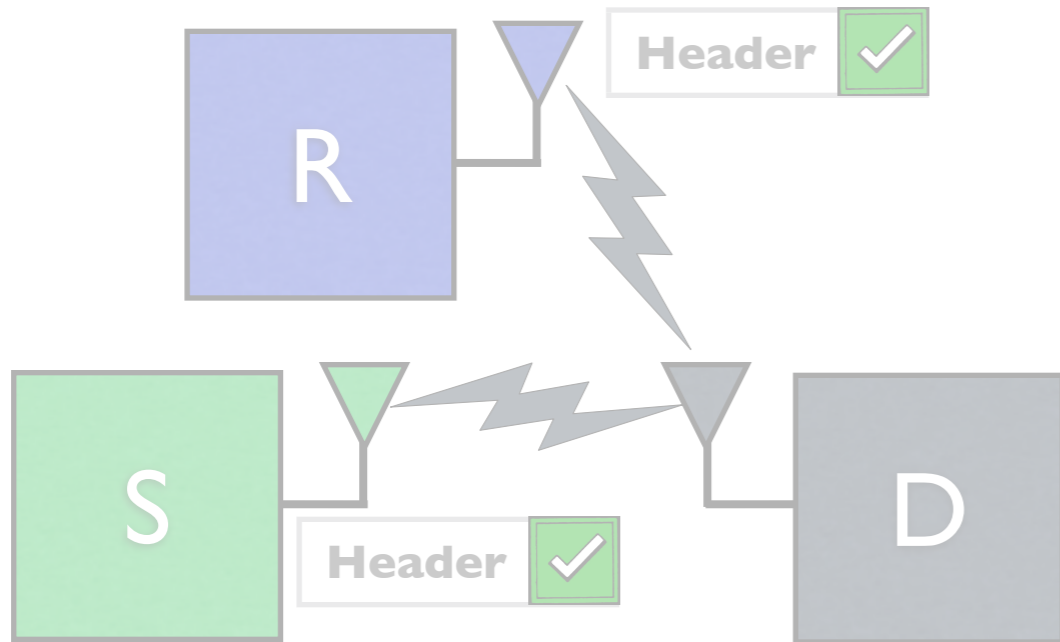


NACK Transmission

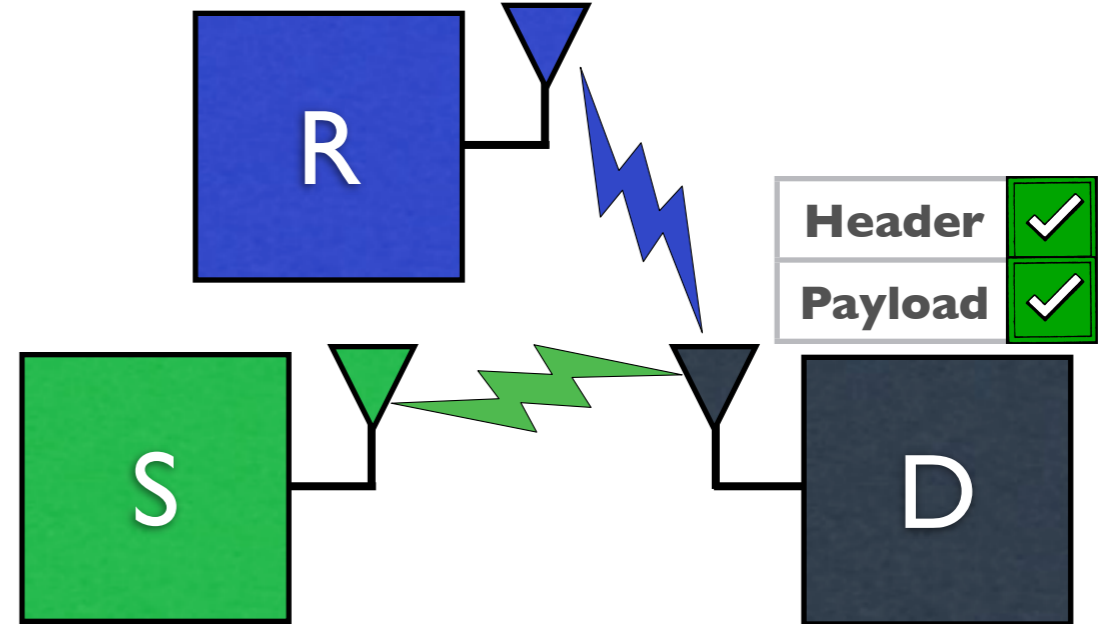


Power-controlled DOC (PDOC)

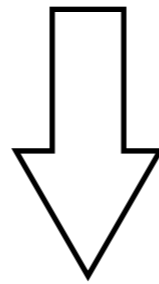
NACK Transmission



Coop. Retransmission
 $T_R = f(\text{SNR}_{SD}, \text{SNR}_{RD})$

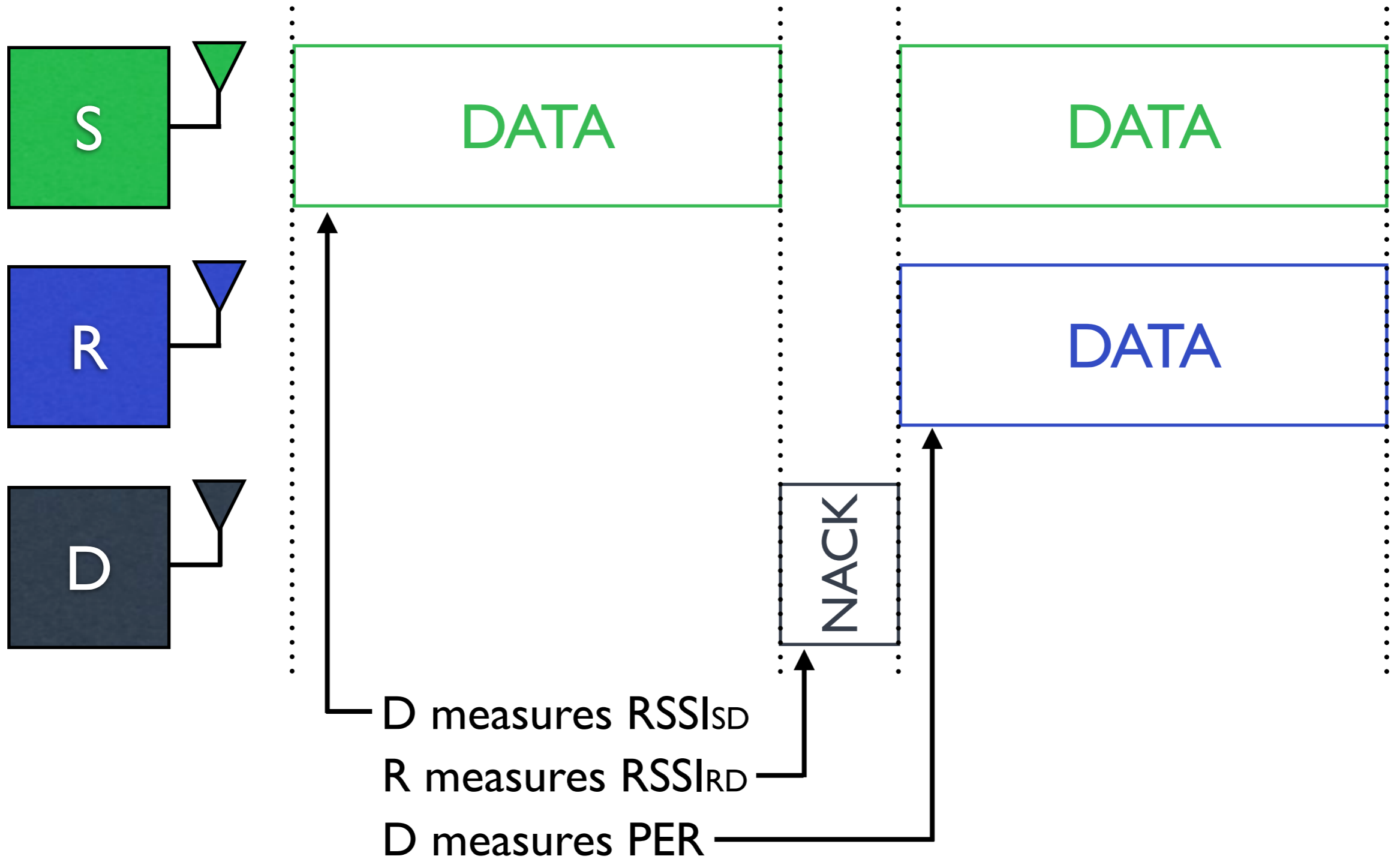


$$T_R = f(\text{SNR}_{SD}, \text{SNR}_{RD})$$



$$T_R = f(\text{RSSI}_{SD}, \text{RSSI}_{RD})$$

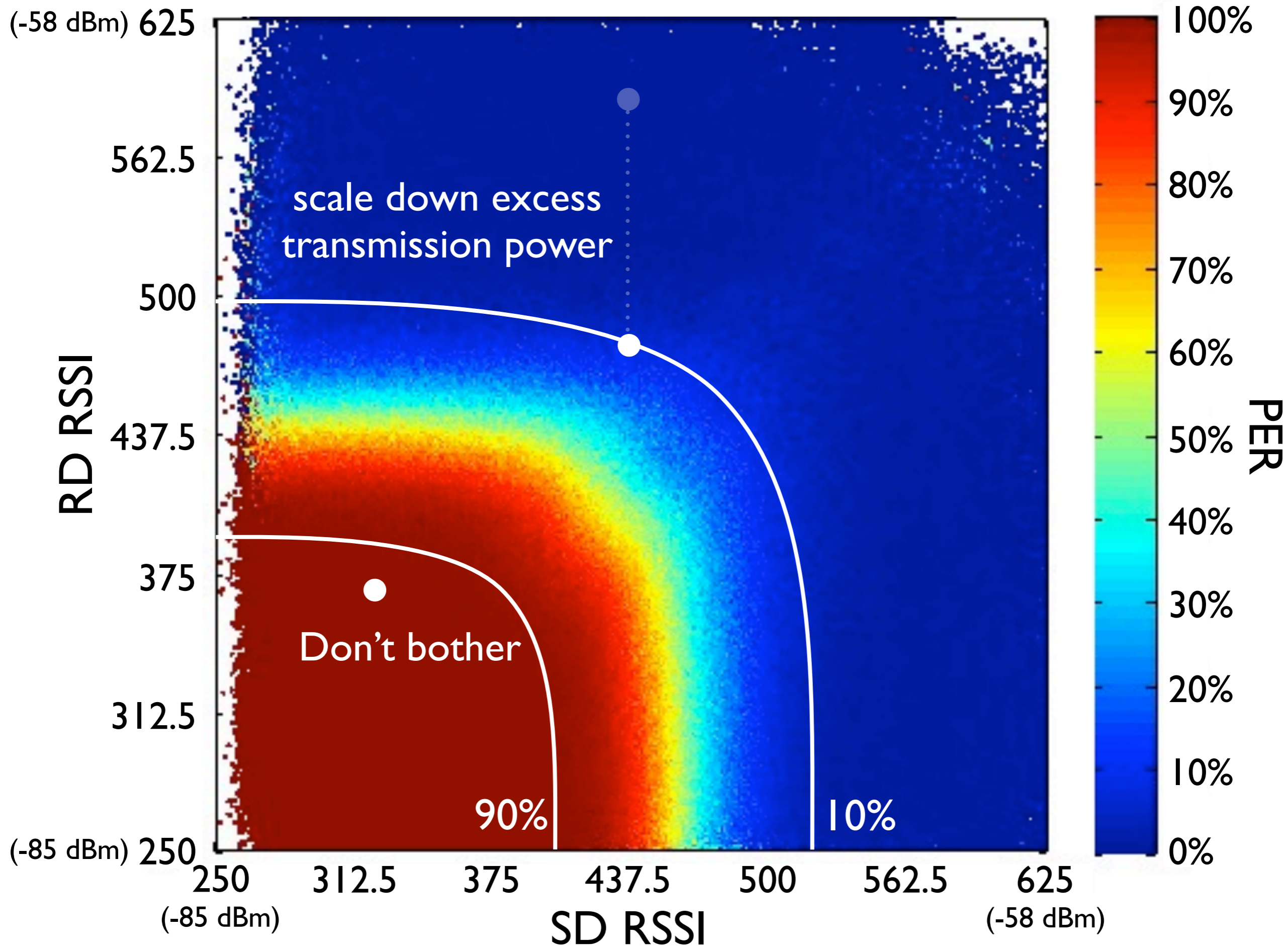
Train this function for the performance of our PHY
(offline... only have to do it once)

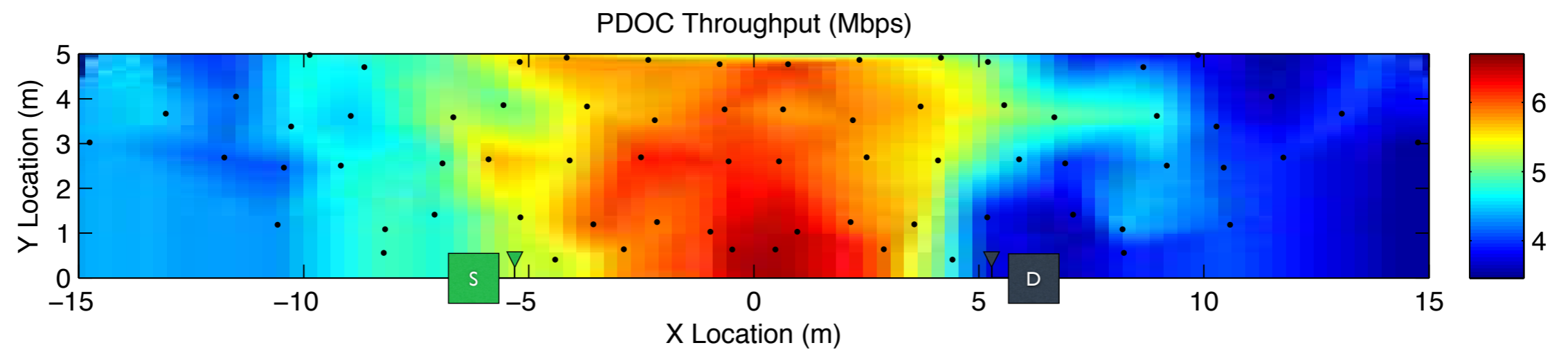
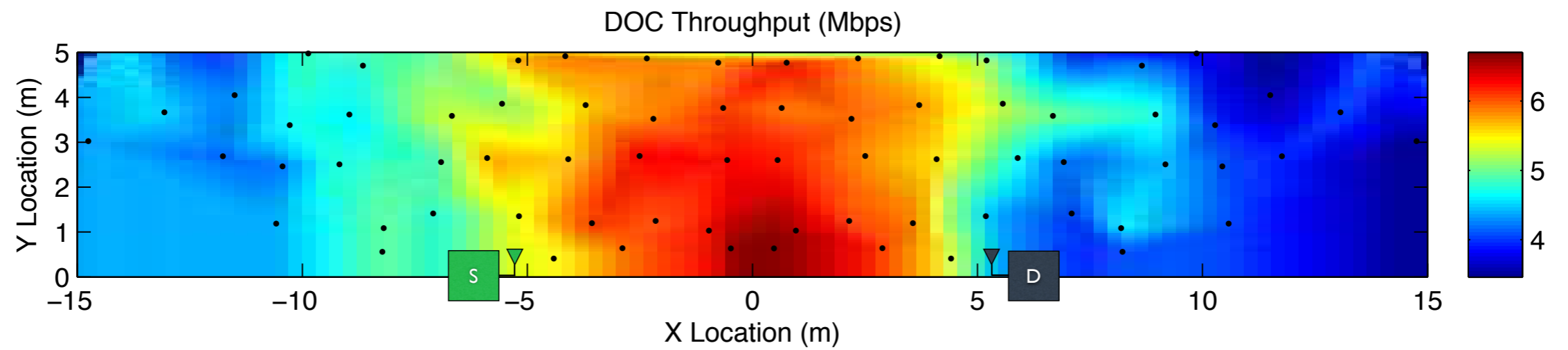


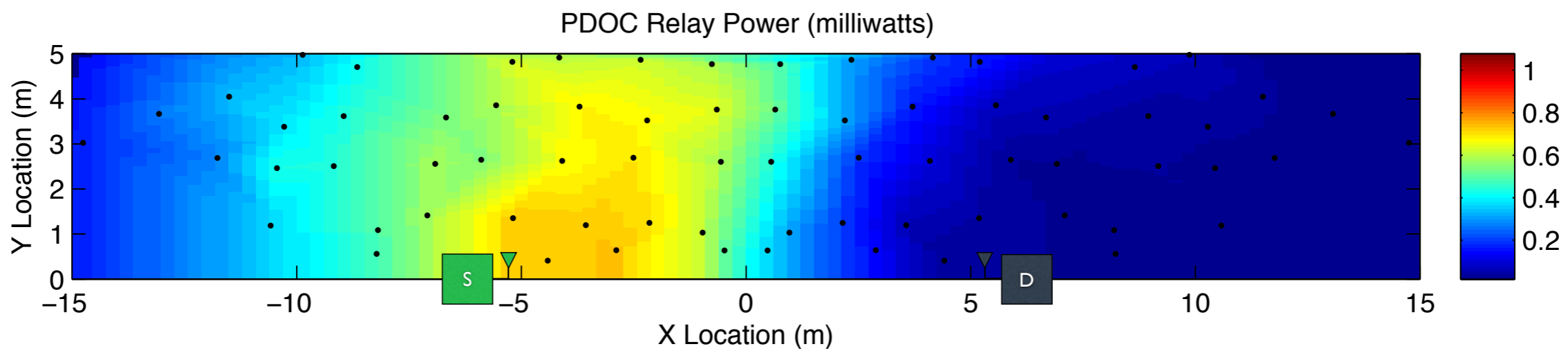
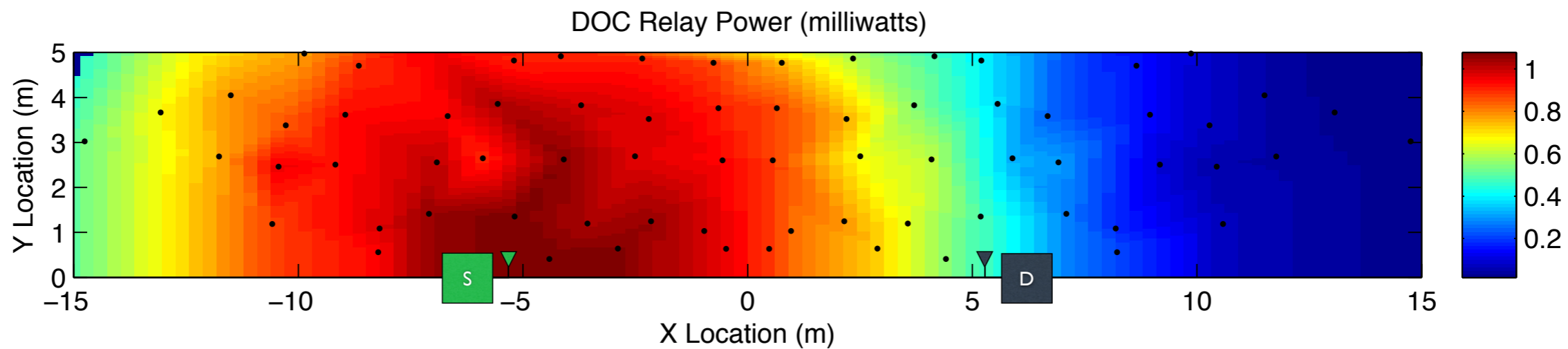


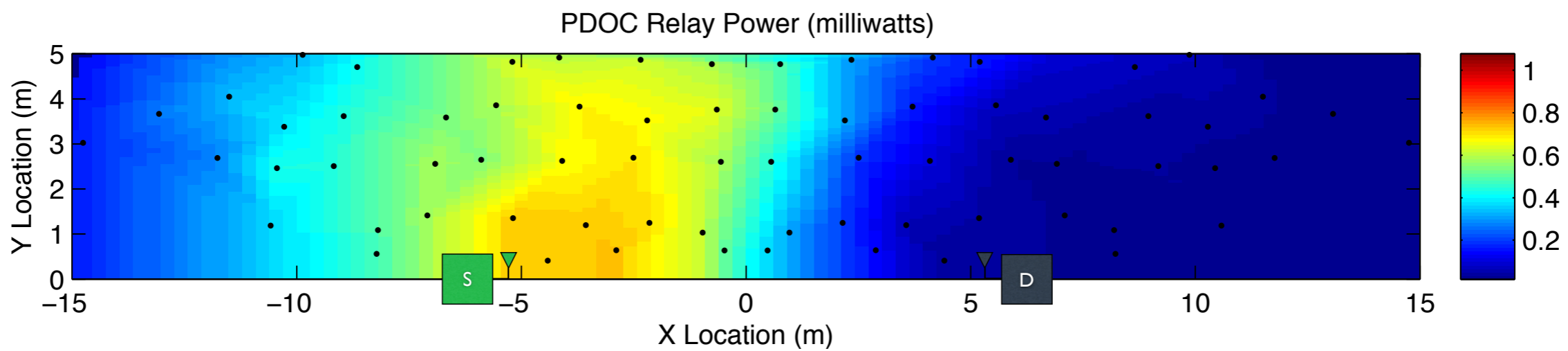
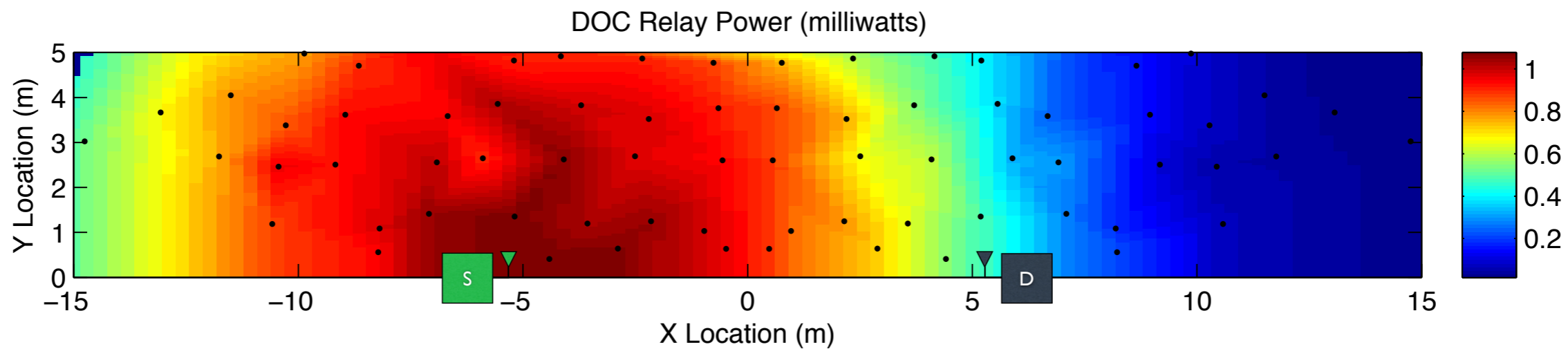
single tap, Rayleigh fading, 1.2km/hr

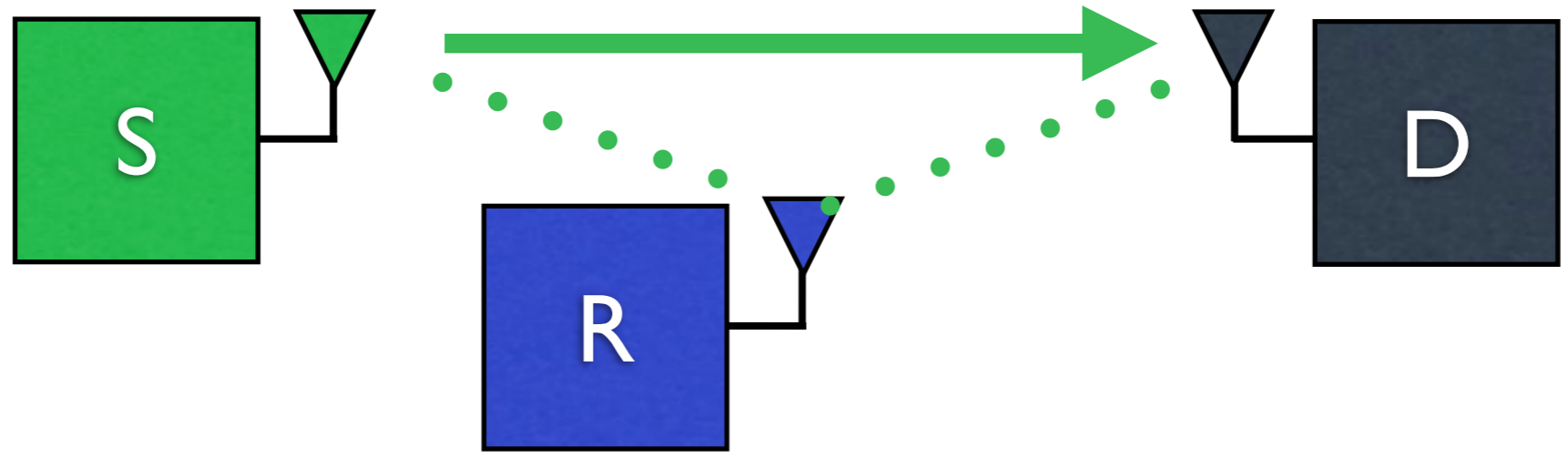
(16-QAM, 1300 byte packets)

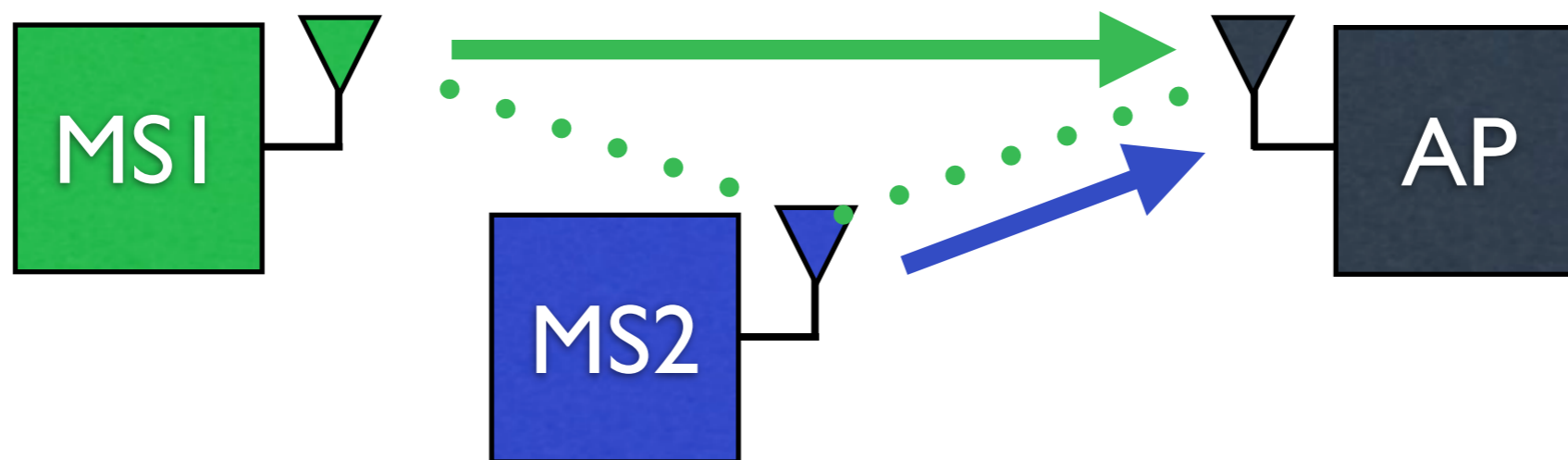












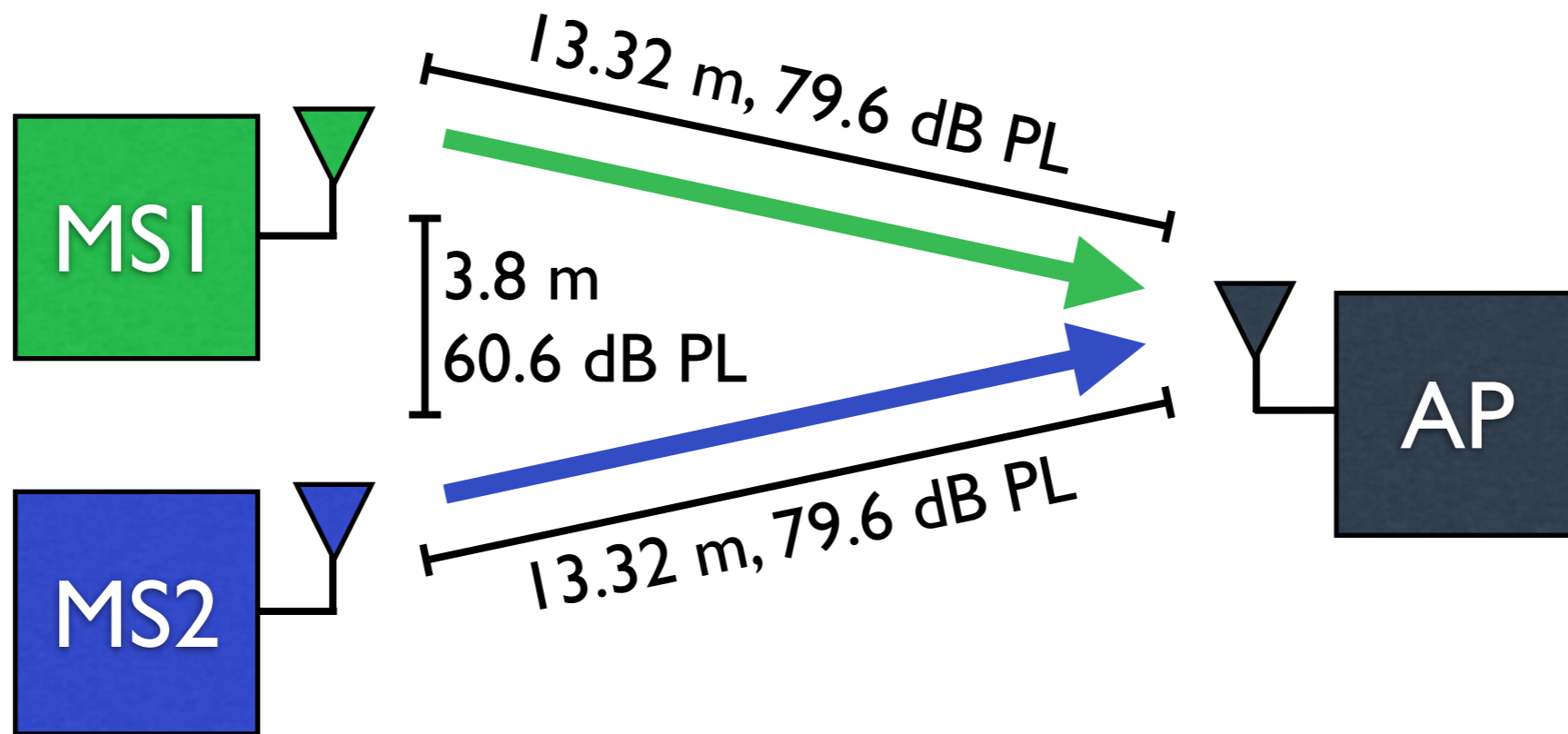
Key Metric: Energy Efficiency

$$\gamma = \frac{\# \text{ of bits transmitted + received (bits)}}{\text{total energy spent (joule)}}$$

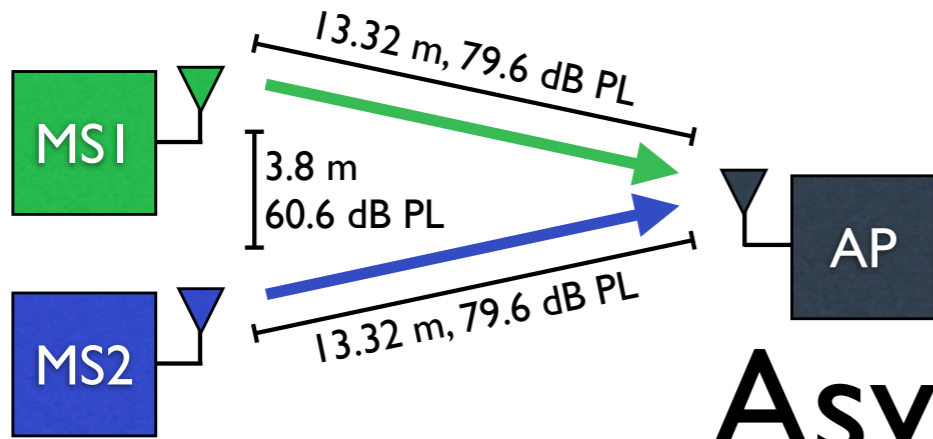
Key Metric: Energy Efficiency

$$\gamma = \frac{\# \text{ of } \textit{bits relevant to my traffic}}{\textit{energy related to all traffic}} \frac{(\text{bits})}{(\text{joule})}$$

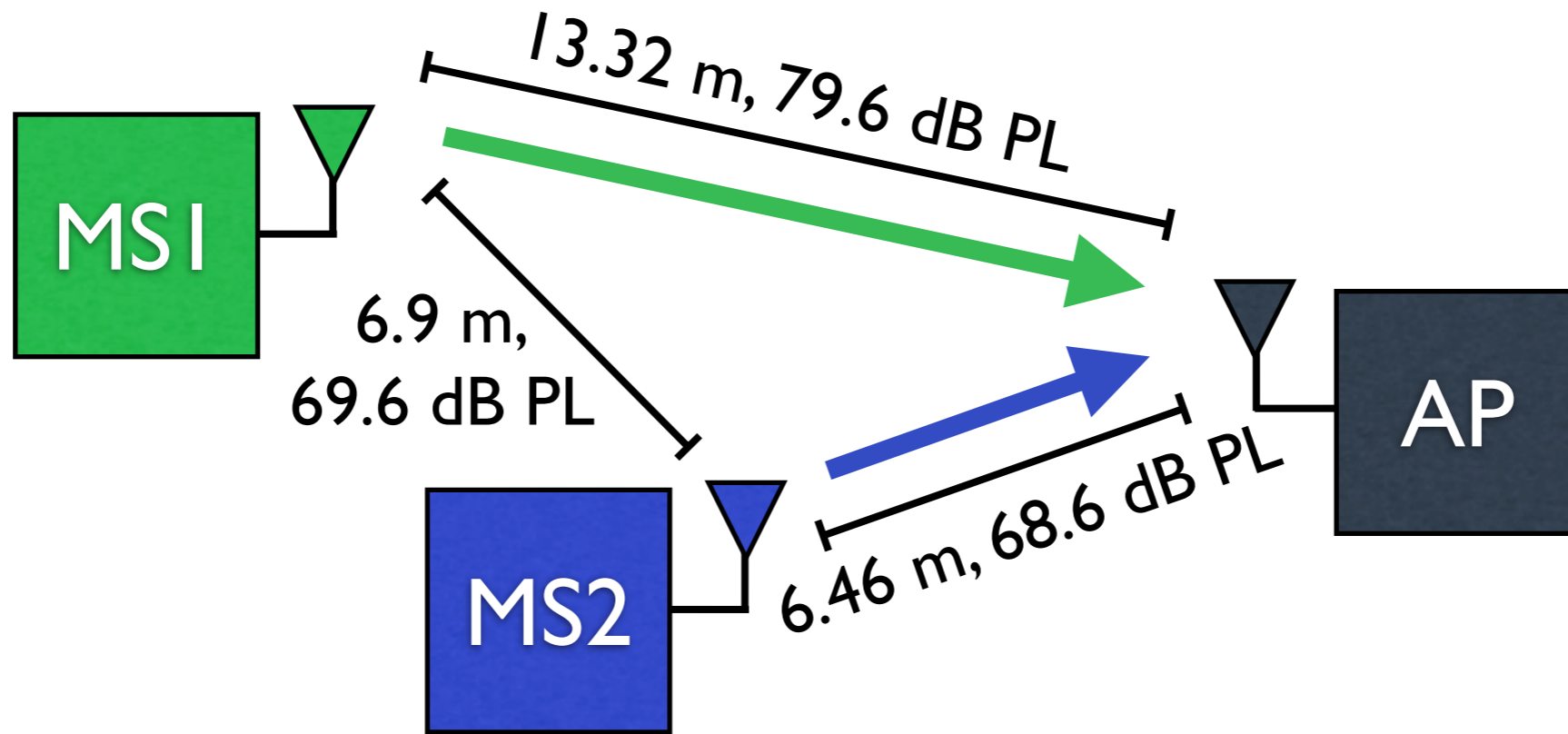
Symmetric



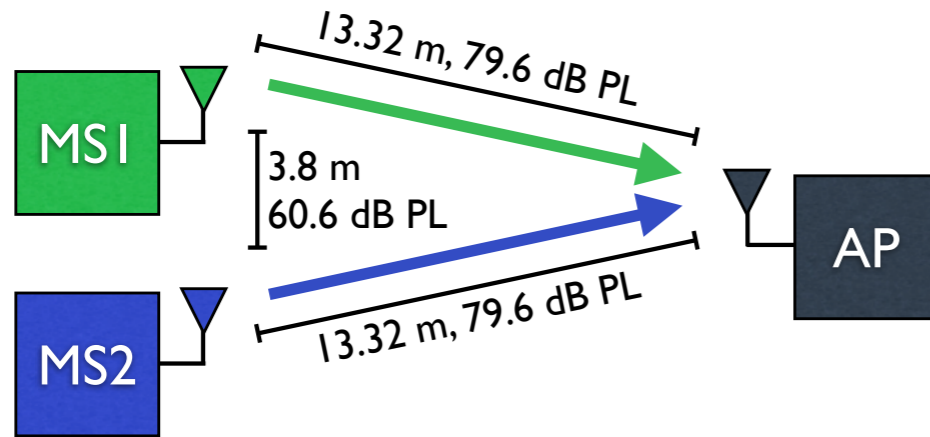
Symmetric



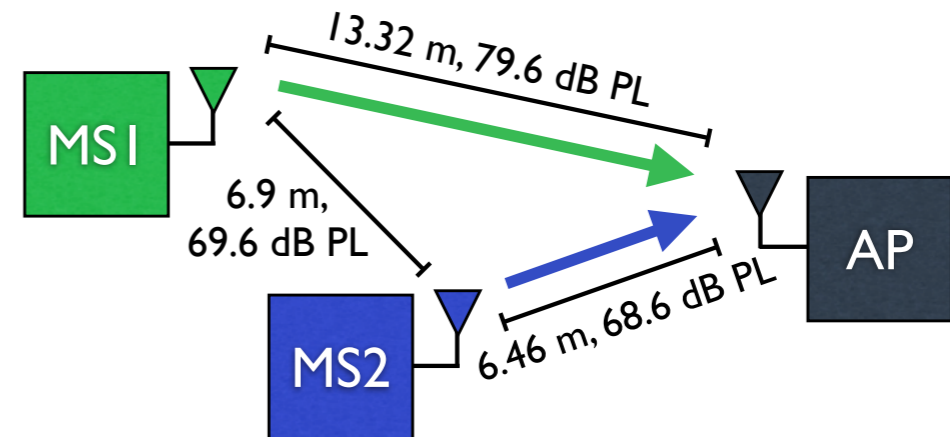
Asymmetric



Symmetric

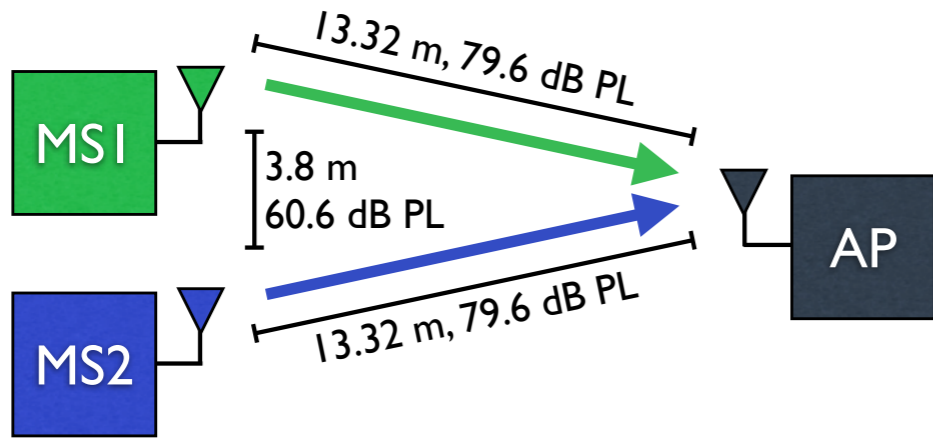


Asymmetric

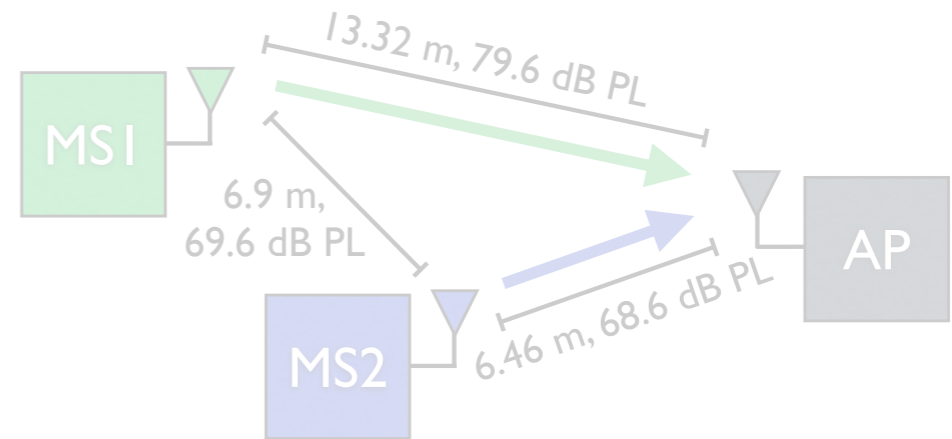


- Backlogged traffic
- 15, 120 second trials - error bars are std. across trials
- Cumulative transmission of over 2.7 million packets

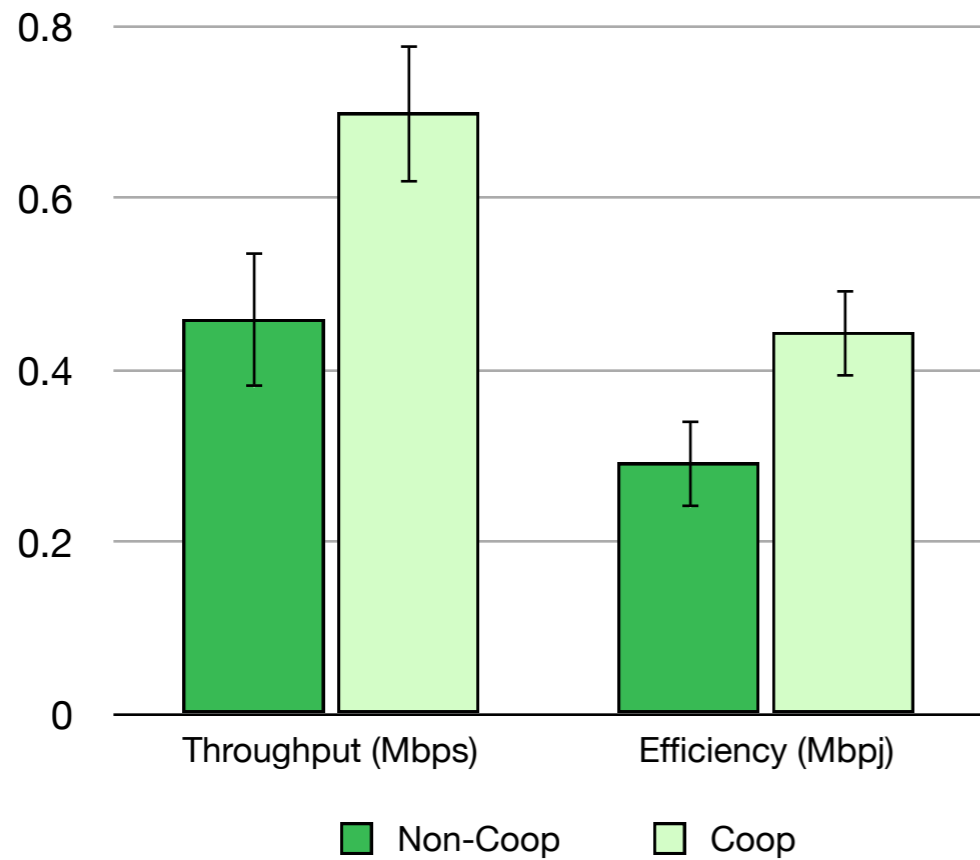
Symmetric



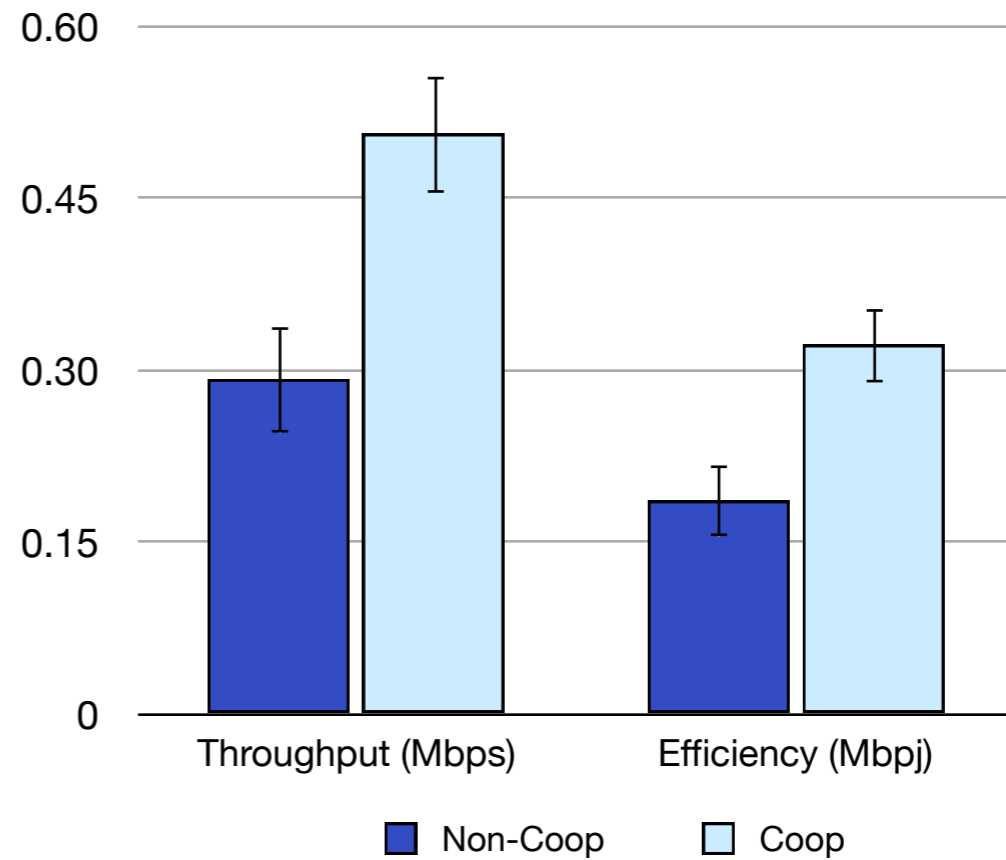
Asymmetric



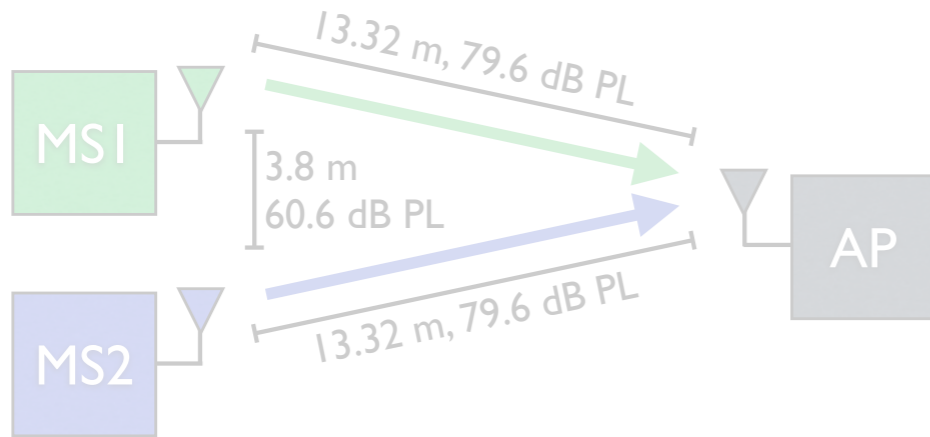
MSI



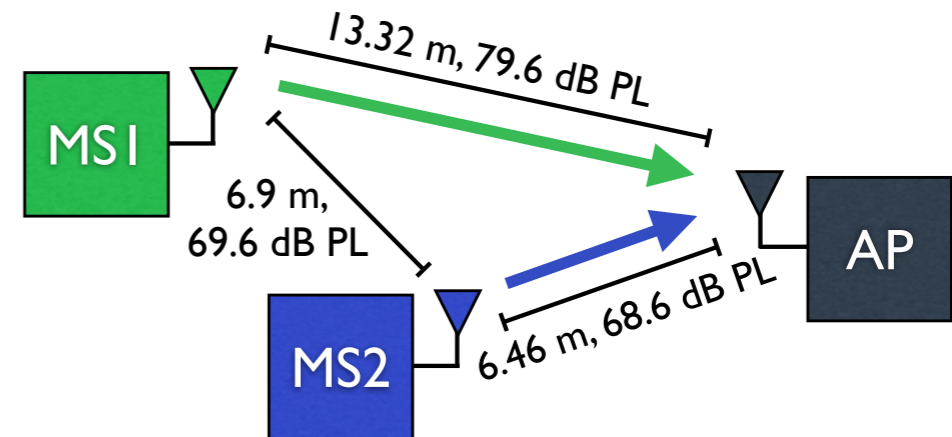
MS2



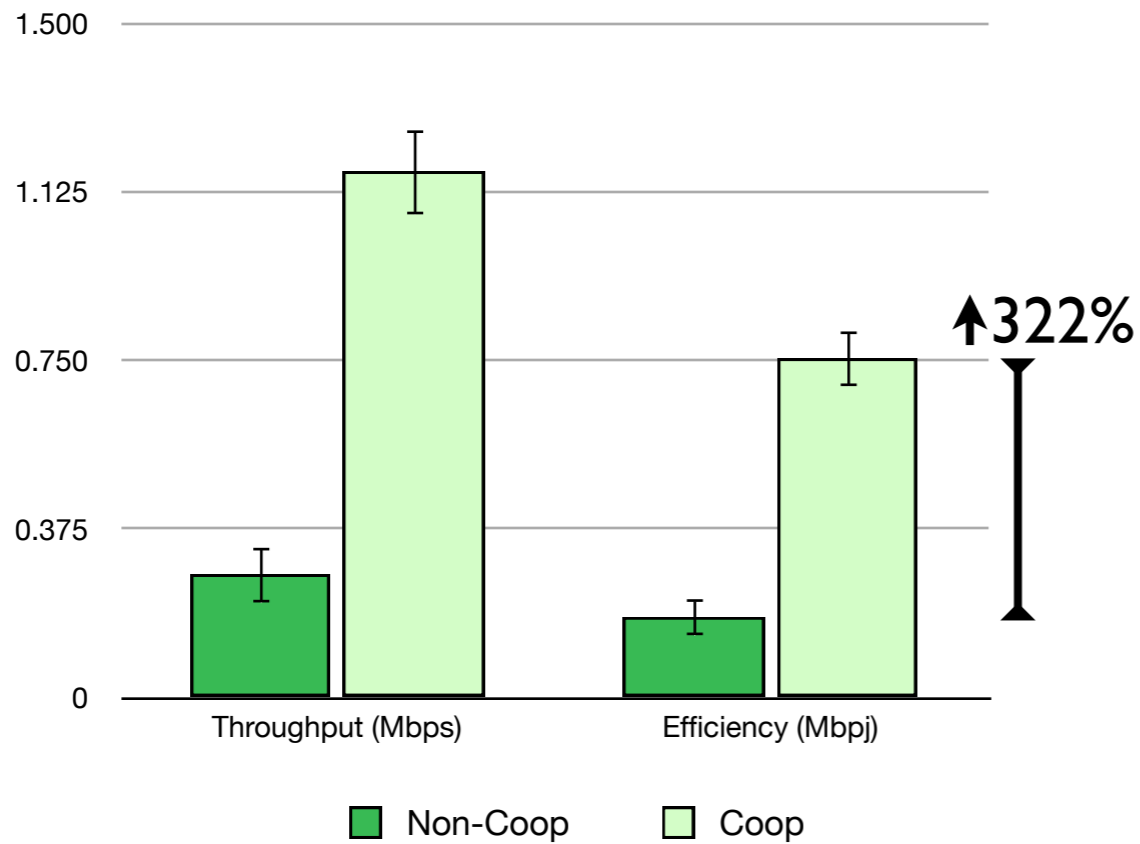
Symmetric



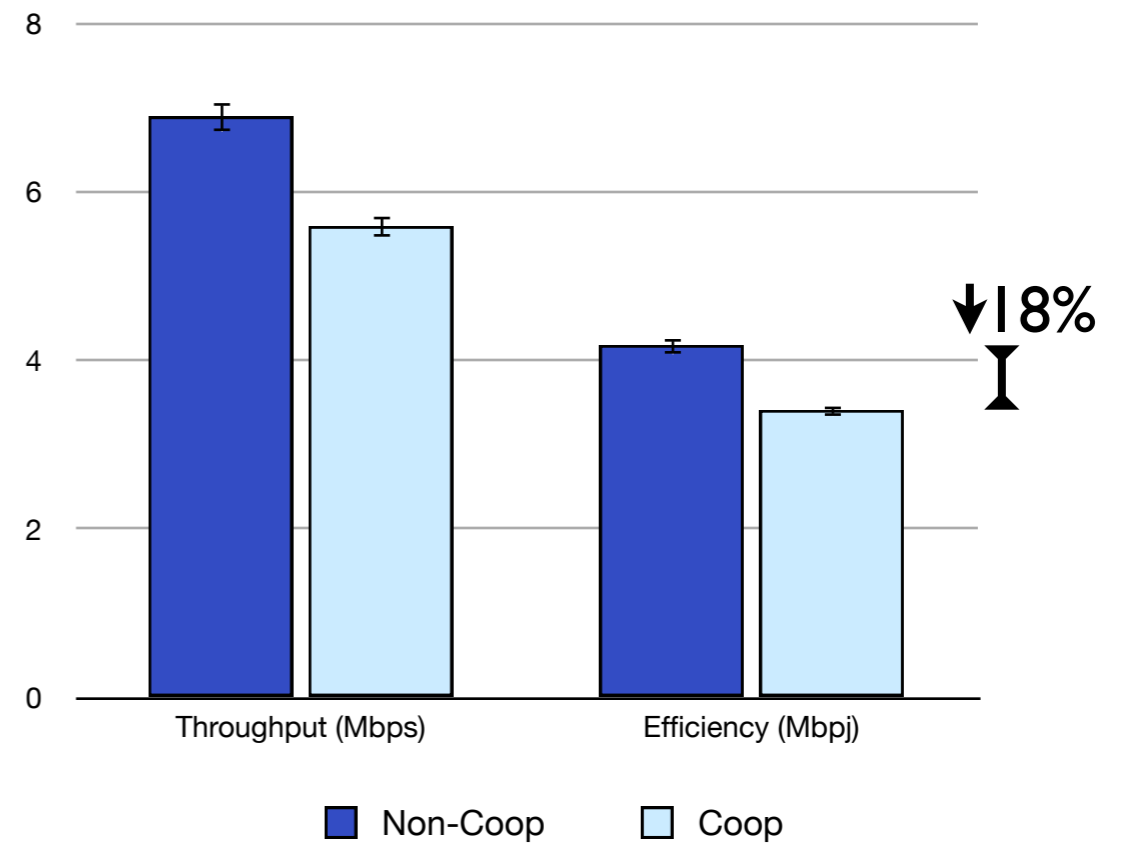
Asymmetric



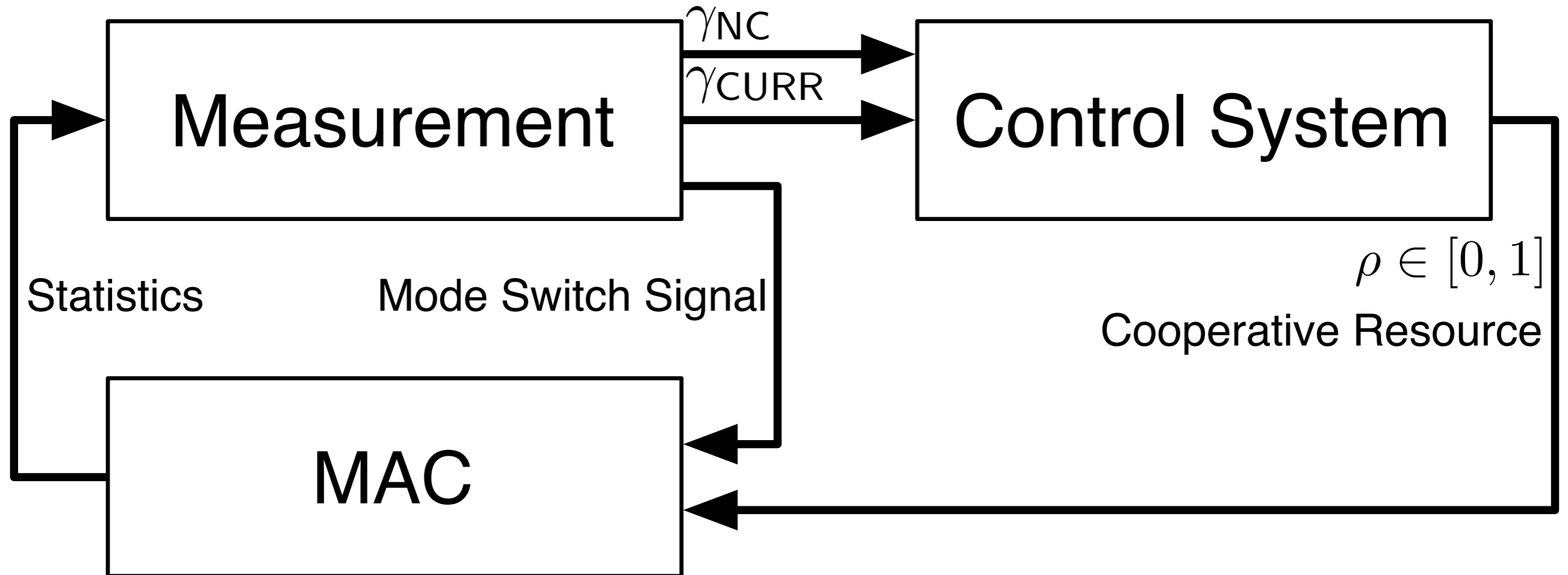
MS1



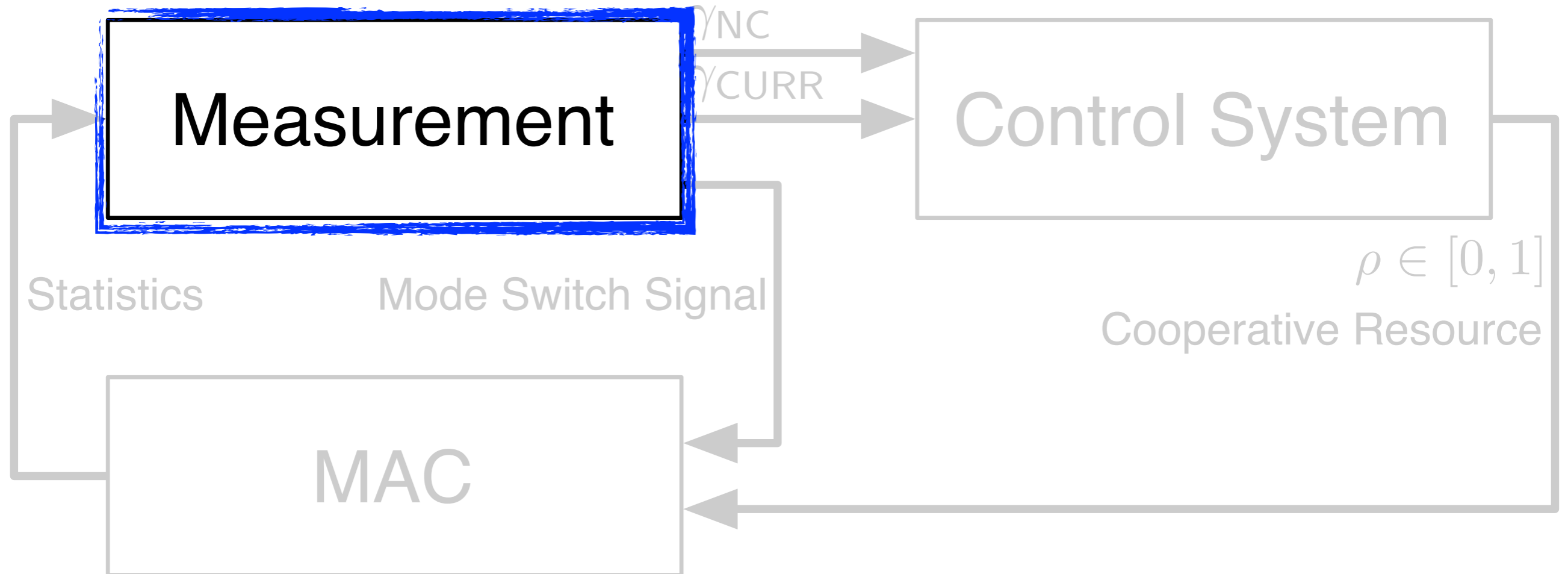
MS2



Distributed Energy-Conserving Cooperation (DECC)



Distributed Energy-Conserving Cooperation (DECC)



Non-Cooperative Mode	Cooperative Mode
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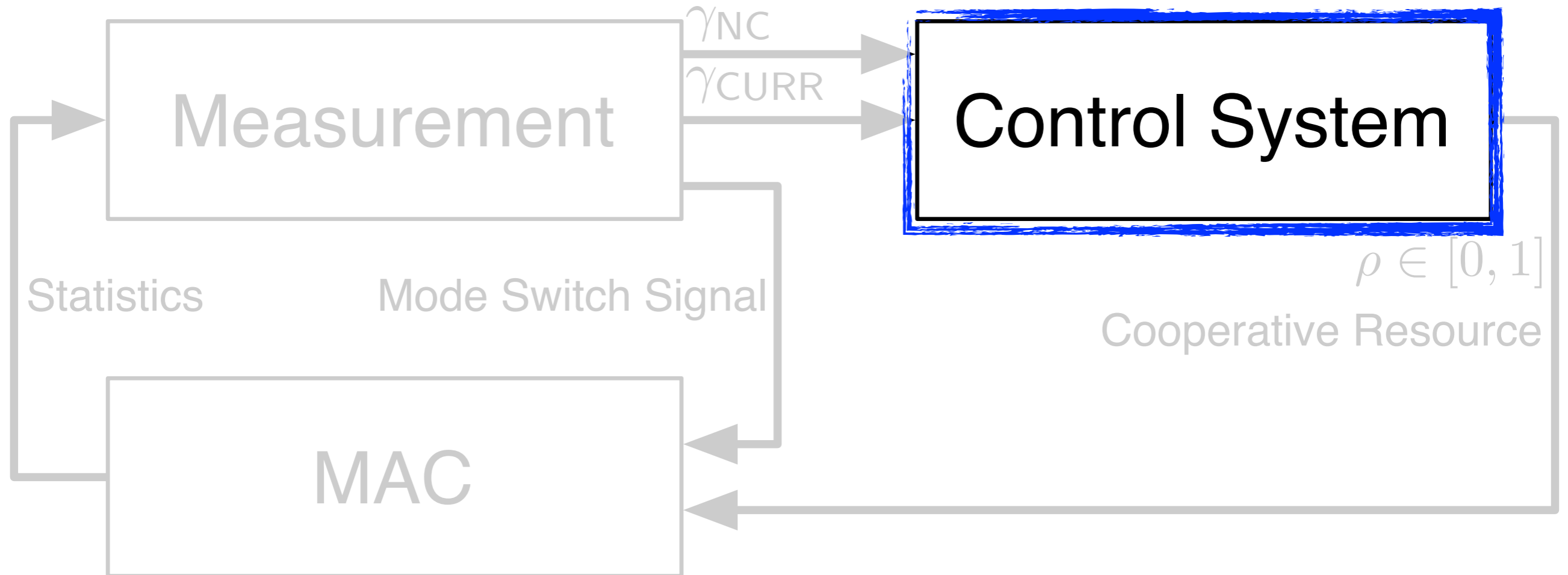
γ_{NC}

*energy efficiency if device
neither helped nor was
helped by others*

γ_{CURR}

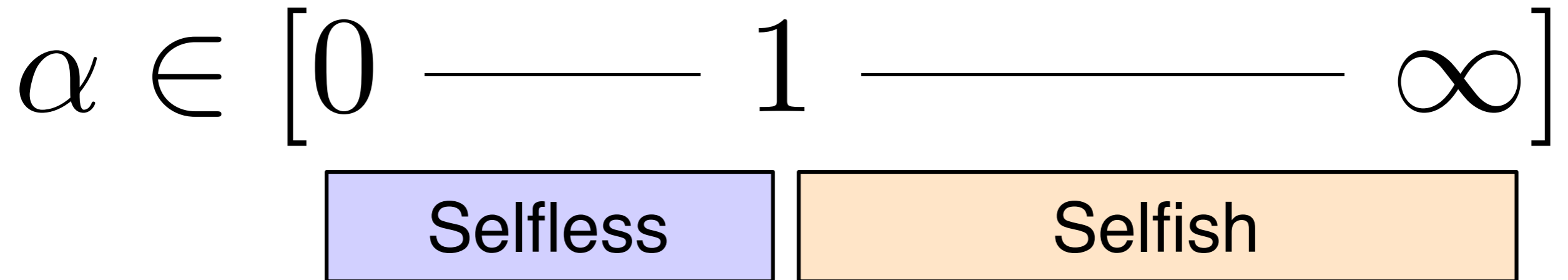
*energy efficiency including
the benefits and costs of
cooperation*

Distributed Energy-Conserving Cooperation (DECC)

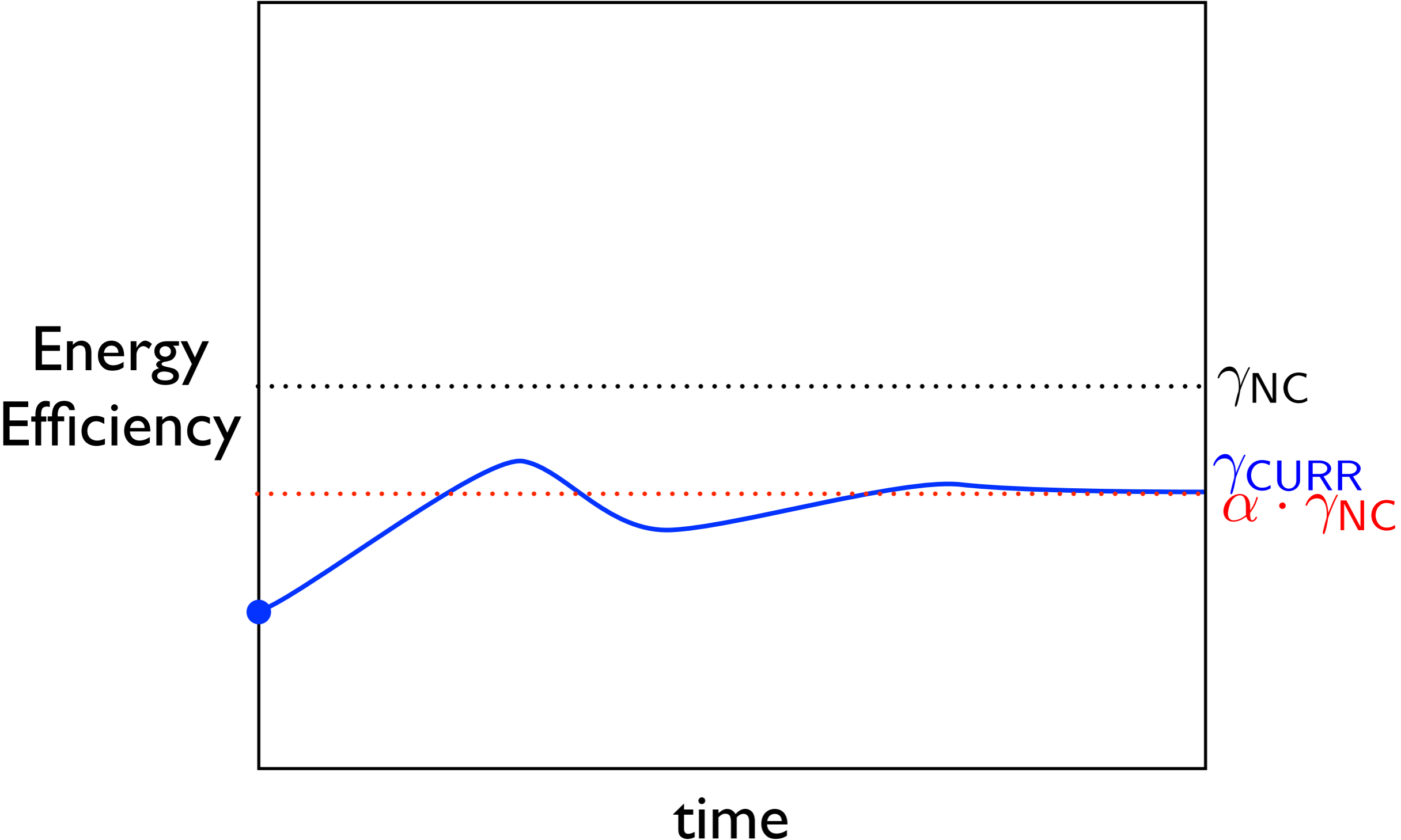


Bounded Altruism

Altruism Parameter:



Bounded Altruism



Bounded Altruism

Cooperative Resource $\rho \in [0, 1]$

Energy
Efficiency

$\rho = 0$ Never help others

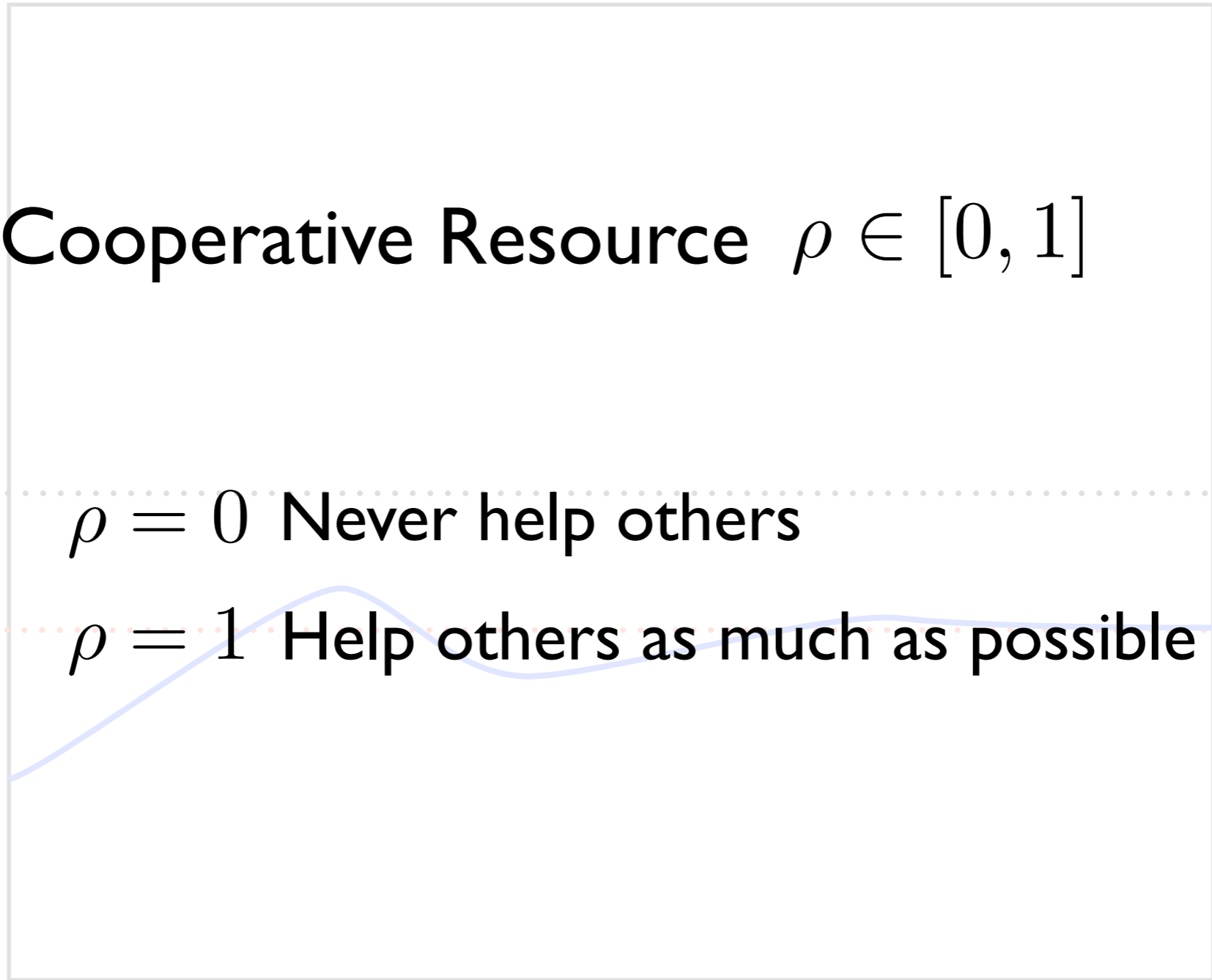
$\rho = 1$ Help others as much as possible

γ_{NC}

γ_{CURR}

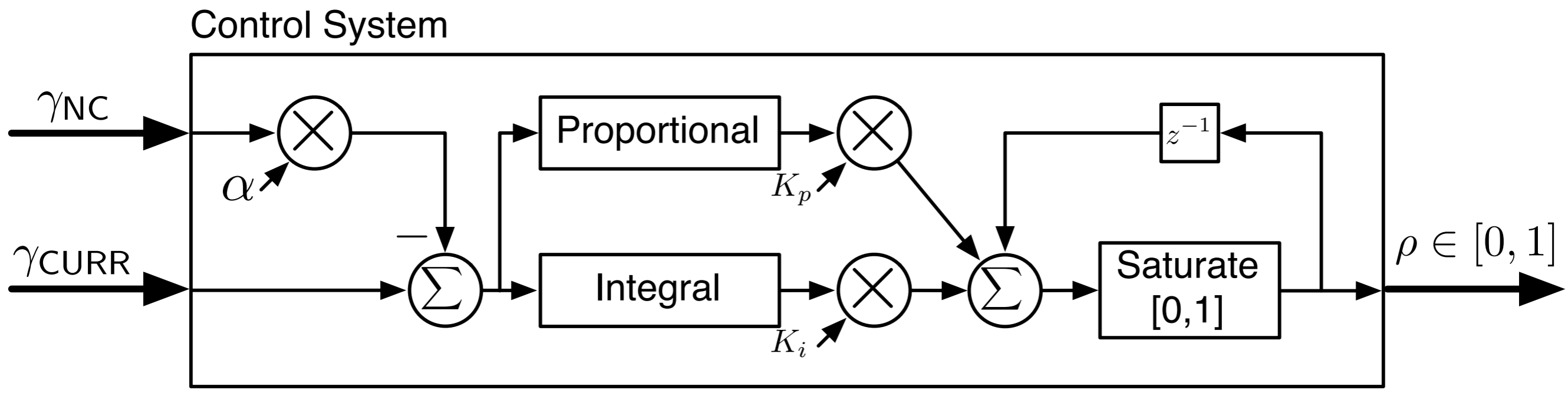
$\alpha \cdot \gamma_{NC}$

time

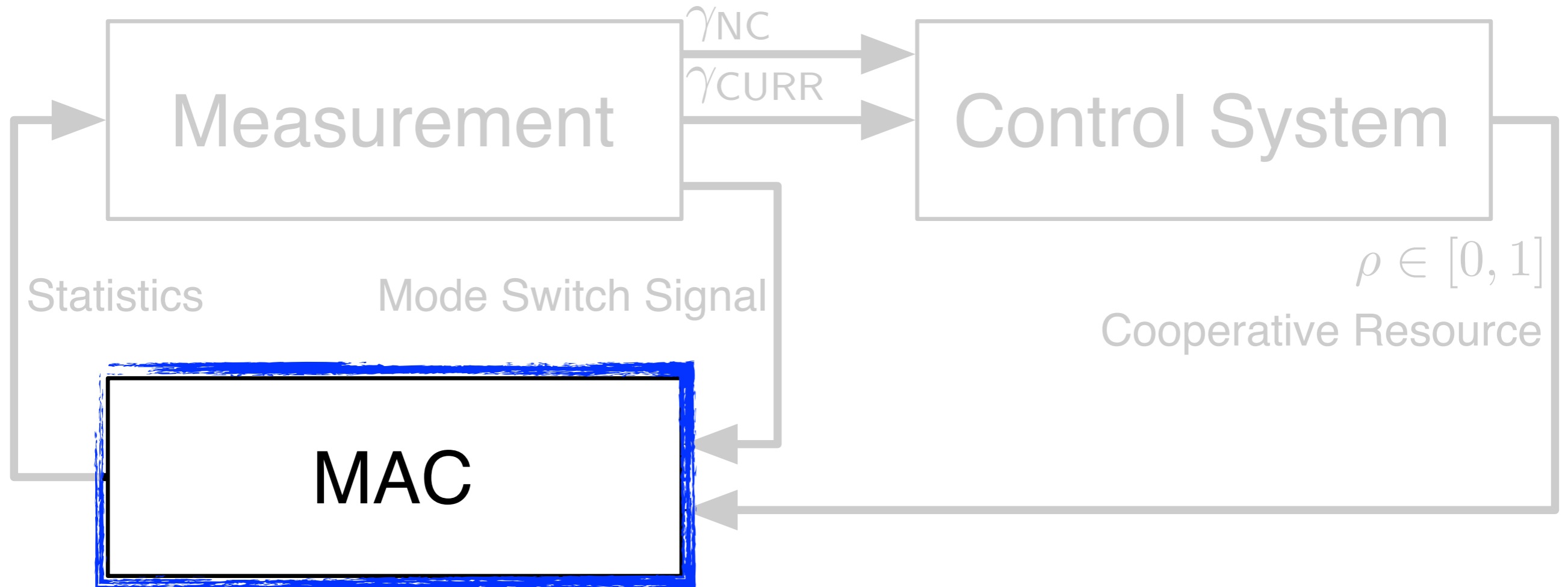


$$\gamma_{\text{CURR}} > \alpha \cdot \gamma_{\text{NC}} \quad \uparrow \rho$$

$$\gamma_{\text{CURR}} < \alpha \cdot \gamma_{\text{NC}} \quad \downarrow \rho$$



Distributed Energy-Conserving Cooperation (DECC)



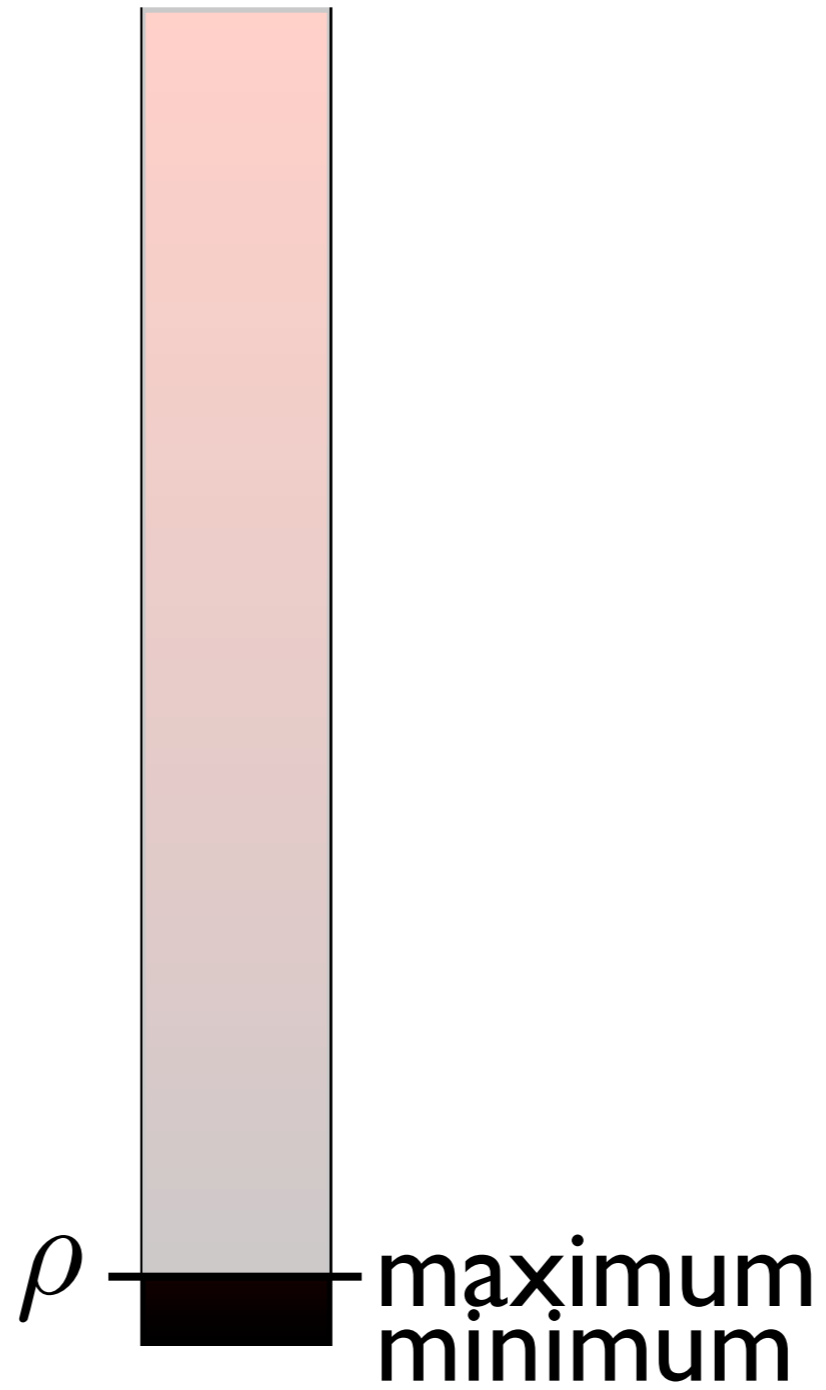
Relay Transmission Power

ρ maximum

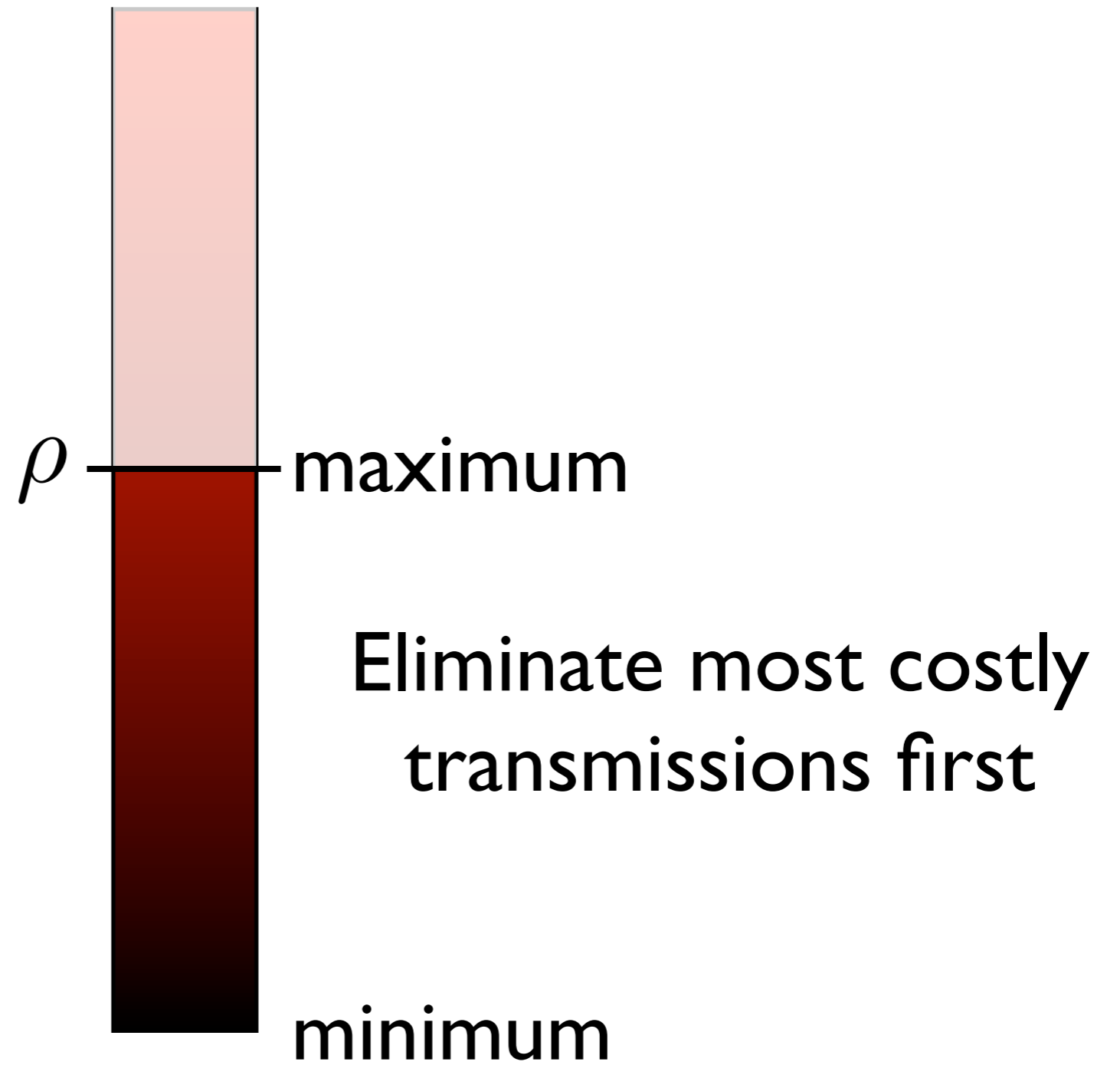


minimum

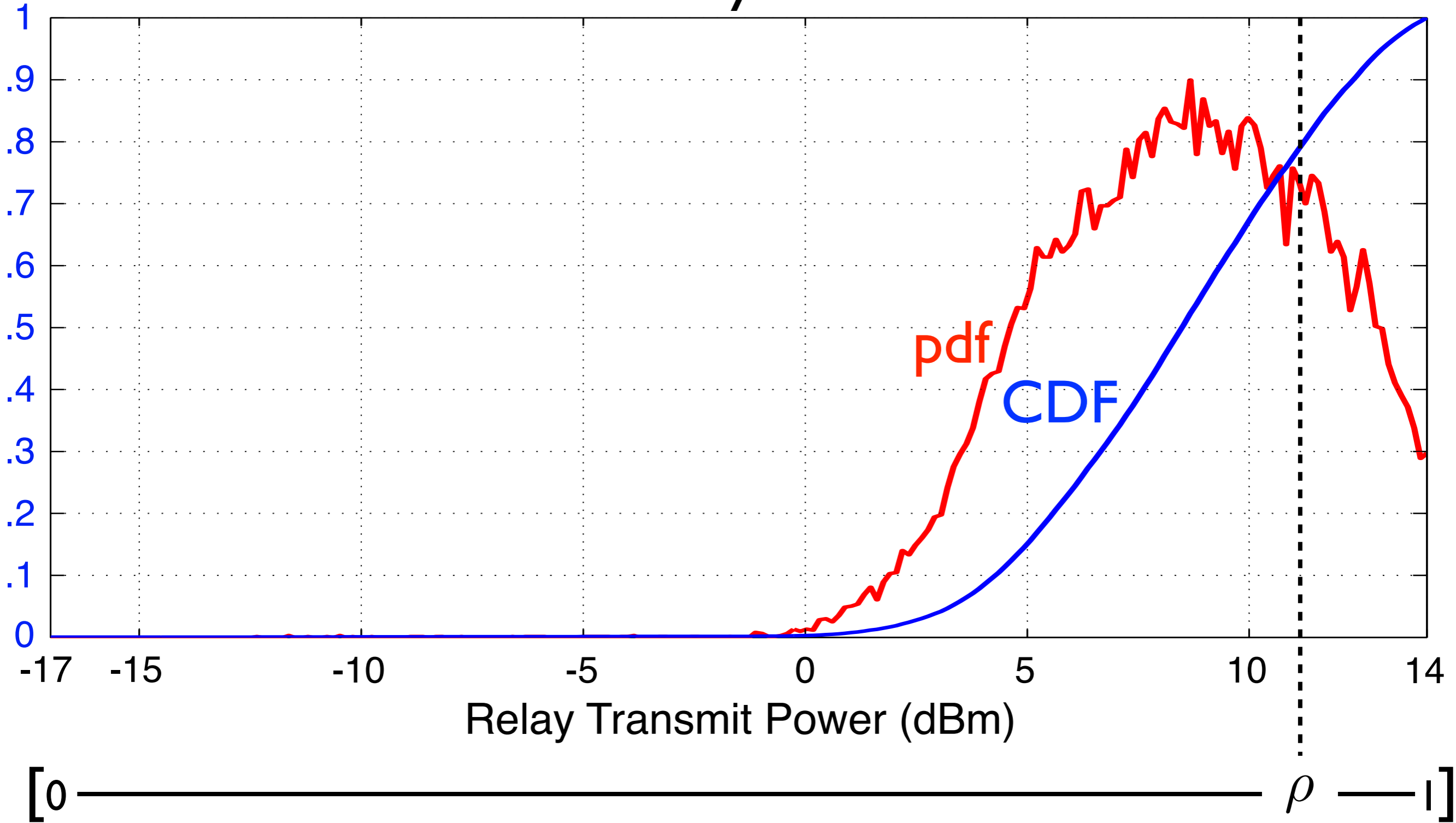
Relay Transmission Power



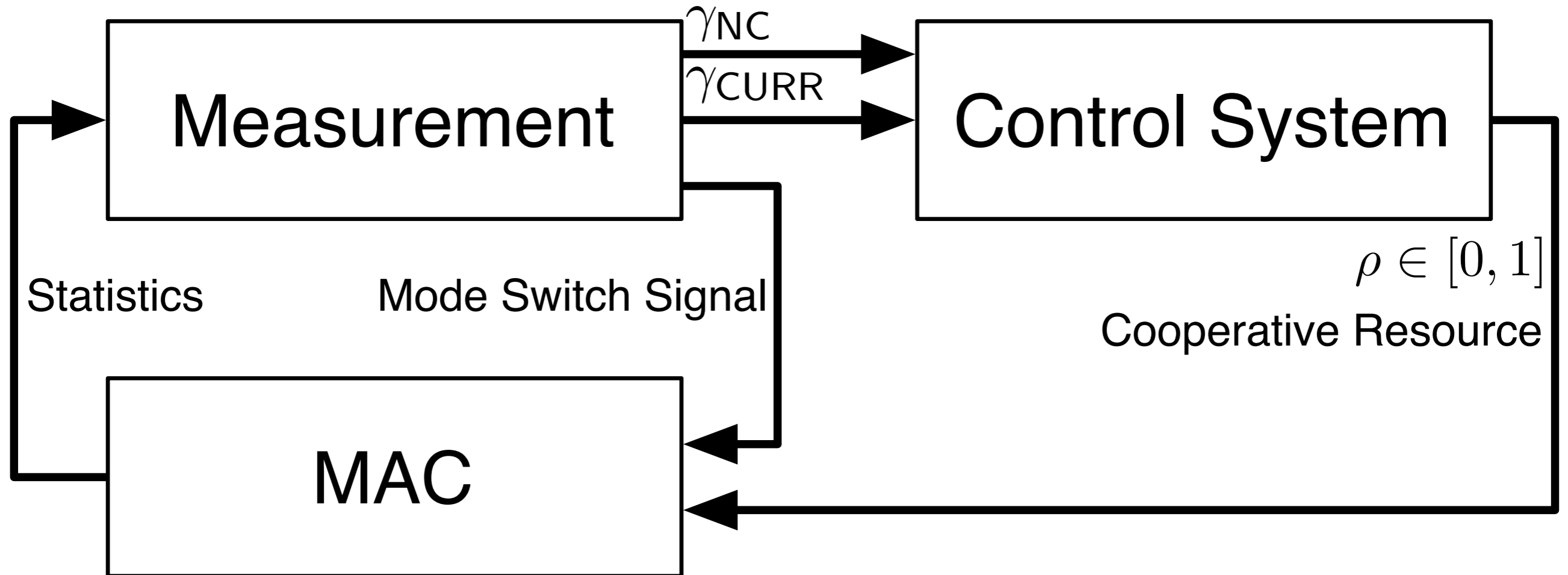
Relay Transmission Power



PDOC Relay Tx Power

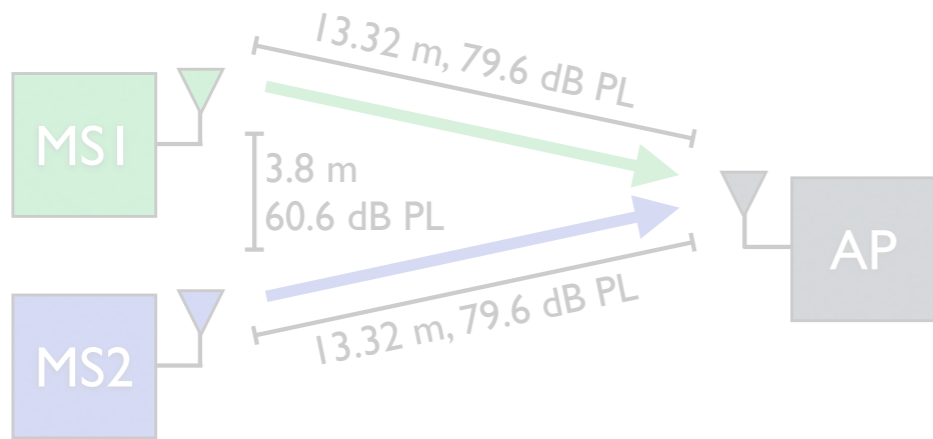


Distributed Energy-Conserving Cooperation (DECC)

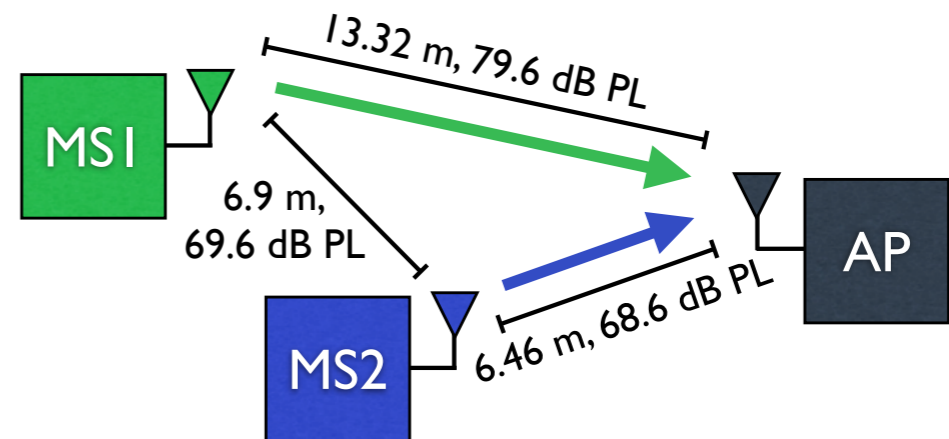


Built in real-time on WARP, all in software

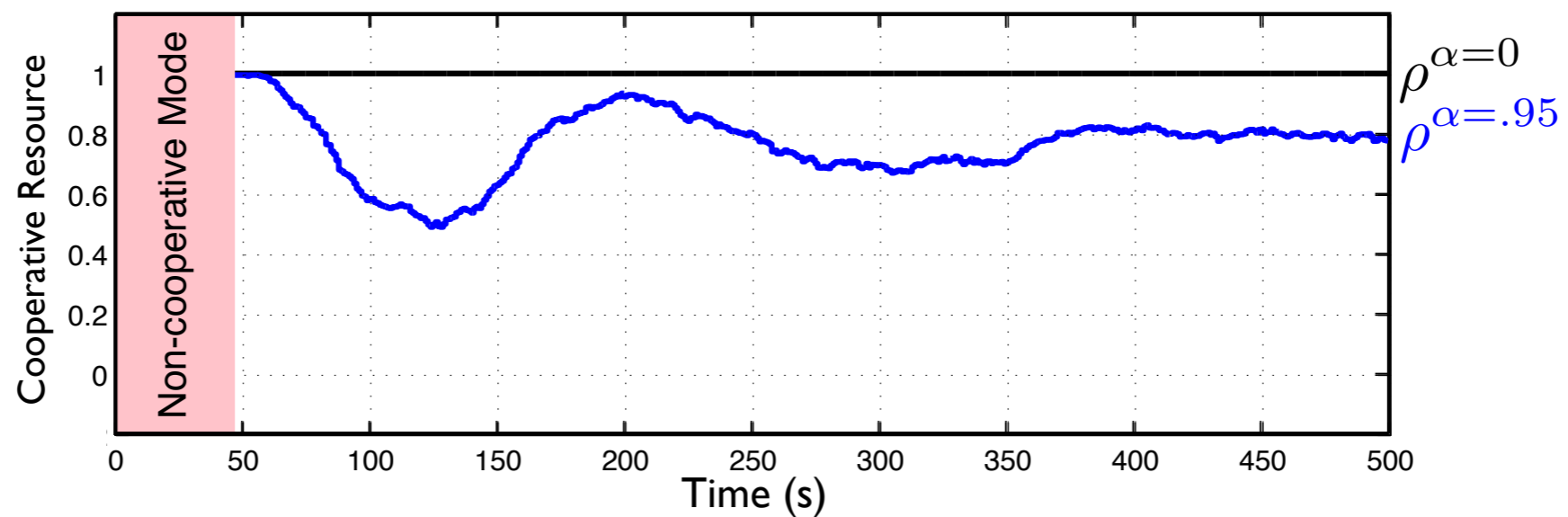
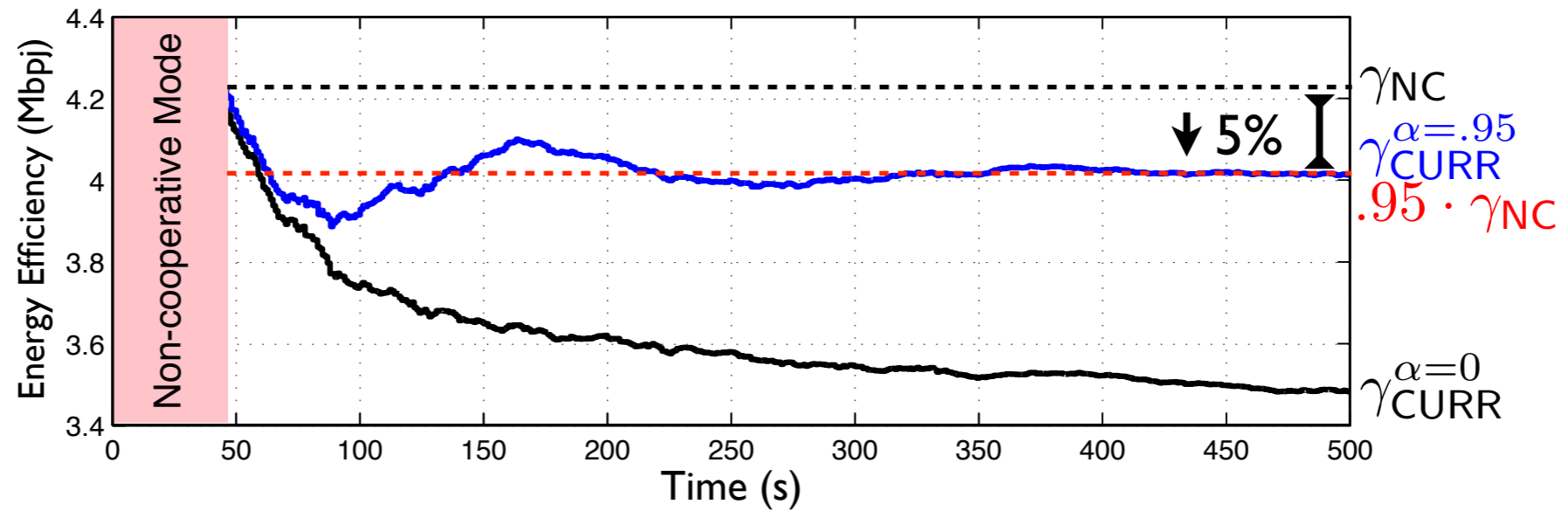
Symmetric



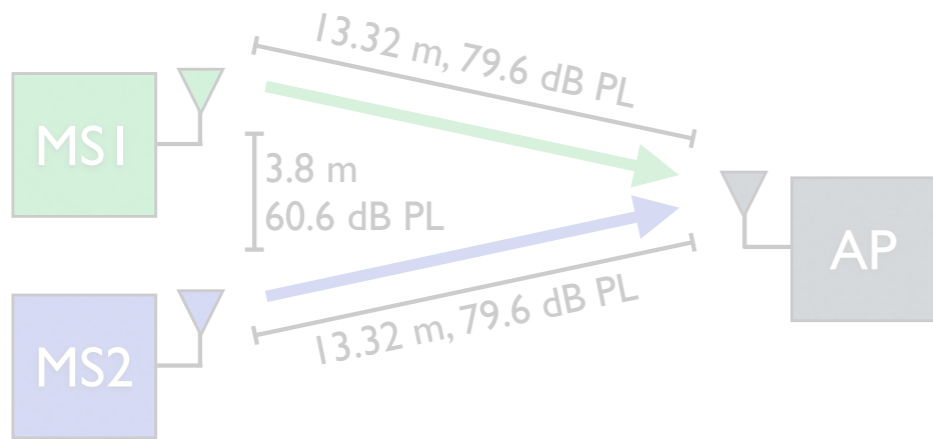
Asymmetric



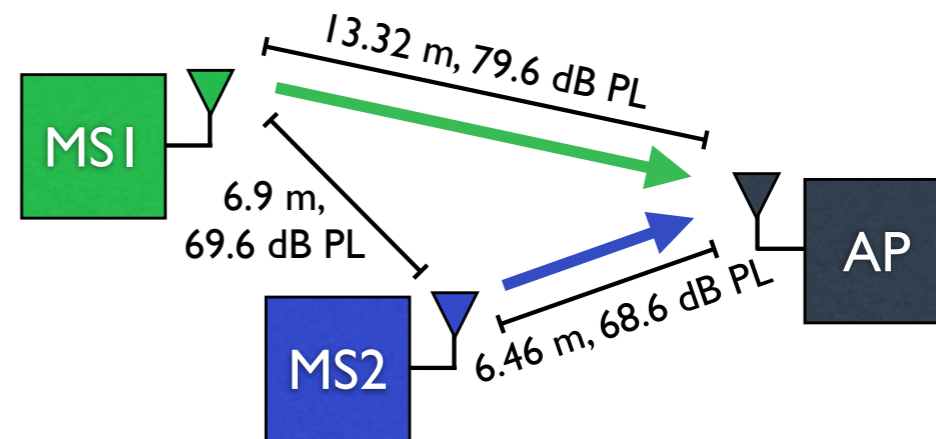
MS2



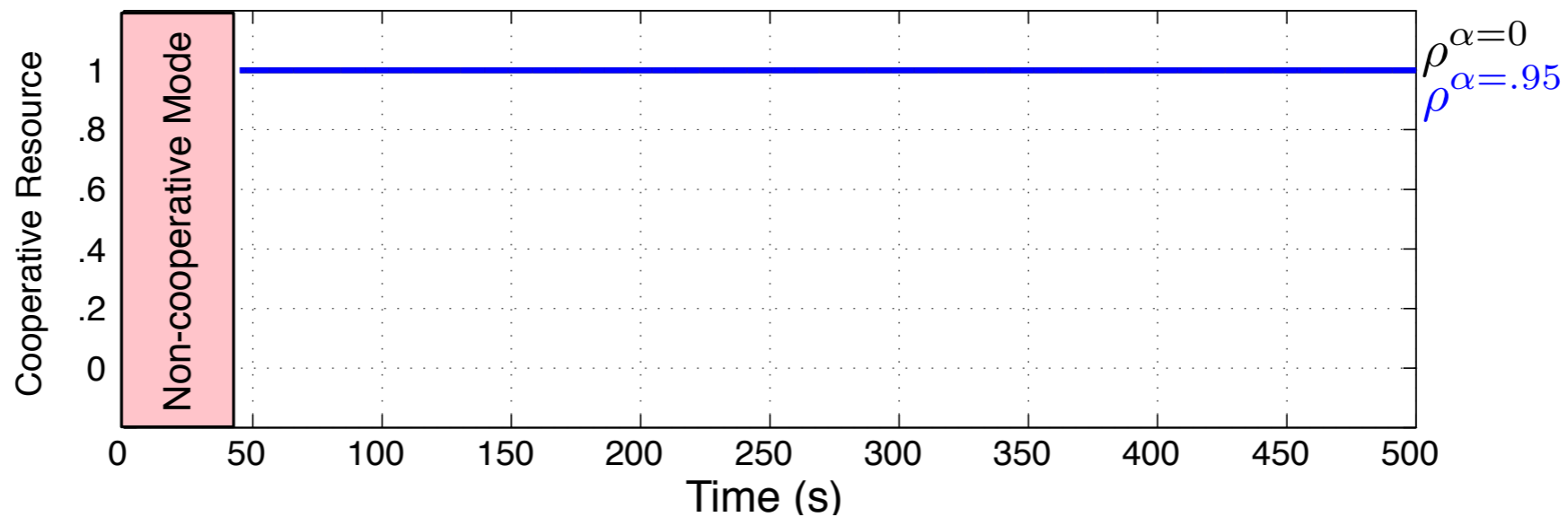
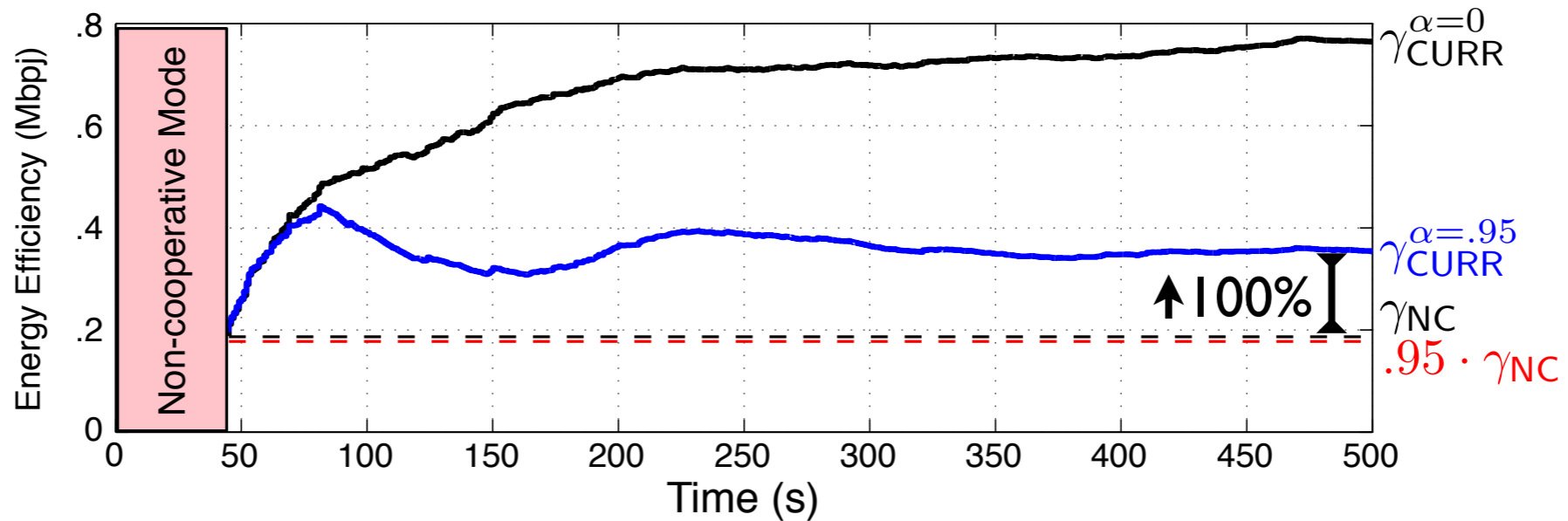
Symmetric

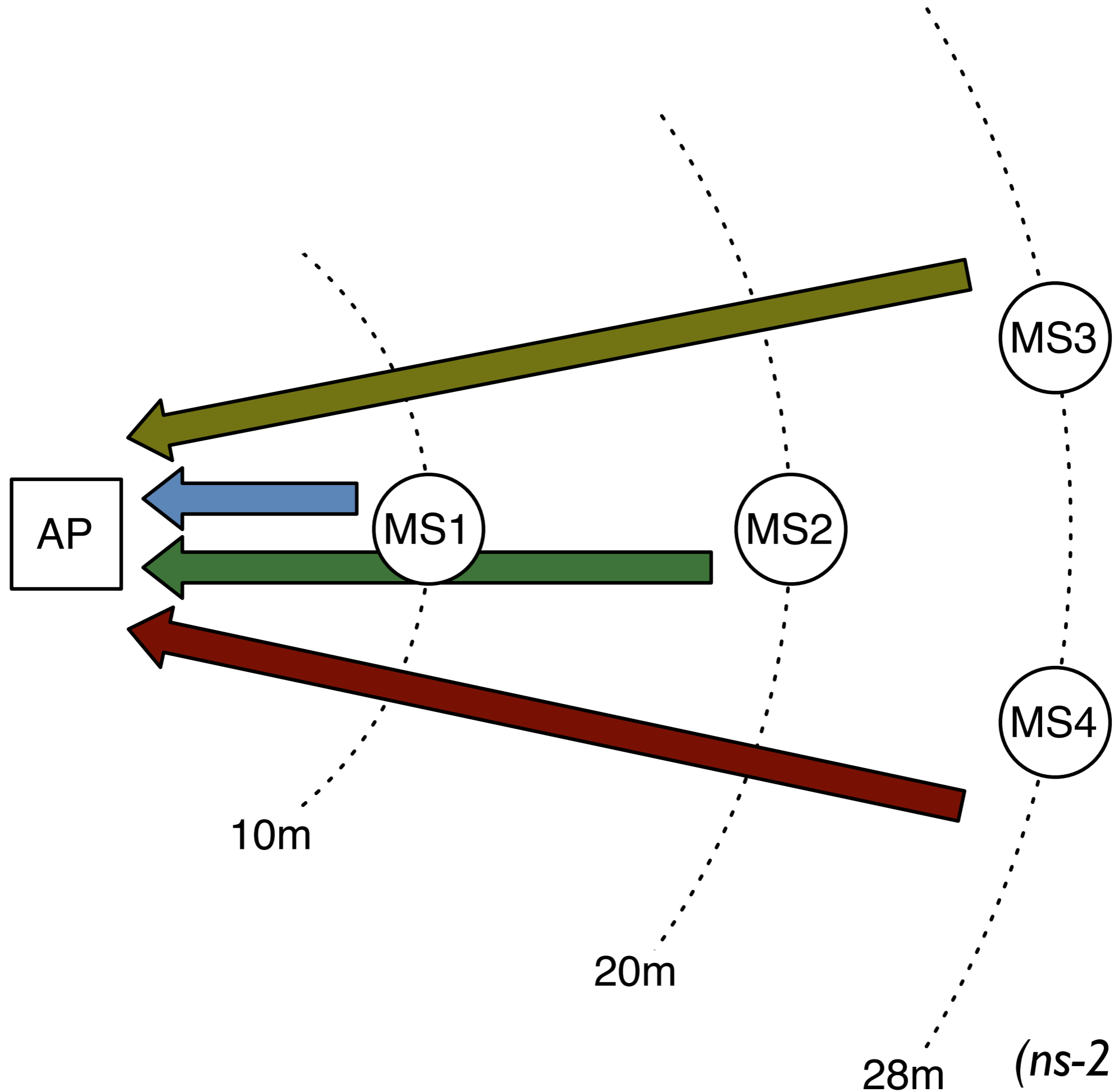


Asymmetric



MSI





MS3

MS1

MS2

MS4

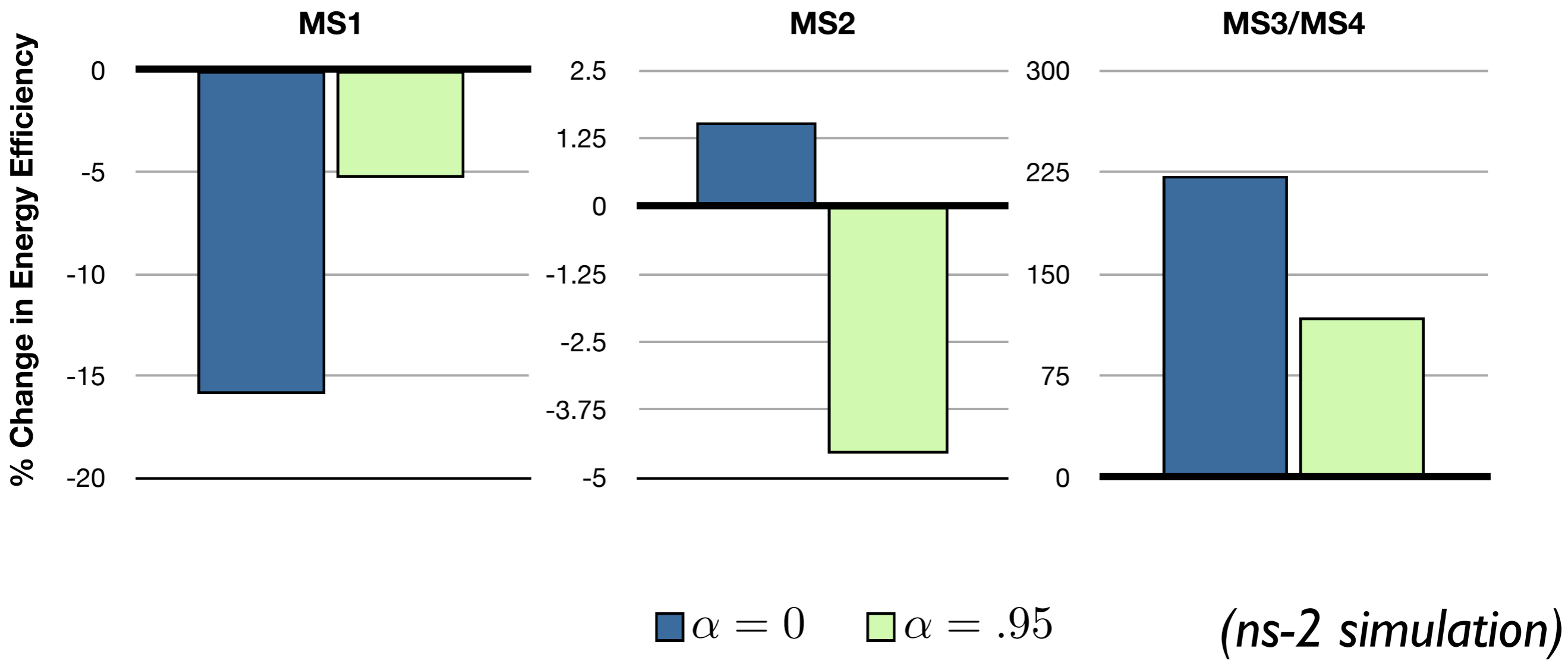
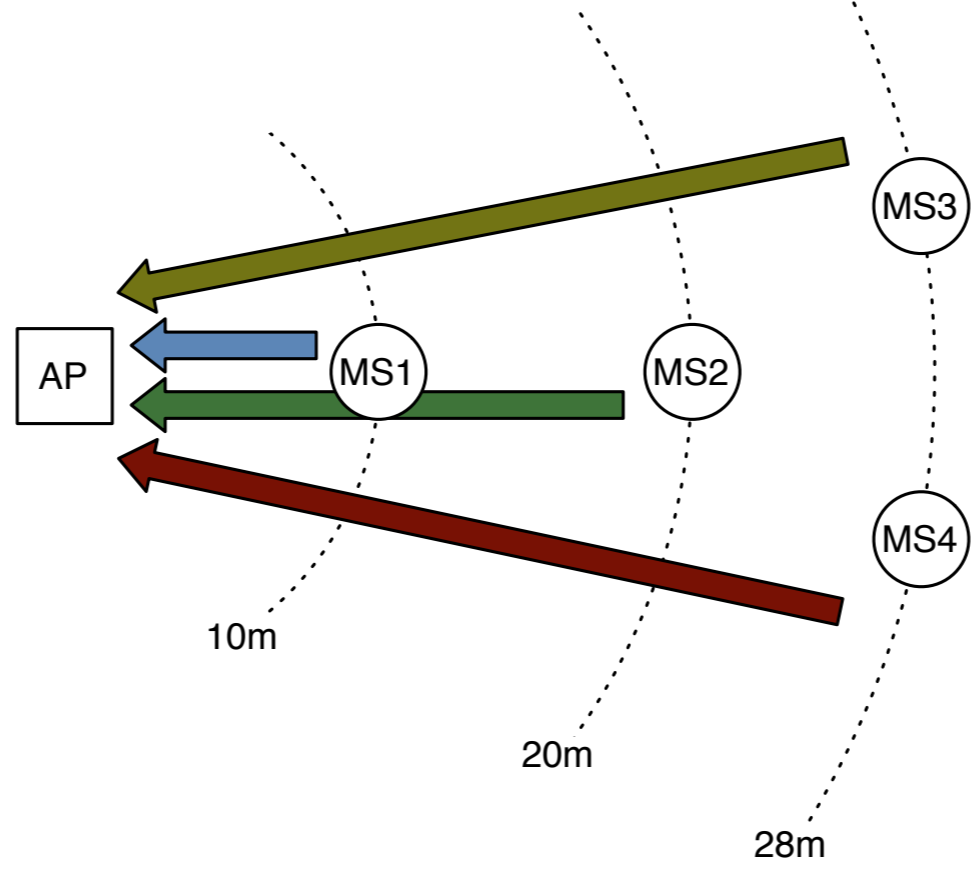
AP

10m

20m

28m

(ns-2 simulation)



Conclusions

With PDOC, devices won't waste energy... when they decide to help someone, they likely will

With DECC, devices may get a big boost in efficiency.
Or, they'll adapt to only suffer a *bounded* amount of harm.

Thank you