Wireless Network Security and Privacy

Cross-layer attacks & defenses

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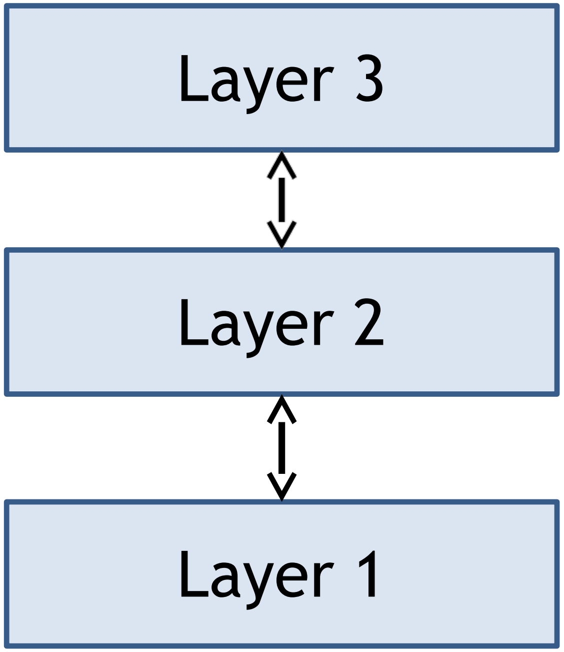
Agenda

- Cross-layer design
- Attacks using cross-layer data
- Cross-layer defenses / games

Layering

- **Layering simplifies network design**
- Layered model:



Layer 3

Layer 2

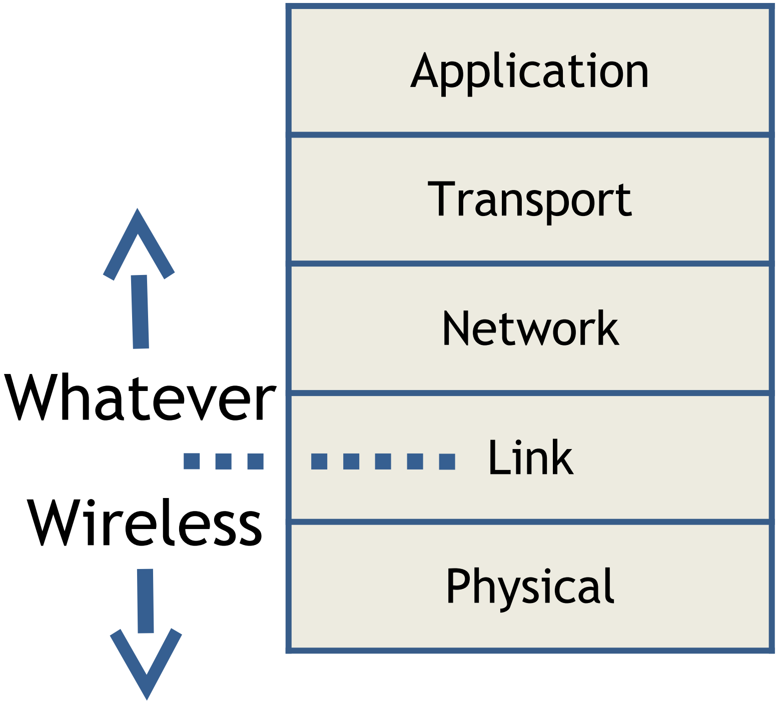
Layer 1

Lower layer provides a service to higher layer

Higher layer doesn’t care (or even know, sometimes) how service is implemented: **lack of visibility**

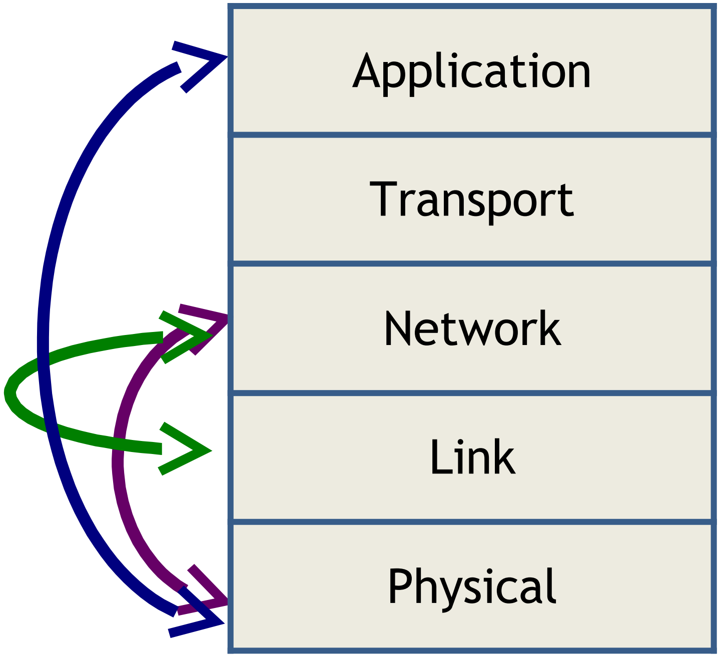
Layering in Wireless

- Layering impacts wireless protocols
  - Hiding physical layer → upper layers see wired
  - Cannot leverage advantages of wireless
- Layering is not appropriate for many wireless systems



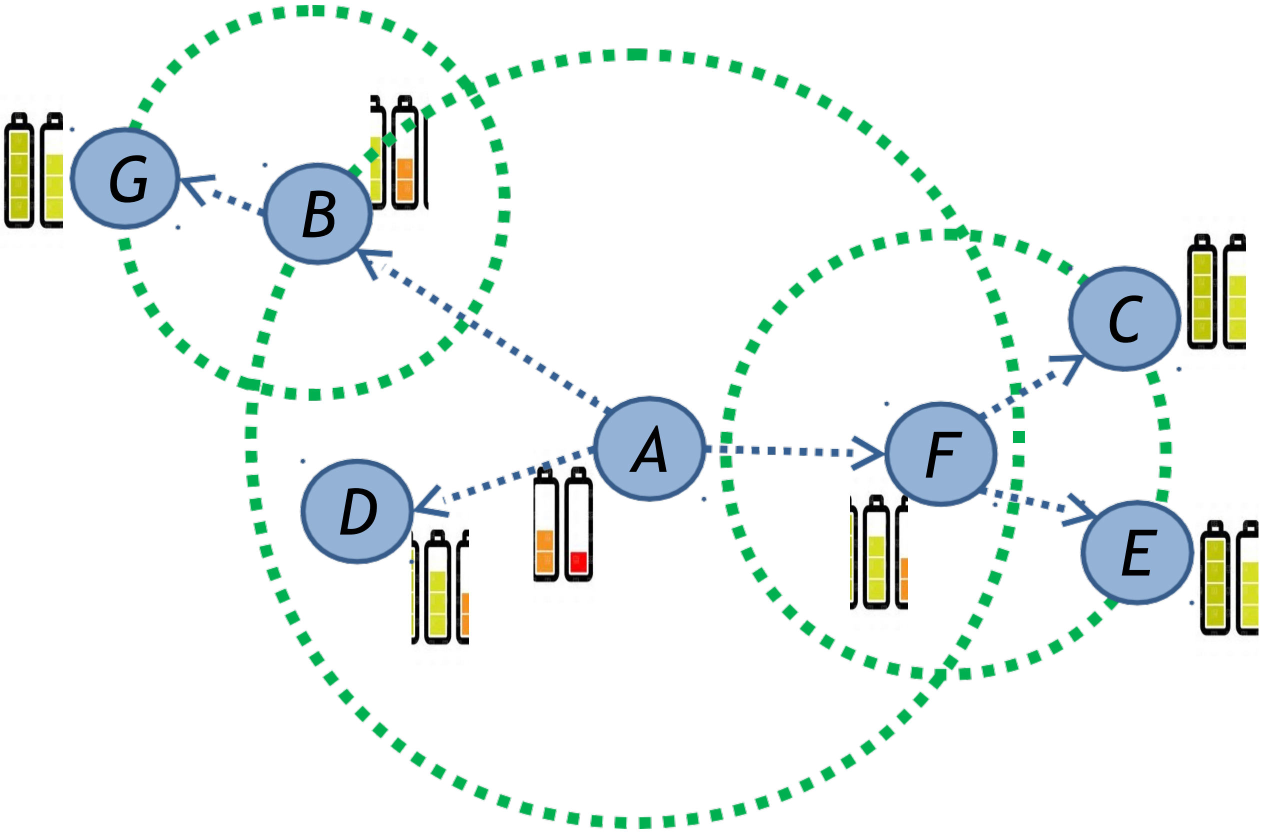
Cross-Layer Design

- Cross-layer design
  - Sharing info helps performance
  - Visibility restored
  - Design is more challenging



Max-Lifetime Broadcast Routing

- **Cross-layer example:**
  - How to broadcast to everyone to balance network lifetime given that wireless allows “overhearing”?

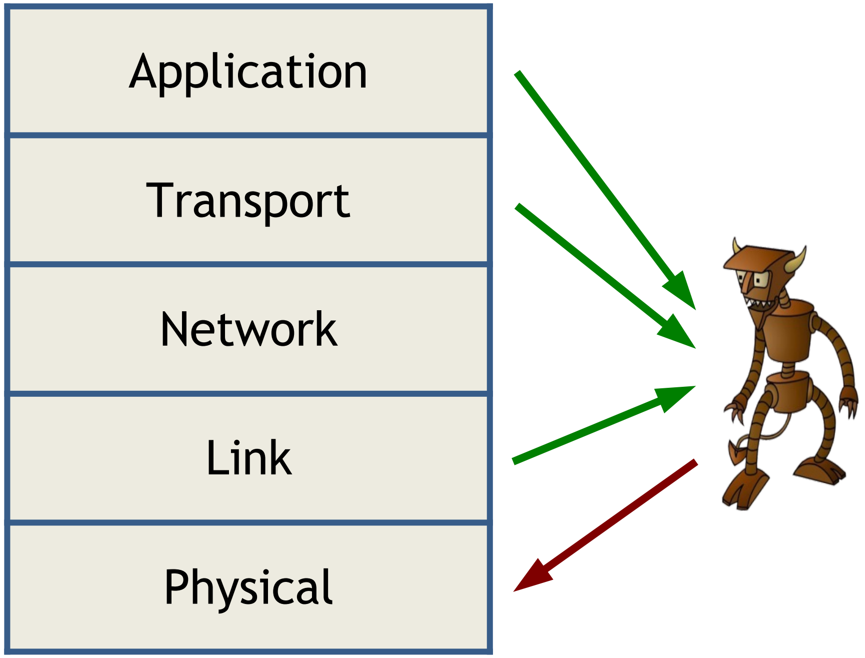


Cross-Layer Information Use

- Most network protocols were designed in the layered architecture
  - Leverage modularity for simple & efficient design
  - But...
    - Attackers don't have to follow the layering assumptions
    - Can learn significantly more about network operations and behaviors by monitoring/probing/interacting with multiple layered protocols
- → Attackers using cross-layer information may be "smarter" than the networks under attack

Cross-Layer Attacks

- Cross-layer attacks
  - Sharing information across protocol layers to improve attack performance
    - For any definition of performance
  - Planning and optimizing attacks may be much more challenging



Application

Transport

Network

Link

Physical

Cross-Layer Attacks

Definition: a *cross-layer attack* is any malicious behavior that explicitly leverages information from one protocol layer to influence or manipulate another

Examples

1. MAC-aware jamming attacks
2. MAC misbehavior targeting transport-layer performance
3. Application-aware packet dropping attacks
4. Traffic-aware collaborative jamming attacks

Examples

1. MAC-aware PHY jamming attacks
2. MAC misbehavior targeting transport-layer performance
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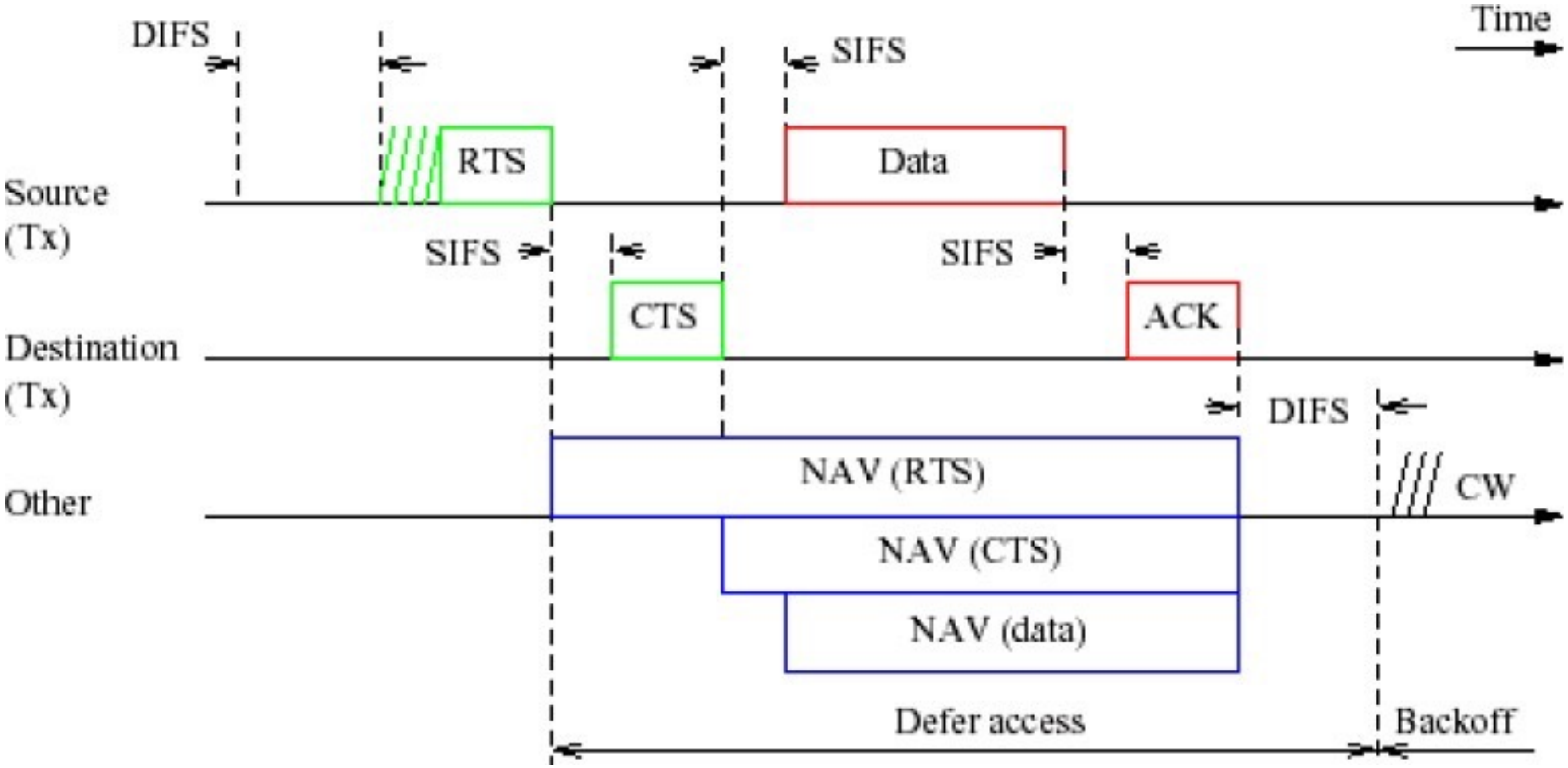
MAC-Aware Jamming

- Protocol-aware jammers can optimize jamming actions based on protocol structure, e.g., MAC



Jamming Attack Metrics

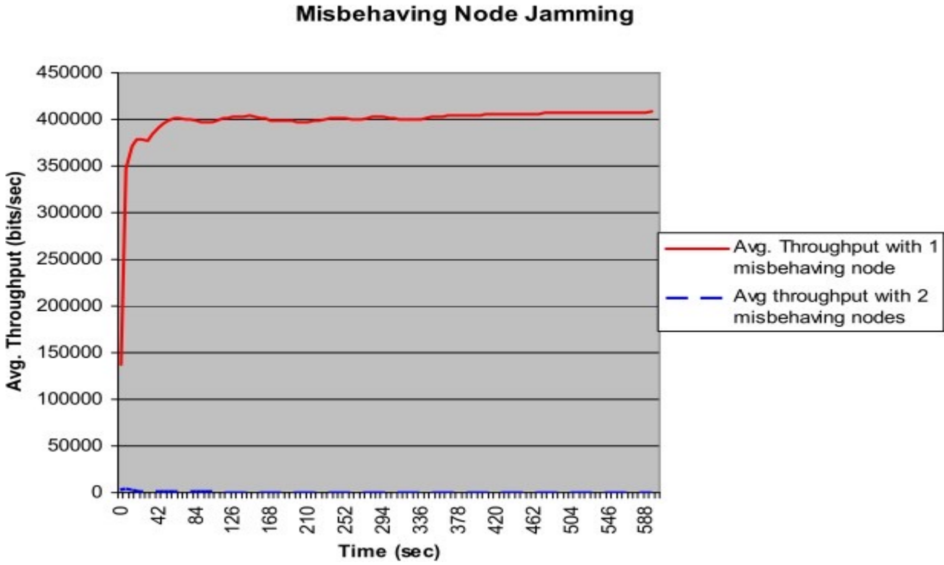
- *Attacks can be optimized in terms of:
  - Energy efficiency
  - Low probability of detection
  - Stealth
  - DoS strength
  - Behavior consistency with/near protocol standard
  - Strength against error correction algorithms
  - Strength against PHY techniques (FHSS, DHSS, CDMA)

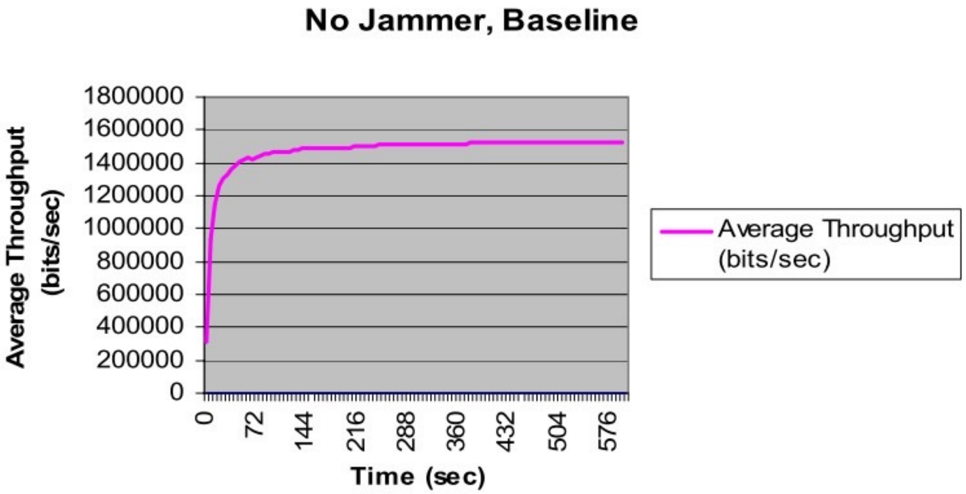
Jamming 802.11 Networks

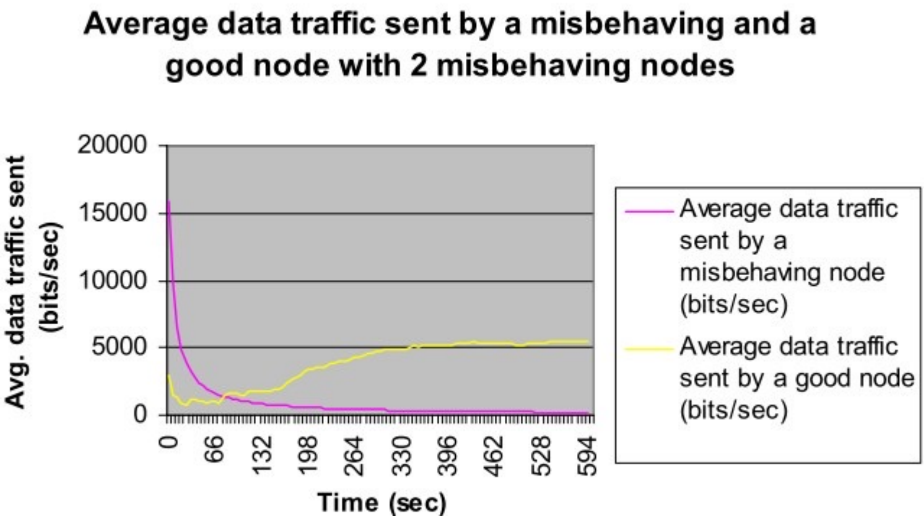
- Cross-layer jamming attacks
  - CTS corruption jamming
    - Jam CTS control packets to deny access and cause low channel utilization, knowing that CTS follows RTS
  - ACK corruption jamming
    - Jam ACK control packets to cause excess retransmission and low utilization, knowing that ACK follows DATA
  - DATA corruption jamming
    - Attempt to jam data packets to reduce throughput, knowing that DATA follows CTS control packet or previous ACK
  - DIFS wait jamming
    - Generate a short jamming pulse during DIFS time slots to prevent protocol continuation, no utilization

Colluding Attackers

- Nodes can collude to decrease probability of attack detection
- Energy required for 2 nodes is only slightly more than single node


Misbehaving Node Jamming


No Jammer, Baseline


Average data traffic sent by a misbehaving and a good node with 2 misbehaving nodes

Examples

1. MAC-aware jamming attacks
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Stasis Trap

- Attacker uses MAC-layer misbehavior to target performance degradation in TCP flows
  - Based on MAC layer back-off manipulation, but only periodically, say on the order of a TCP timeout
    - Similar to a JellyFish attack, only executed at a lower layer
  - Overall, Stasis Trap has little effect on MAC layer performance, so MAC misbehavior detection will not be able to identify the attack
  - Attacker can target multiple flows to further reduce detectability

Examples

1. MAC-aware jamming attacks

2. MAC misbehavior targeting transport-layer performance

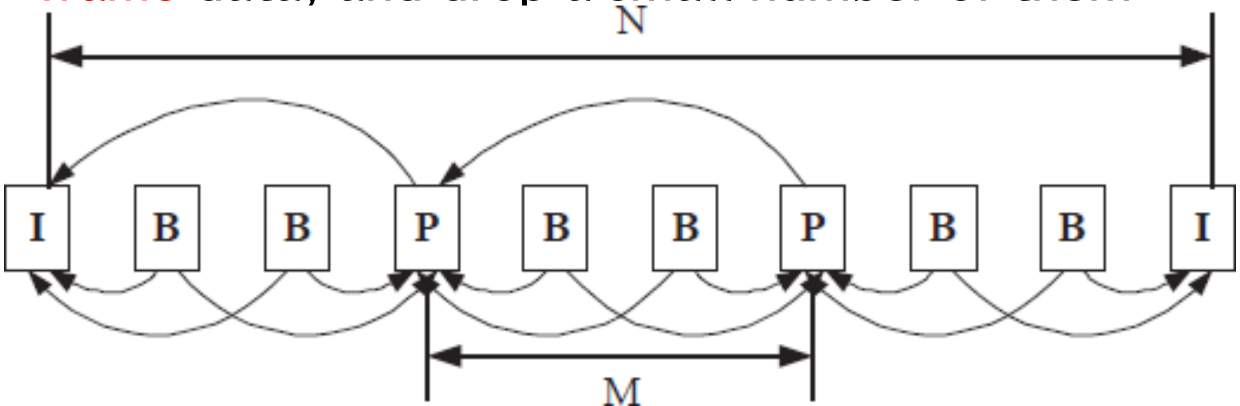
3. Application-aware packet dropping attacks

4. Traffic-aware collaborative jamming attacks

App-Aware Packet Dropping

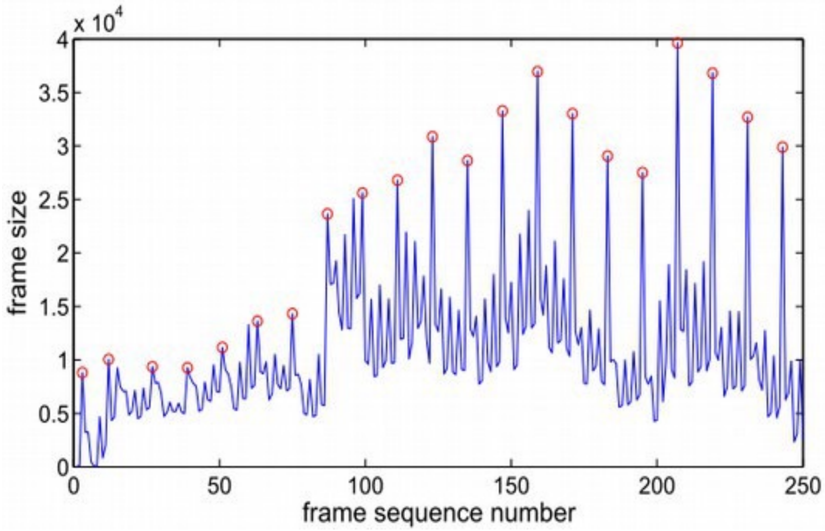
[Shao et al., SecureComm 2008]

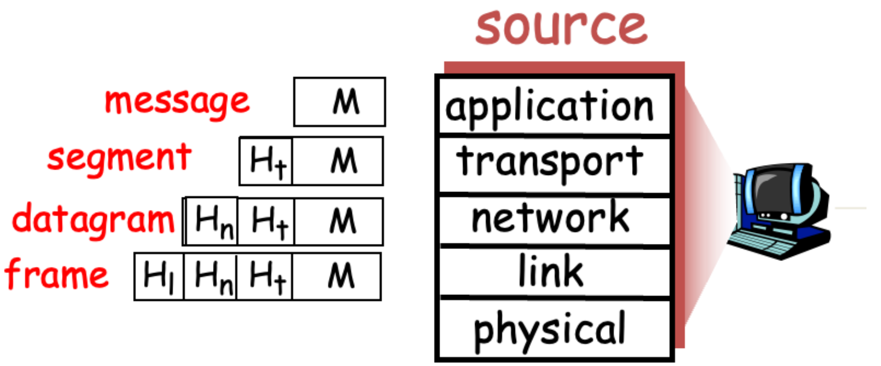
- Attackers can use application-layer information to improve attack performance at lower layers
  - Attackers can drop the most valuable packets
  - Example: MPEG video
    - I-frames are more valuable to MPEG decoding capability and video quality than B- or P- frames
    - Cross-layer attackers can identify which packets contain I-frame data, and drop a small number of them



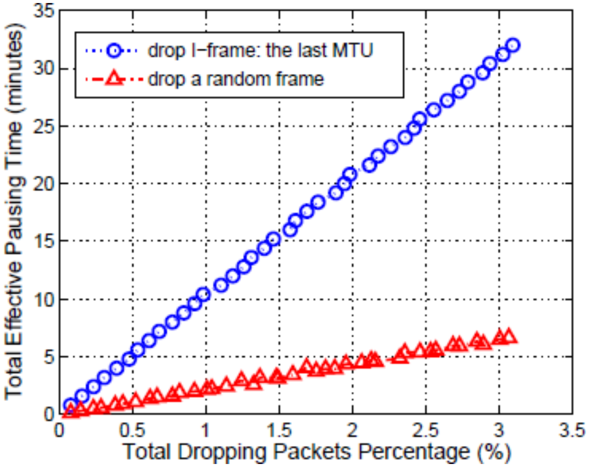
Sensing I-Frame Packets

- Router can observe frame sizes and attempt to identify which packets belong to I-frames
  - Analyzing frame size statistics reveals I-frame period N
  - Additional check tell router whether each packet is from an I- frame with high probability



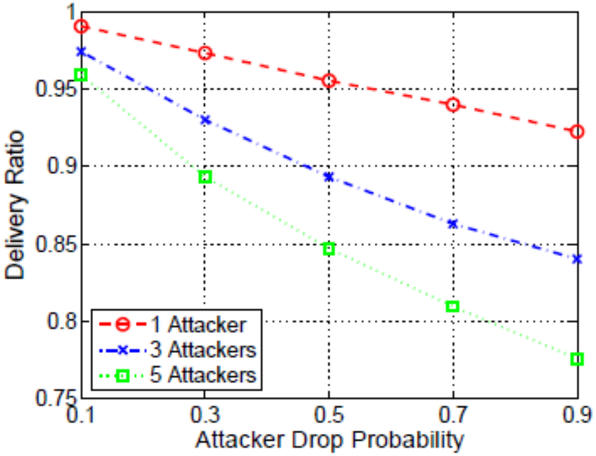


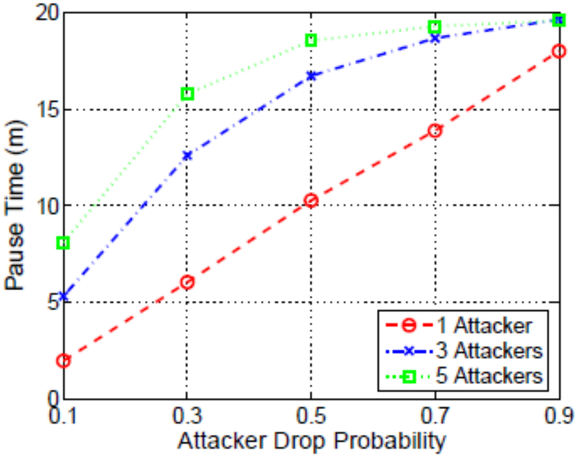
I-Frame Packet Dropping



Application-aware attack degrades video performance much more effectively compared to blind attack

Collaboration between multiple attackers yields further degradation





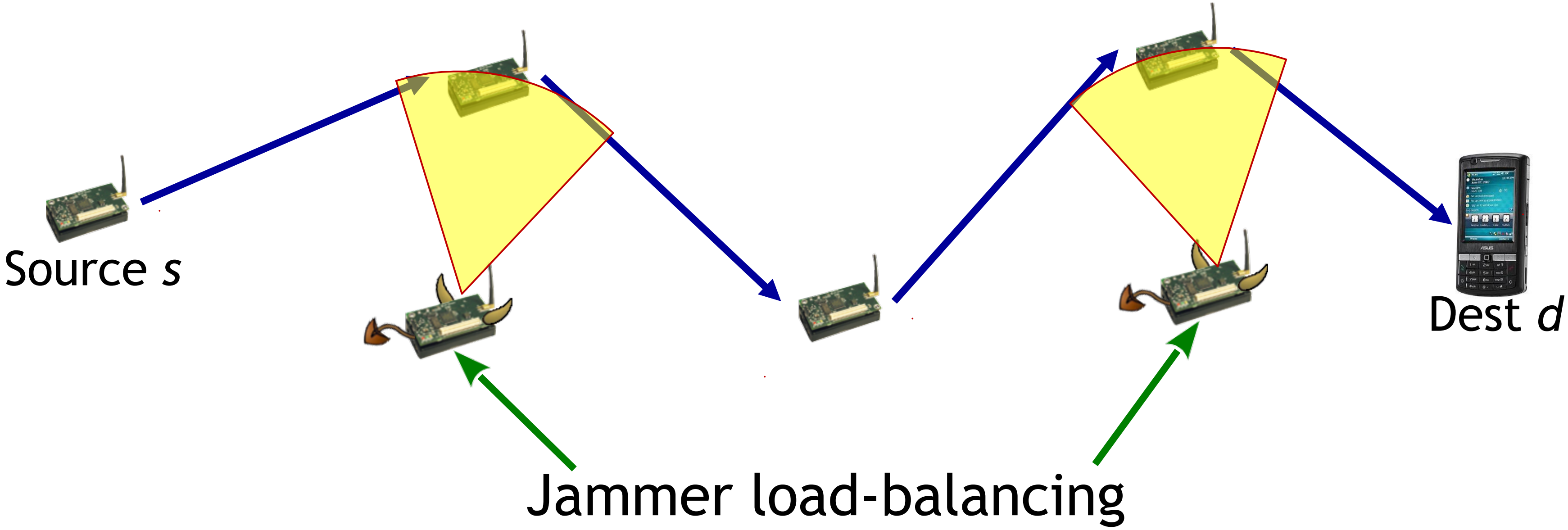
Examples

1. MAC-aware jamming attacks
2. MAC misbehavior targeting transport-layer performance
3. Application-aware packet dropping attacks
4. Traffic-aware collaborative PHY jamming attacks

Traffic-Aware Jamming

[Tague et al., WiOpt 2008]

- Collaborating jammers with information about network flow topology and traffic rates can load-balance to control end-to-end flow



What about cross-layer defenses?

Layered Defenses for Layered Attacks

- Layered Attack vs. Layered Defense
  - This is what I consider "classical" network security
  - Layer *n* protocols protect against layer *n* vulnerabilities
  - Little/no protection from *cascading attack impacts*

Layered Defenses for Cross-Layer Attacks

- Cross-Layer Attack vs. Layered Defense
  - Advanced attacks developed against “classical” network defenses
  - Most likely, the attackers are going to win
    - At a cost, of course

Cross-Layer Defenses for Layered Attacks

- Layered Attack vs. Cross-Layer Defense
  - “Classical” attacks applied to advanced networking
  - If well designed, defenses should come out ahead
    - Again, at a cost

Cross-Layer Defenses for Cross-Layer Attacks

- Advanced Attack vs. Advanced Defense
  - Most interesting case where there isn't much work yet
  - How "advanced" do defenses need to be to keep up with the "advanced" attacks?
    - Hard question...
  - Can we come up with a general framework to allow a defender to learn and adapt to what it sees?
    - Attacker can do the same thing…
    - …now we have a game

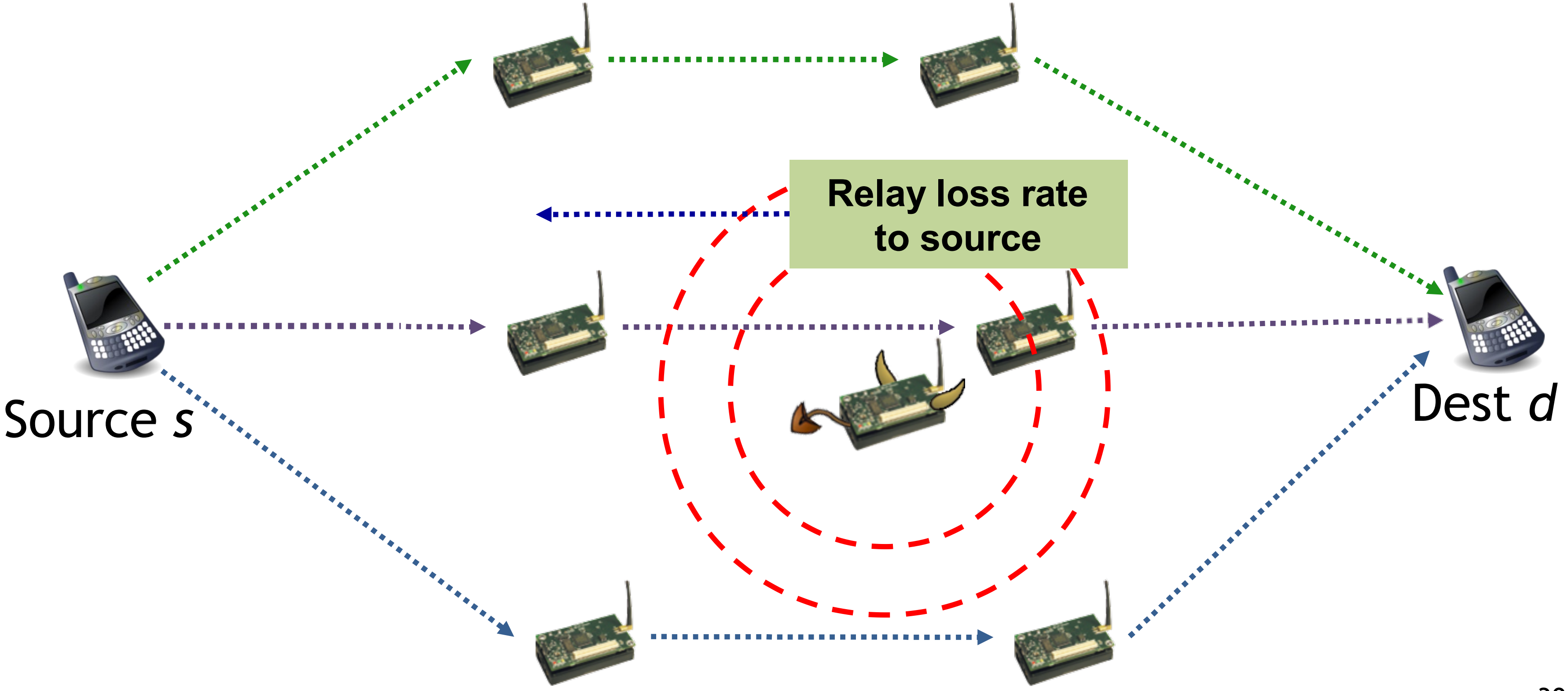
Comparison

	Layered Attack	Cross-Layer Attack
Layered Defense	Attack elements can target specific protocol performance Attacks are easy to plan, but probably sub-optimal	Attacker may be "smarter" than the network under attack Attack has fairly low cost to optimize, but likely to succeed
Cross-Layer Defense	Detection of attacks is more likely due to cross-layer impacts Defense is more costly, but likely to succeed	More difficult to characterize, optimize, predict, plan, … Attack and defense are more costly Red vs. Blue games

Jamming-Aware Traffic Flow

[Tague et al., ToN 2011]

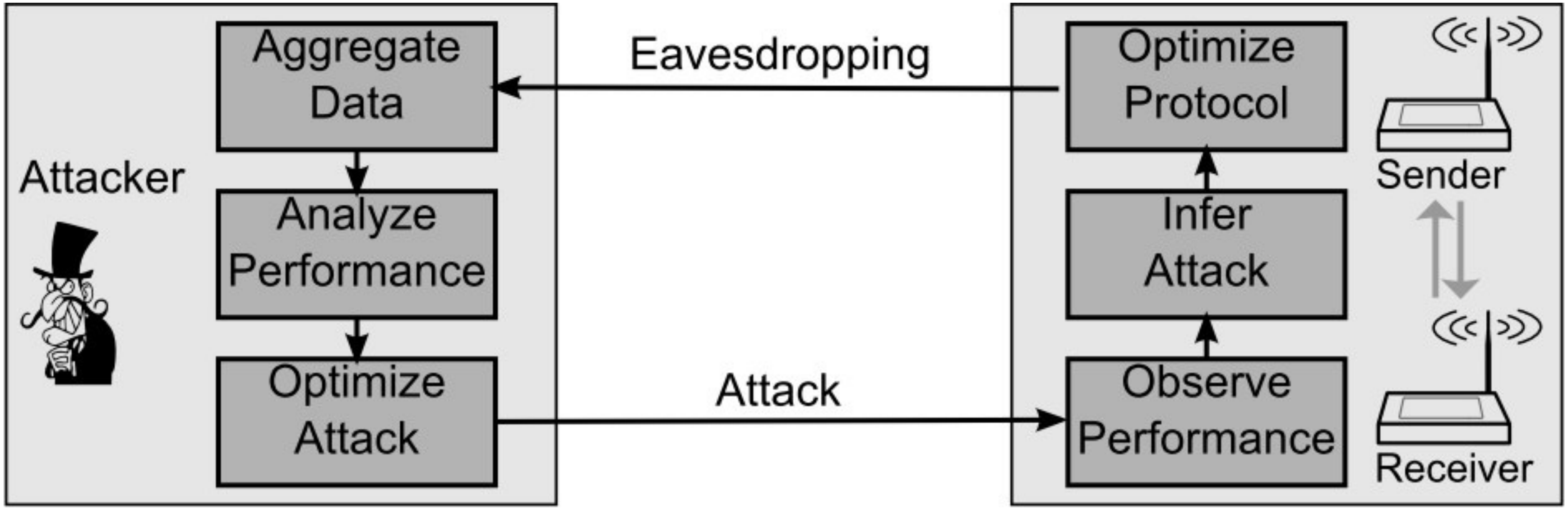
- Feedback from relay nodes allows source to dynamically adjust traffic allocation over multiple fixed routing paths



Observation-Based (Anti-)Jamming

[DeBruhl & Tague, PMC 2014]

- Opponents can observe actions, analyze what those actions mean, then adapt attack/defense algorithms accordingly



Summary

- Attackers and defenders can use cross-layer information sharing to improve performance
  - Examples:
    - MAC-aware jamming, TCP-aware MAC misbehavior, APP-aware packet dropping, NET-aware jamming, PHY/LINK-aware flow control

- Adaptation in response to cross-layer observations provides further value

- Mutual adaptation is super interesting, still not really understood