MobiCom 2009 Beijing, China

Order Matters: Transmission Reordering in Wireless Networks

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Souvik Sen, Romit Roy Choudhury,
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Outline

- ***Message-in-message (MIM)***, a new physical layer capability
- The potential of an ***MIM-aware*** link layer
- ***Shuffle***, an MIM-aware architecture
  - For enterprise WLANs

Frame Synchronization

- Transmissions start with preamble (PLCP)
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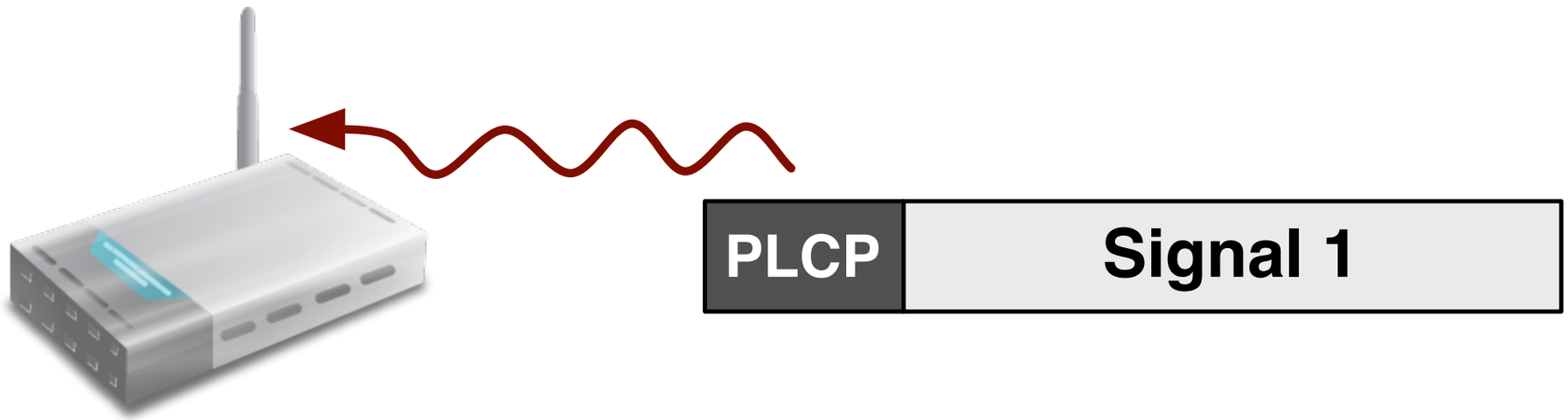

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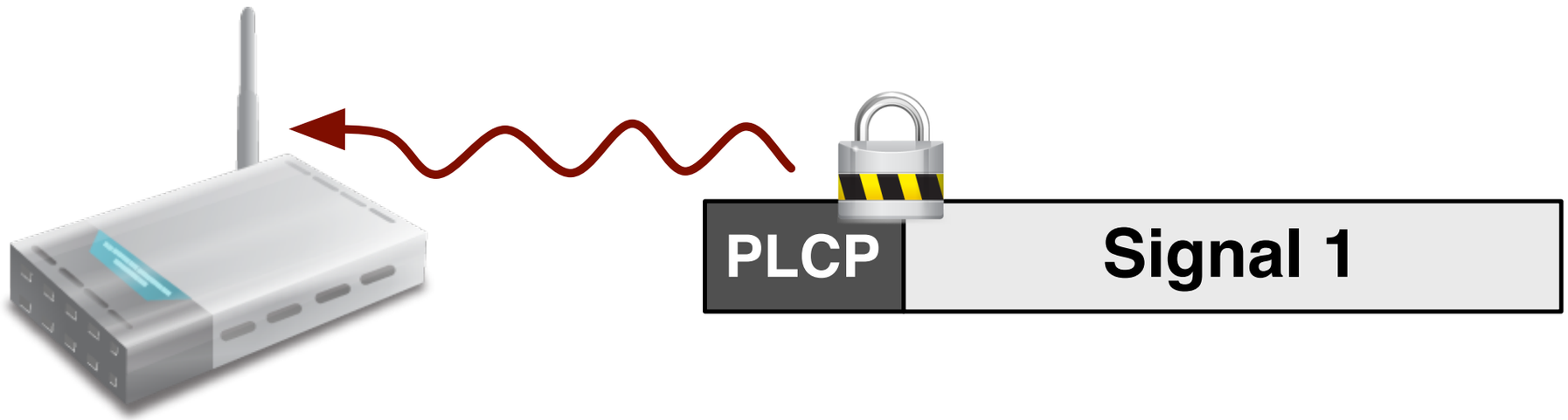

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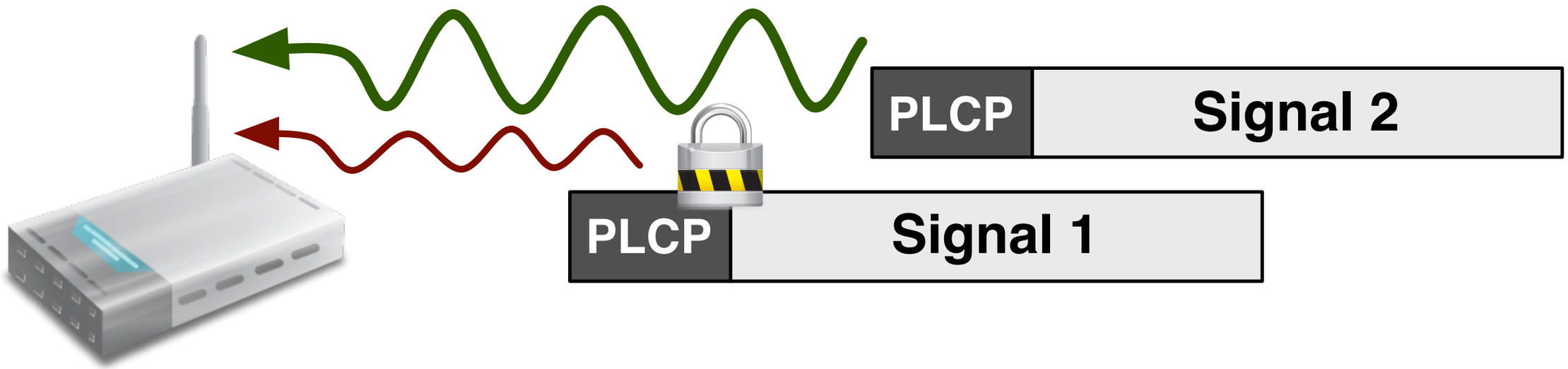

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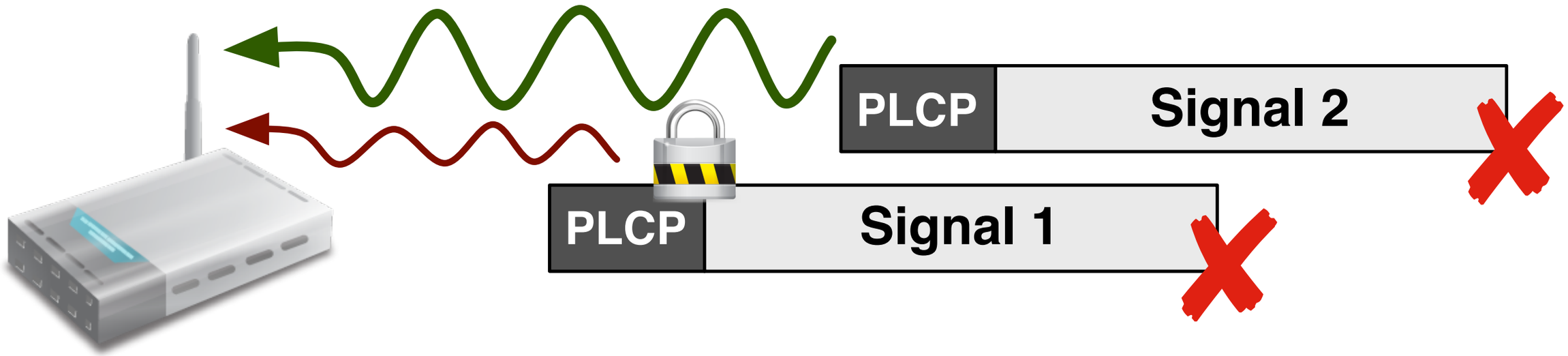

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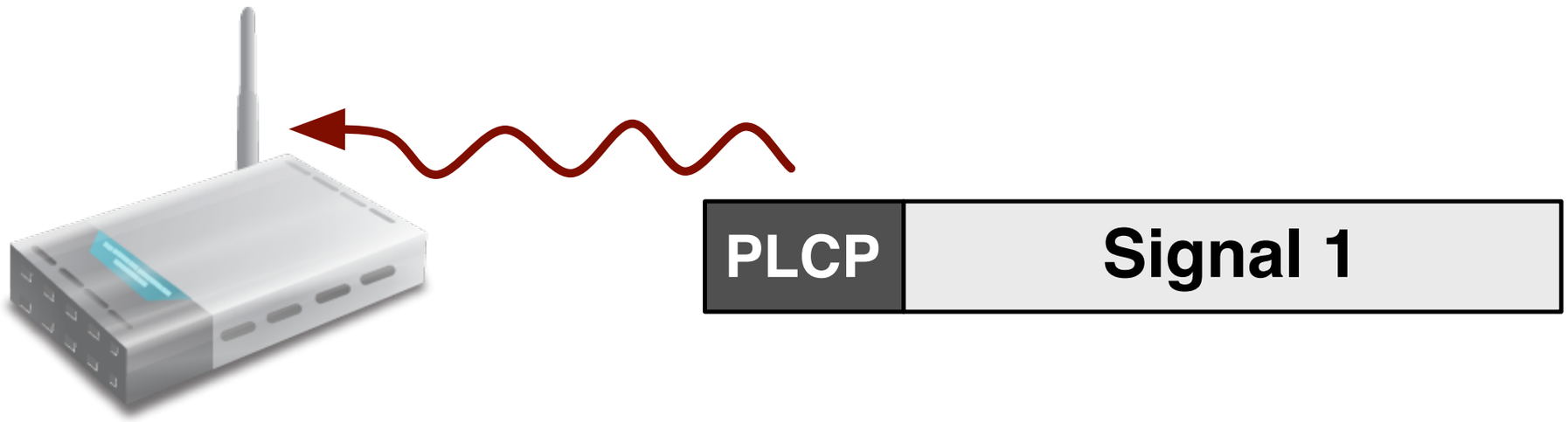

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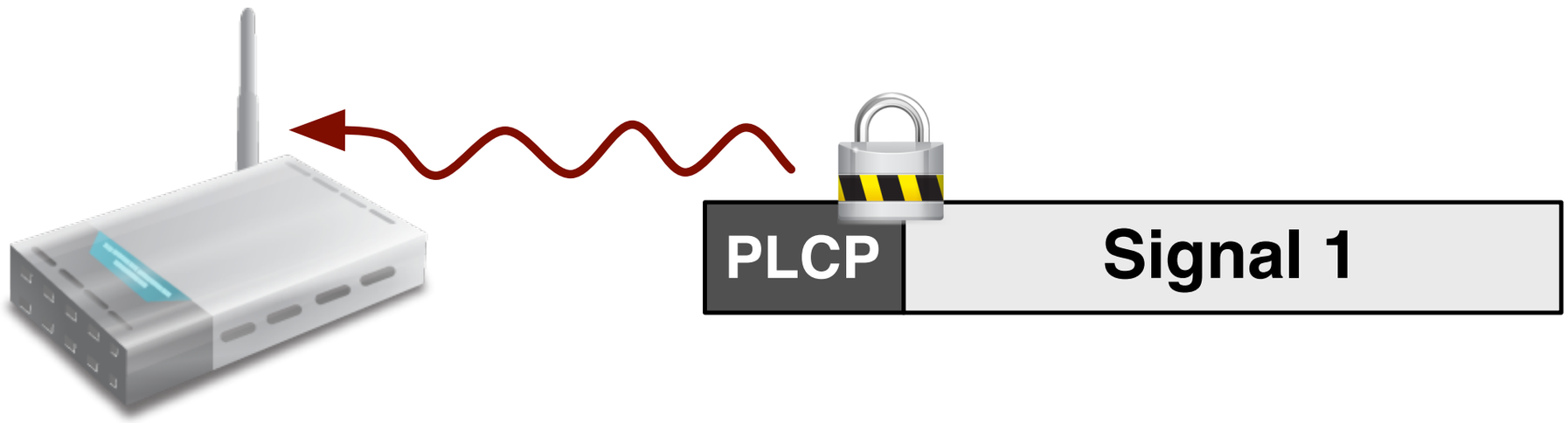

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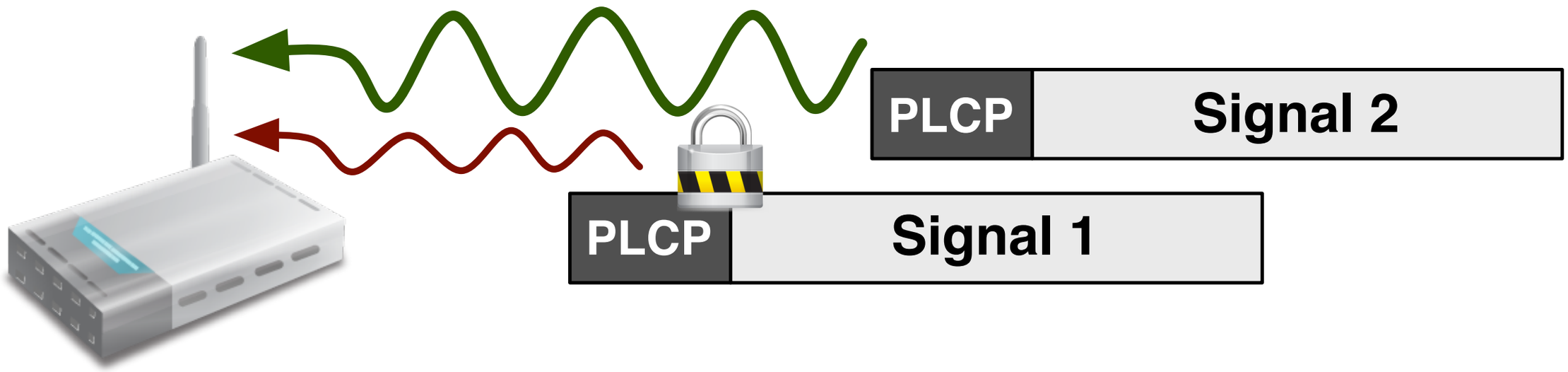

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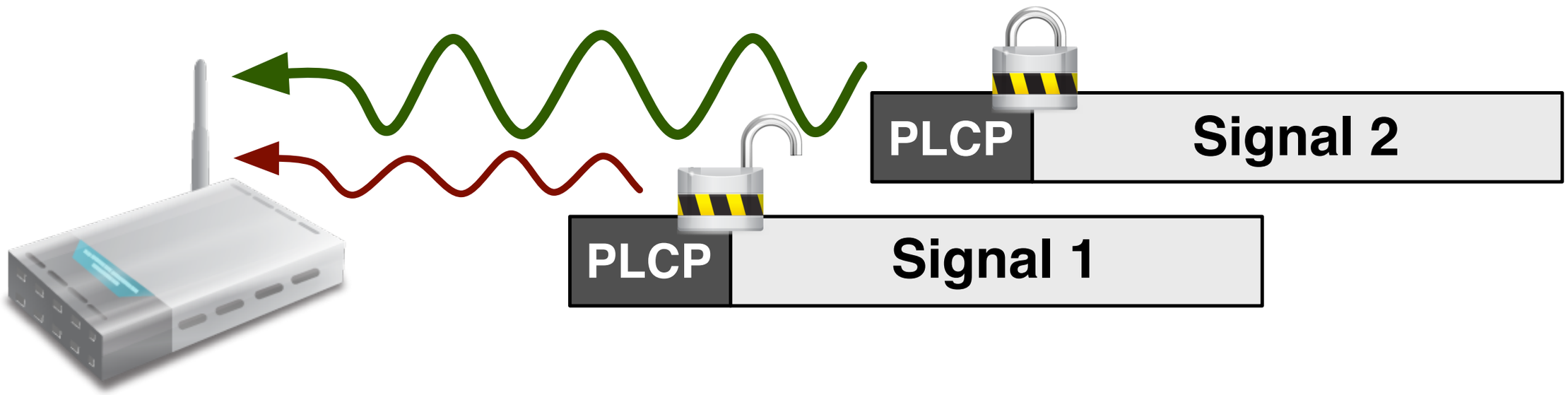

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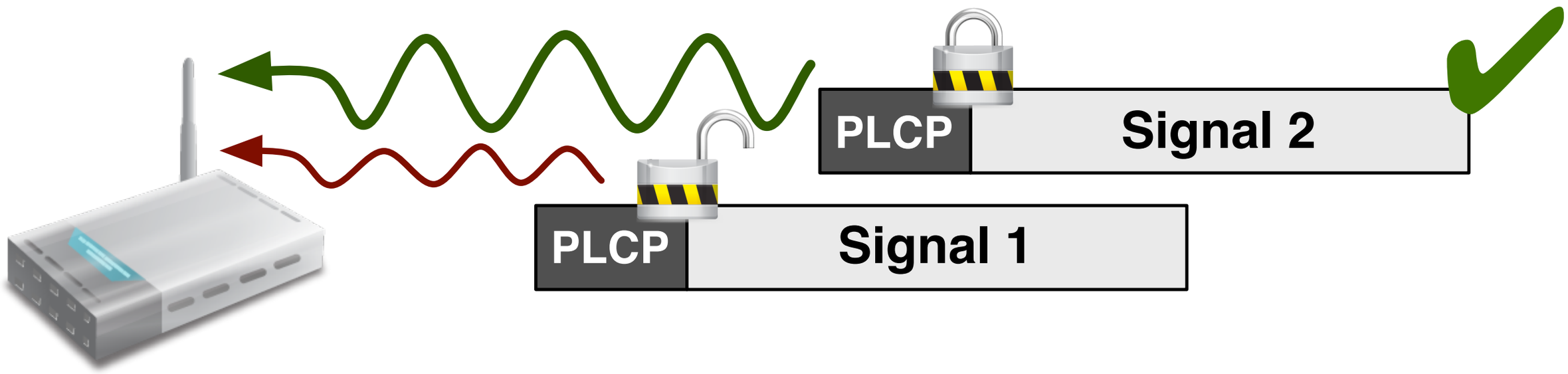

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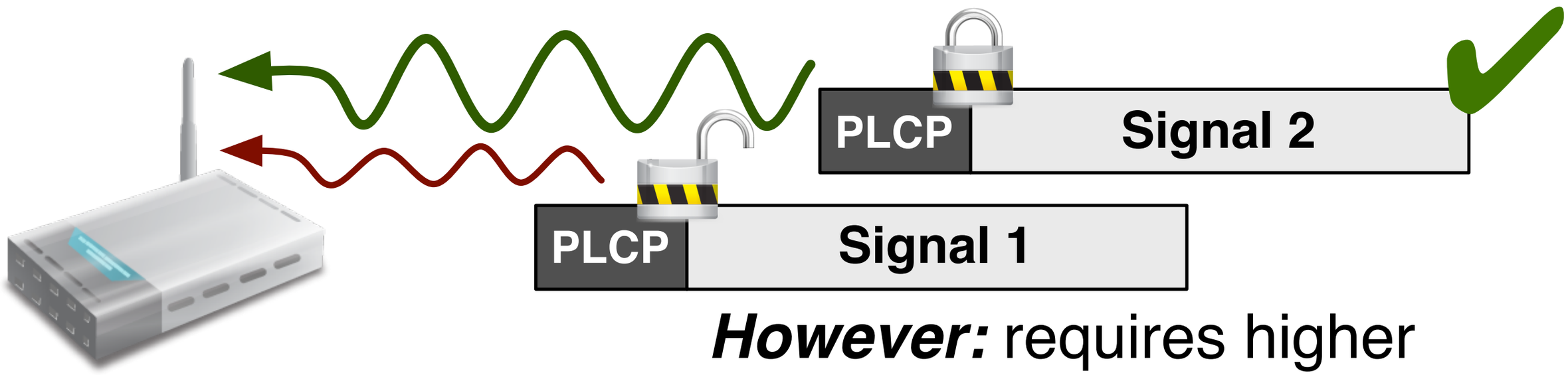
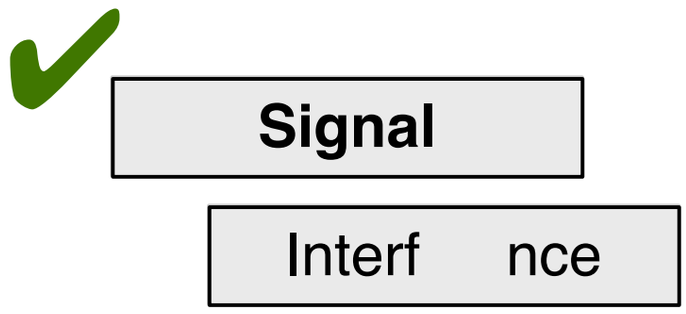


However: requires higher SINR than traditional reception

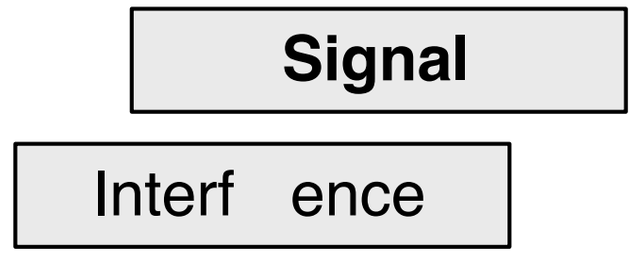
Sum ry

Basic recept n
(simulators)

S cess



Collision



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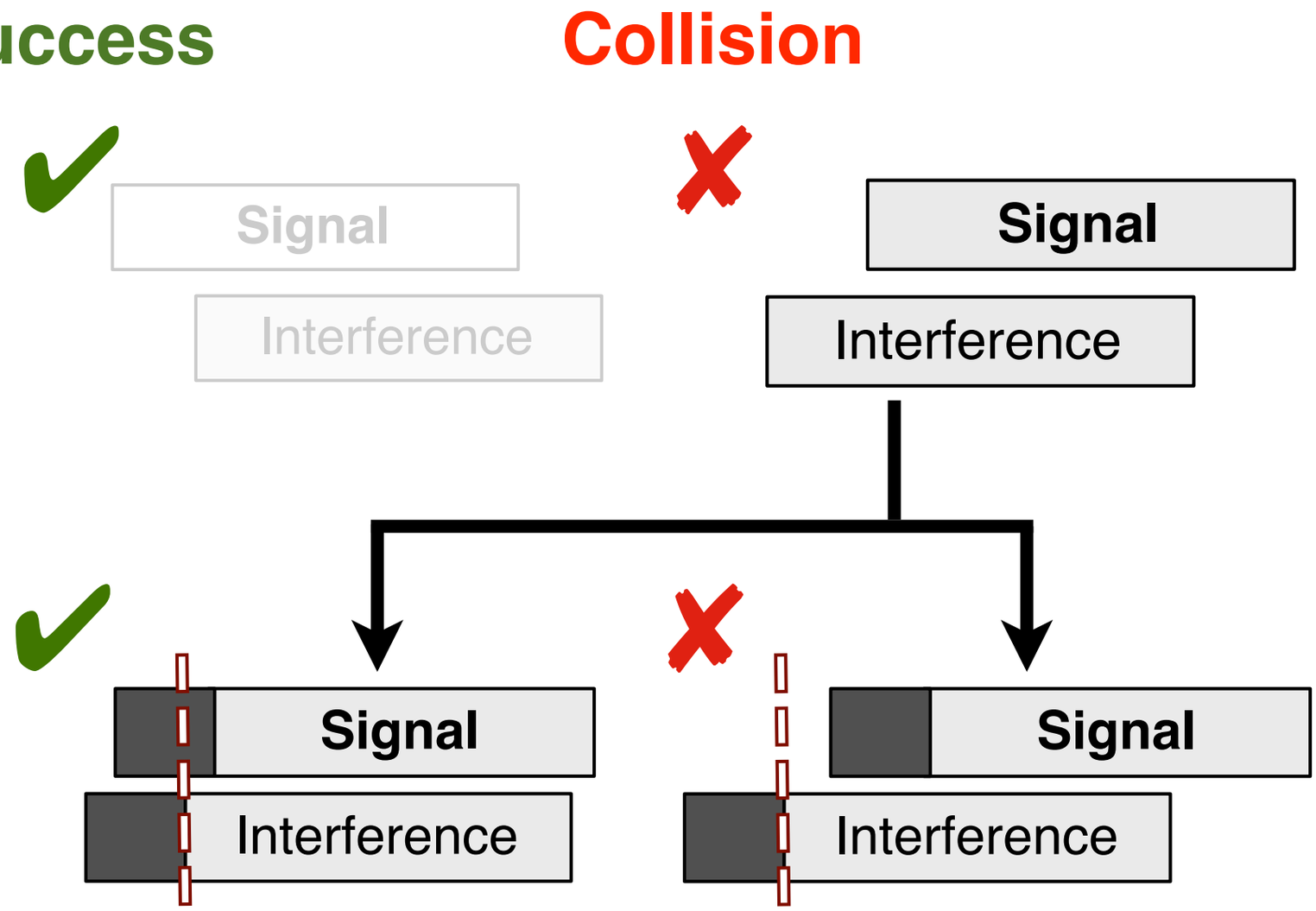

Capture

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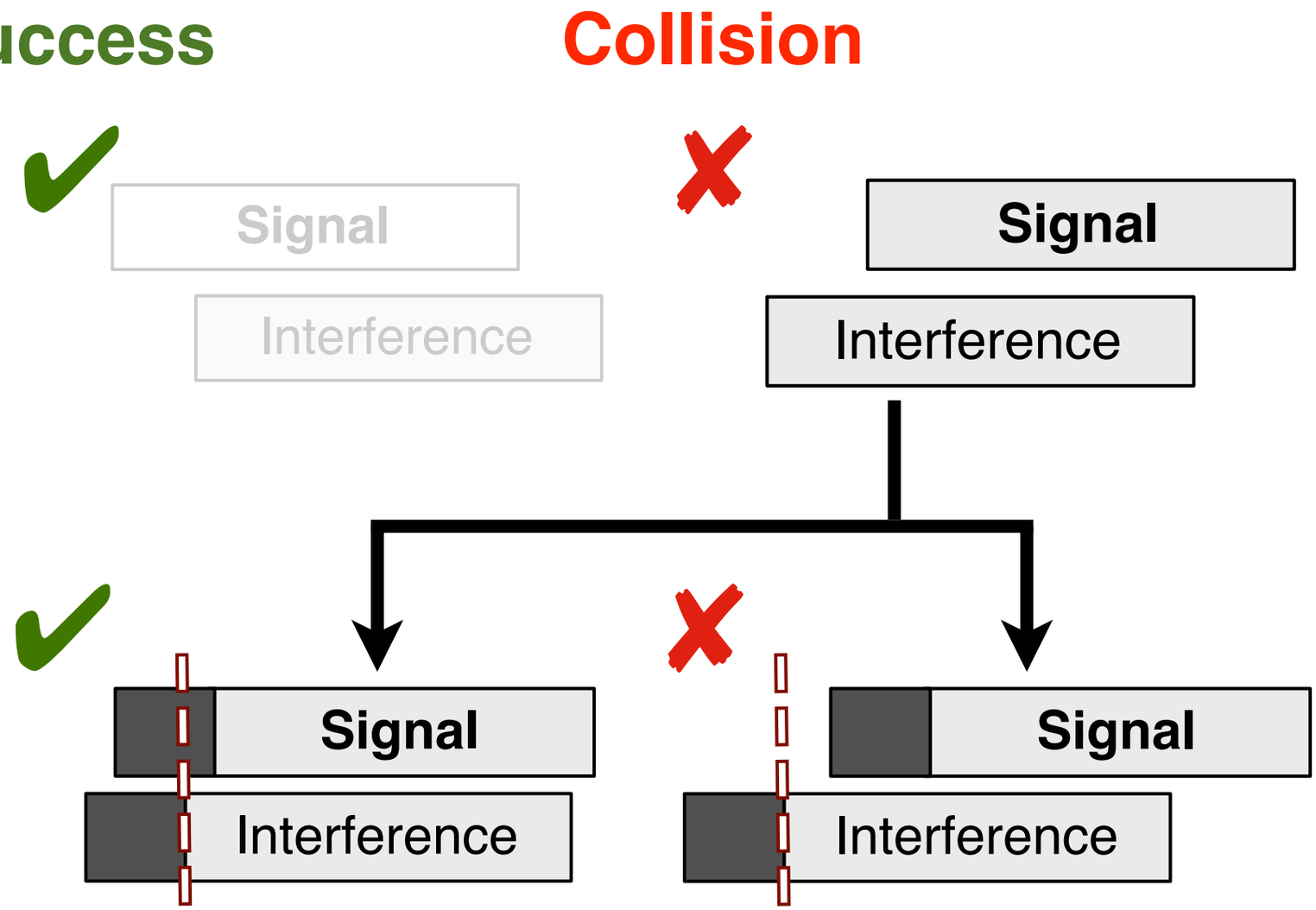

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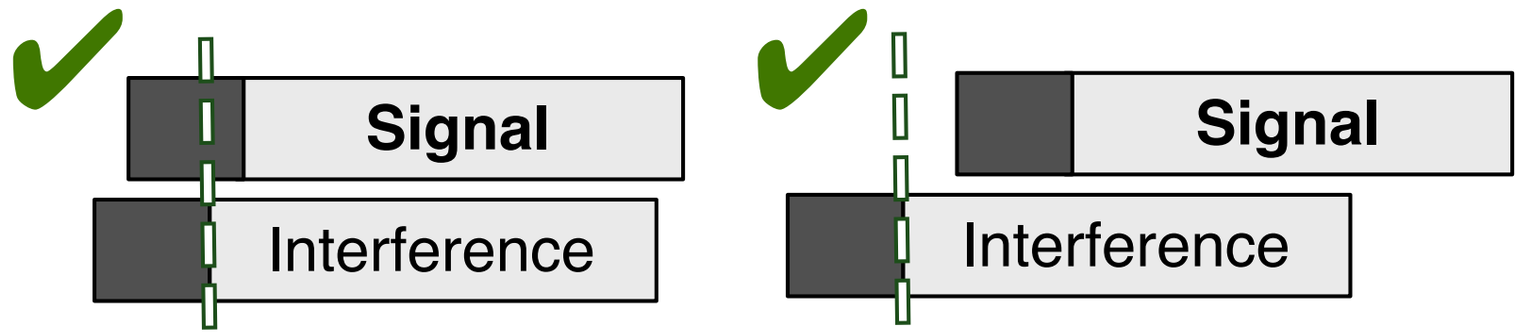

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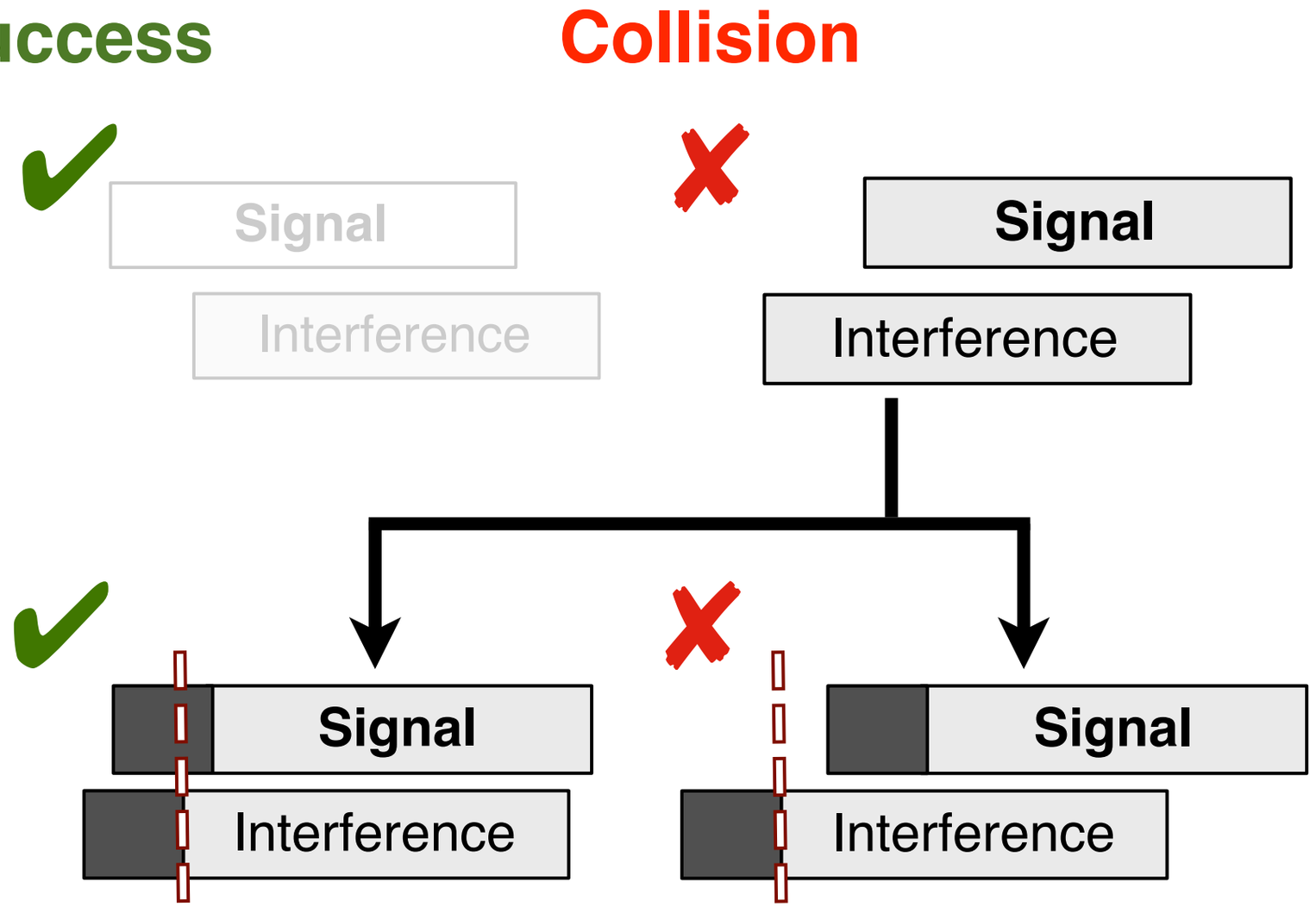
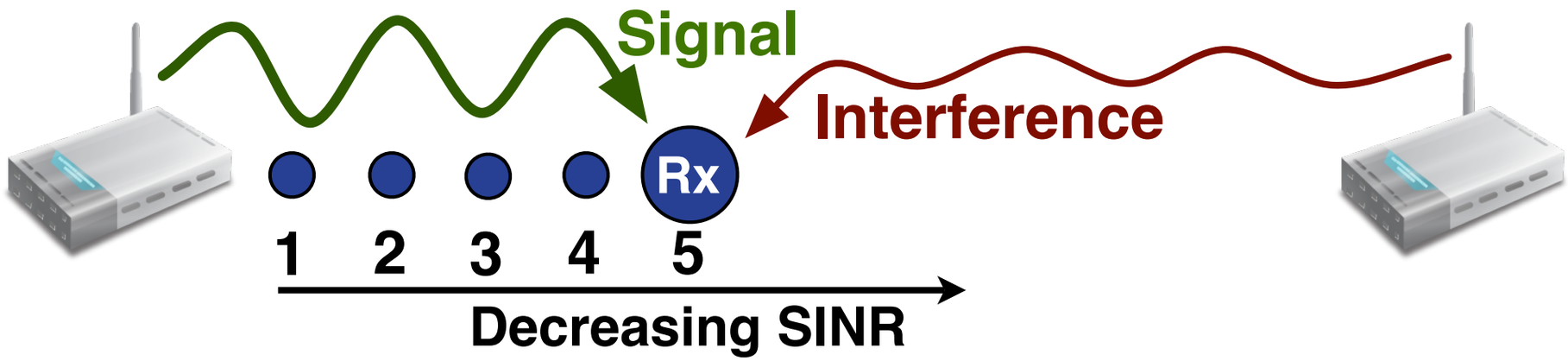


Requires **high** SINR

Validating MIM



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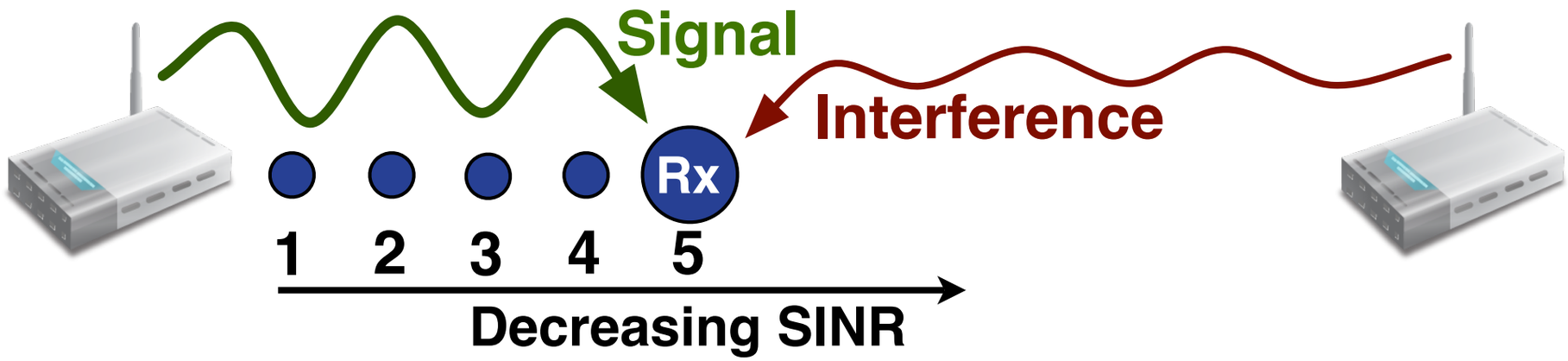

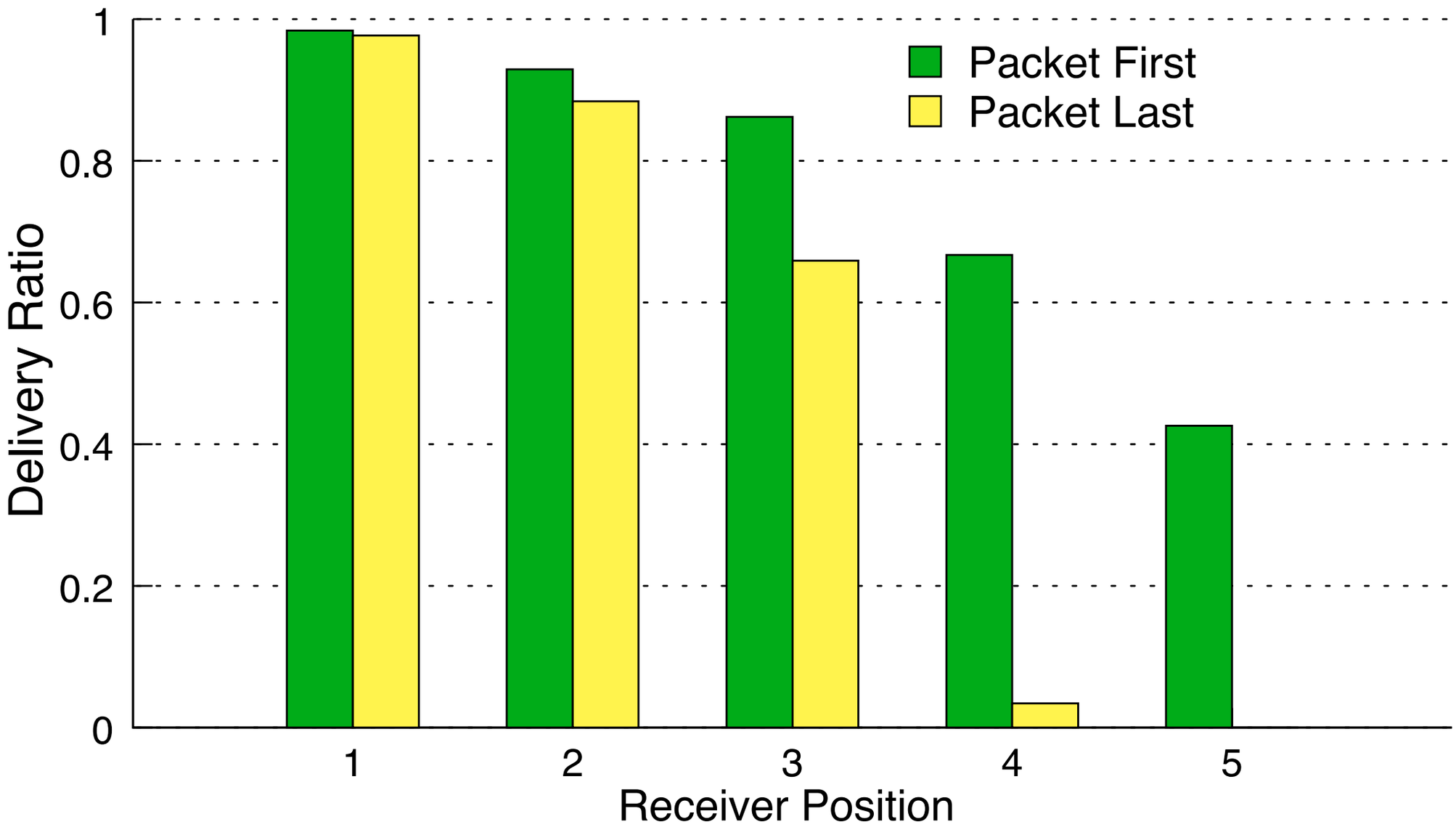

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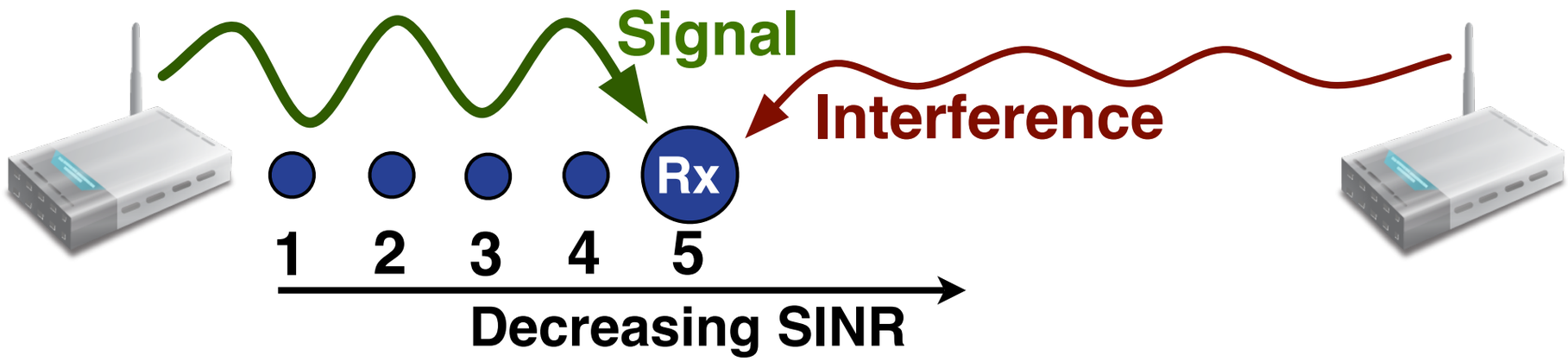
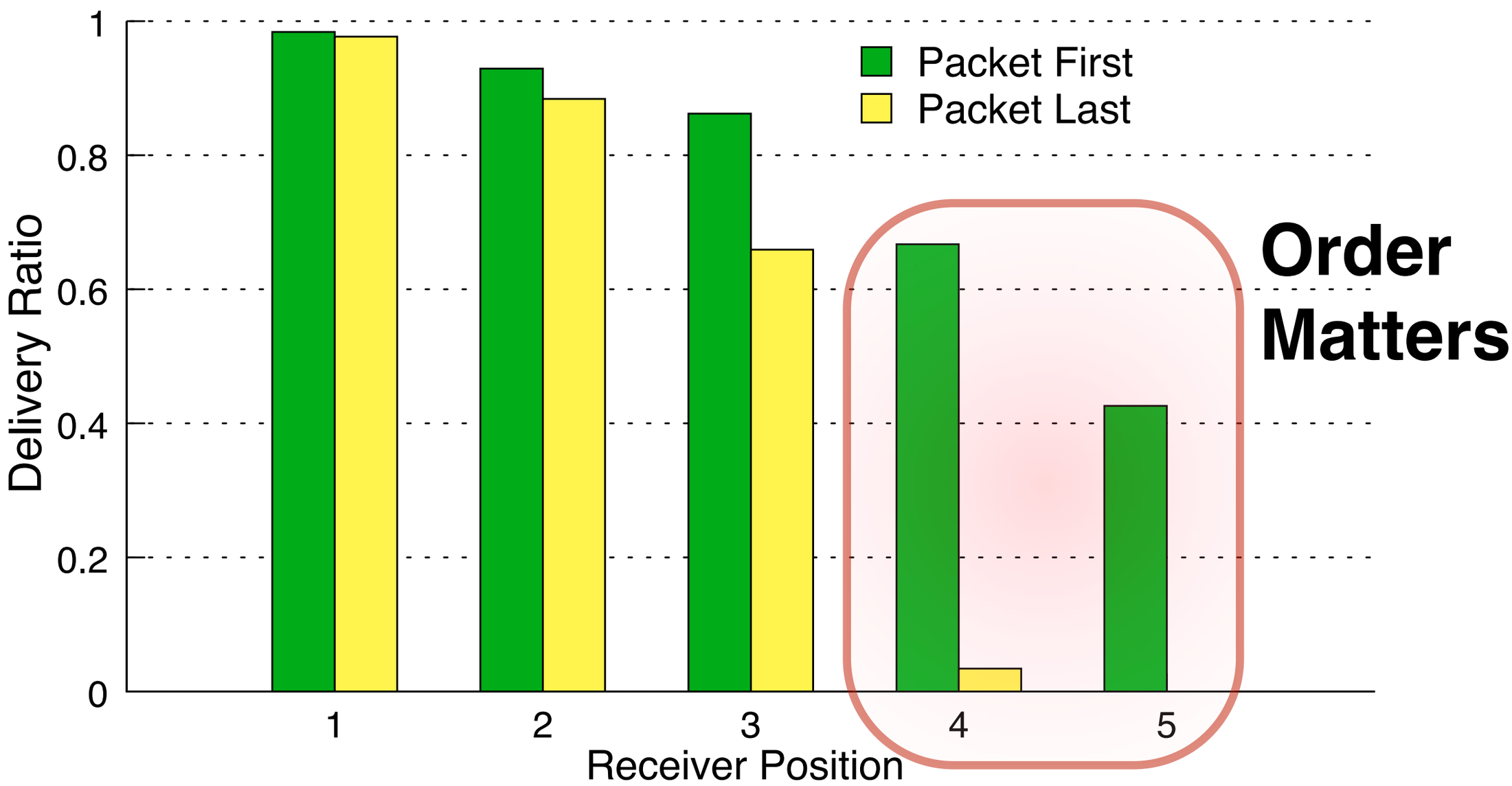
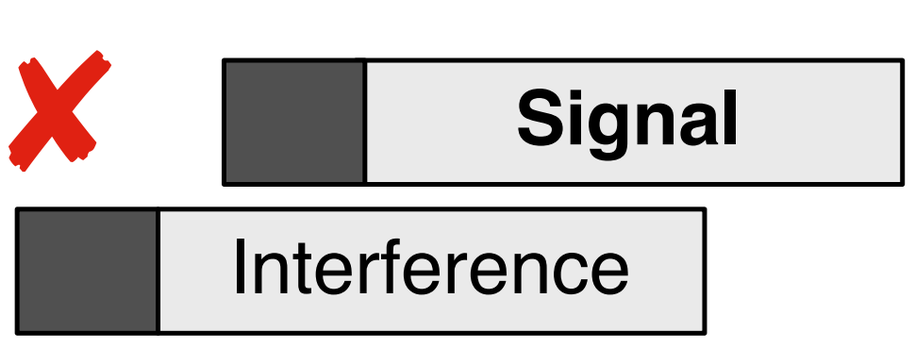




Order matters



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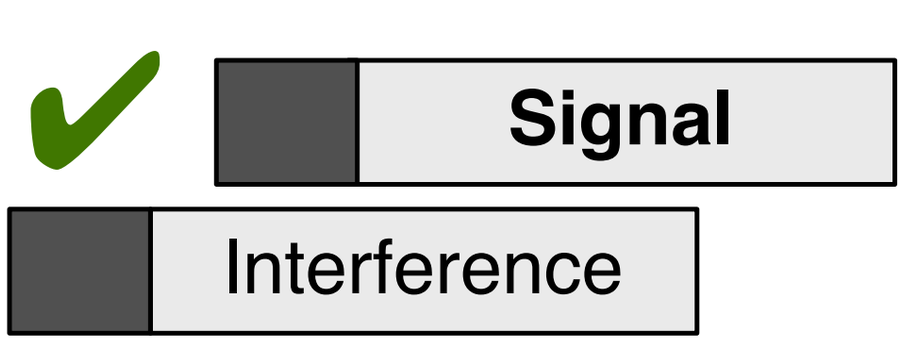

MIM Threshold

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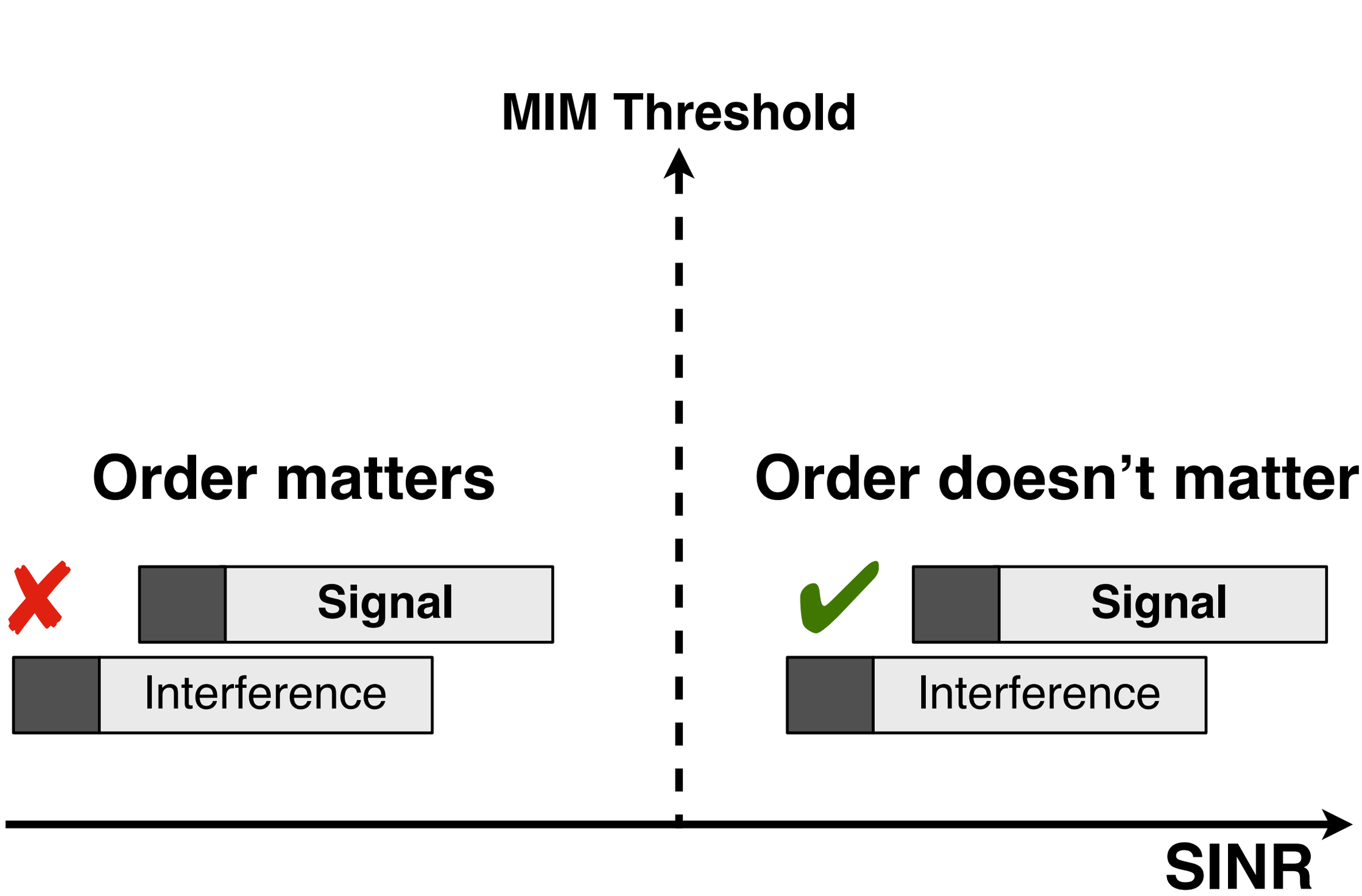

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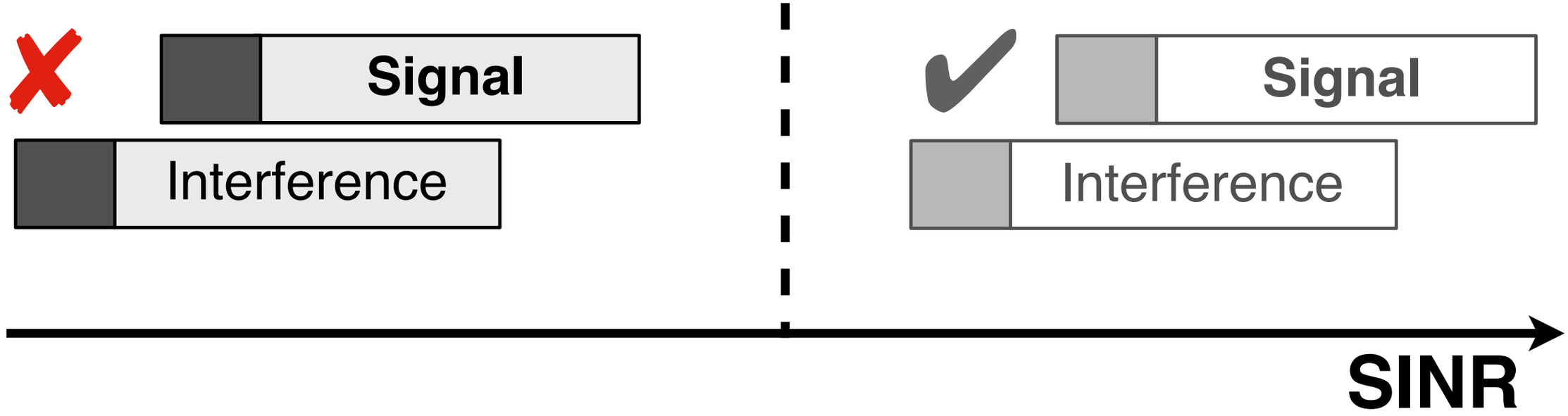
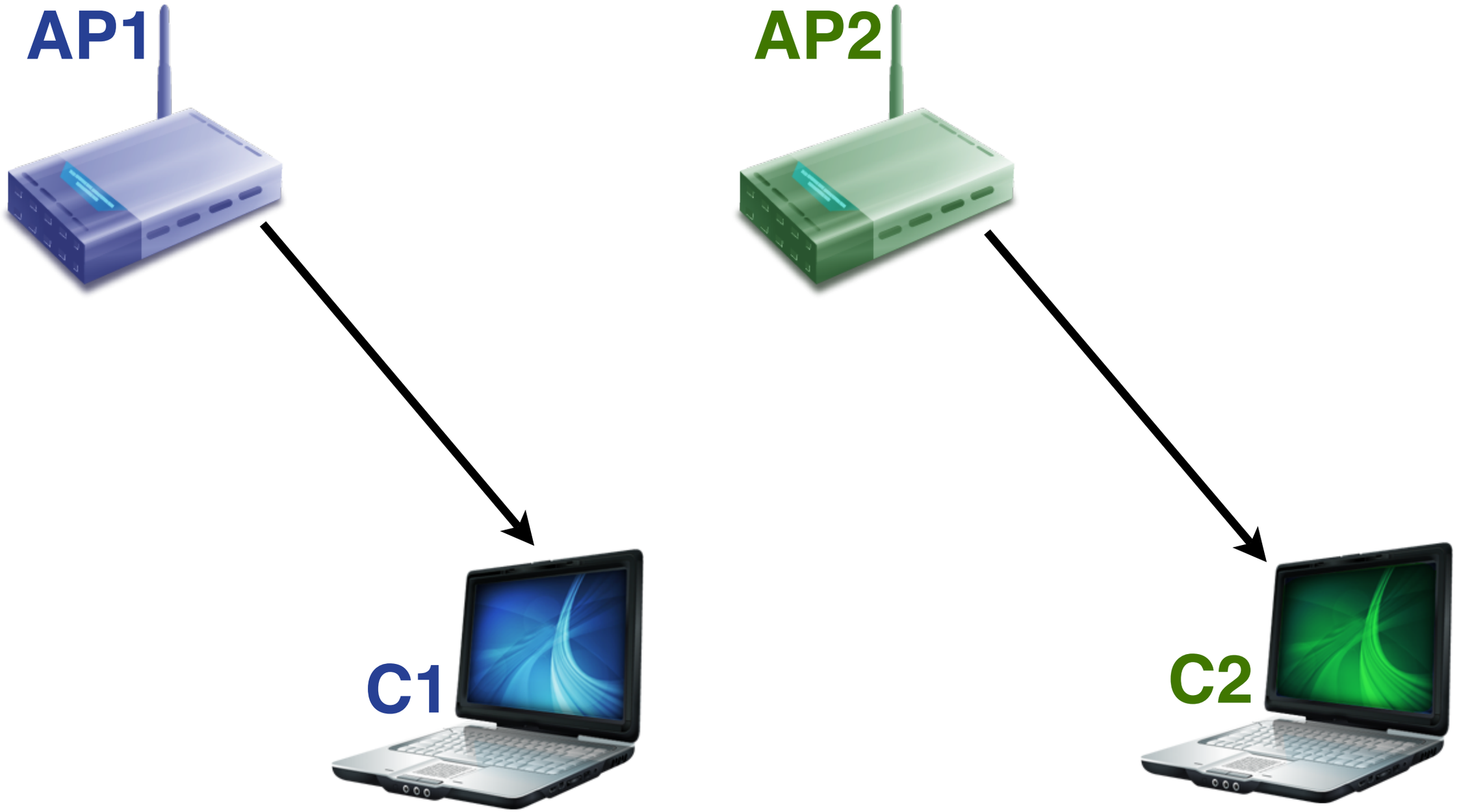
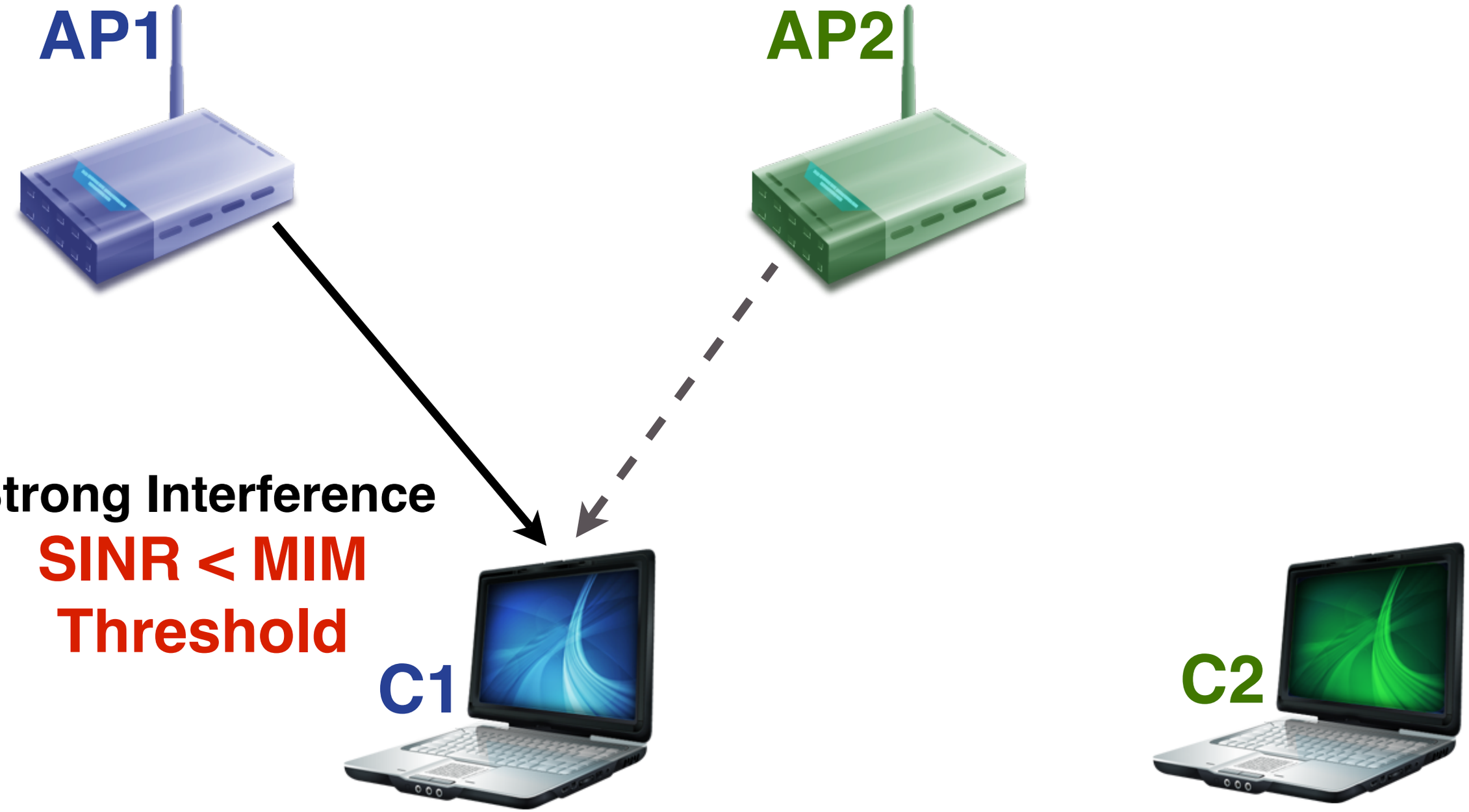


Motivating Example




AP1
AP2
Strong Interference
SINR < MIM
Threshold
C1
C2

AP1

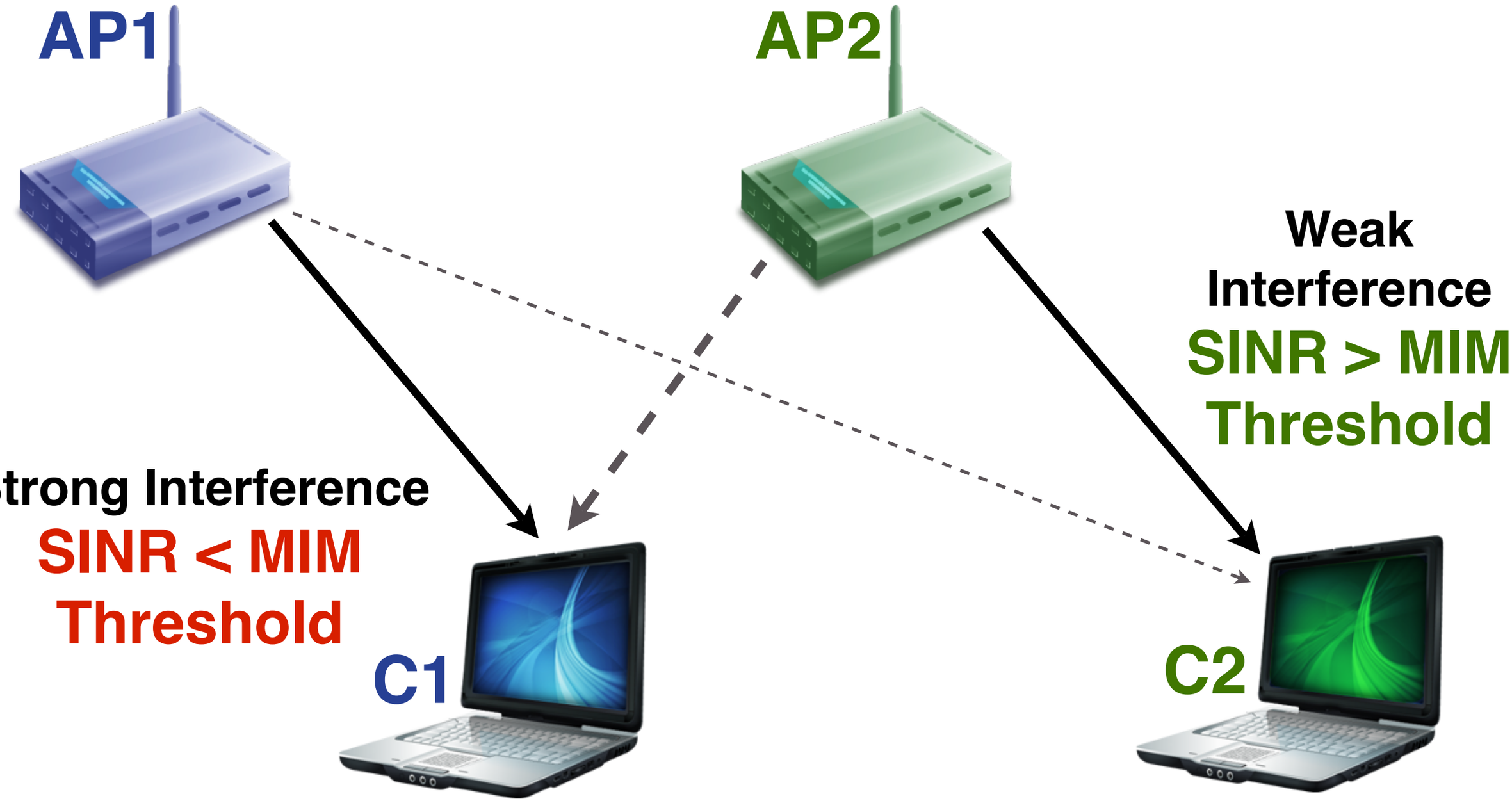
AP2

Weak Interference

SINR > MIM Threshold

C1

C2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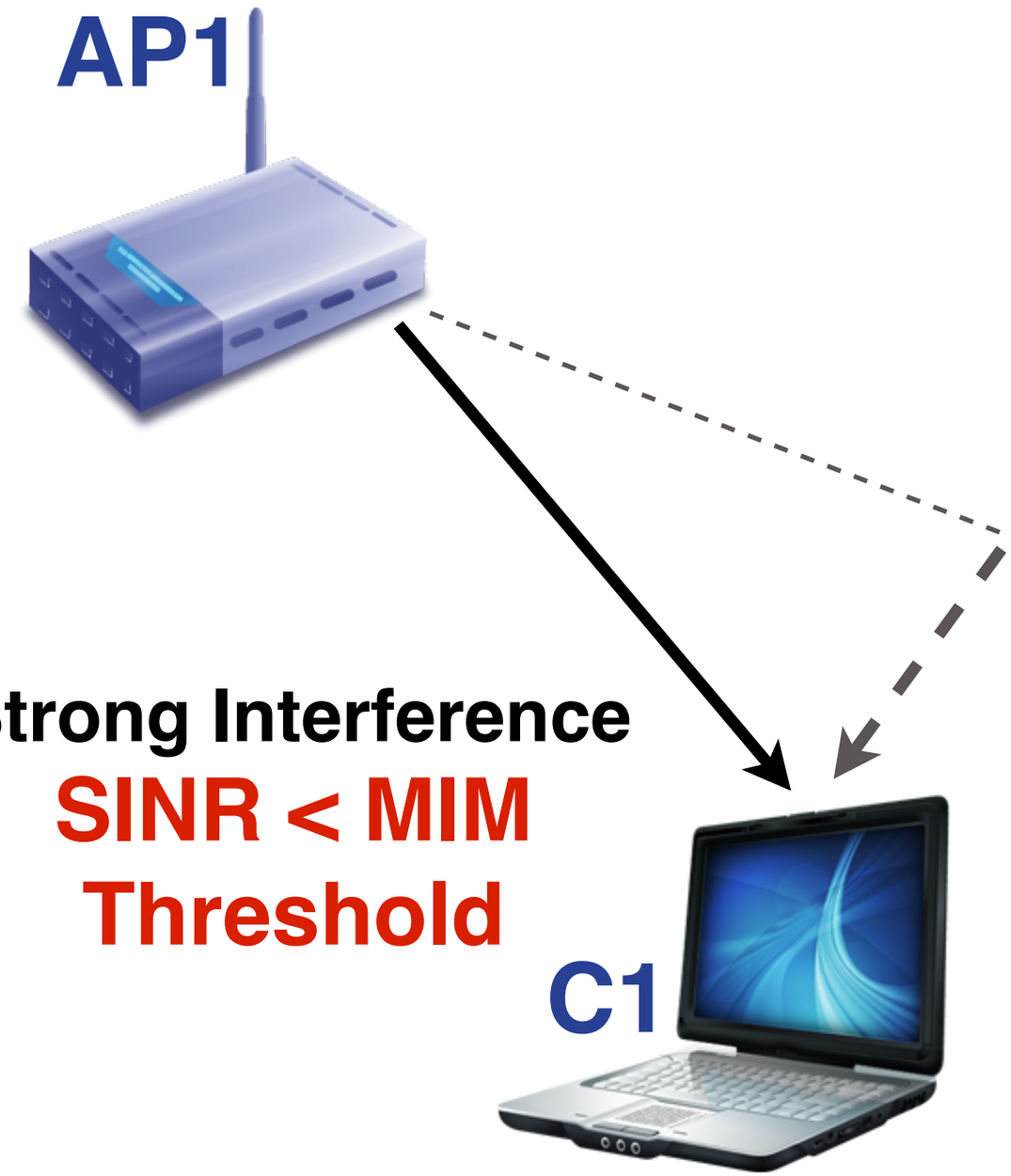
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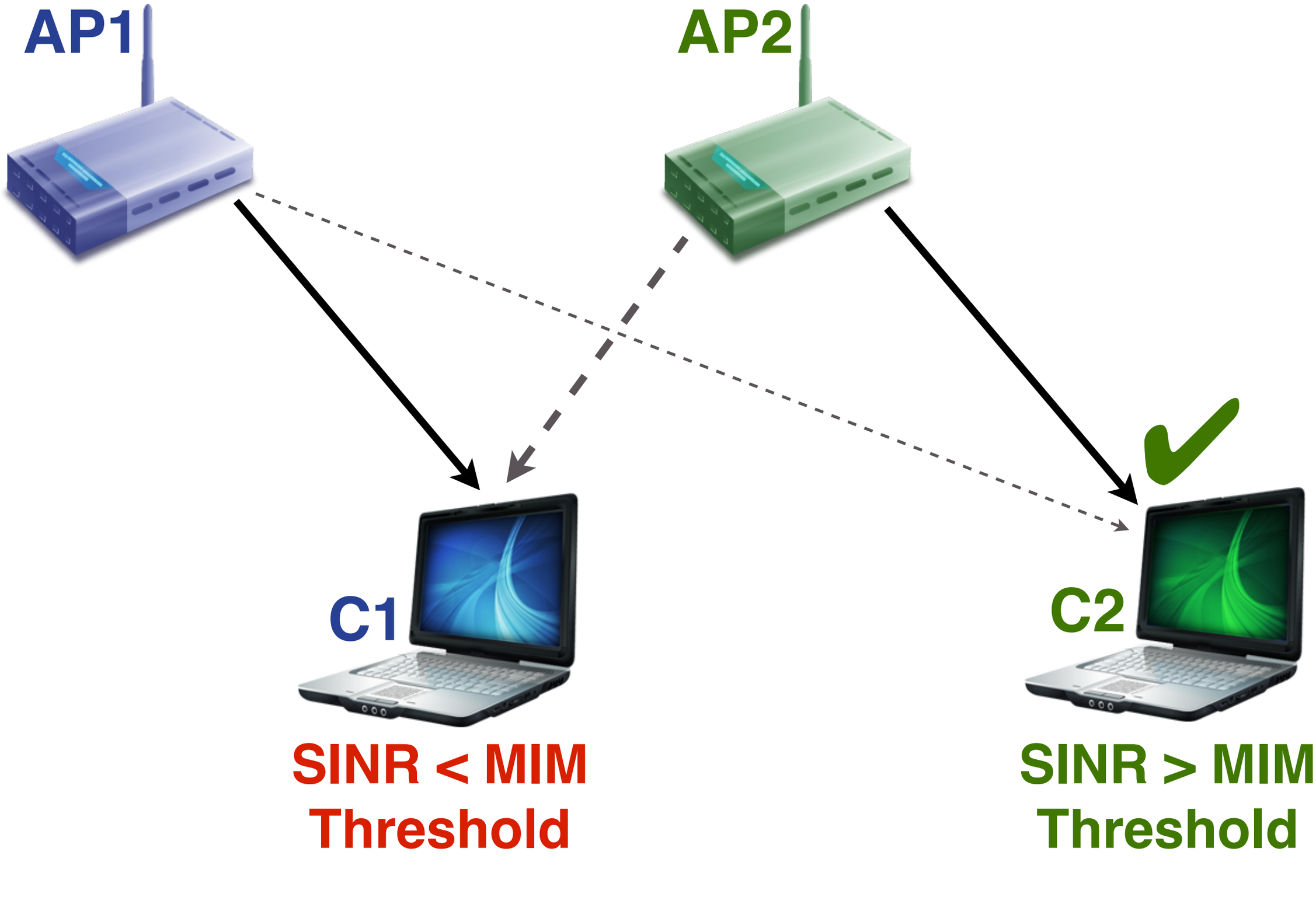
Uncontrolled ordering



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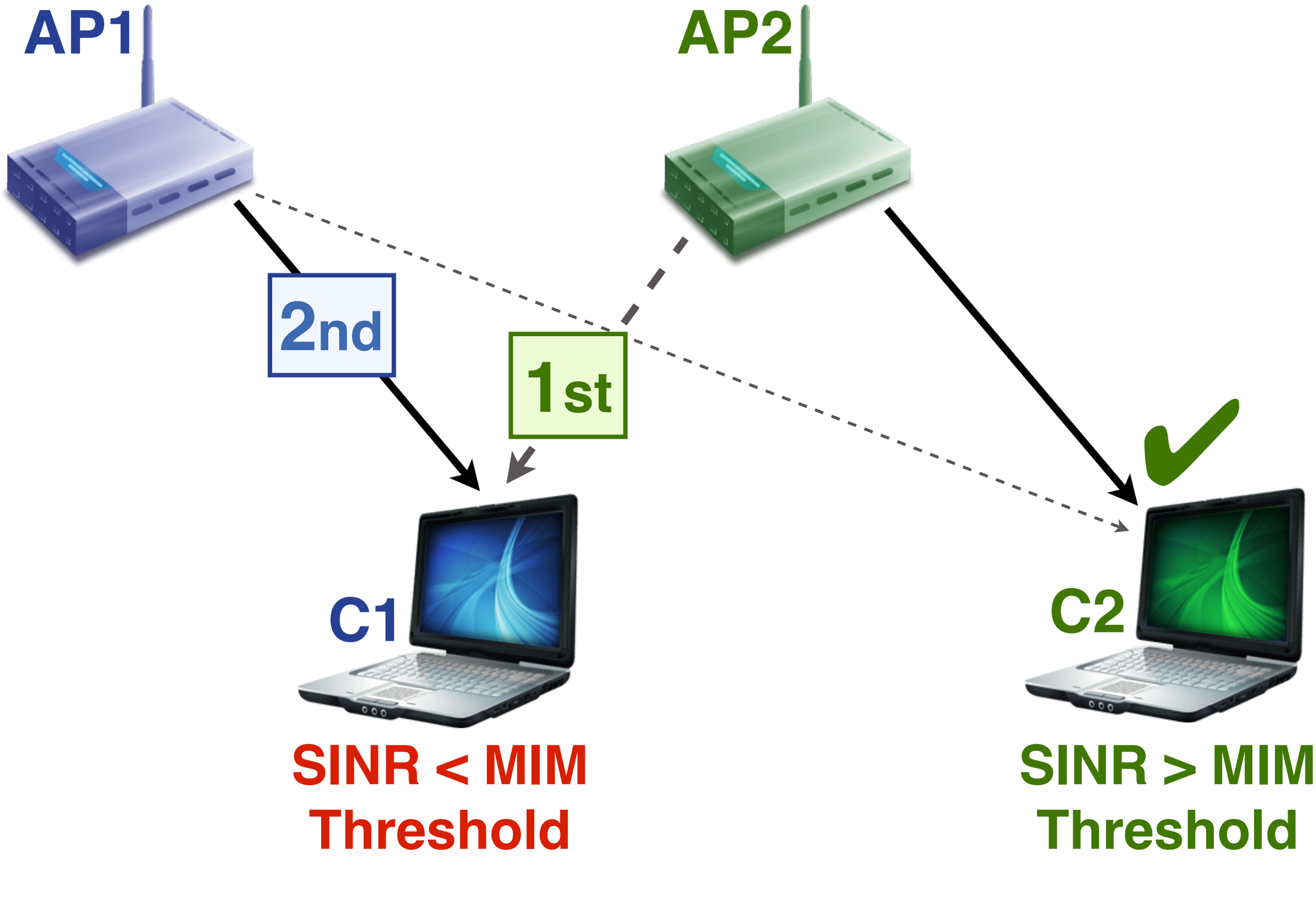

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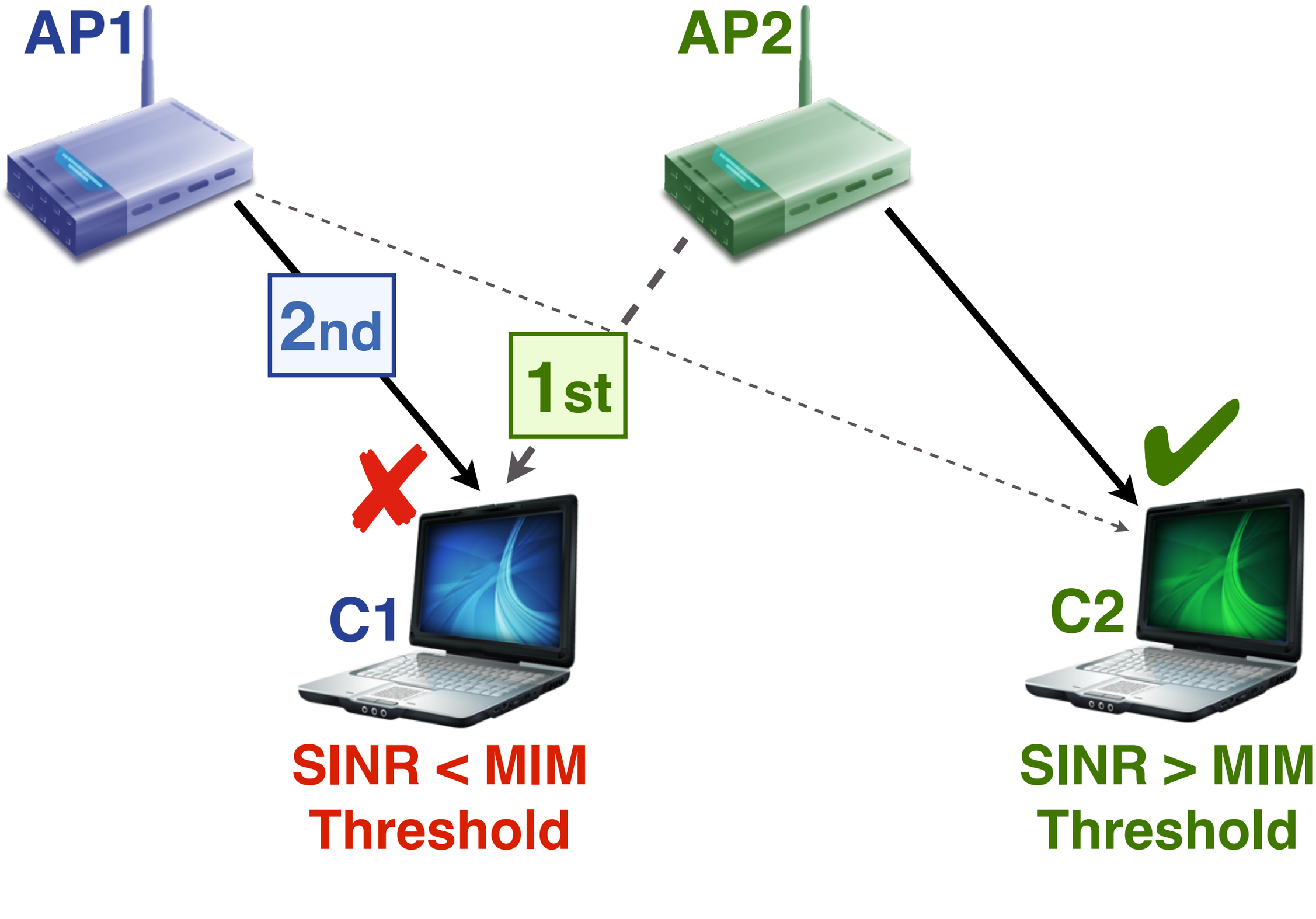
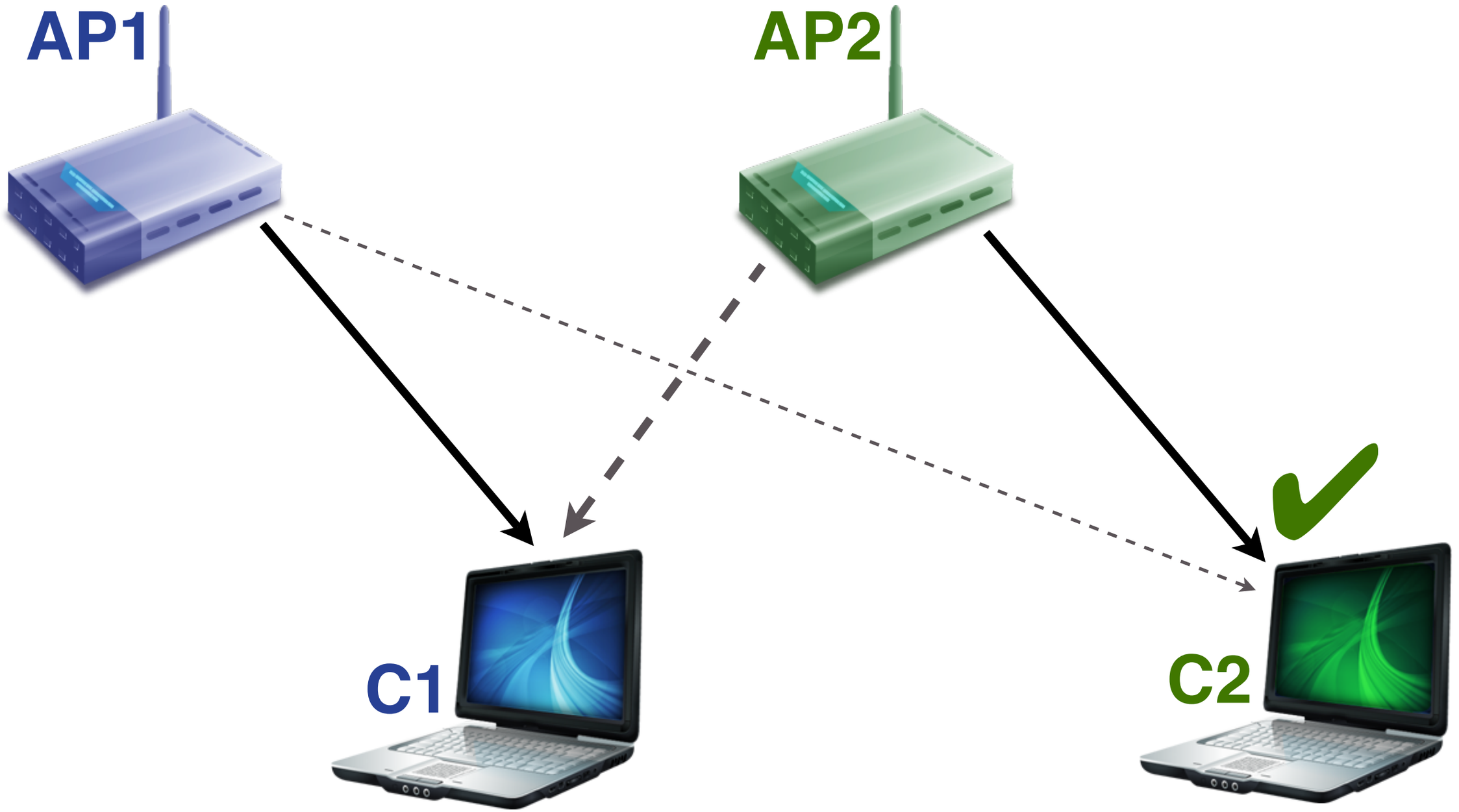


Corrected ordering



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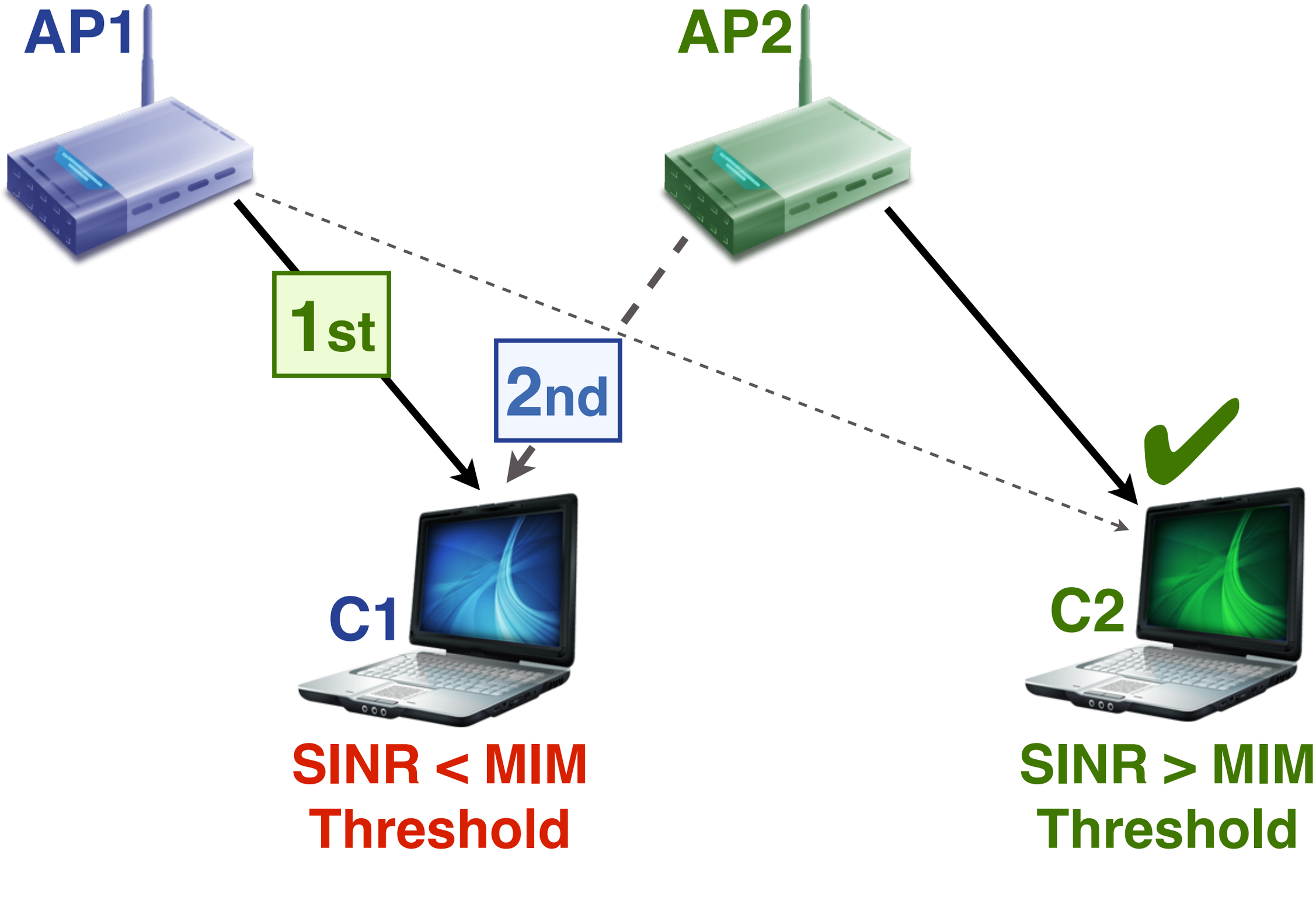

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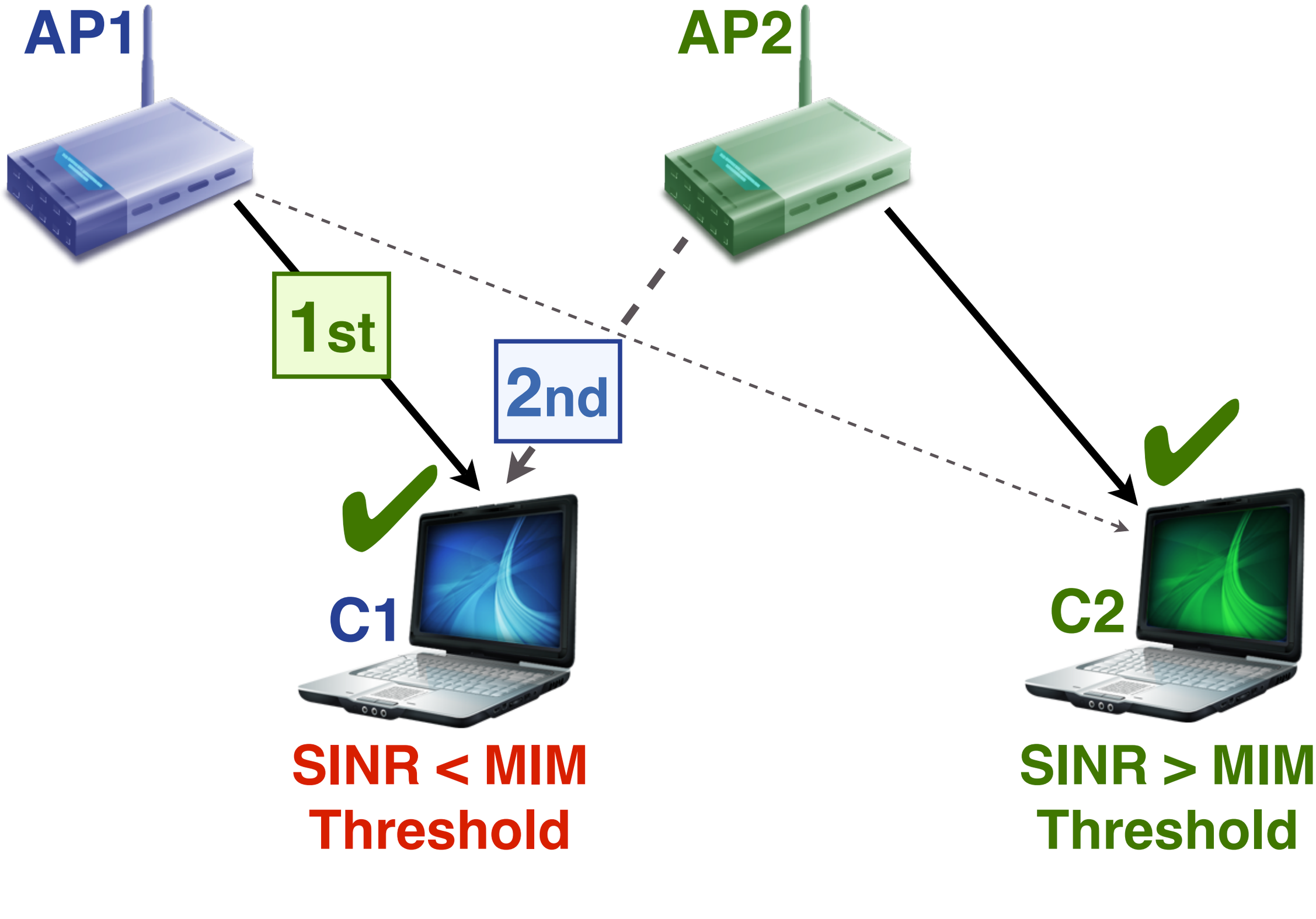
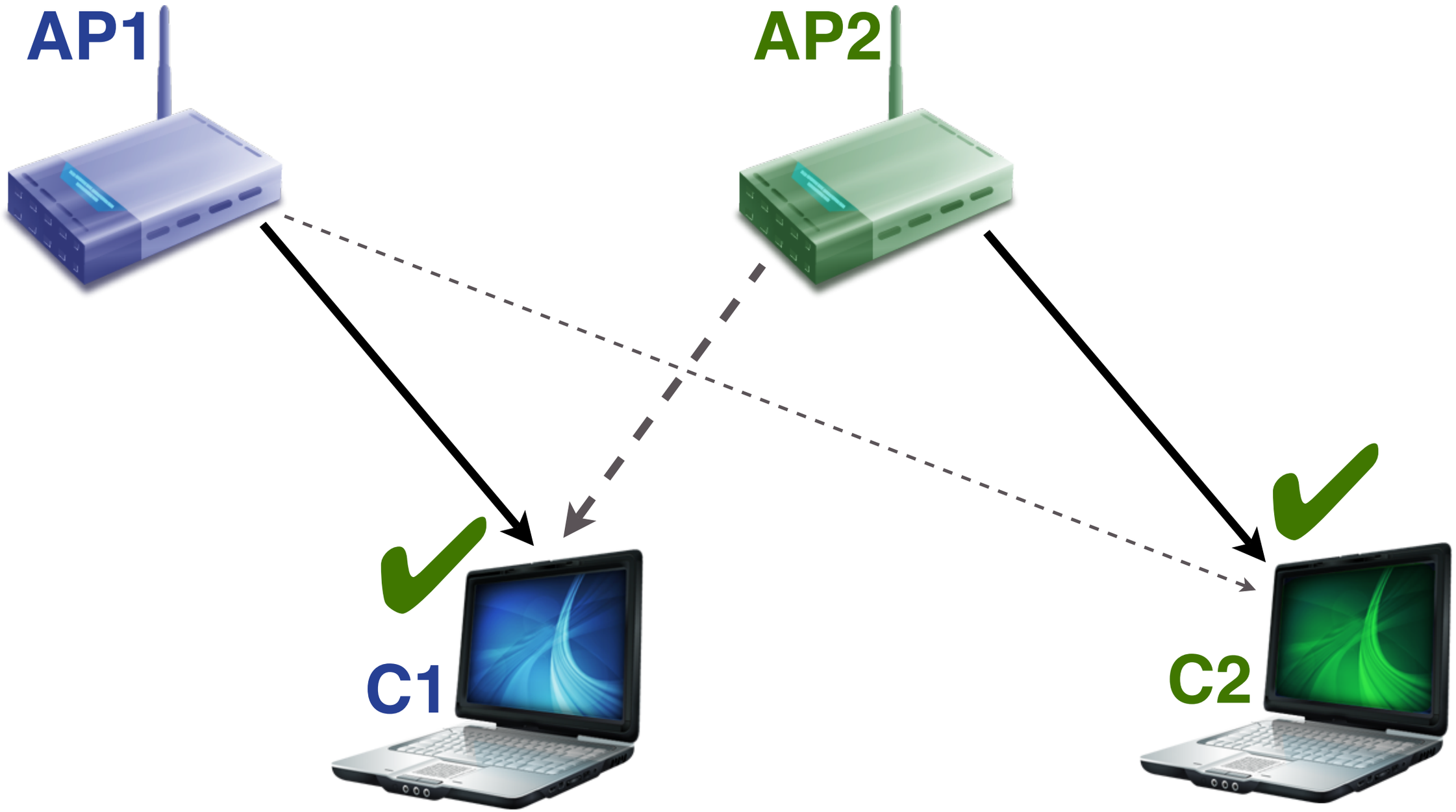


Corrected ordering achieves concurrency

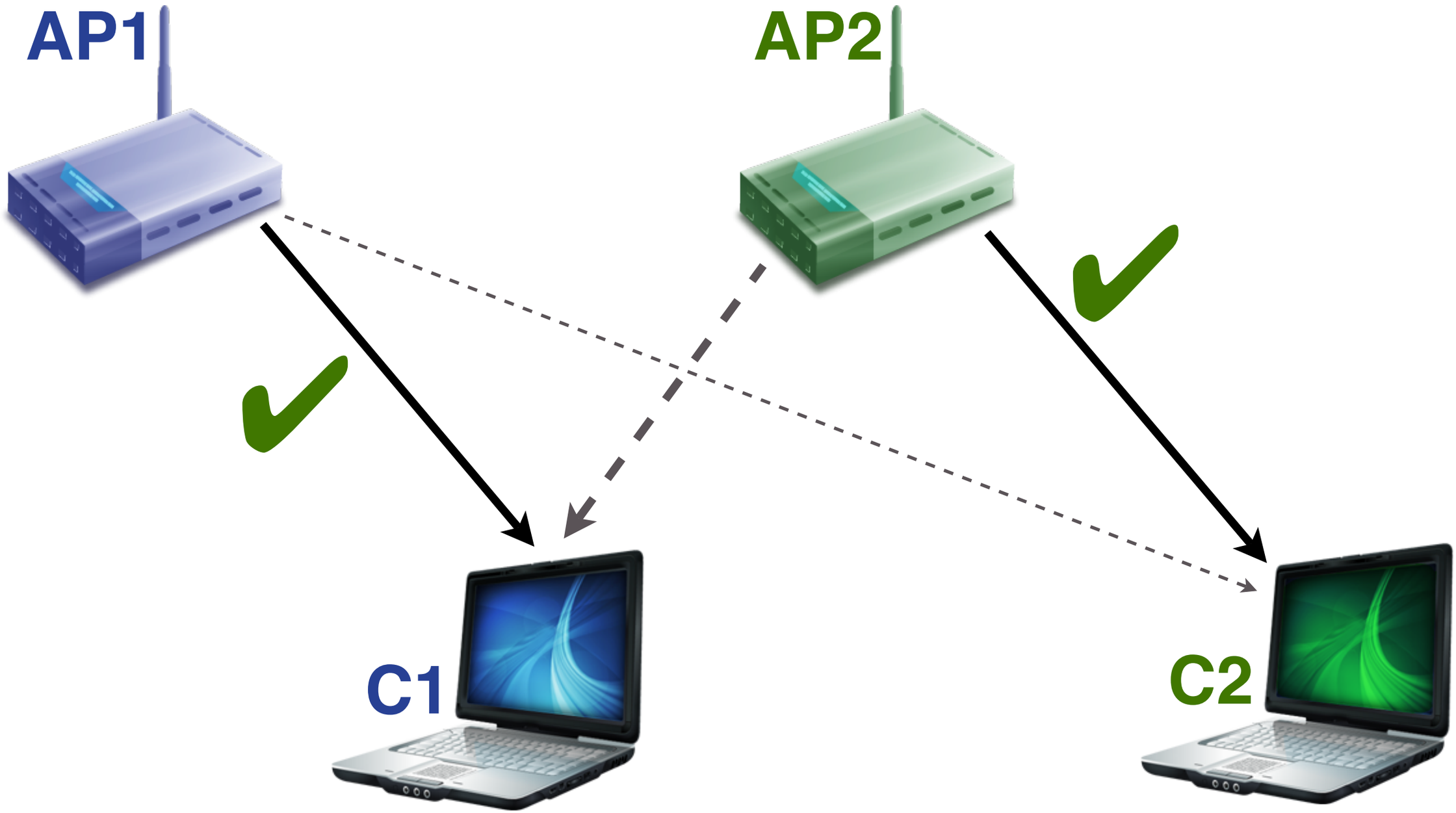


MIM-awareness

- MIM-capable hardware available today
  - Validated on Atheros chipset

- Current MAC layer unaware of MIM
  - Ordering happens accidentally

- Can order-awareness improve throughput?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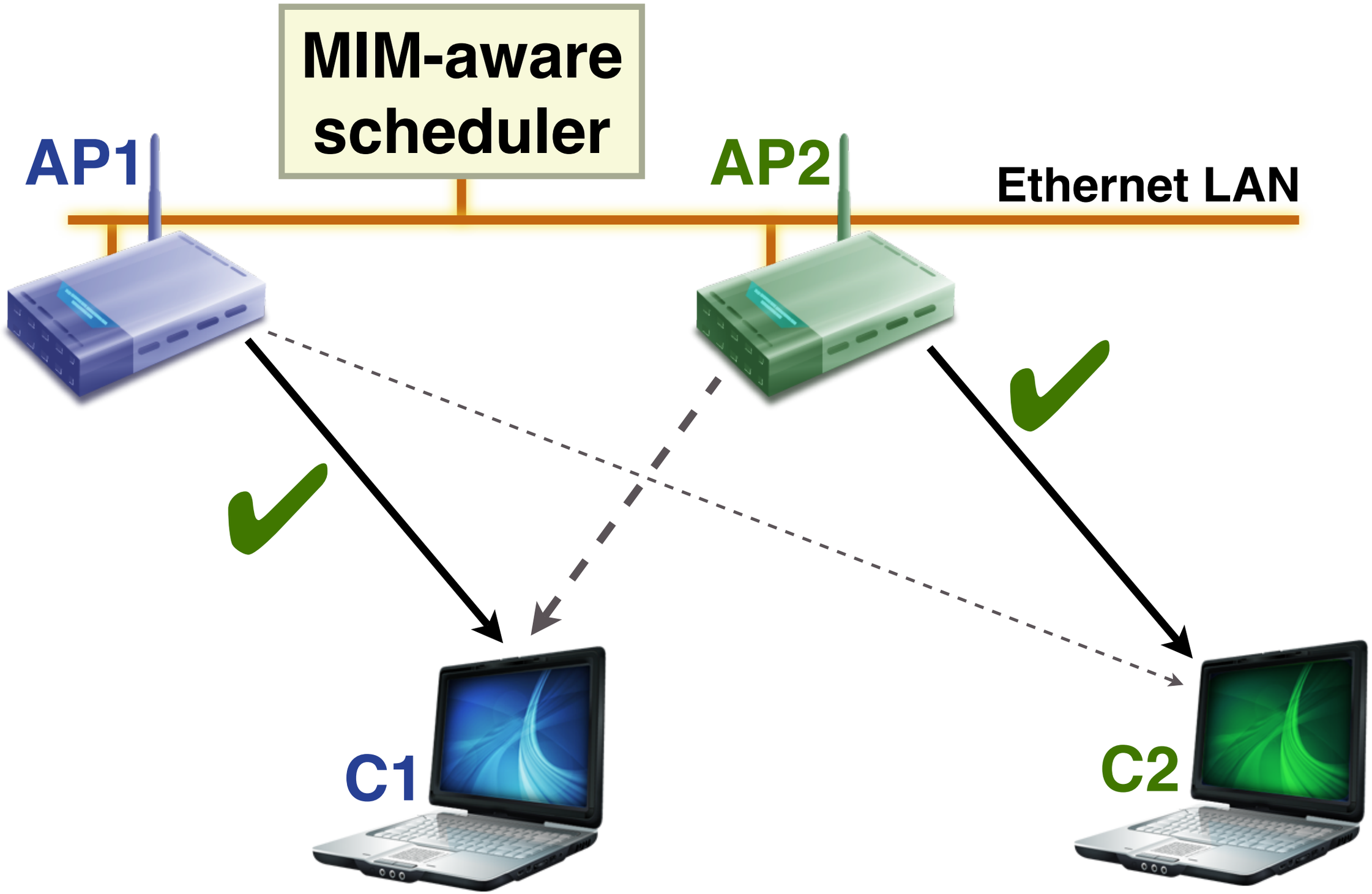
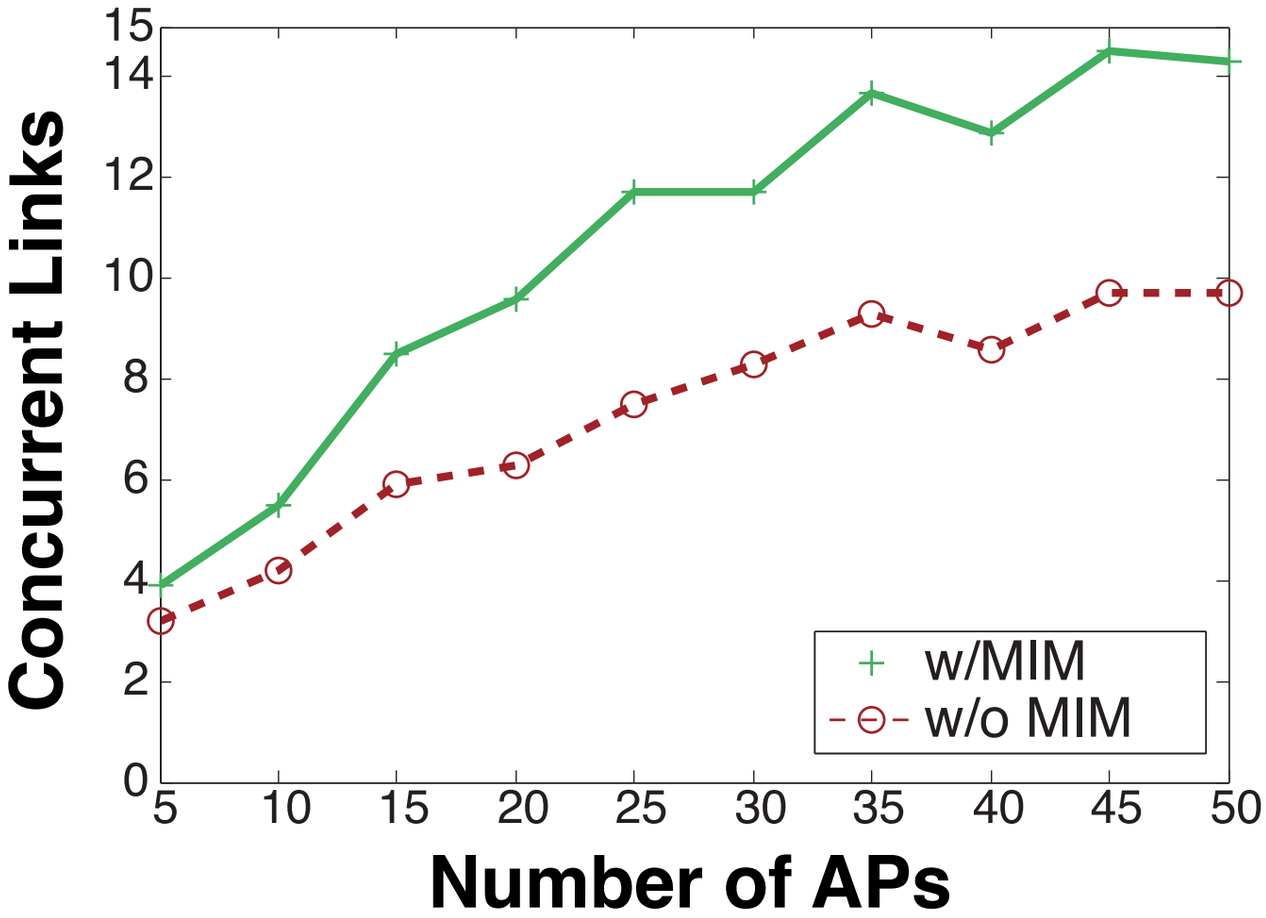
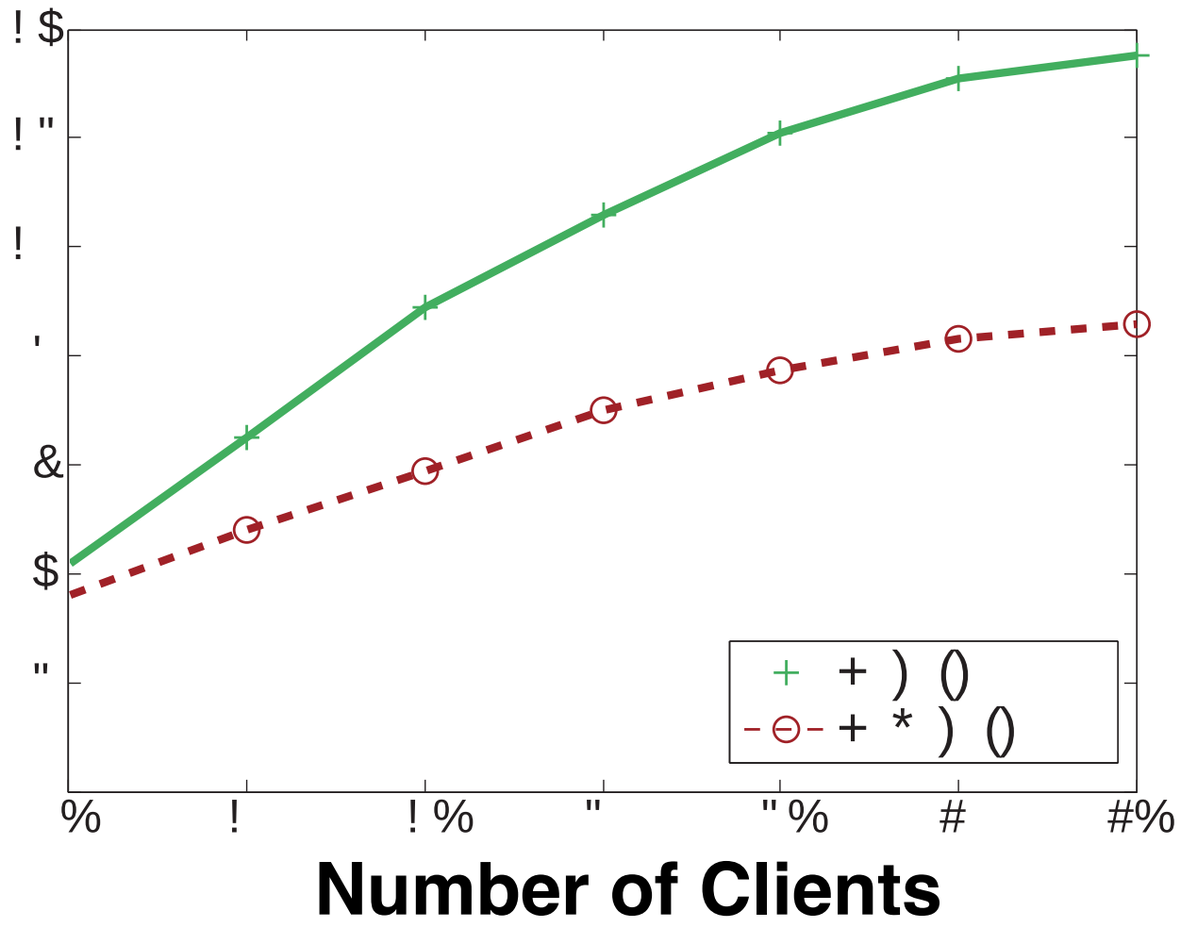

MIM-aware scheduler
AP1
AP2
Ethernet LAN
C1
C2

How much gain from MIM?

Integer programming analysis (optimal NP-hard)





Link scheduling **with** and **without** MIM:

improved spatial reuse ➧ higher throughput

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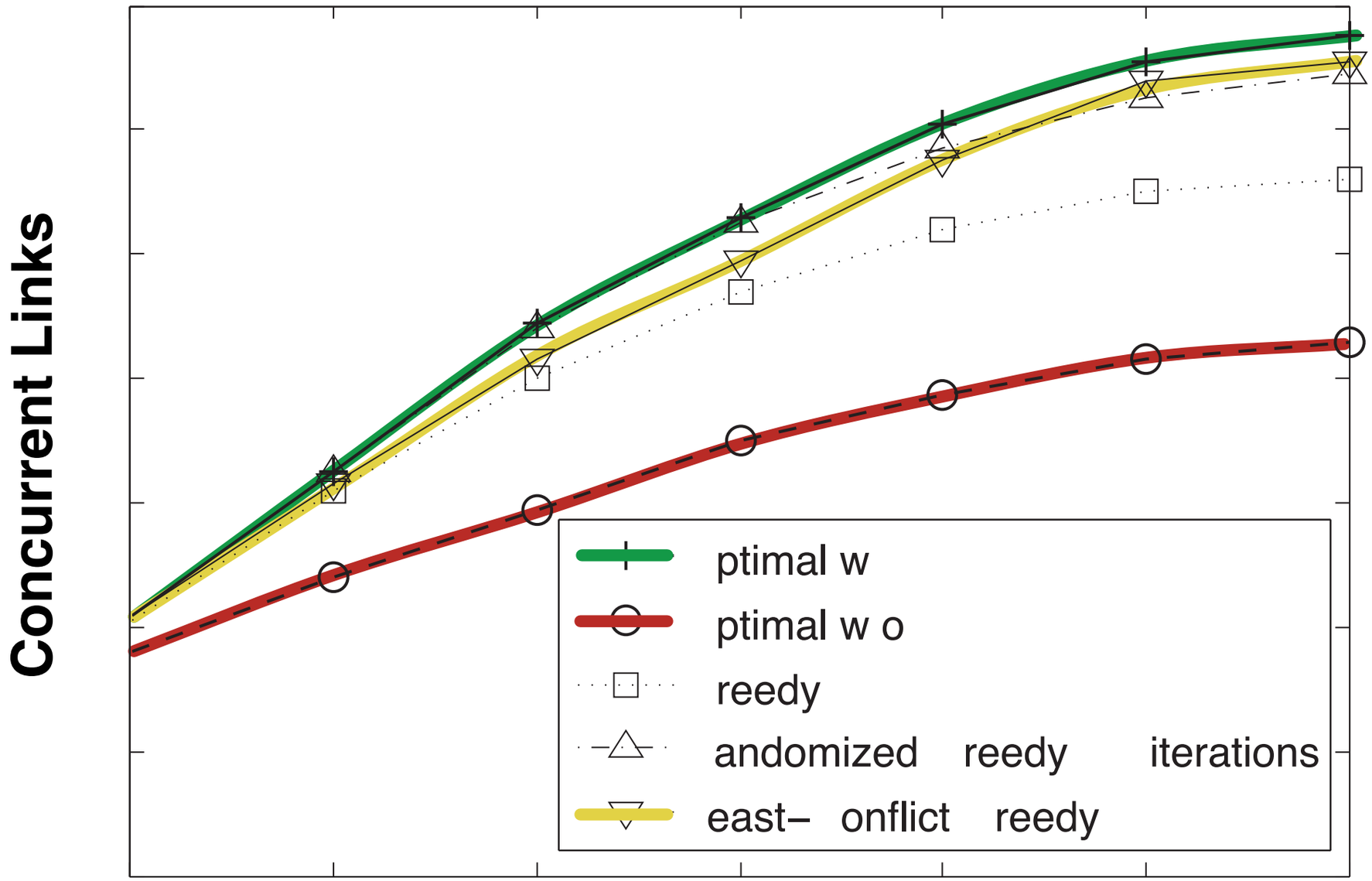
Integer programming analysis (optimal NP-hard)

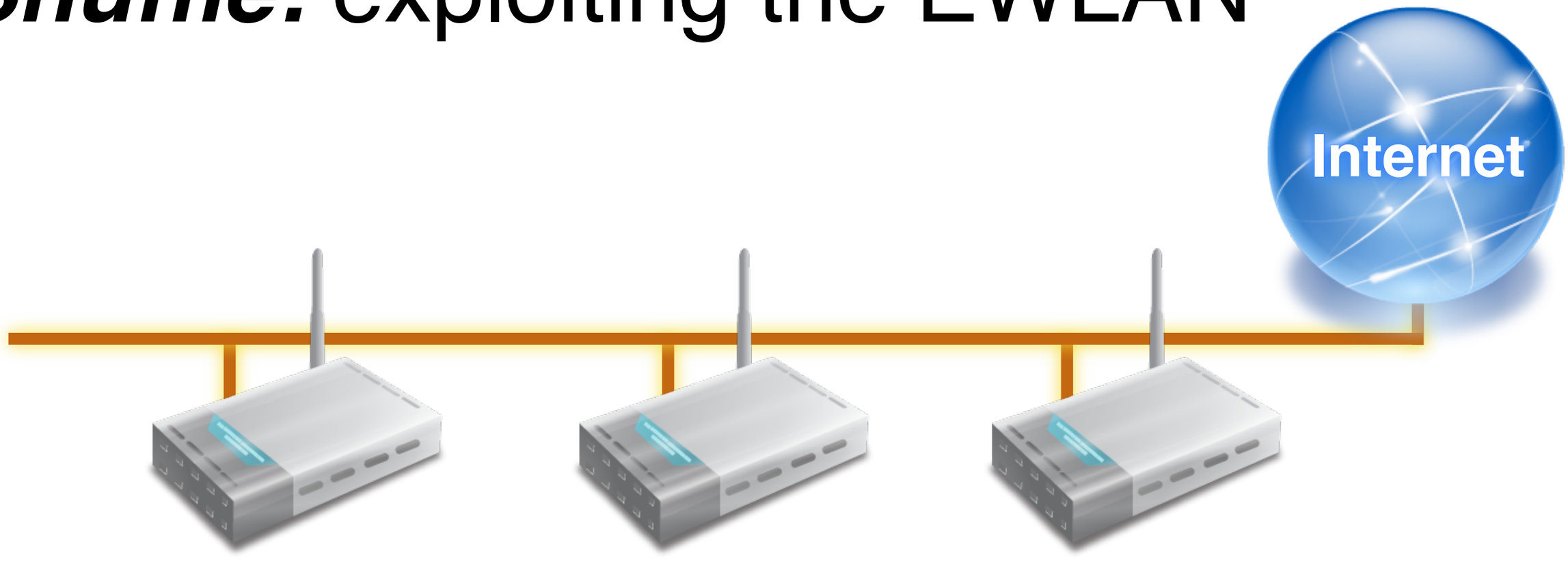
Practical heuristics extract most available gain



Shuffle

An MIM-aware link-layer for the enterprise

Shuffle: exploiting the EWLAN



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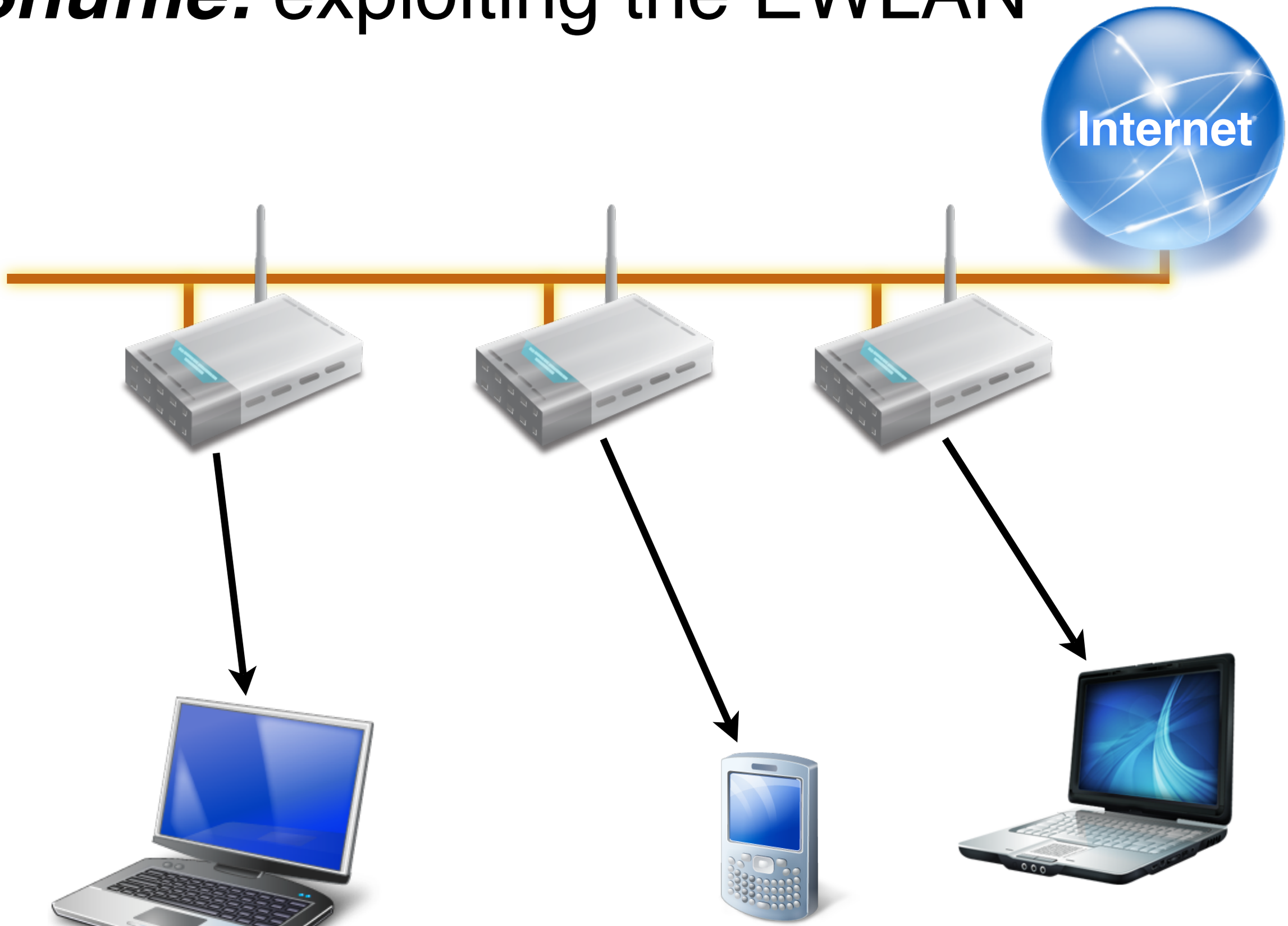

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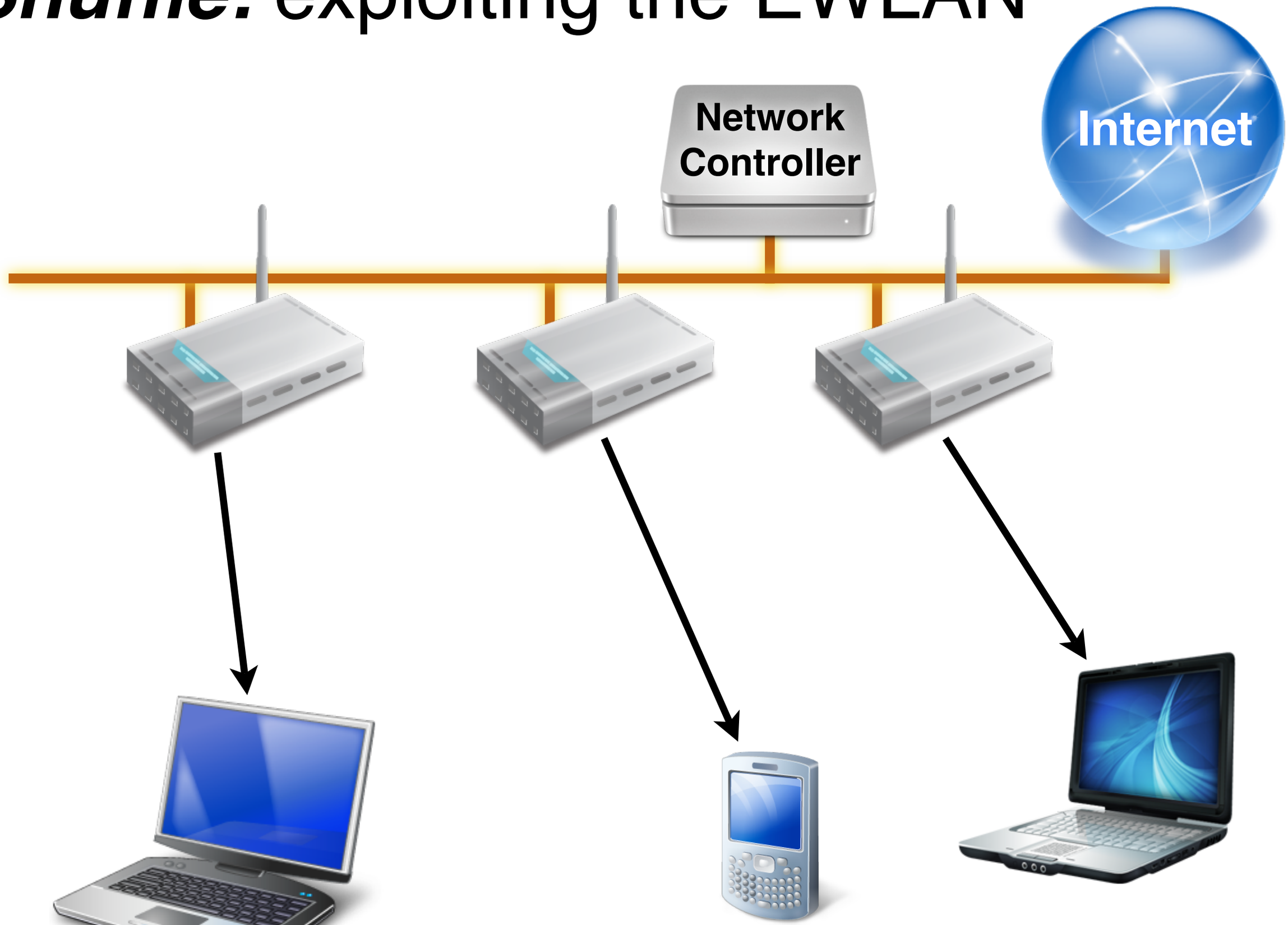
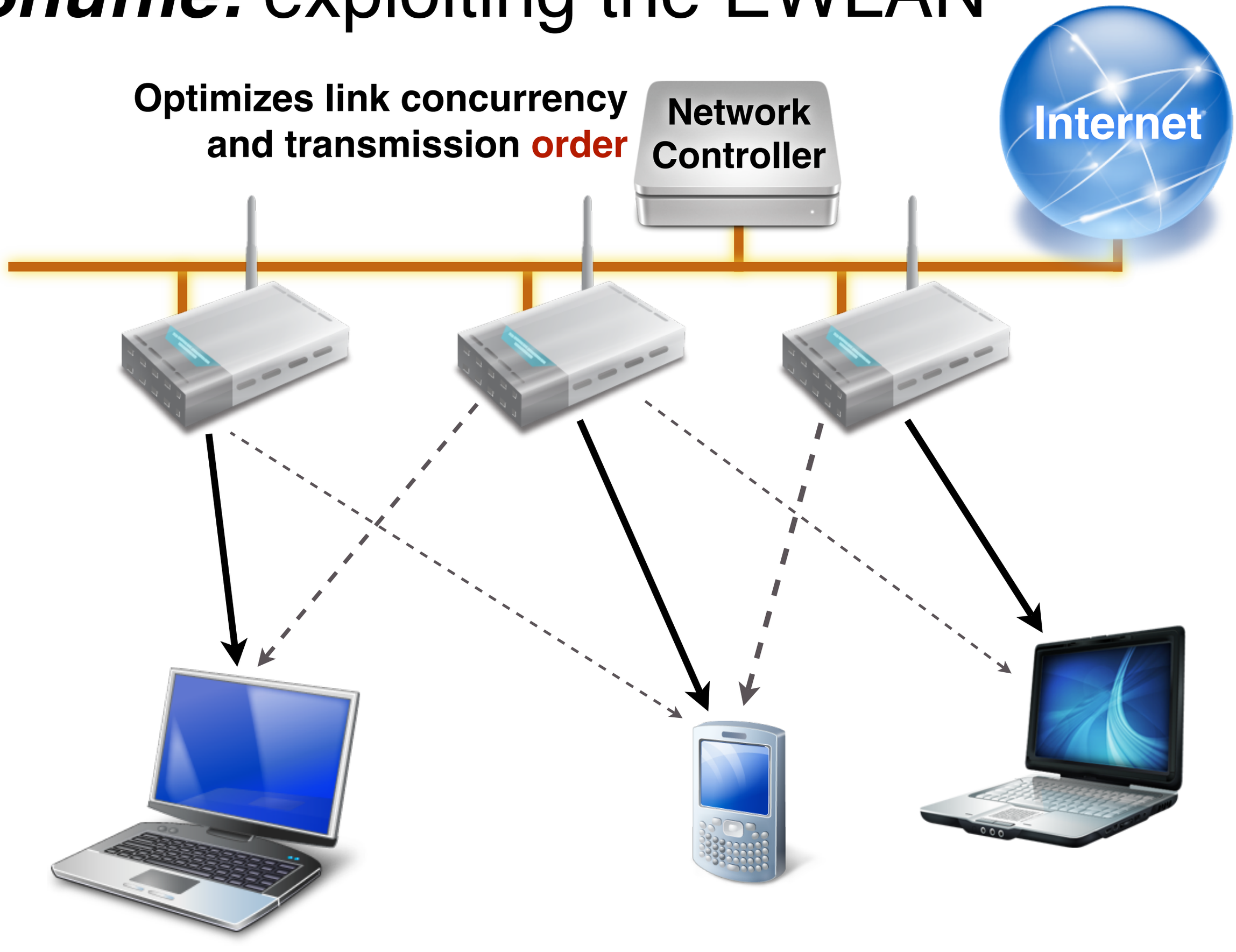


Shuffle: exploiting the EWLAN

Optimizes link concurrency and transmission order



Shuffle Architecture

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- **Packet Scheduling**
- **Schedule Execution**

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  - Achieve desired time synchronization
  - Loss detection, recovery

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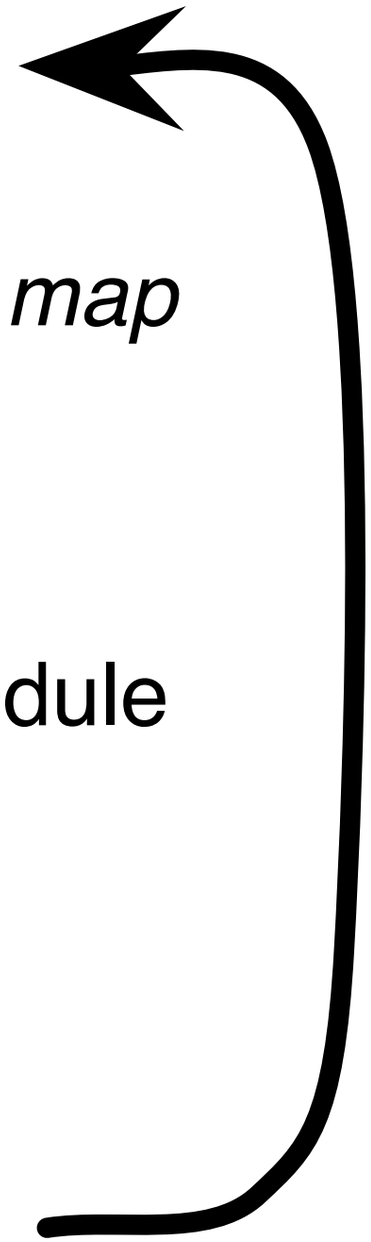
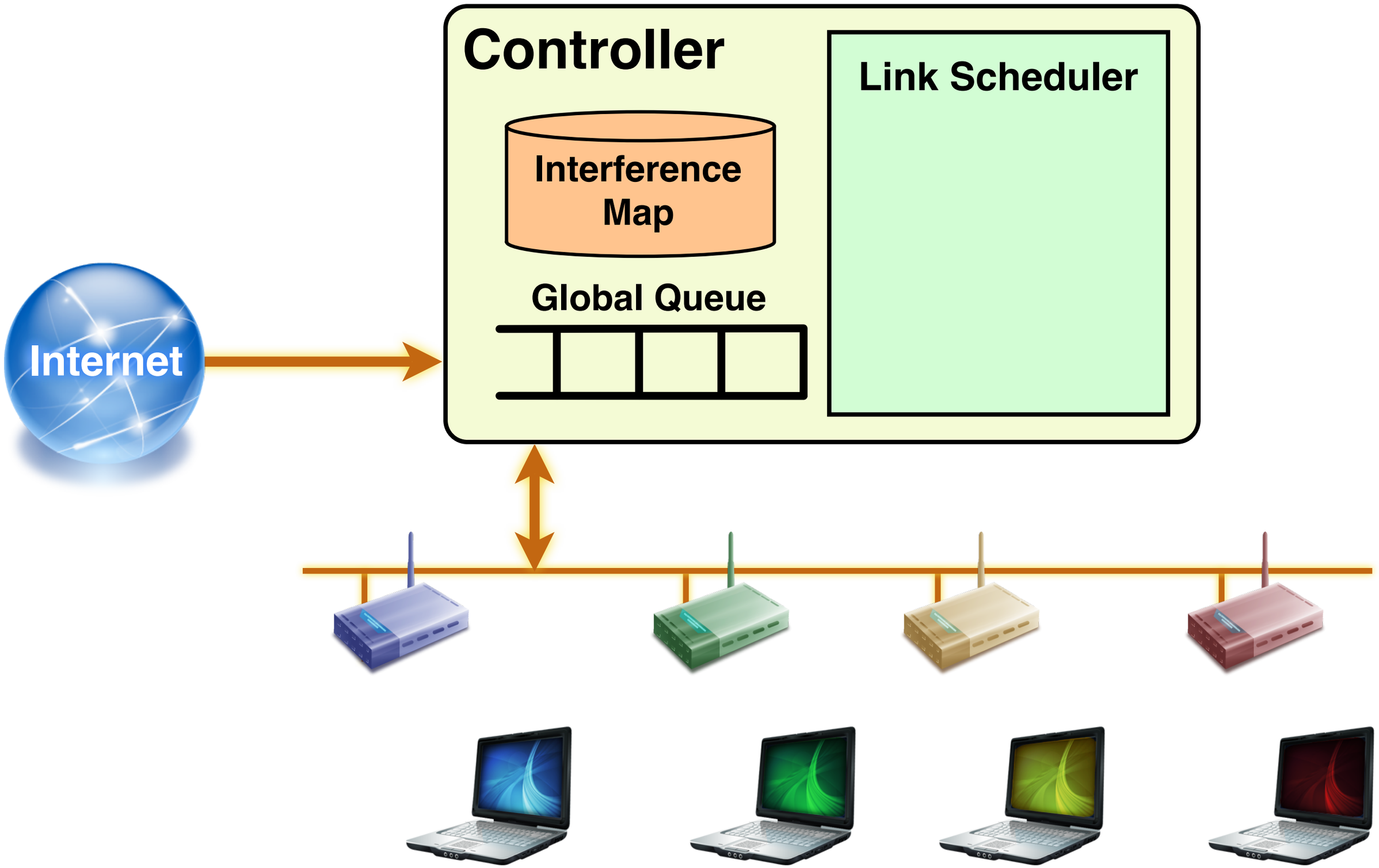
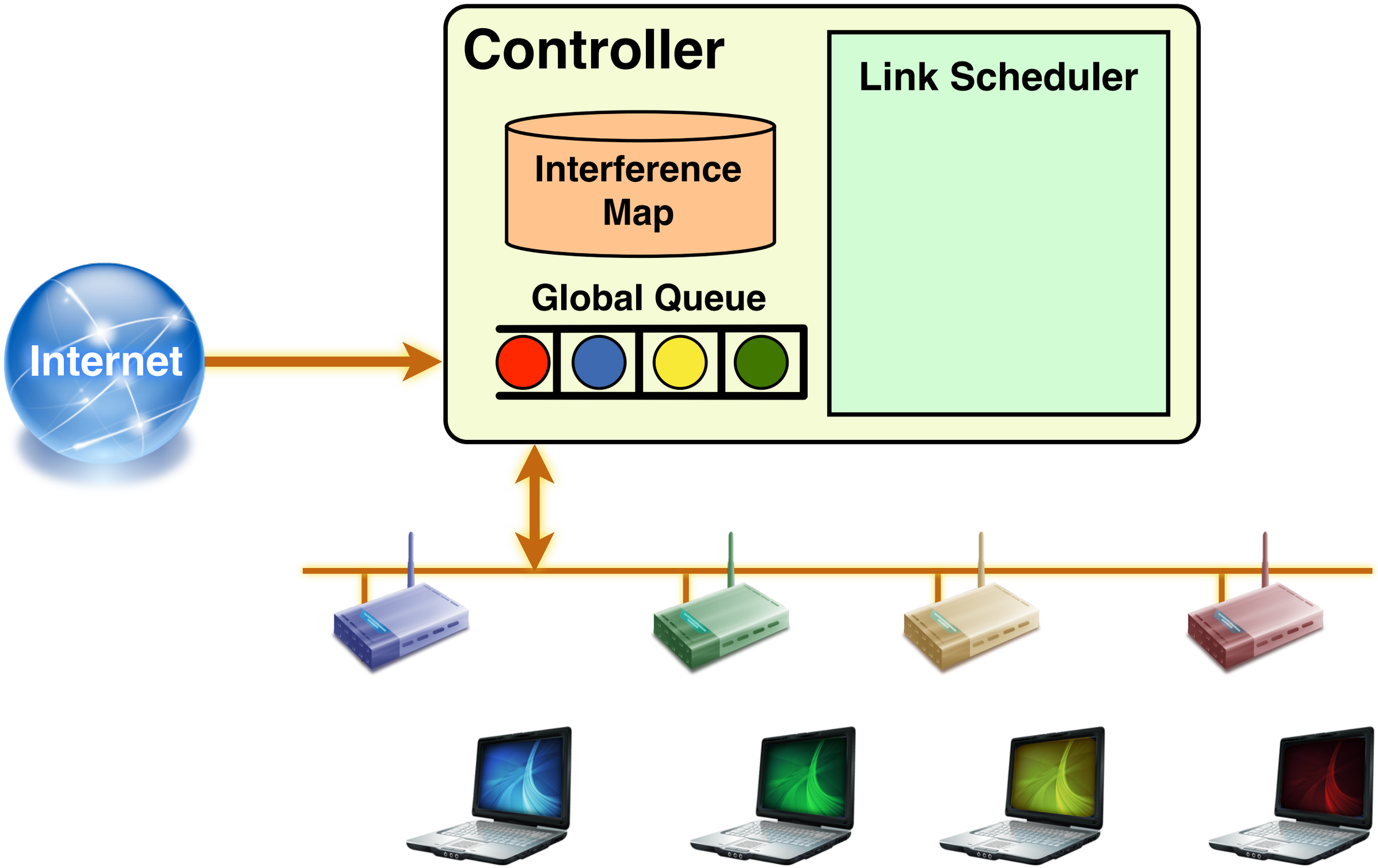
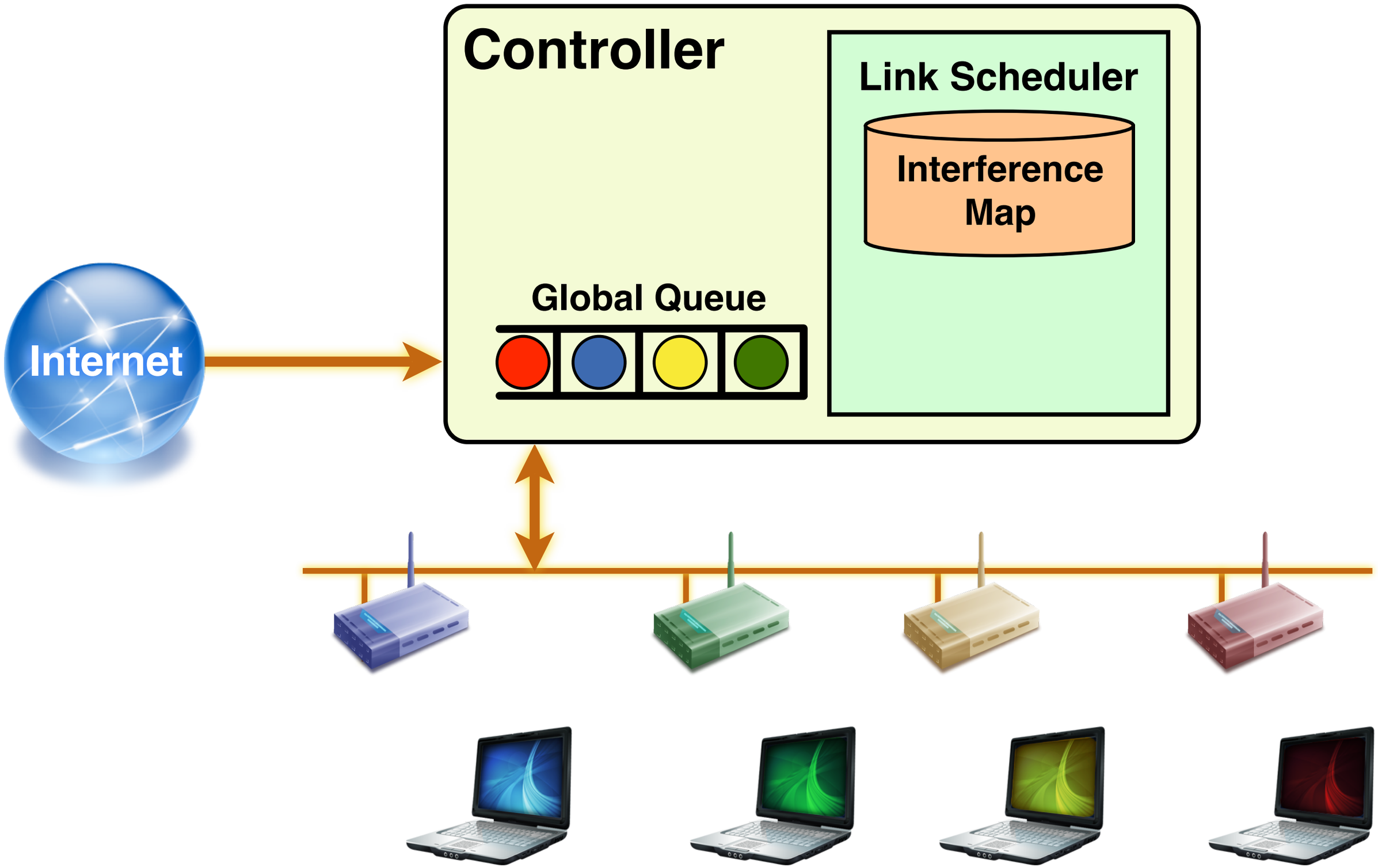


In the steady state...




Controller
Interference Map
Global Queue
Link Scheduler
Internet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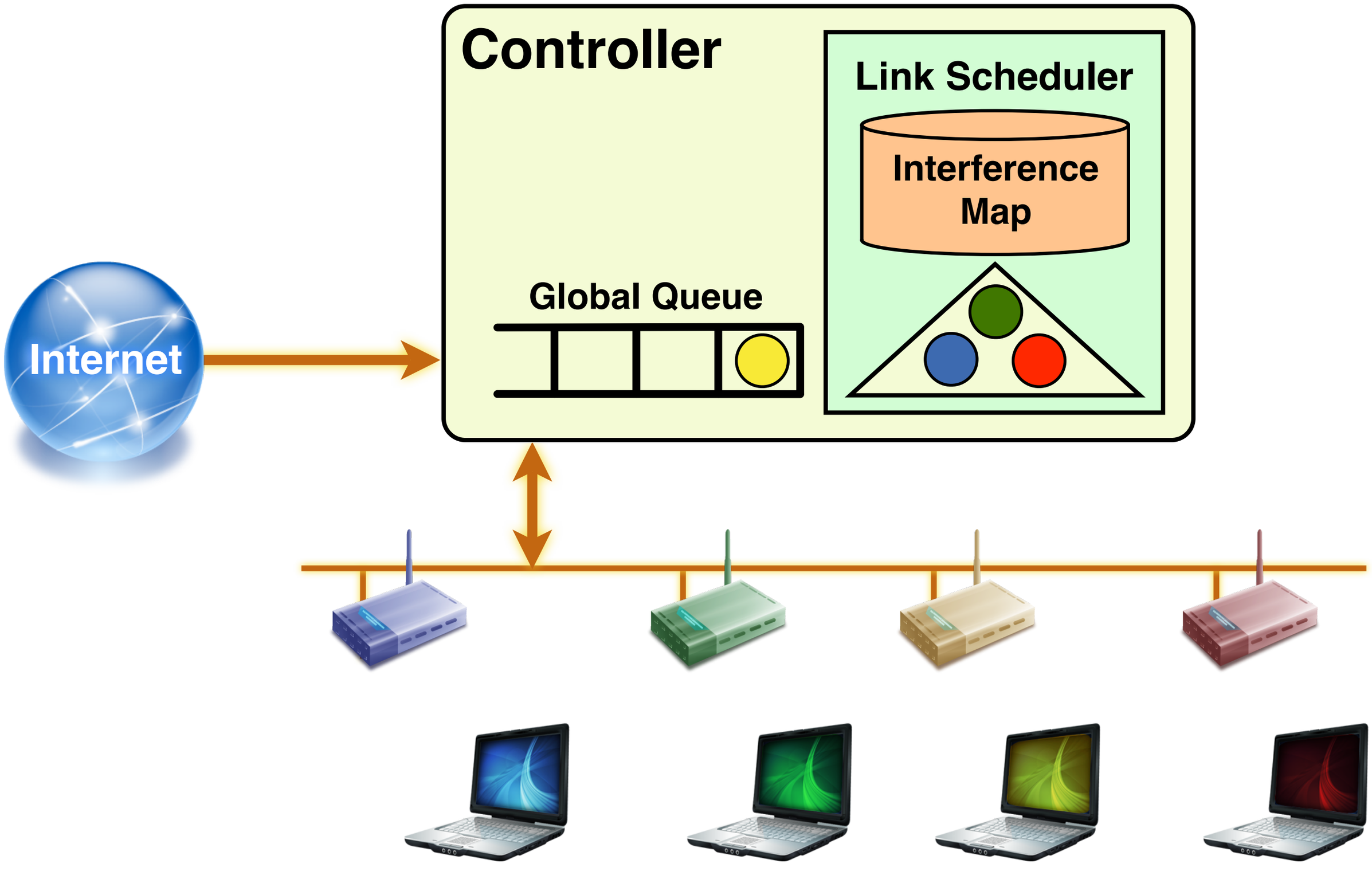
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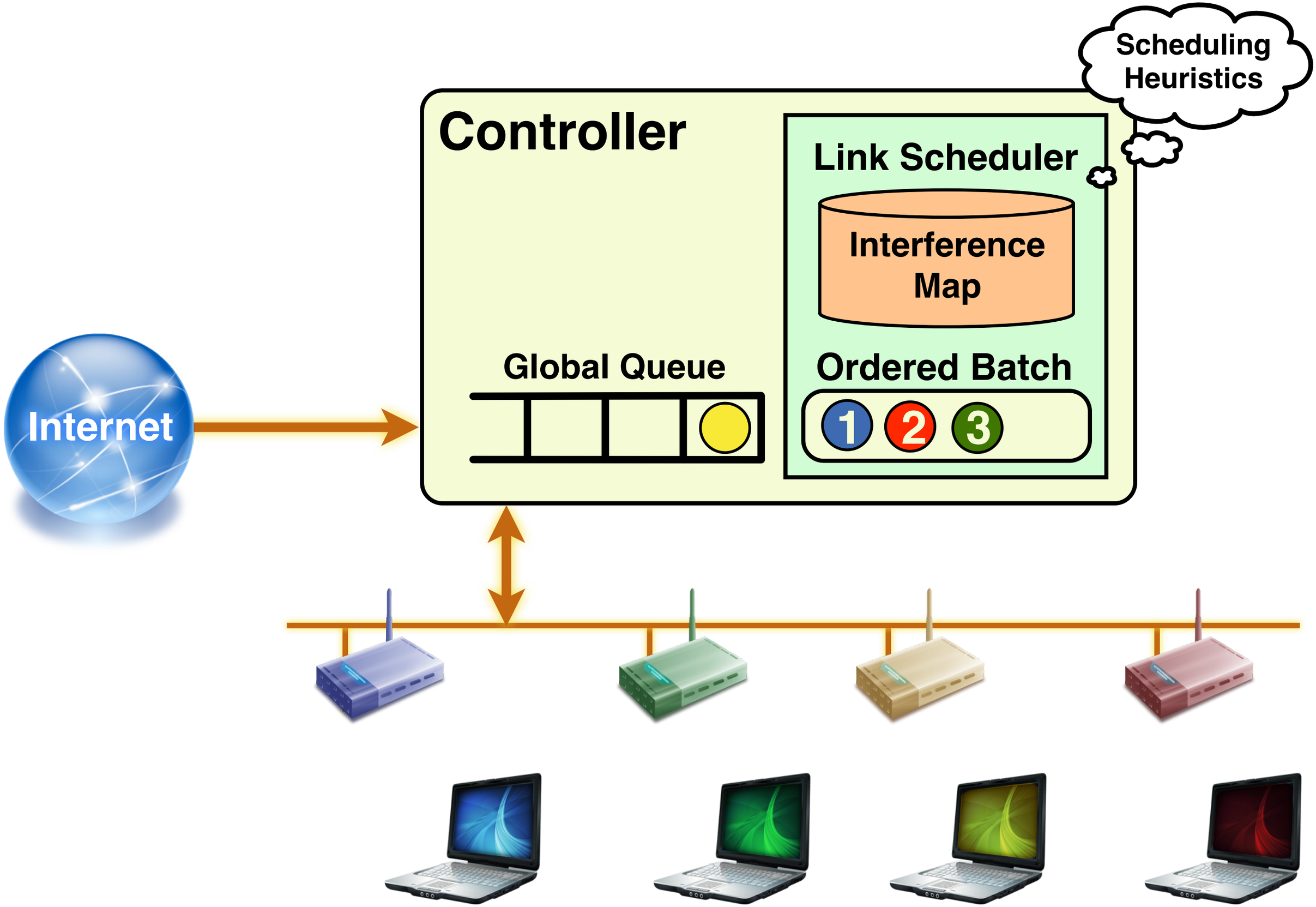
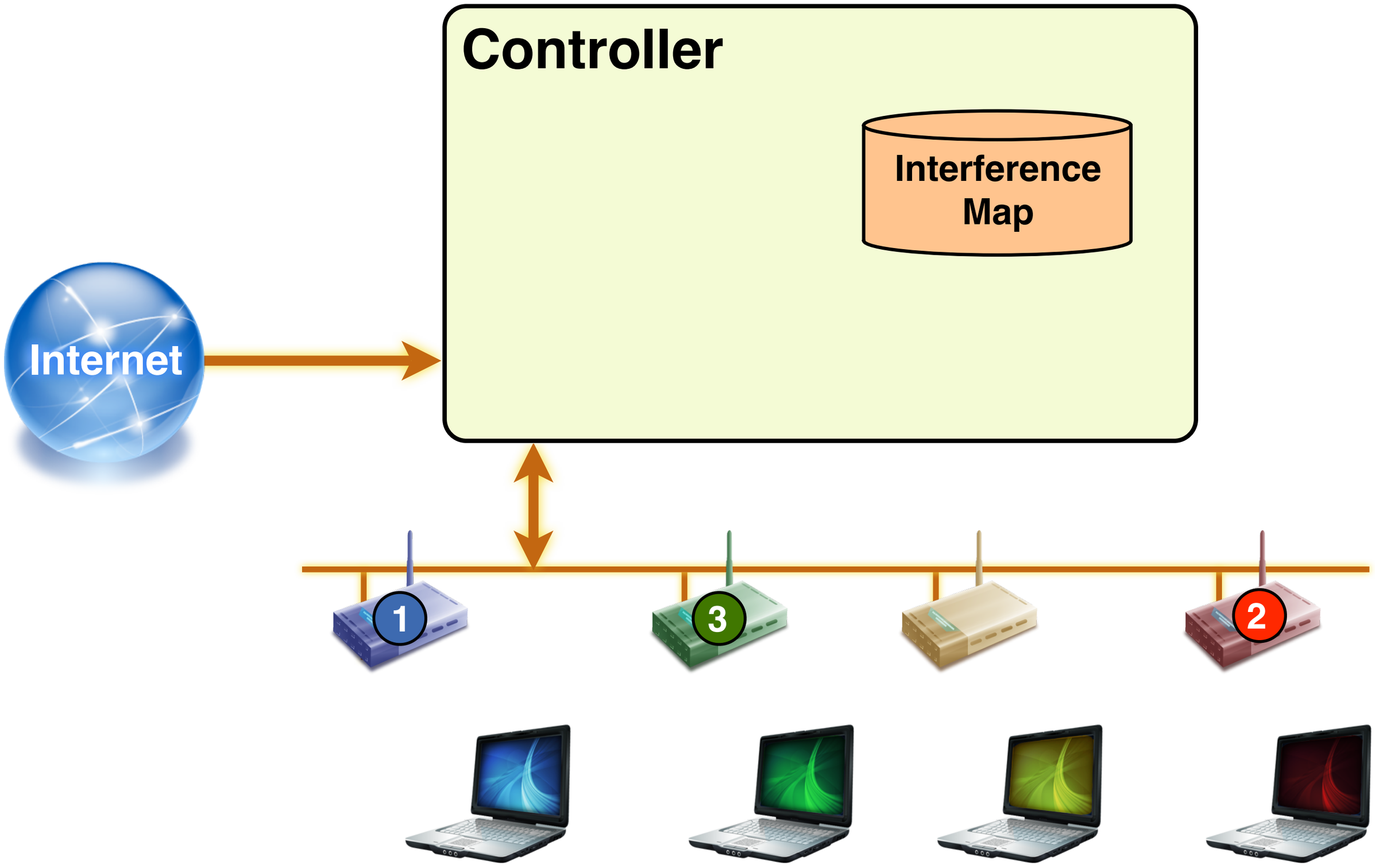
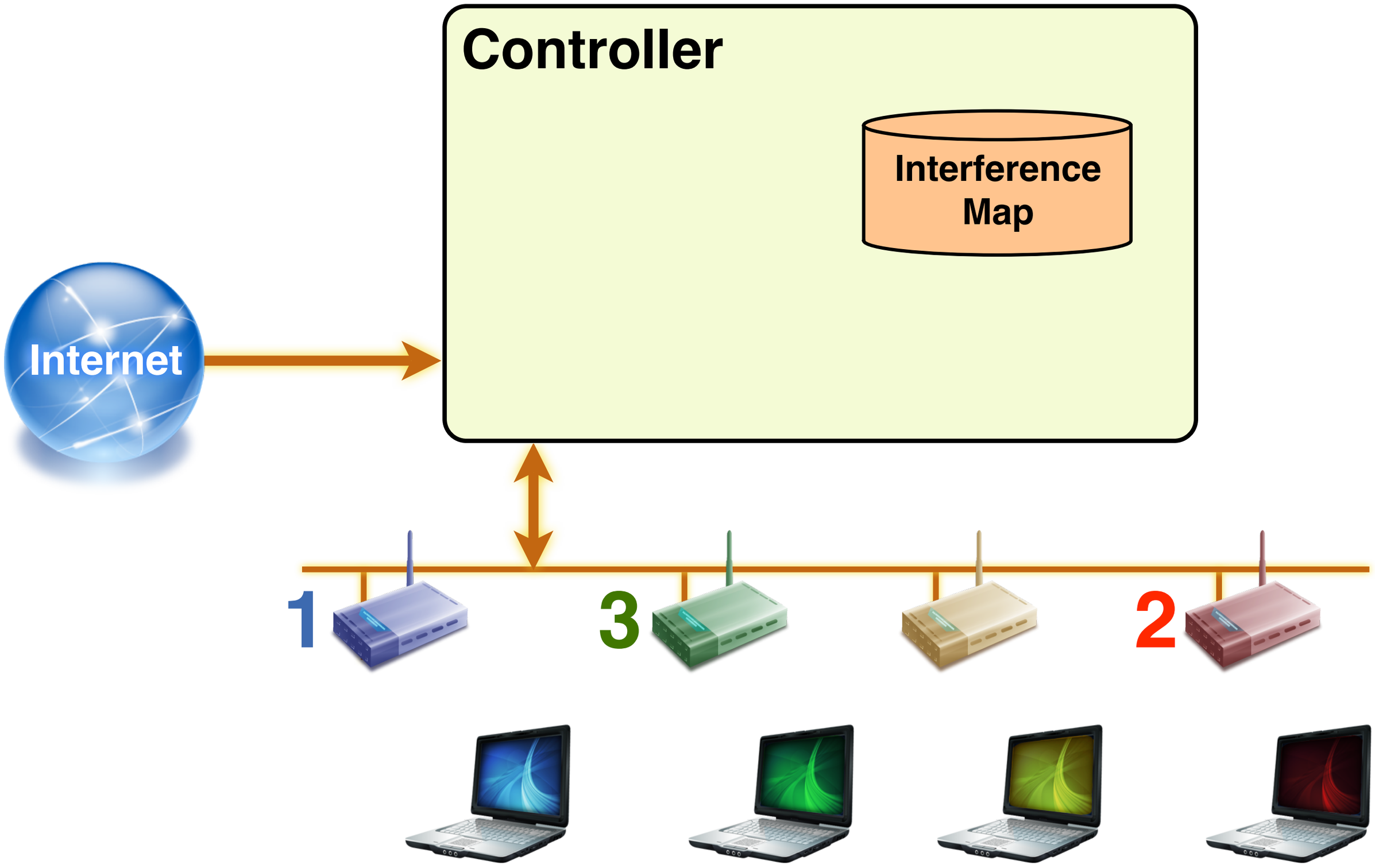
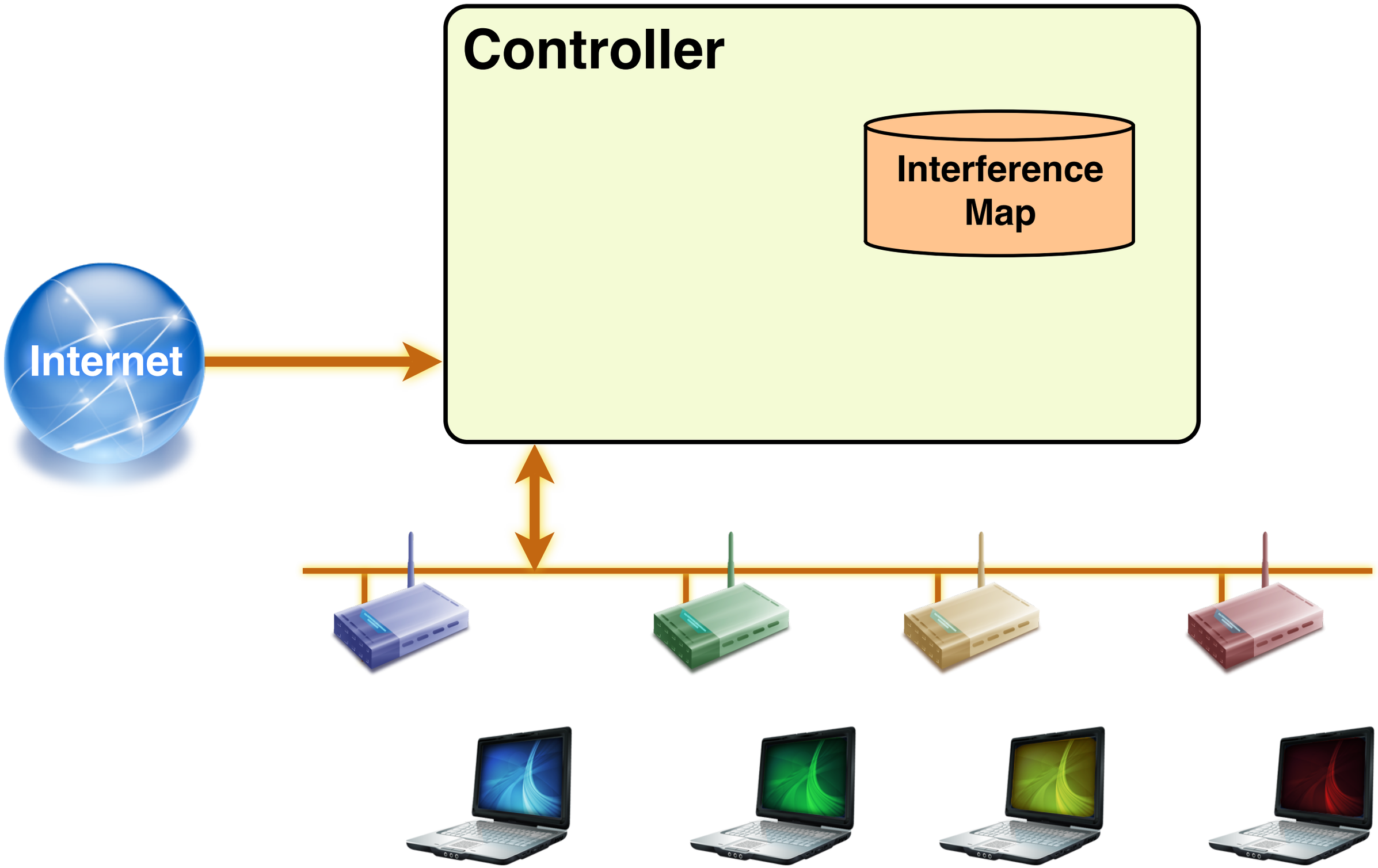
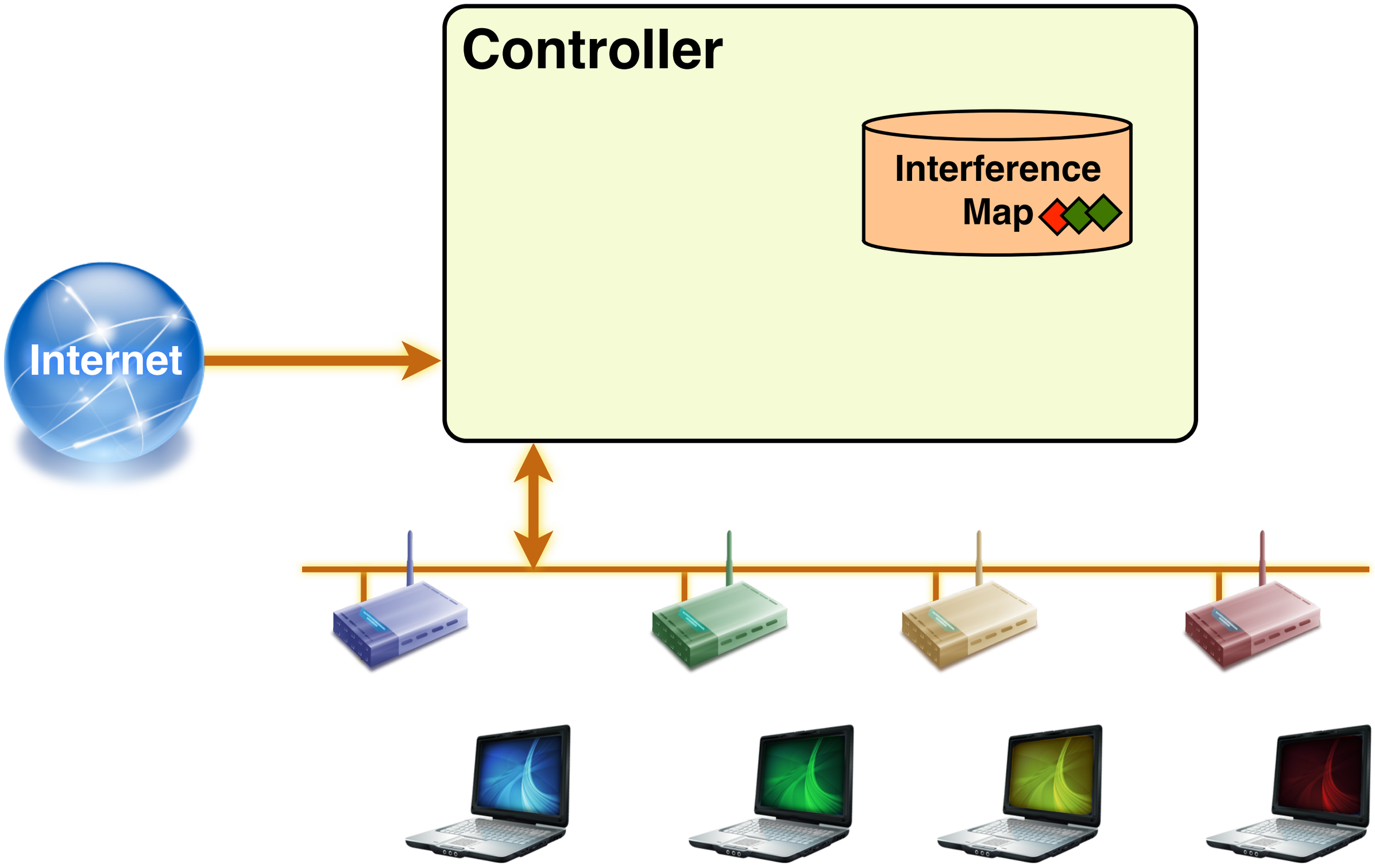
Global Queue
Internet

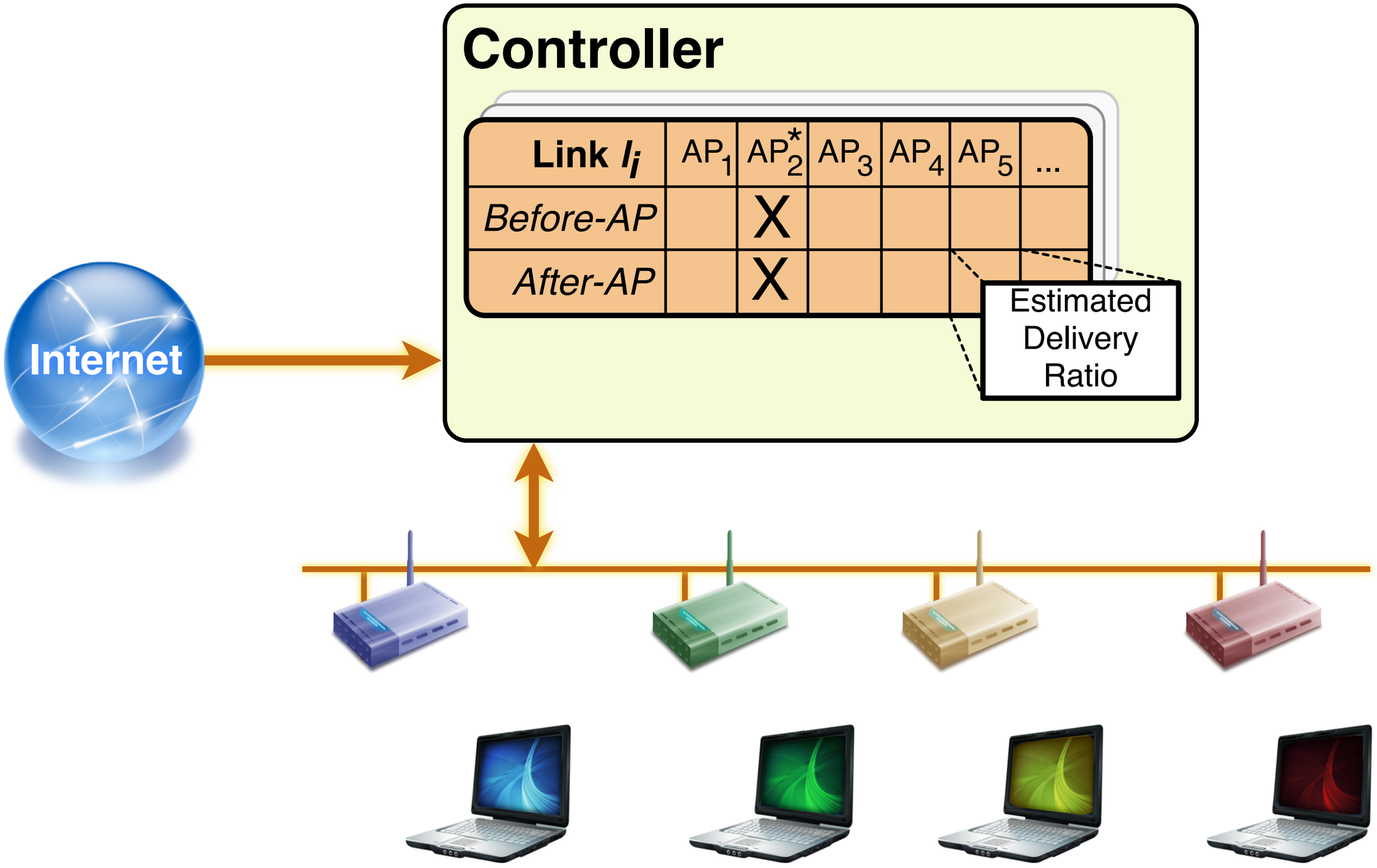

Scheduling Heuristics
Controller
Link Scheduler
Interference Map
Global Queue
Ordered Batch
1
2
3
Internet


Controller
Interference Map
Internet
1
3
2


Controller
Interference Map
Internet
1
3
2


Controller
Interference Map
Internet


Controller
Interference Map
Internet


Controller
Link l_i
AP_1
AP_2^*
AP_3
AP_4
AP_5
...
Before-AP
X
After-AP
X
Estimated Delivery Ratio
Internet

Shuffle Evaluation

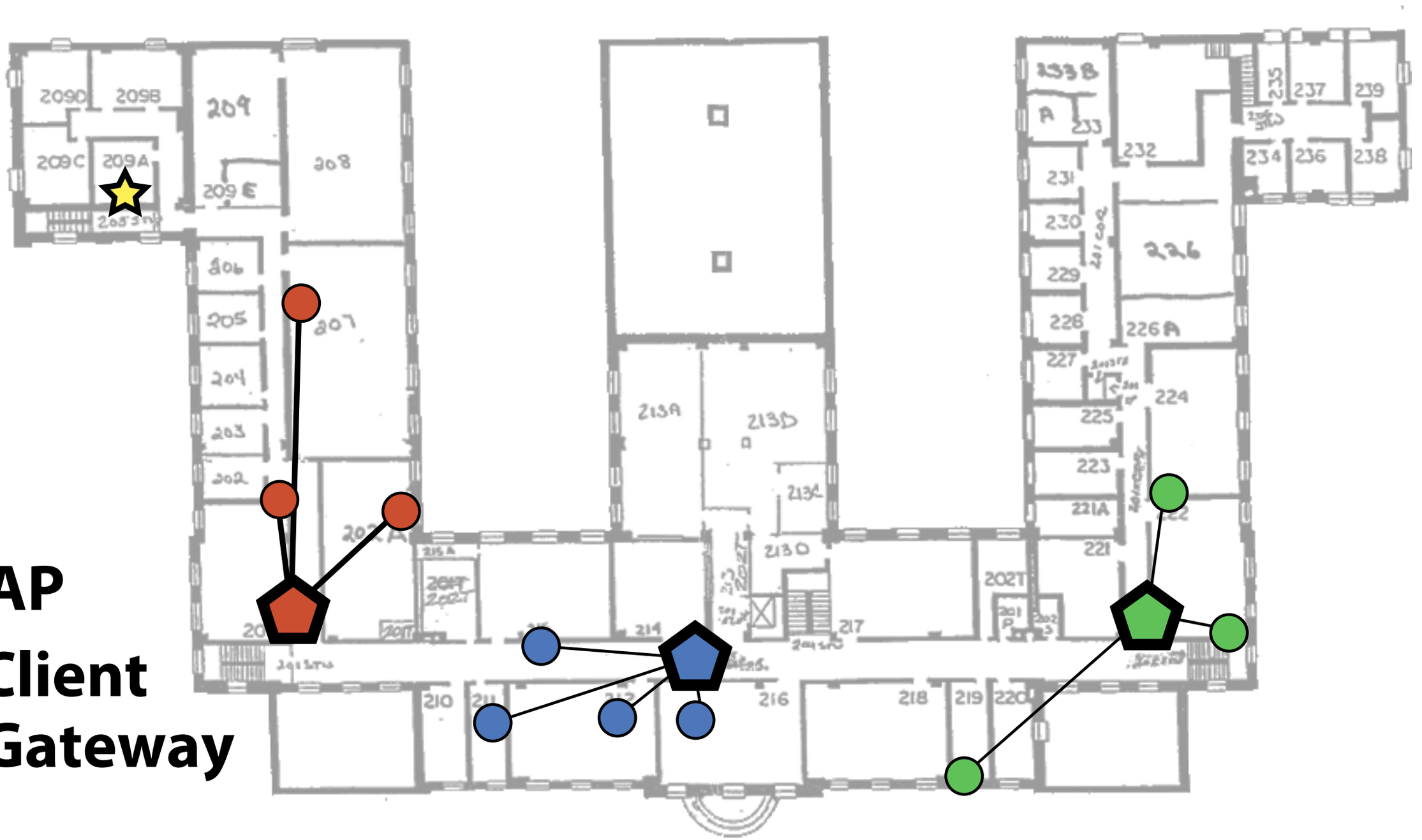
- **Integer programming analysis**
  - Characterizes potential for gain

- **Simulation** (in paper)
  - Gains from scale

- **Testbed implementation**
  - Validates deployment feasibility

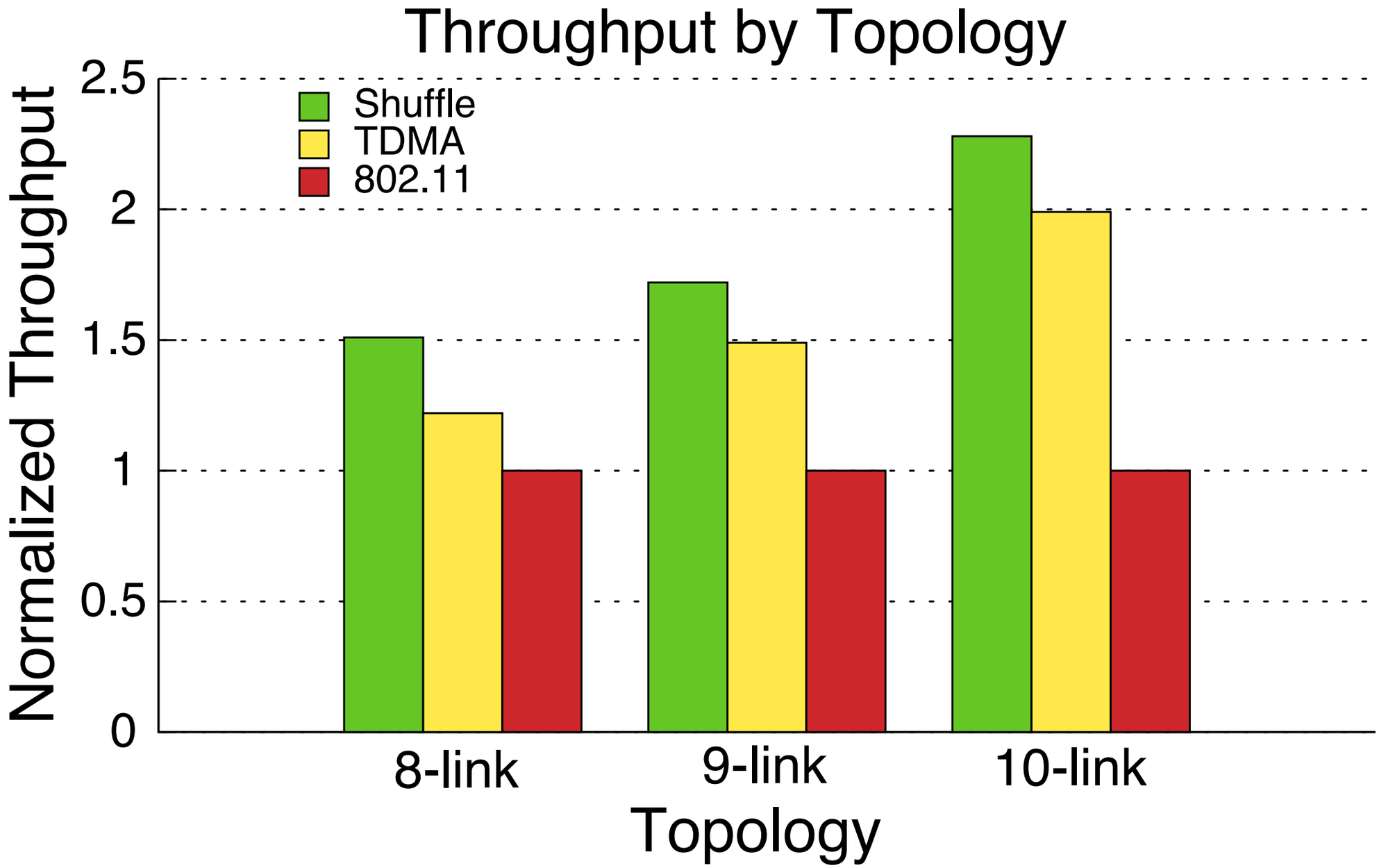
Testbed Deployment

Testbed Deployment



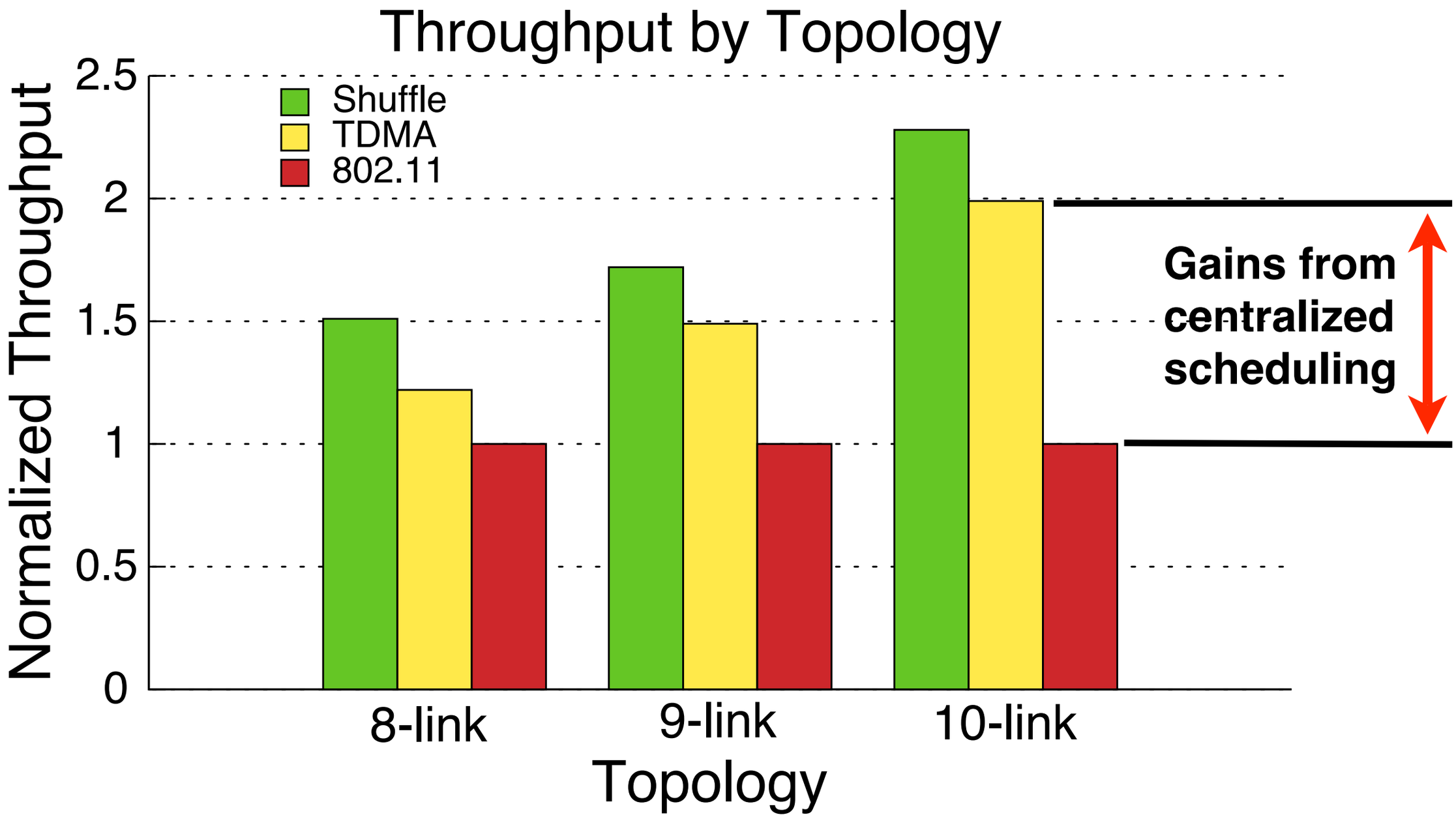
Fixed rate comparison

Shuffle achieves higher delivery ratios than TDMA



Fixed rate comparison

Shuffle achieves higher delivery ratios than TDMA



Fixed rate comparison

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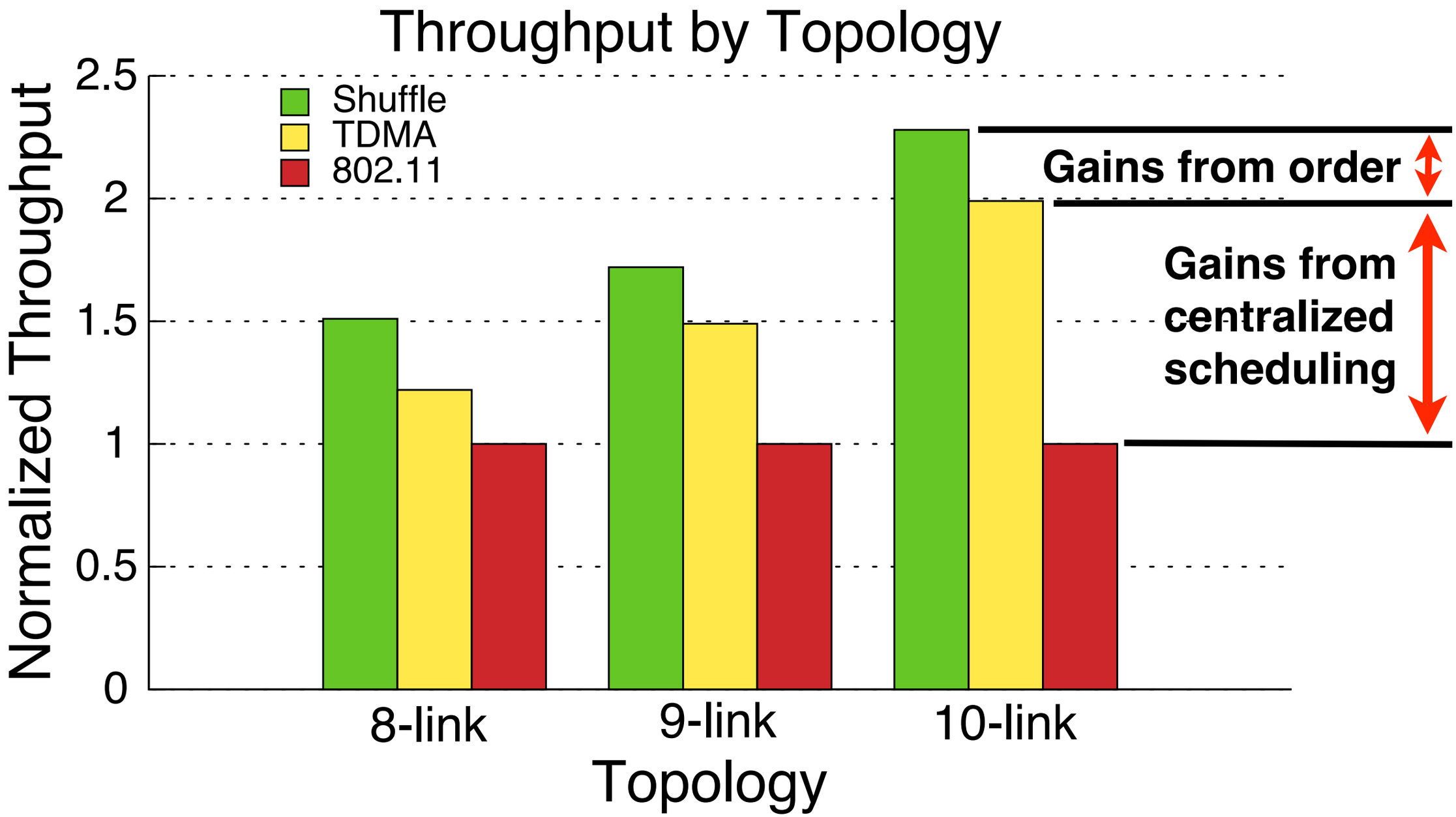
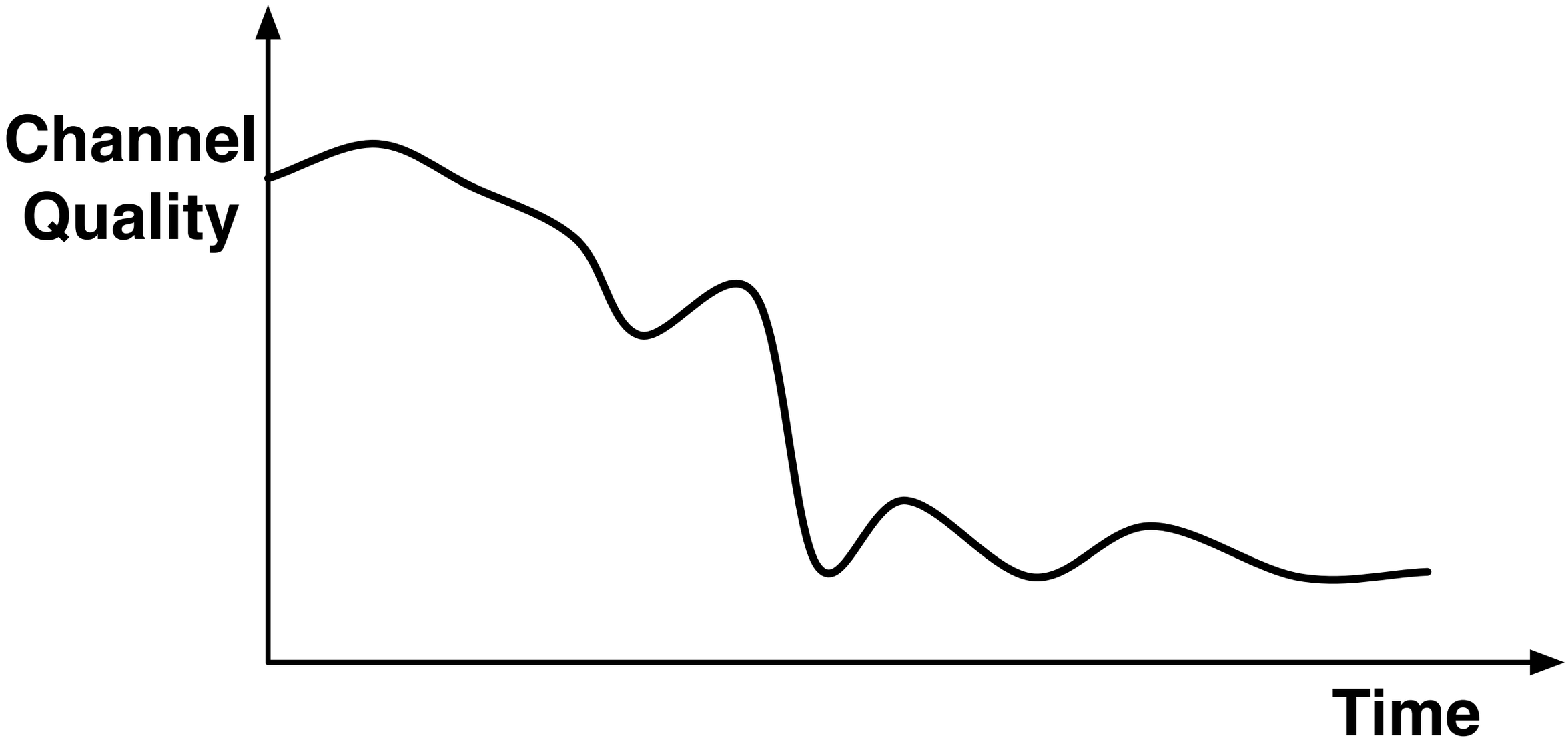


Multiplexing experiments

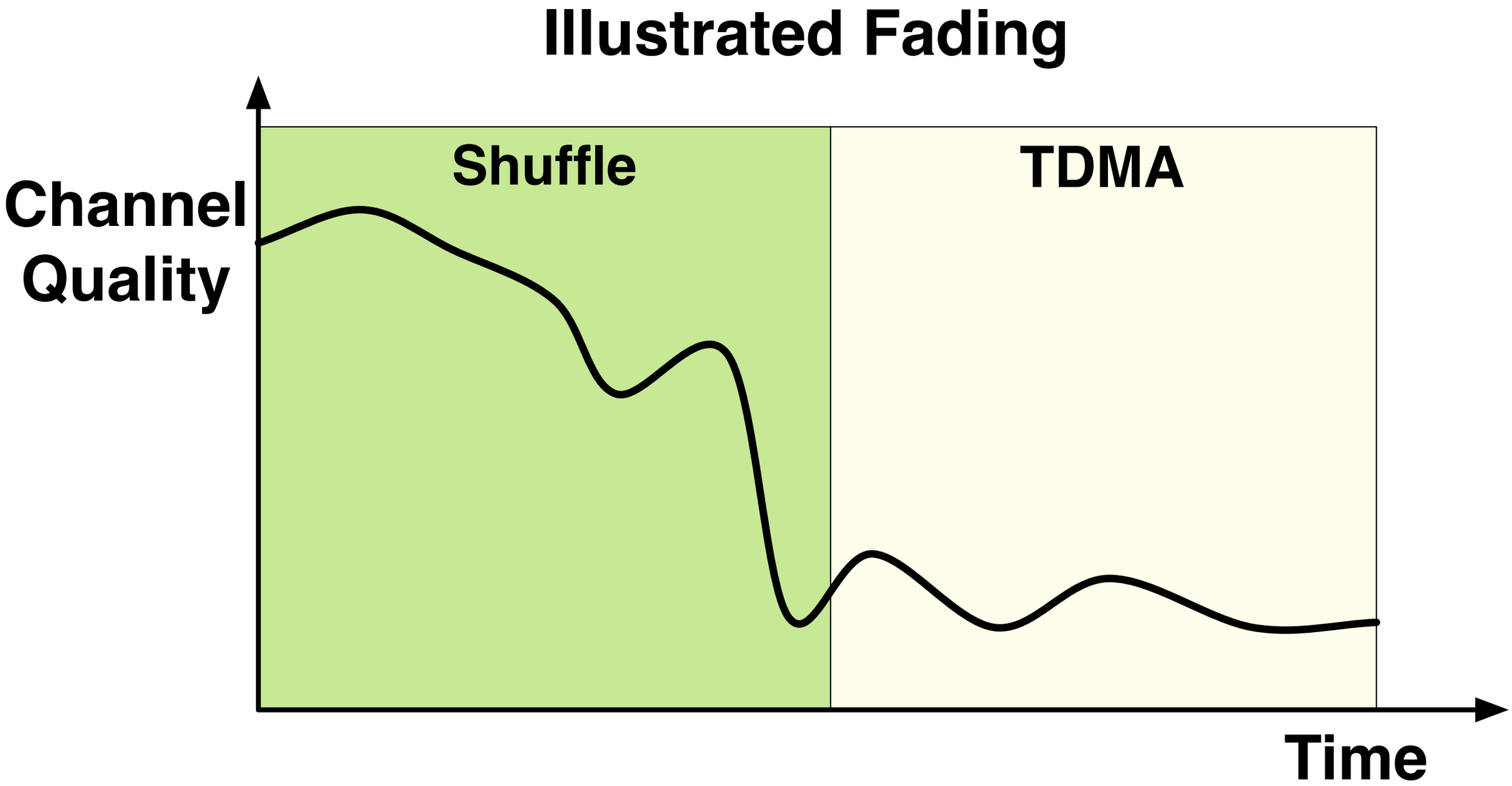
Under time-varying channel

Illustrated Fading



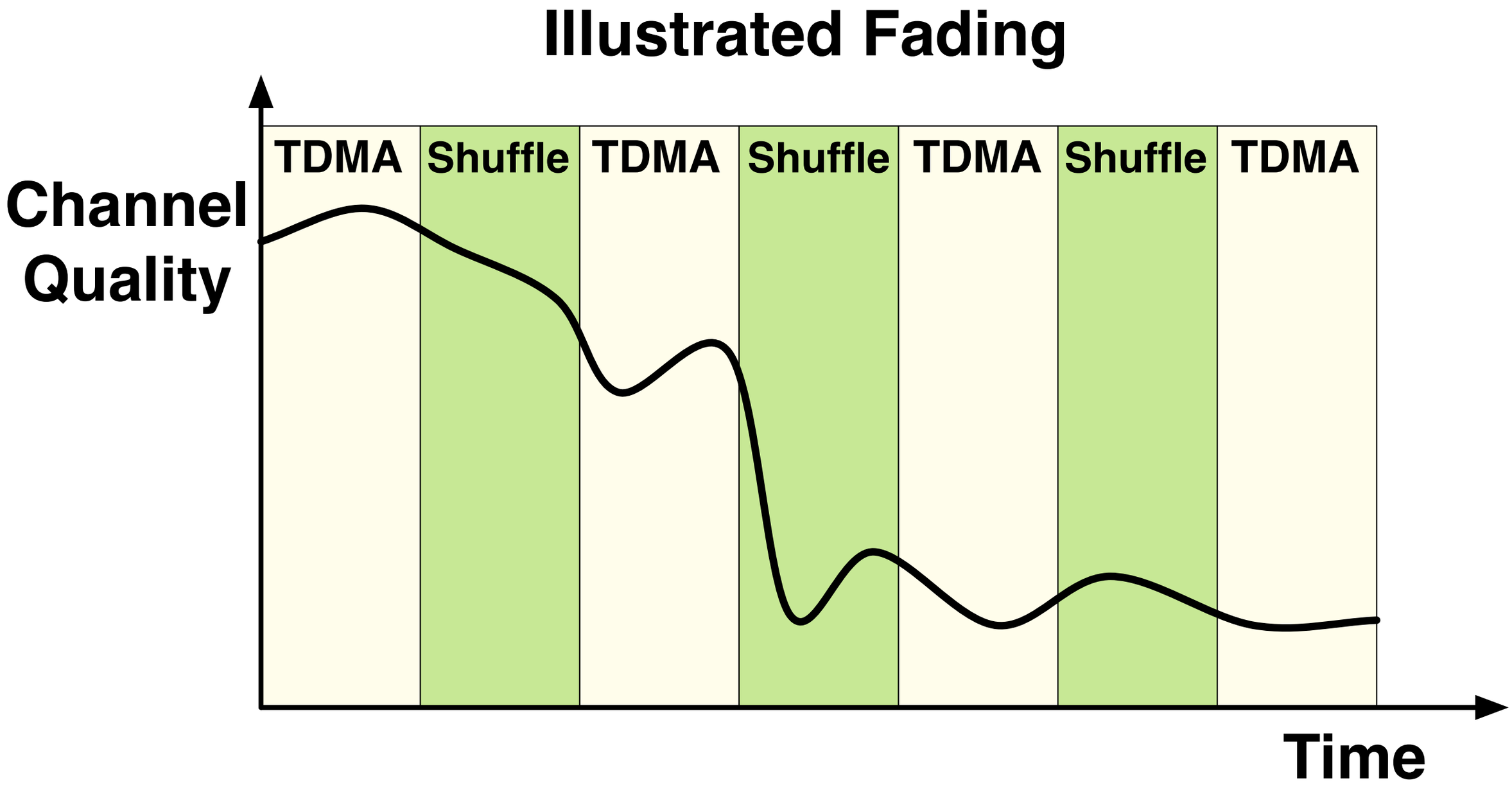
Multiplexing experiments

Under time-varying channel

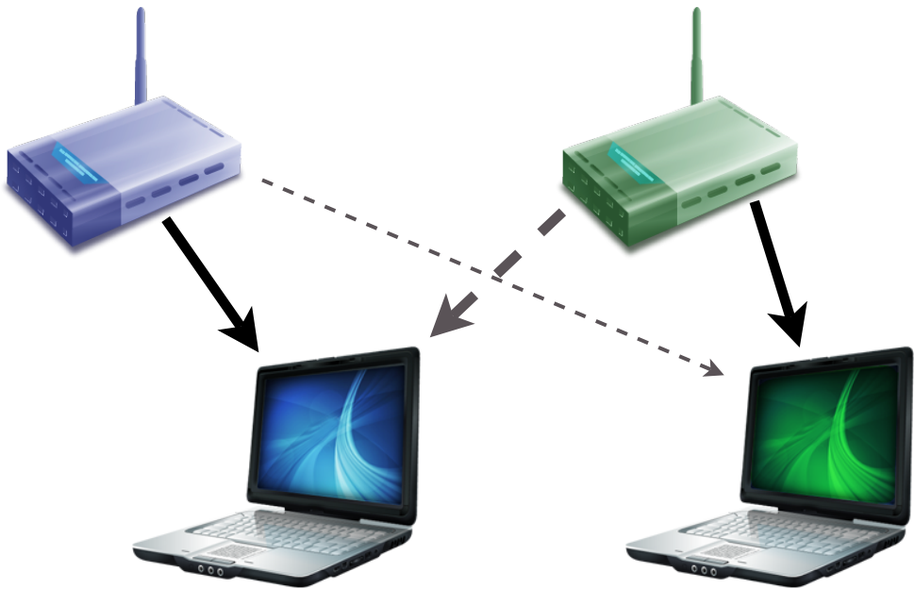


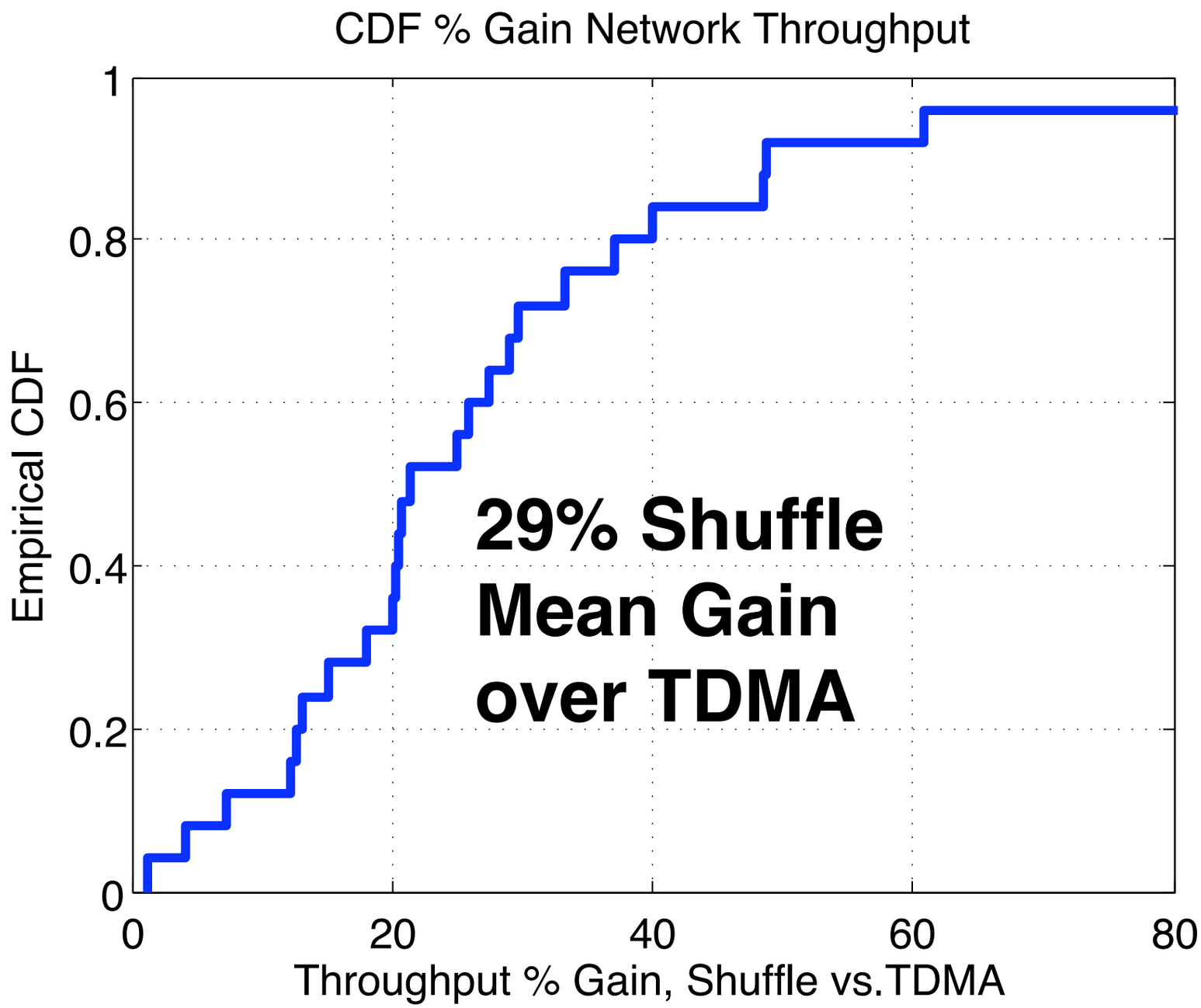
Multiplexing experiments

Under time-varying channel



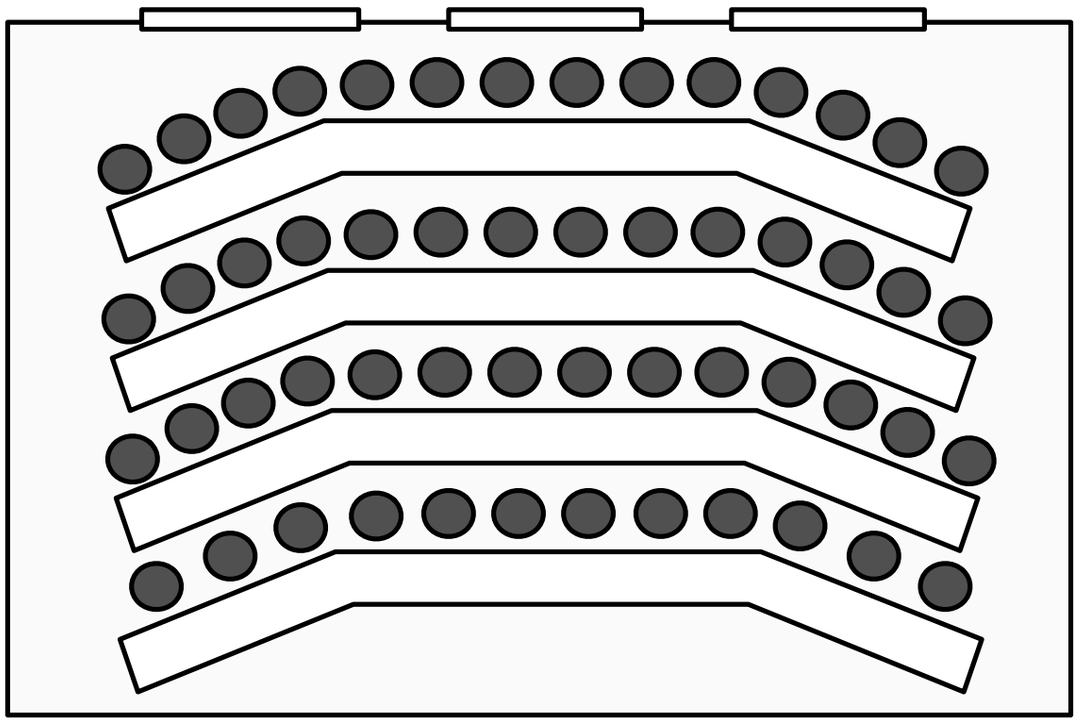
Motivating example



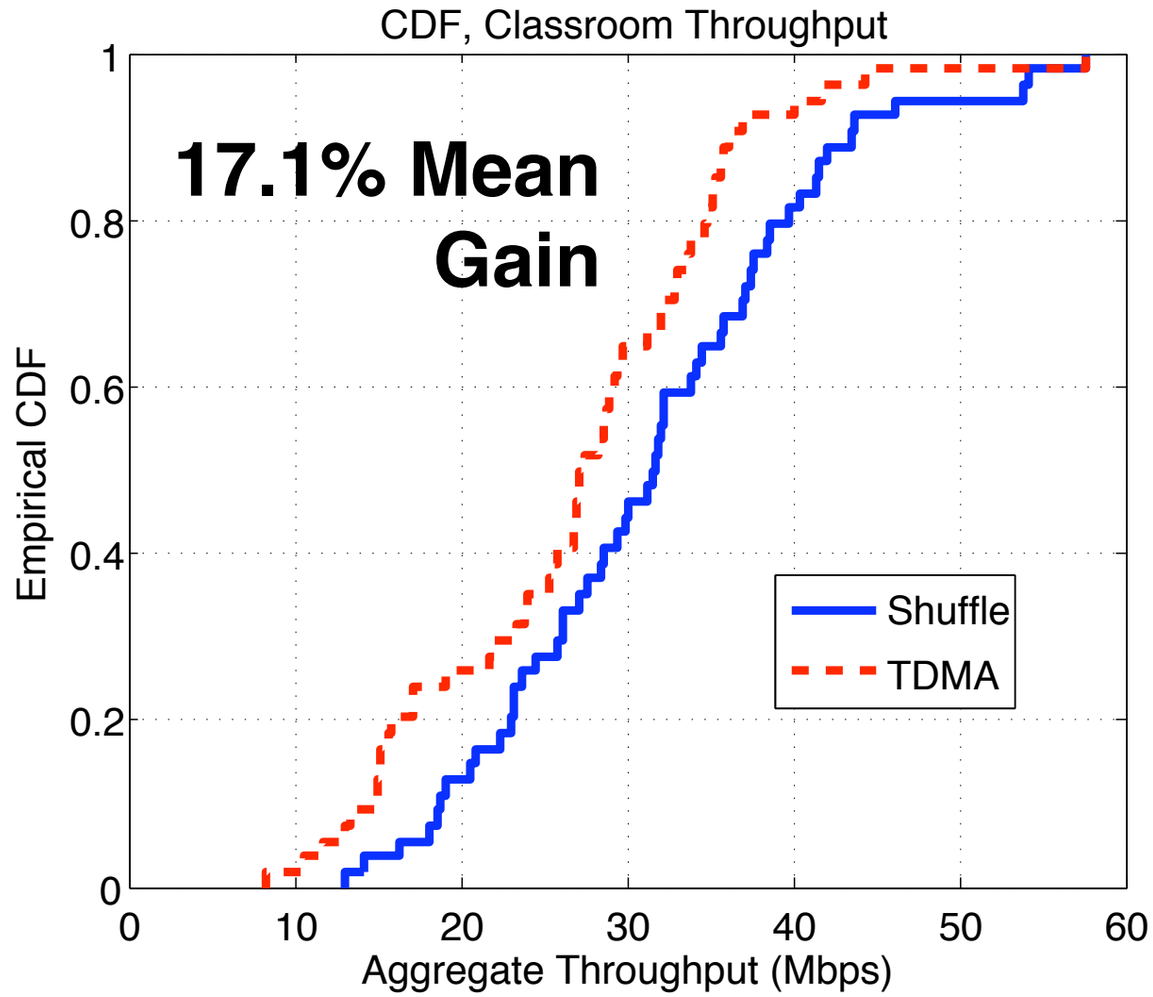


Systematic “classroom” test

Characterizes gains in a practical scenario



Classroom setting



Limitations and Future Work

- **Complications to the interference map**
  - External network interference
  - Client mobility
- **Delays**
  - End-to-end latency
  - Jitter from queue reordering
- **Limited testbed scale**

Related Work

- **Capture and MIM**
  - Analysis/model of capture [A. Kochut et al. ICNP 04]
  - Capture/MIM thresholds [J. Lee et al. WinTECH 07]
- **Spatial Reuse**
  - CMAP [Vutukuru et al. NSDI 08]
- **EWLANs and Scheduling**
  - DAIR [P. Bahl et al. HotNets 05]
  - CENTAUR [Shrivastava et al. MobiCom 09]

Conclusion

- MIM **expands capture** potential
- **Transmission reordering** provides opportunities for enhanced concurrency
- Naive MACs such as 802.11, TDMA are unable to enforce a desirable link **order**
- **Shuffle** presents scheduling solution for enterprise environments

Questions, comments?

Thank you

Duke SyNRG Research Group

http://synrg.ee.duke.edu

*µ*sec-precision timing and sync

Synchronization

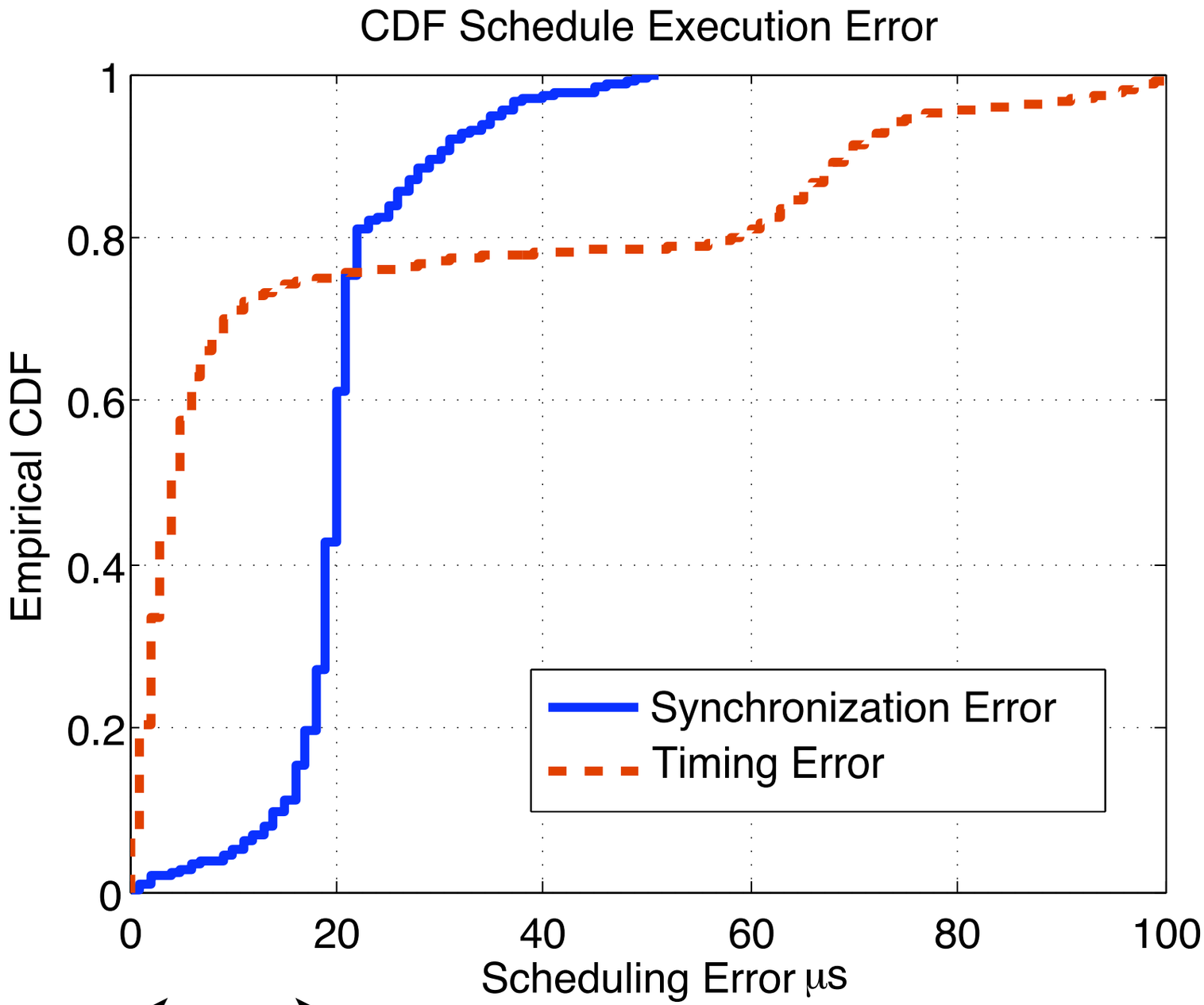
(Controller ↔ AP)

- Ethernet propagation
- Switching
- Processing latency

Timing

(AP → client)

- Lack of HW support
- Coarse OS interrupts



20*µ*sec 802.11a/g/n preamble duration

AP1

AP2

Weak Interference

SINR > MIM Threshold

Strong Interference

SINR < MIM Threshold

C1

C2

Order matters

Order doesn't matter

Centralized AP operation

Central controller optimizes concurrency