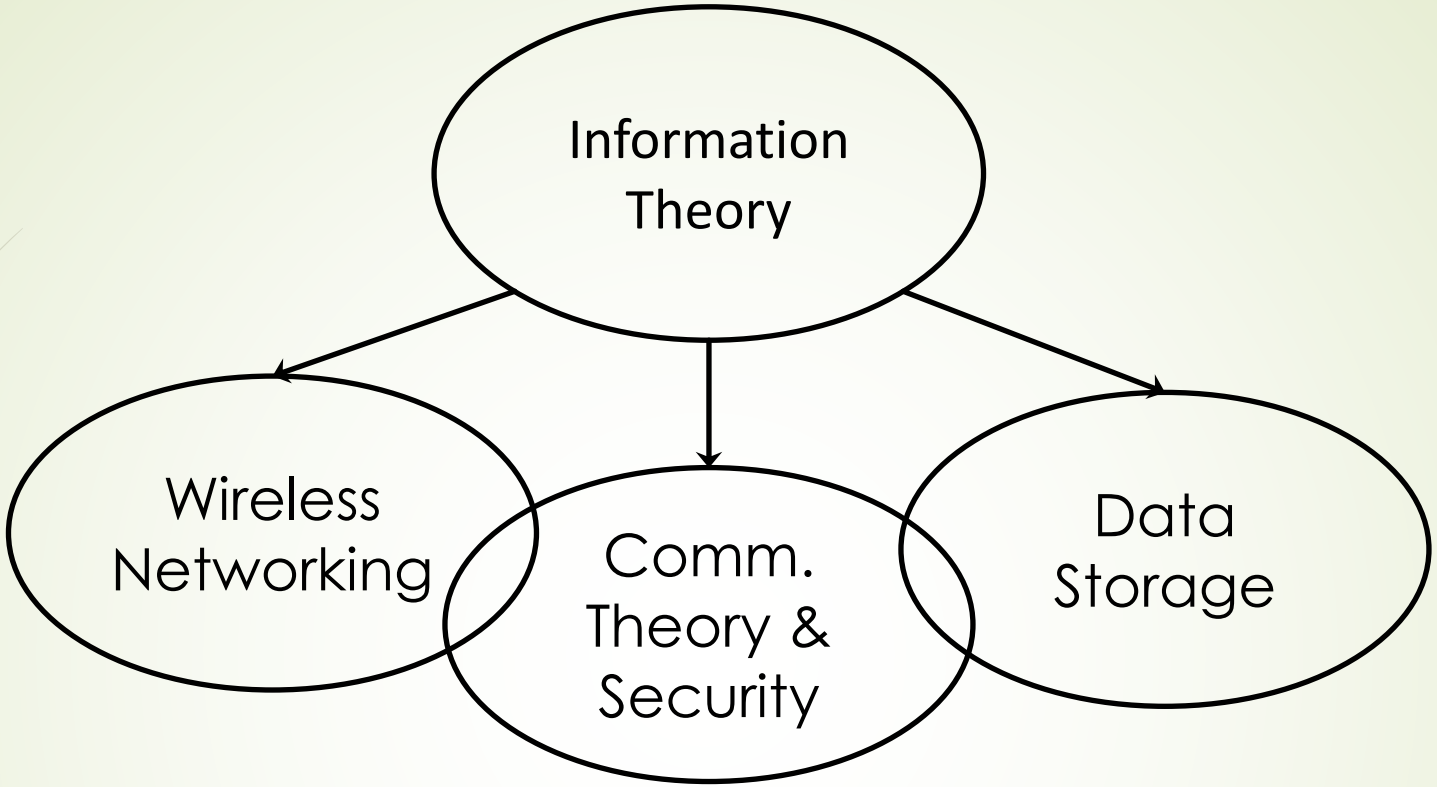
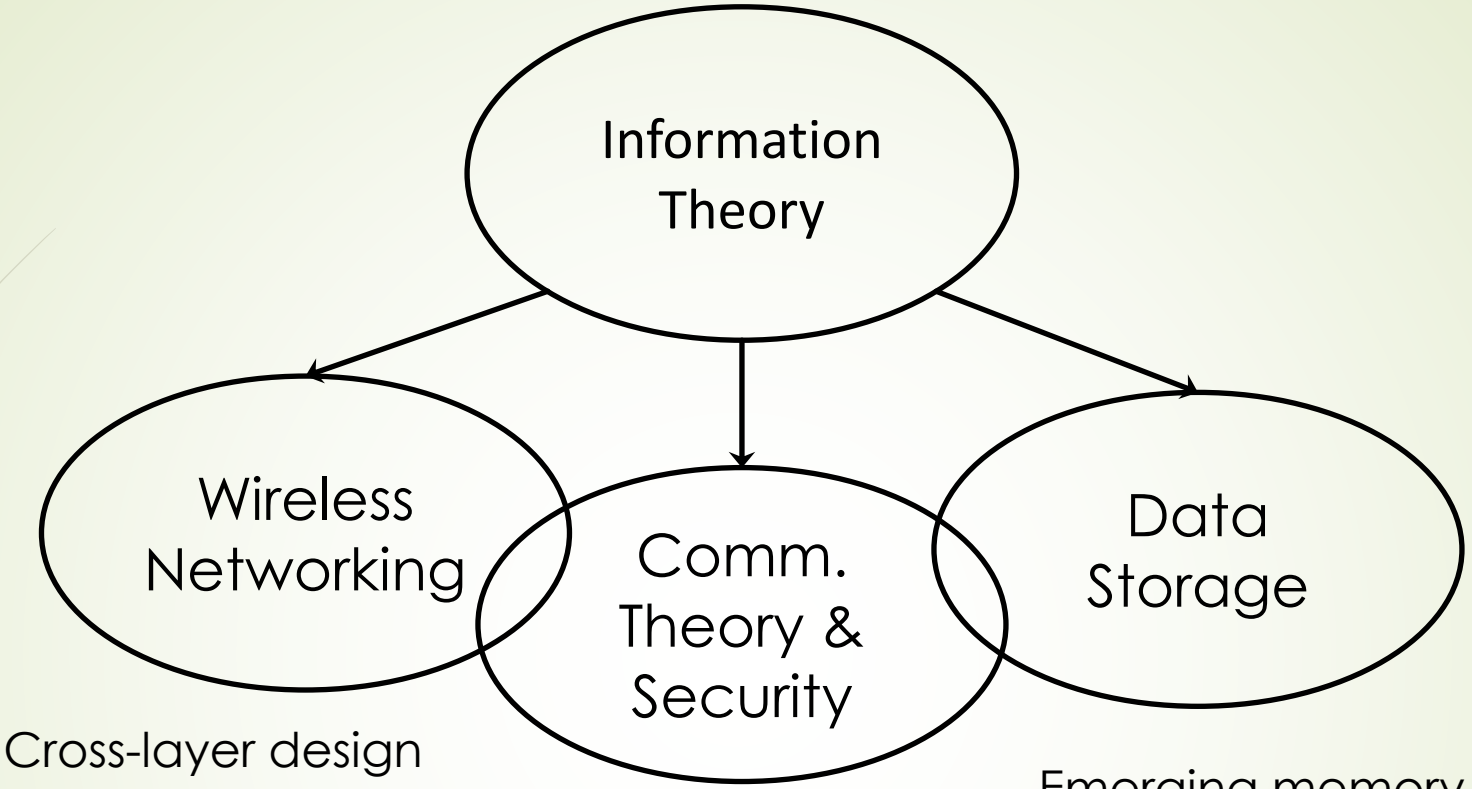
Defending WiFi Networks against Control Channel Attacks

Alireza Vahid, PhD

University of Colorado Denver


Information Theory
Wireless Networking
Comm. Theory & Security
Data Storage



Cross-layer design

Spectrum sharing

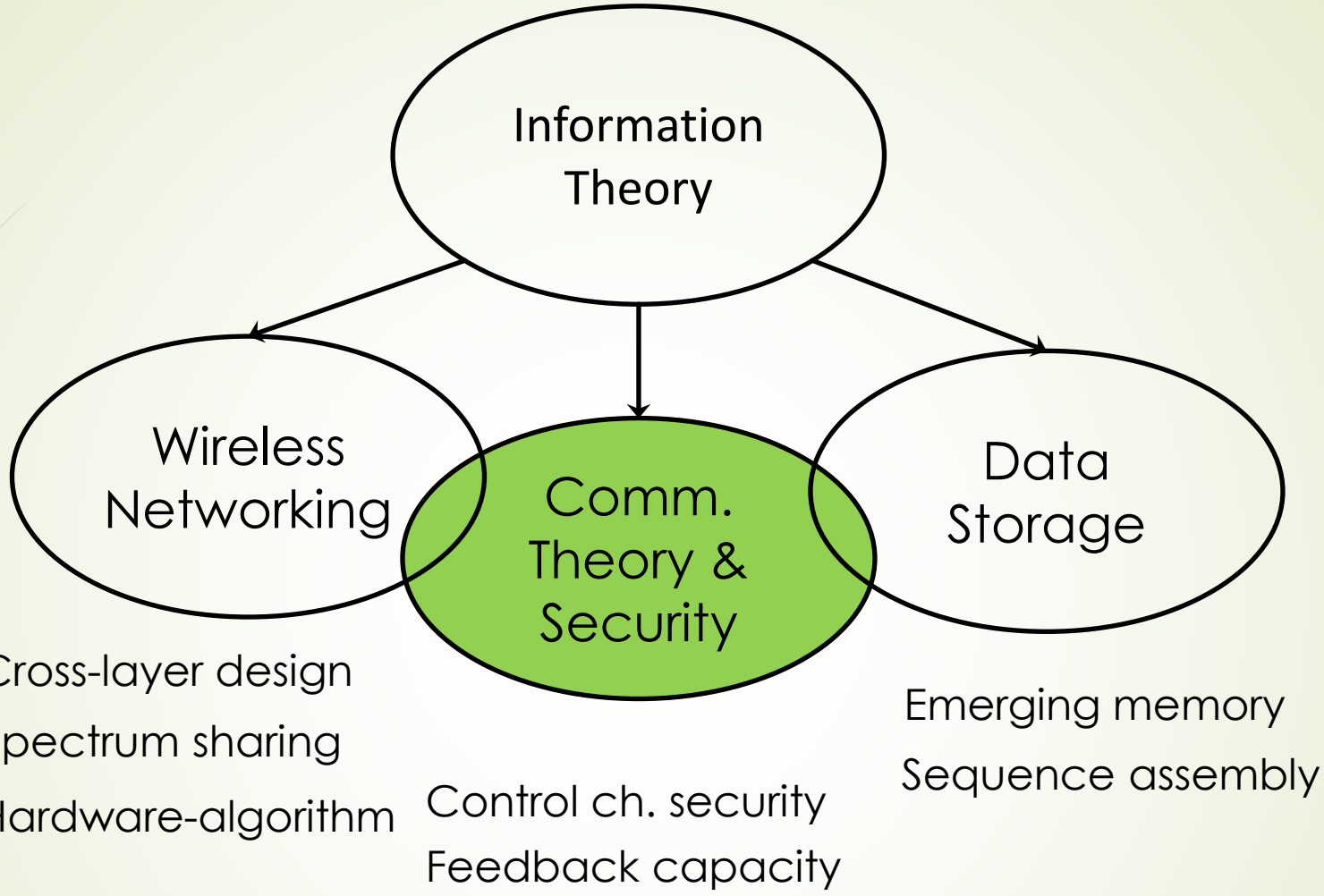
Hardware-algorithm

Control ch. security

Feedback capacity

Emerging memory

Sequence assembly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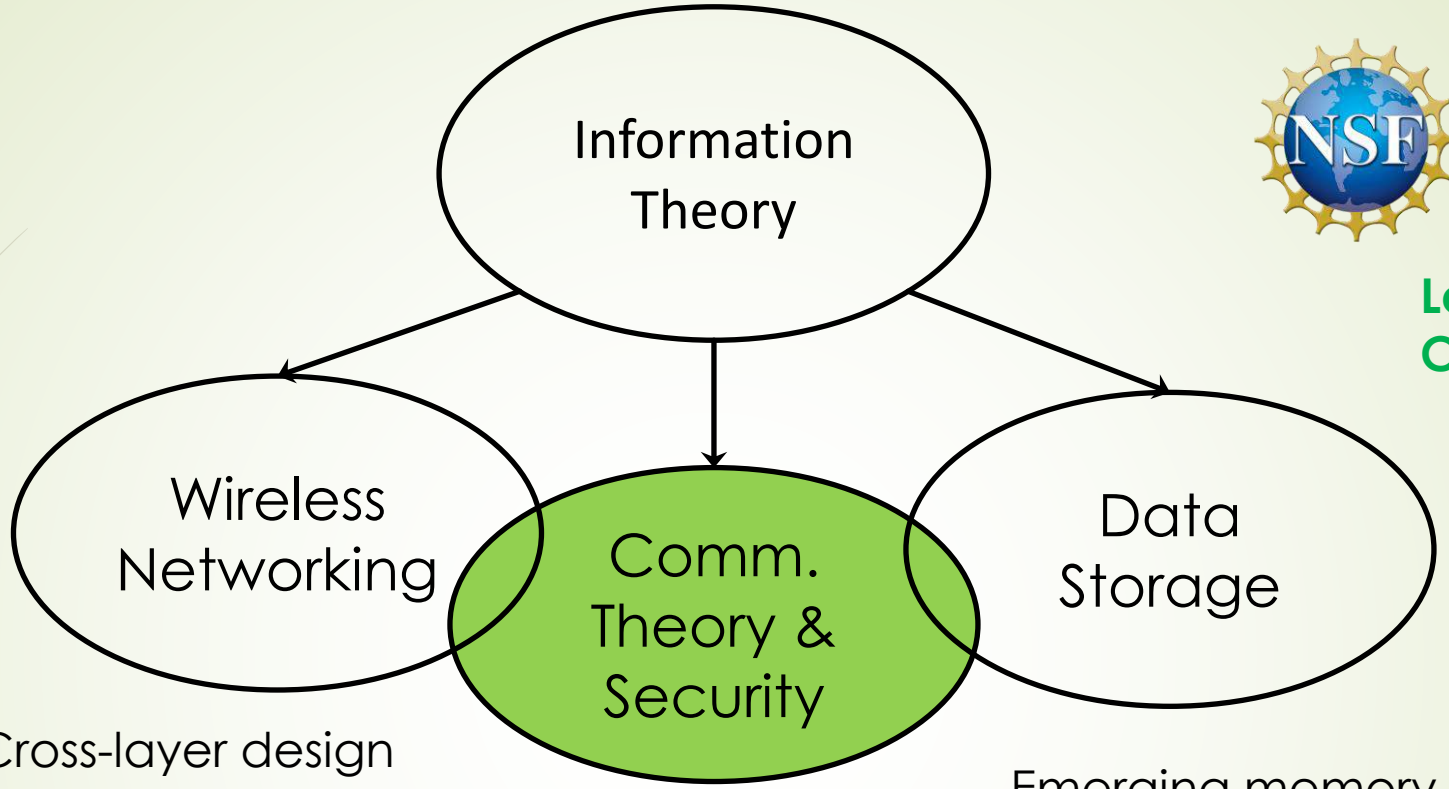

SWIFT
NRDZ
CNS

Lab Venture Challenge Award!

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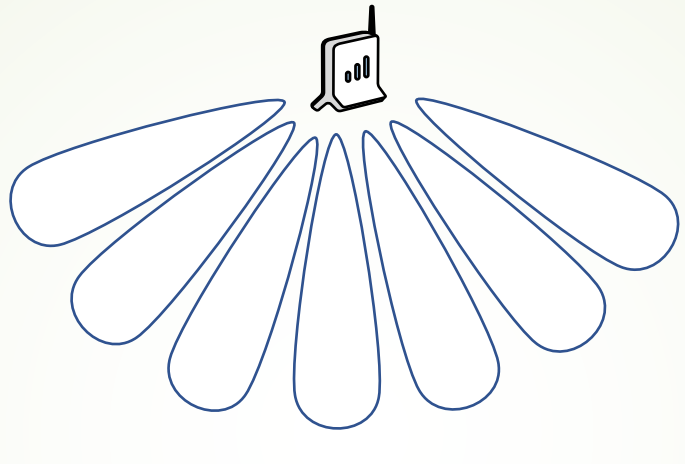
Future Wireless Networks

Future Wireless Networks

Control Channel Attack on WiFi-6 (-7)



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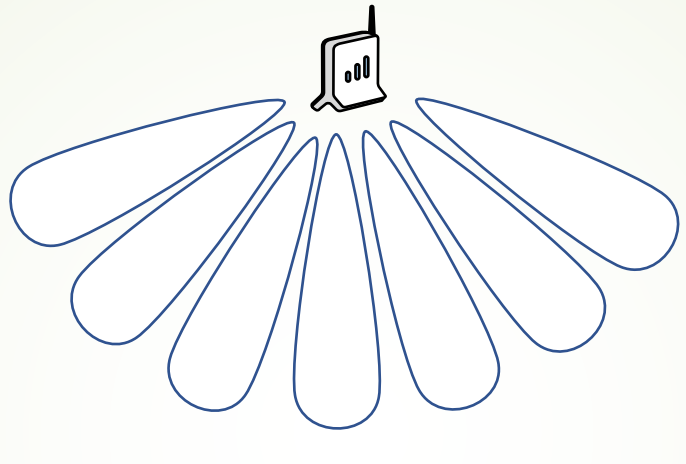

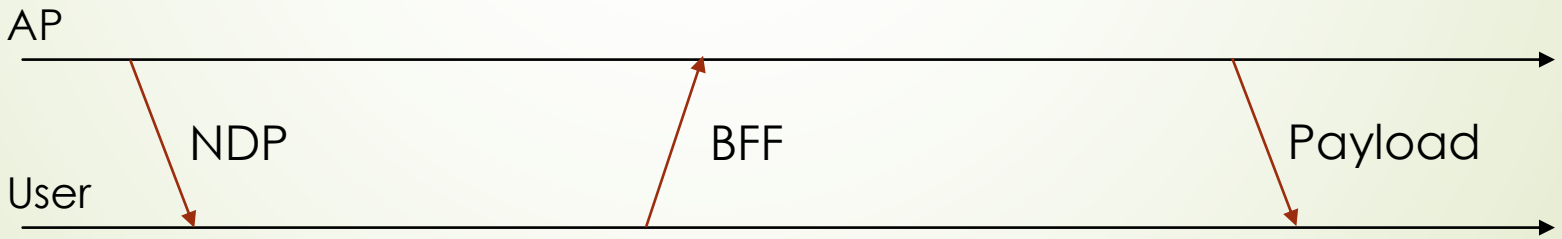

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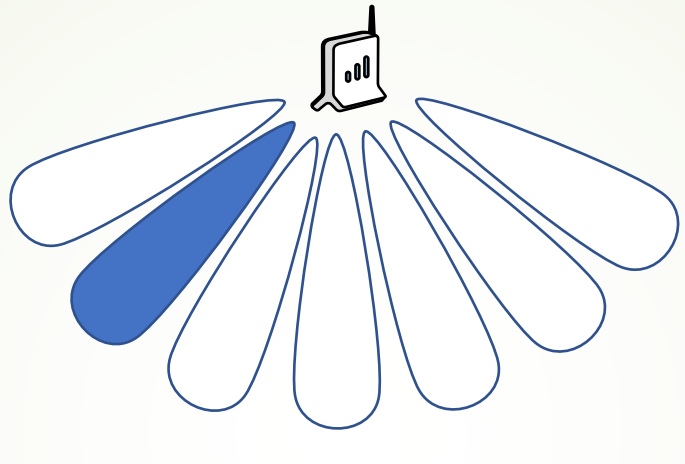

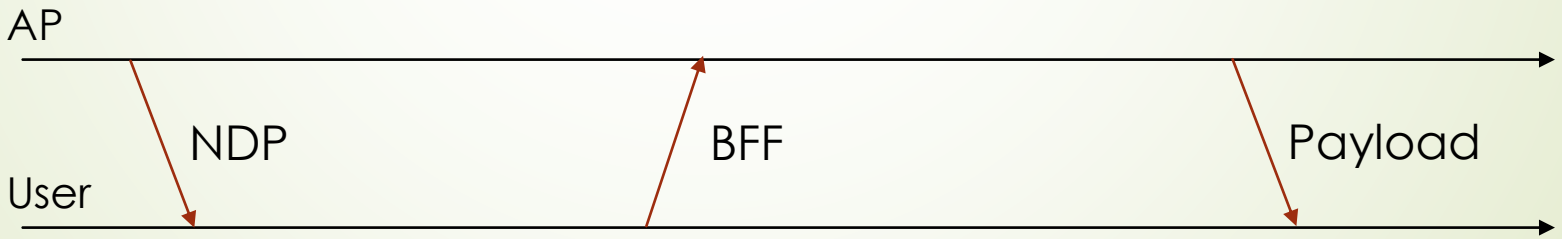

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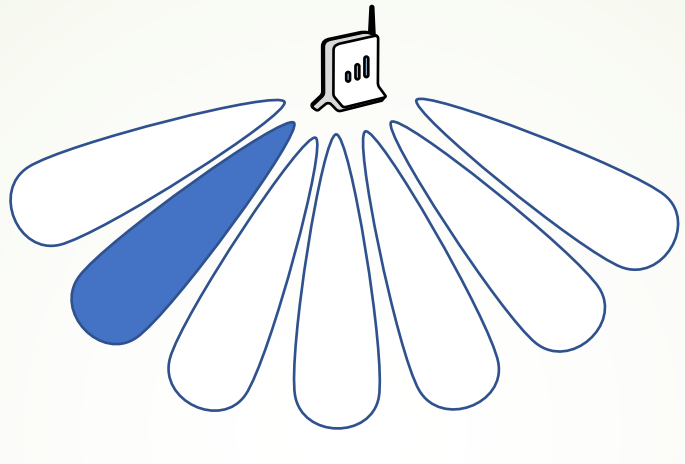

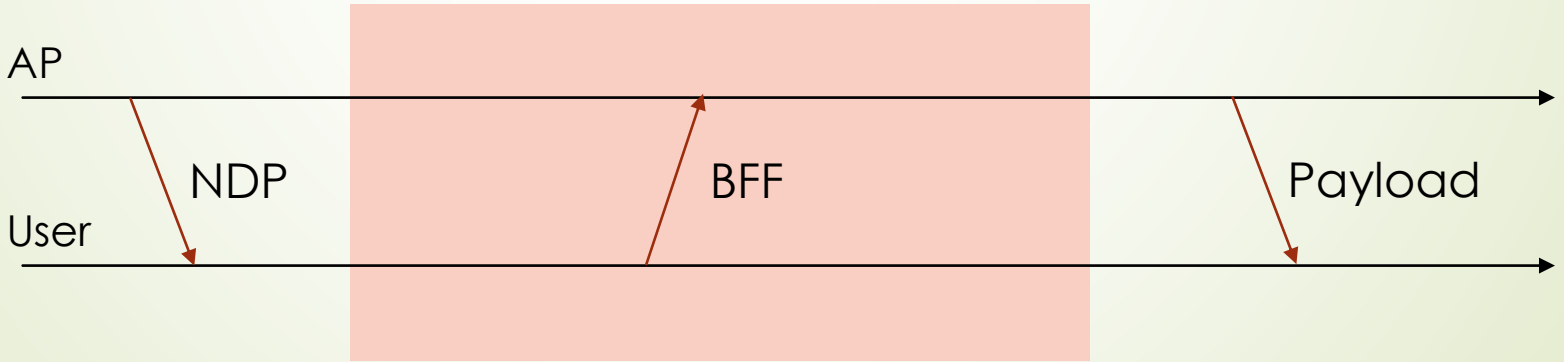

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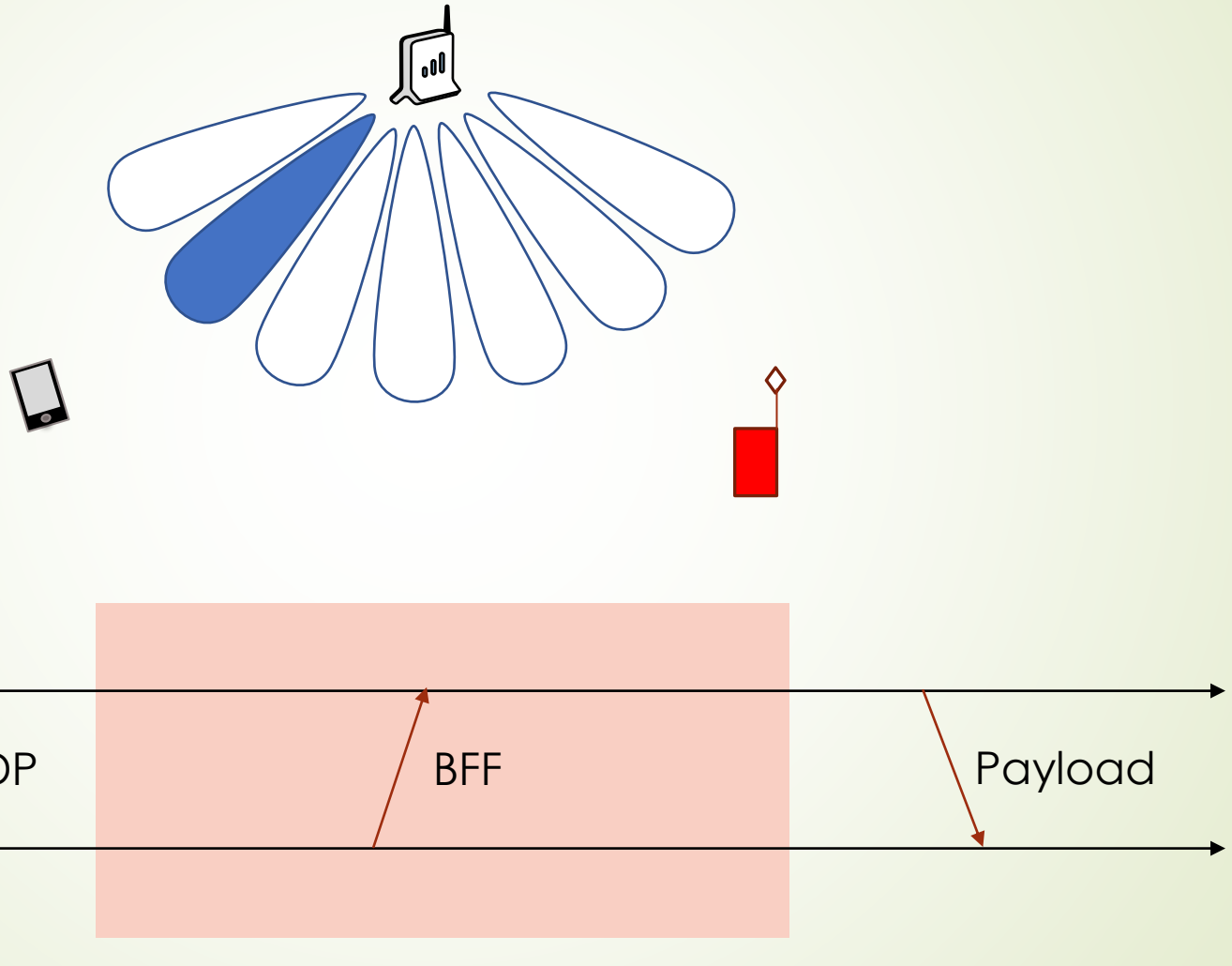

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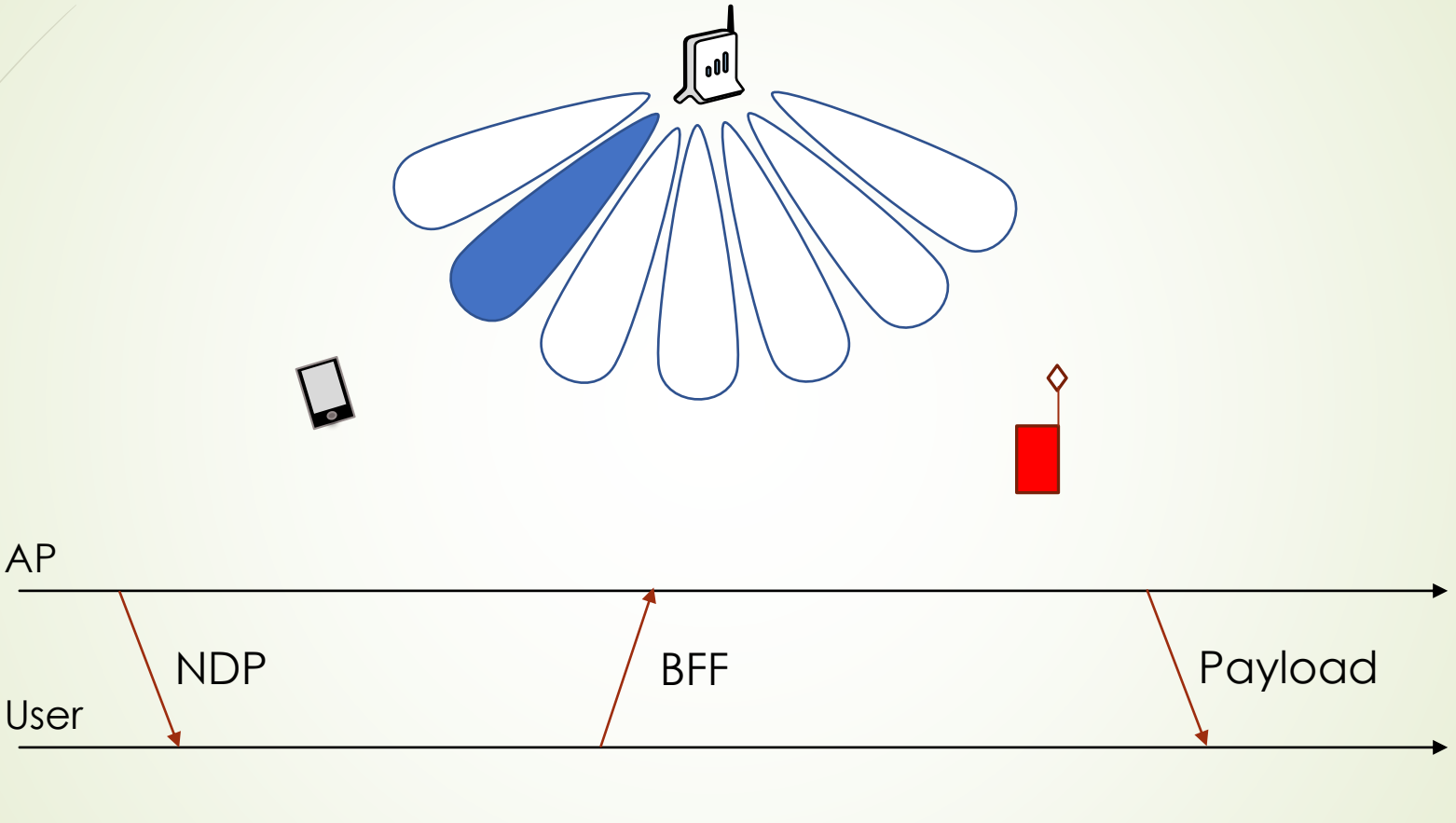

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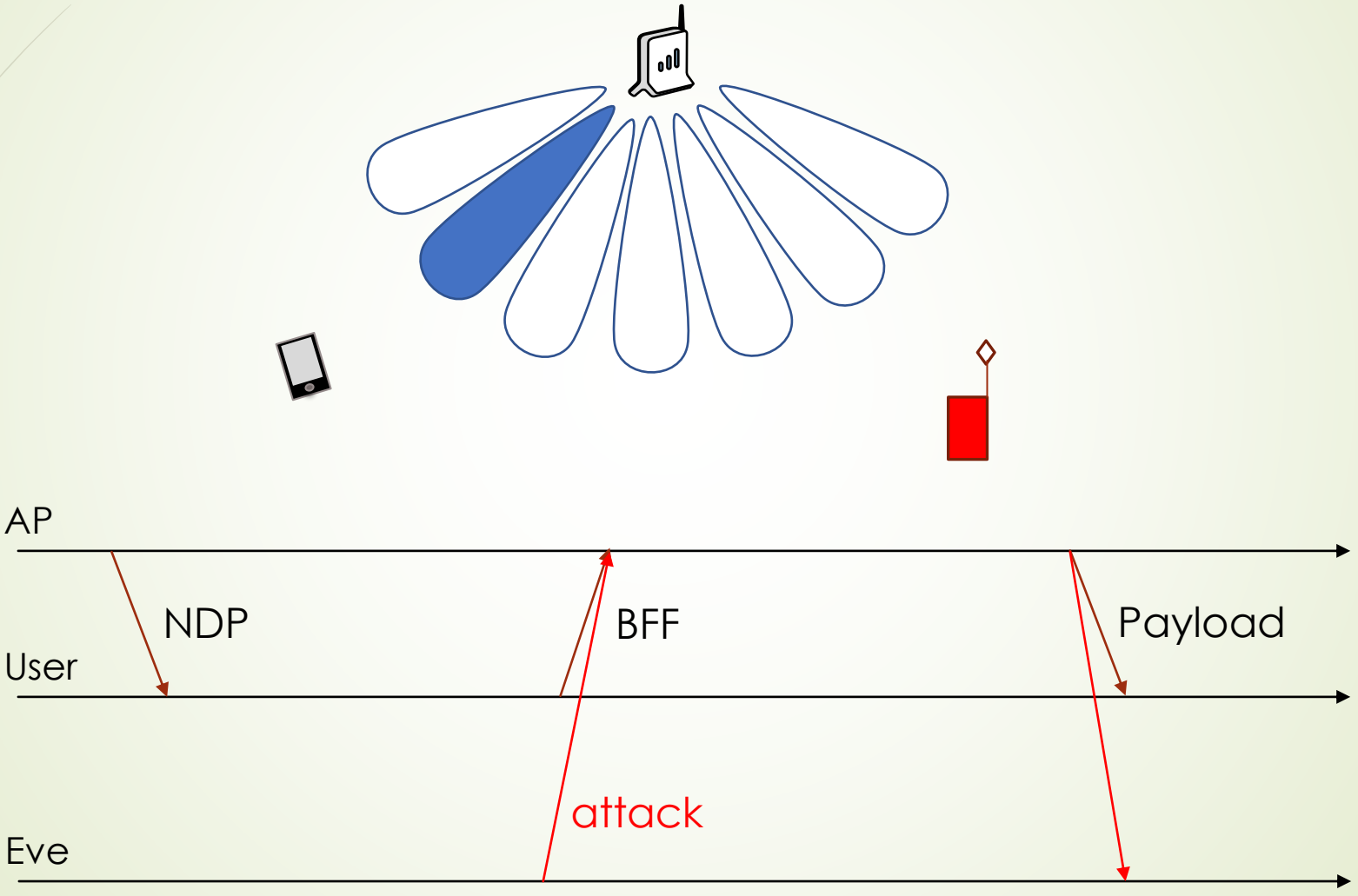

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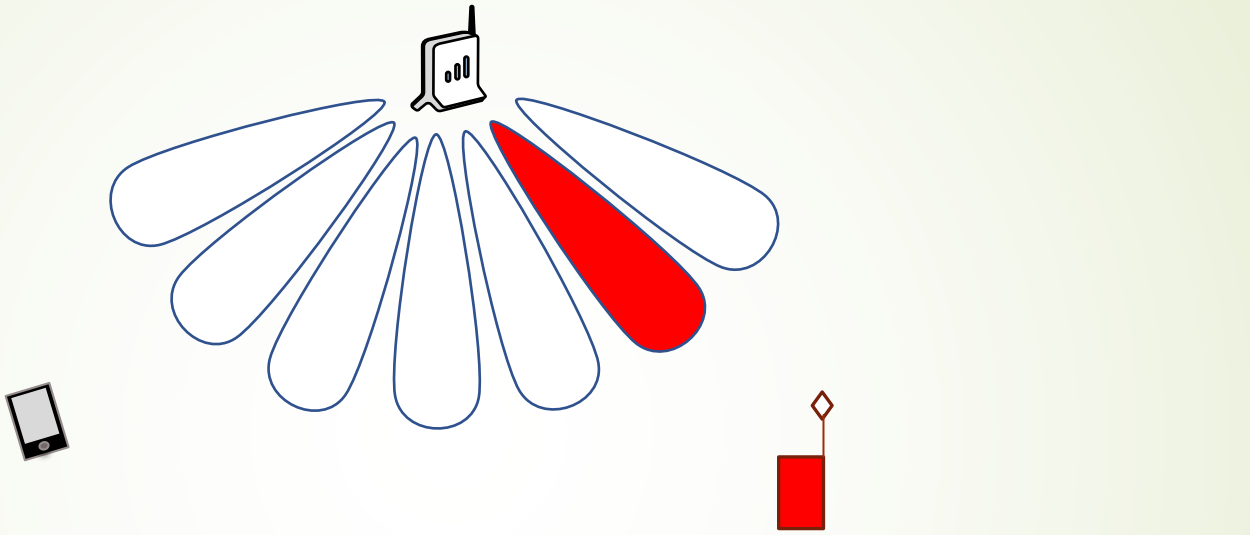

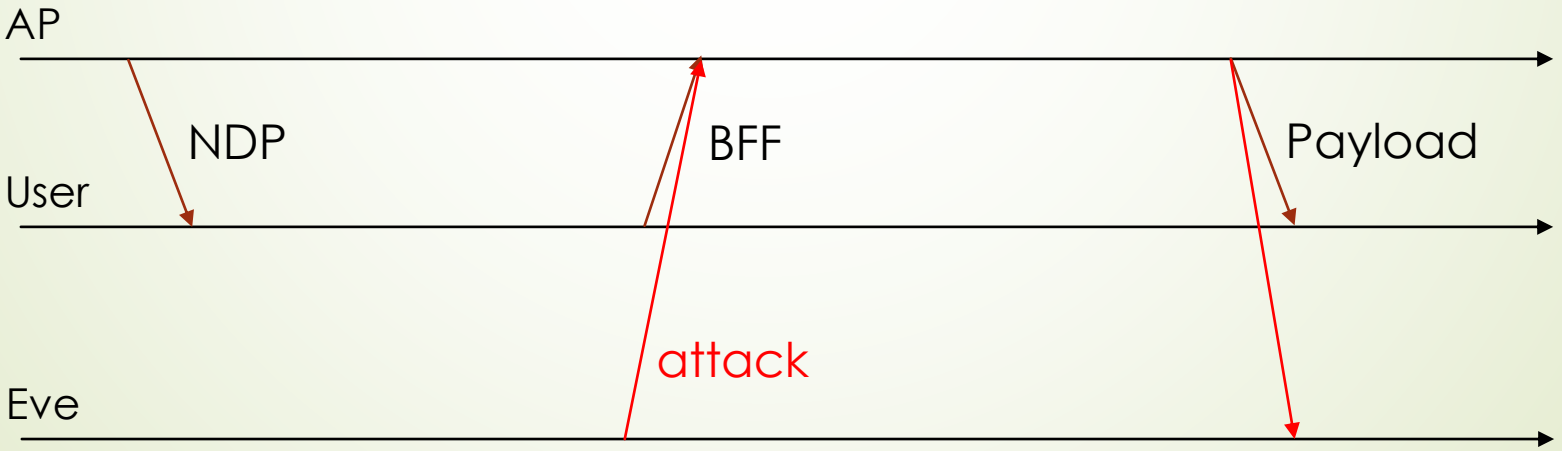

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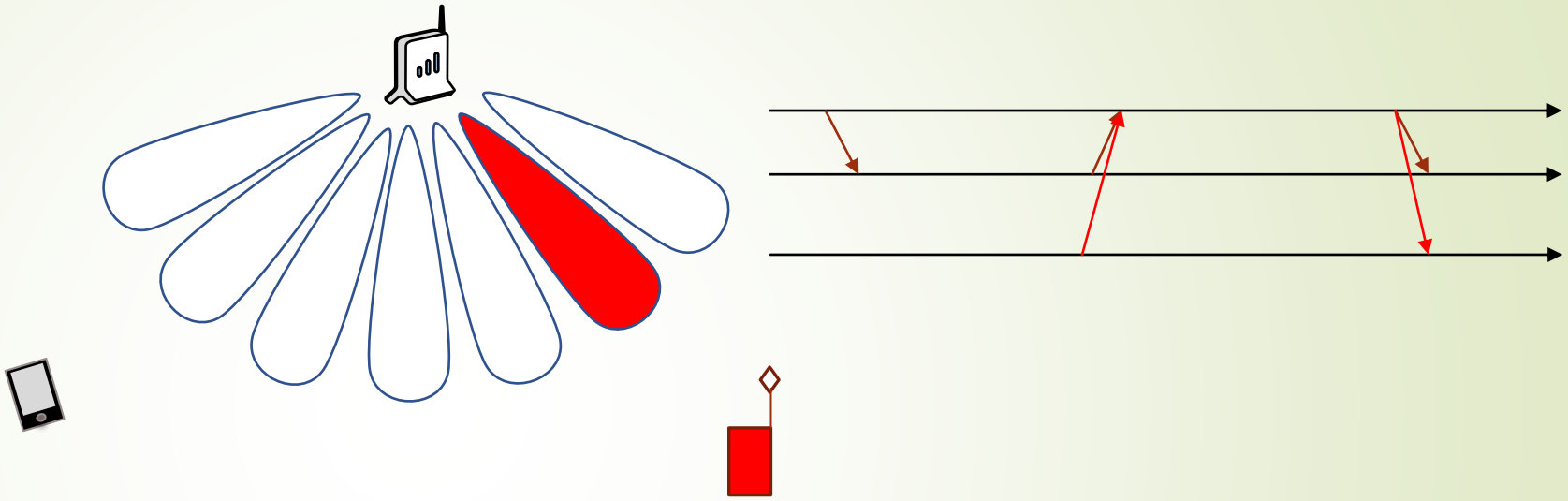

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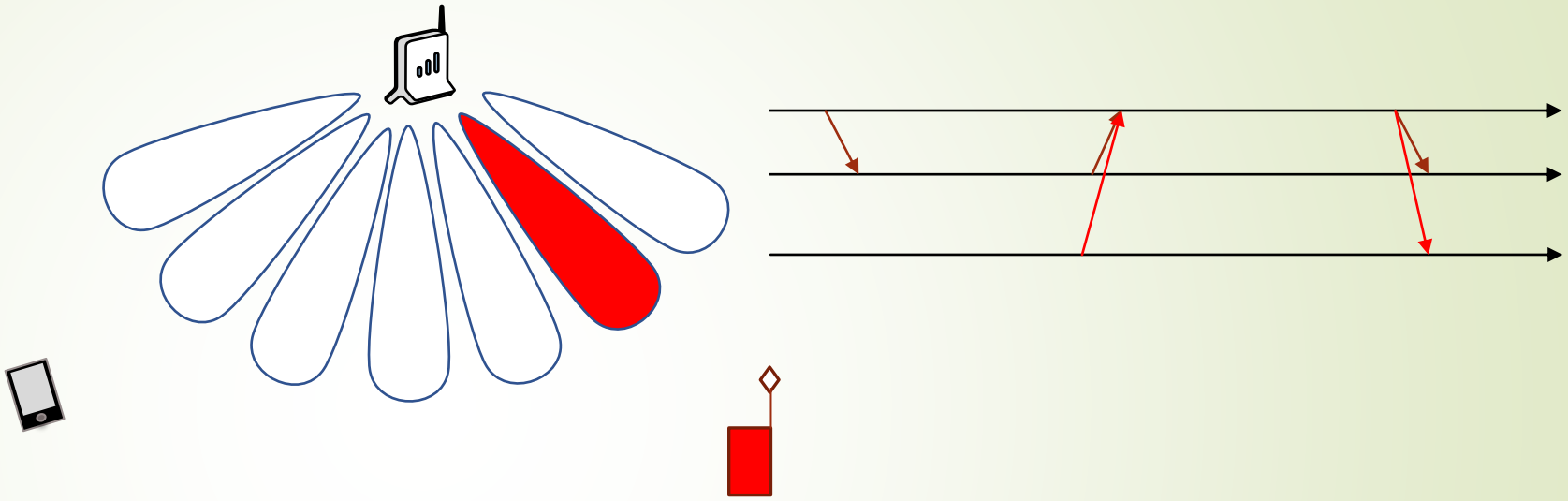

User	Legacy Preamble	RL-SIG	. . . . .	HE-STF	HE-LTF	Data
Eve					HE-LTF	Data

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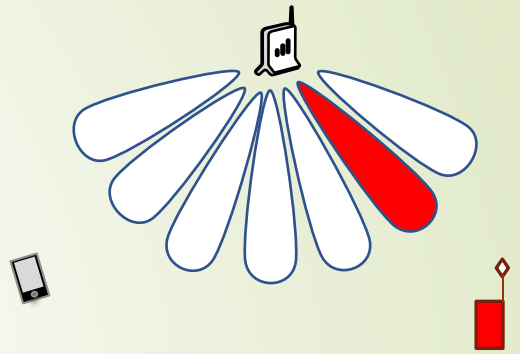

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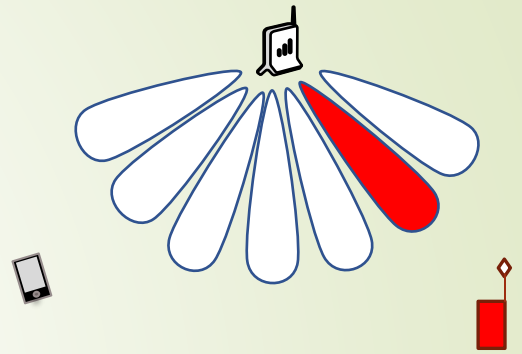

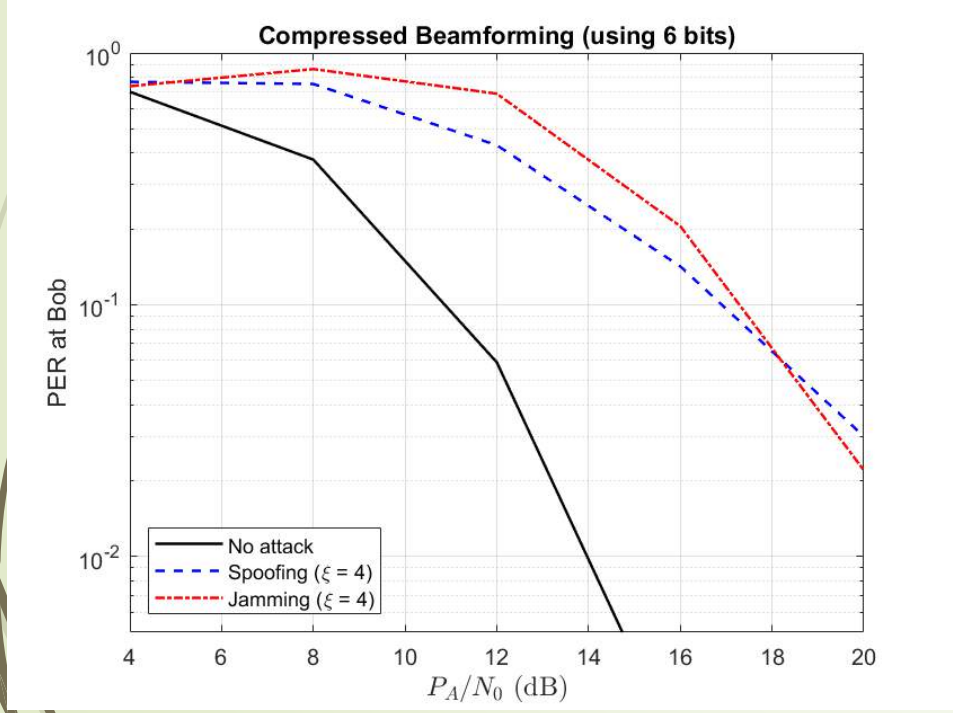

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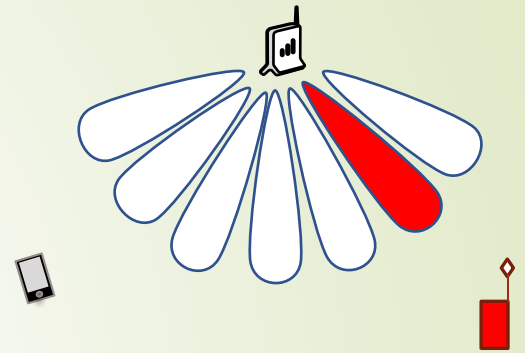

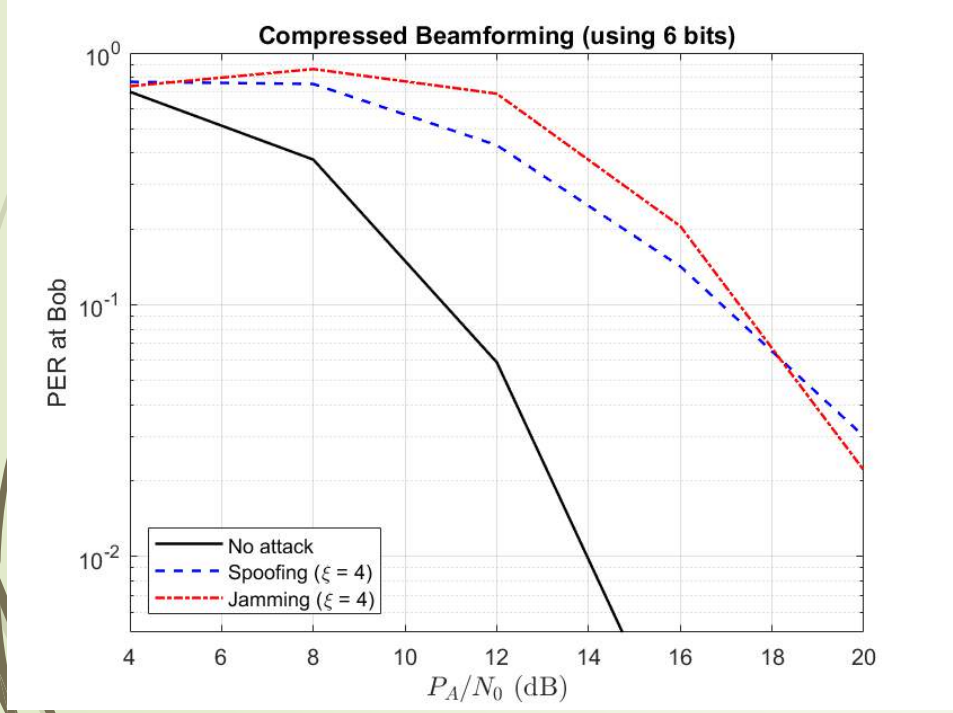

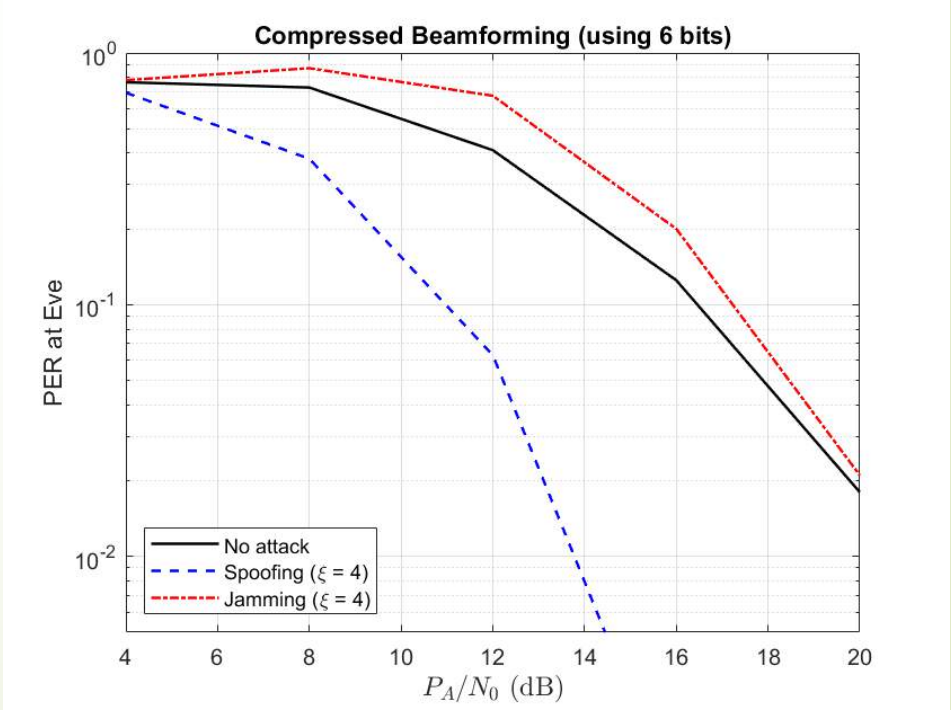

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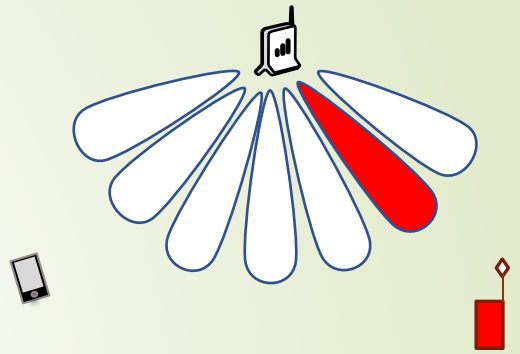

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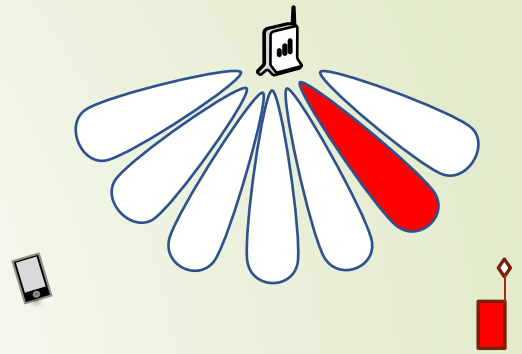
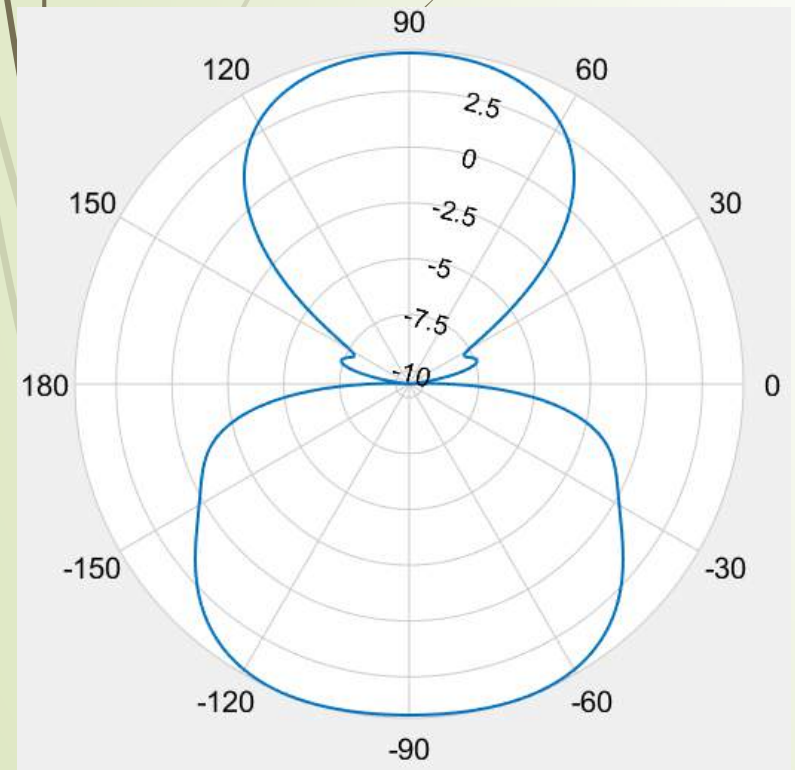
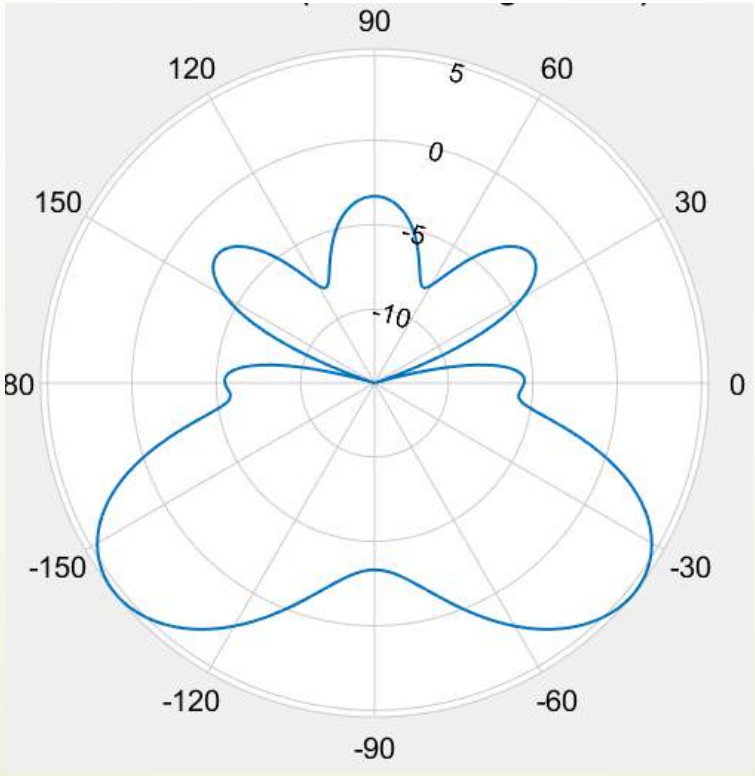


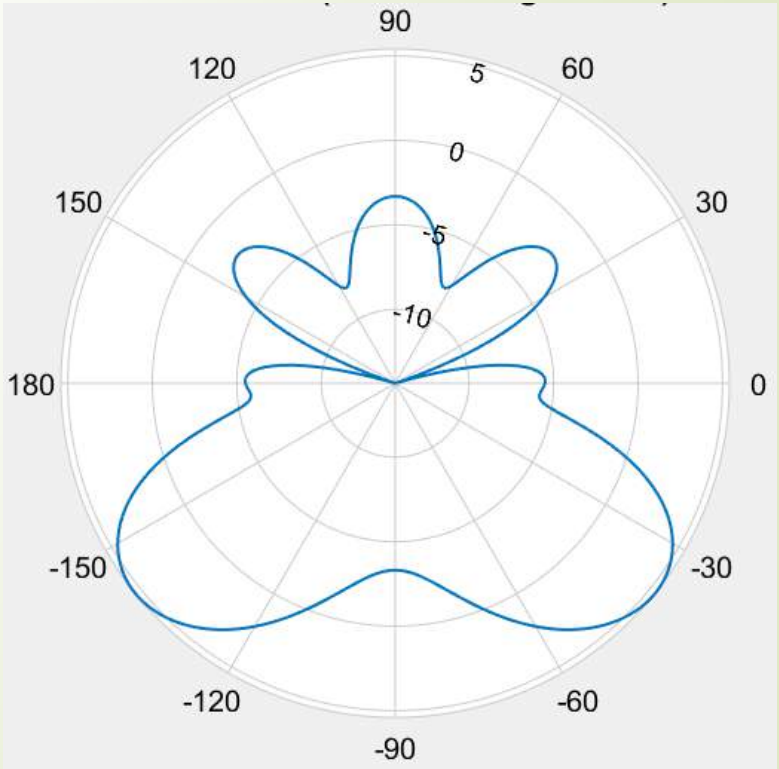
User



Eve



AP



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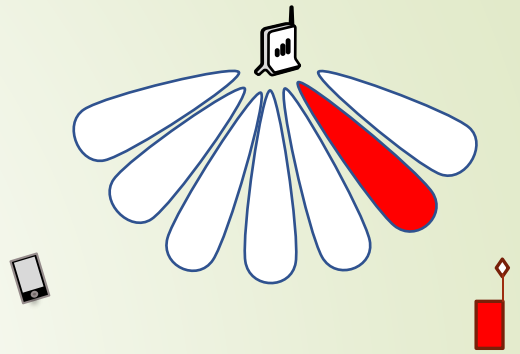

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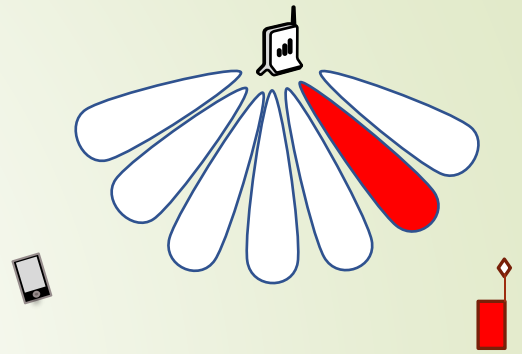

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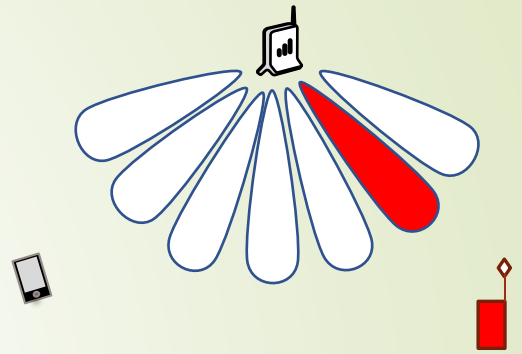

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- Plan:
  - Quantify the impact
  - Detect
  - Defend

Understanding the fundamentals

- We want to quantify the impact and devise the protocols accordingly.

Understanding the fundamentals

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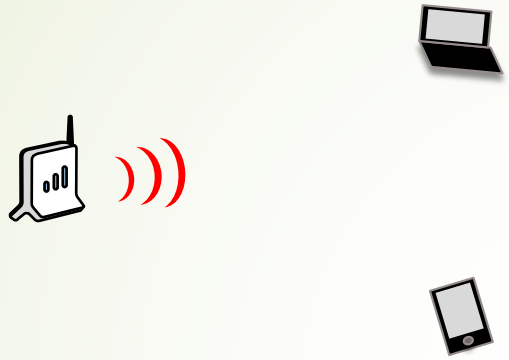
- We focus on small ACK/NACK control packets in a broadcast setting.

Denial-of-service attack

- We look at a fundamental model, the packet broadcast channel.

Denial-of-service attack



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- Each user informs the transmitter whether the transmitted packet was received successfully or not.

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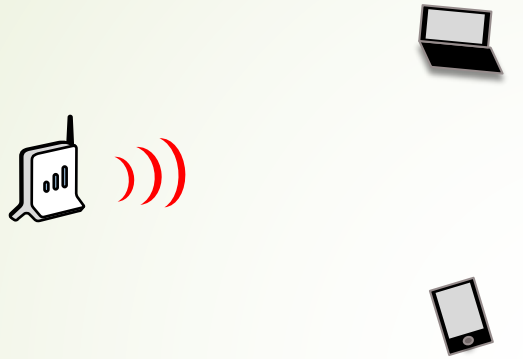

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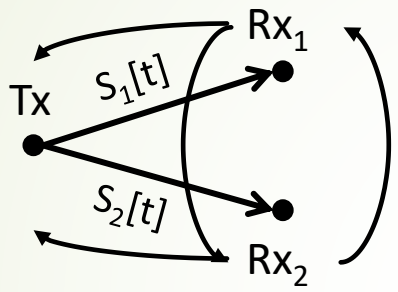
- Why this model?

Channel model and baseline



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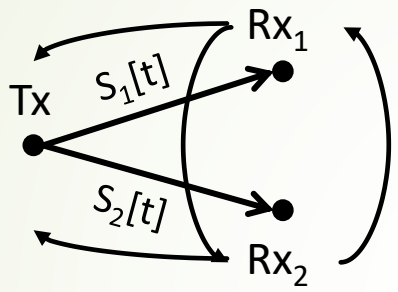

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S1[t] & S2[t] distributed independently over time

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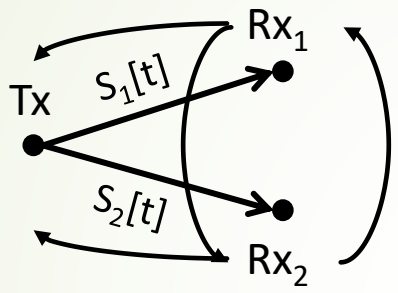

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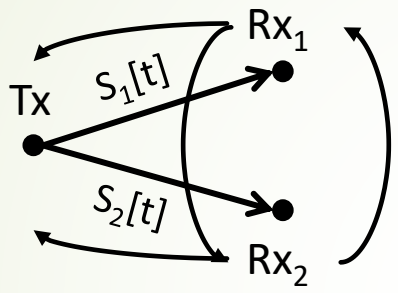

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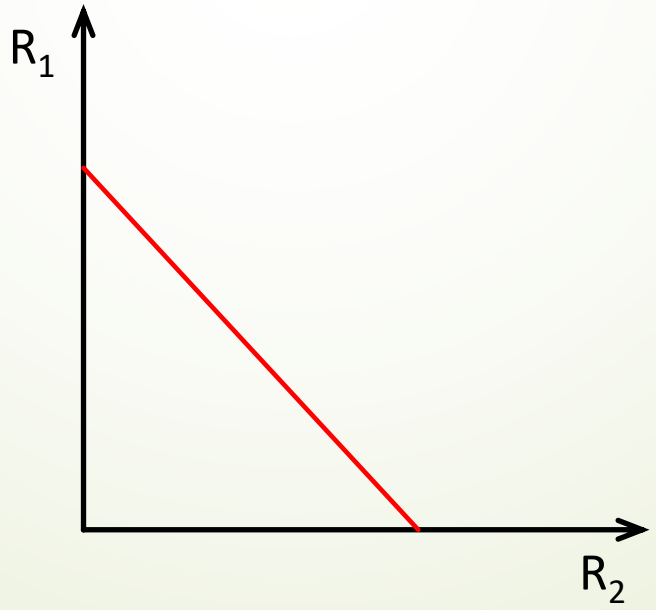

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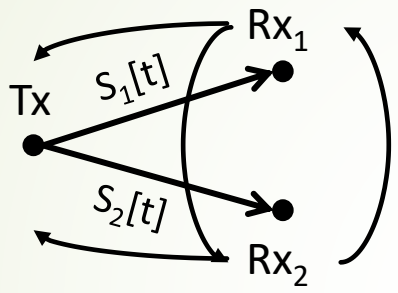

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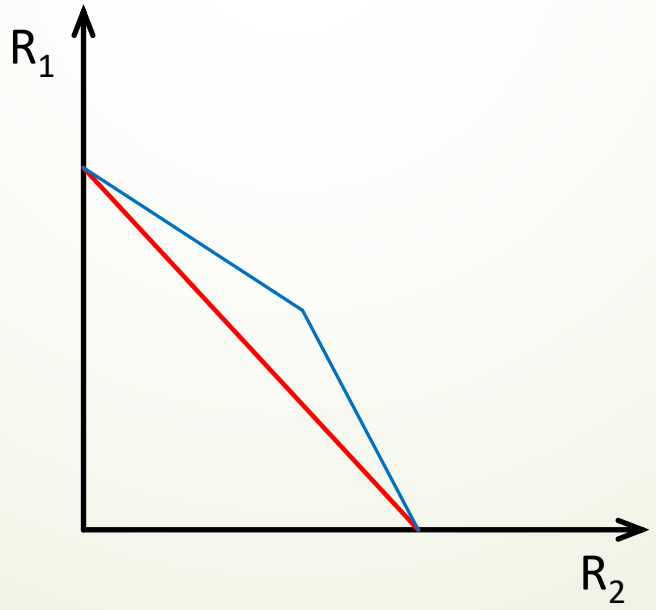
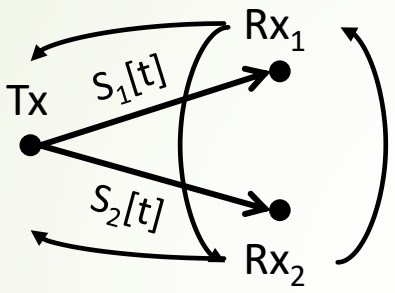
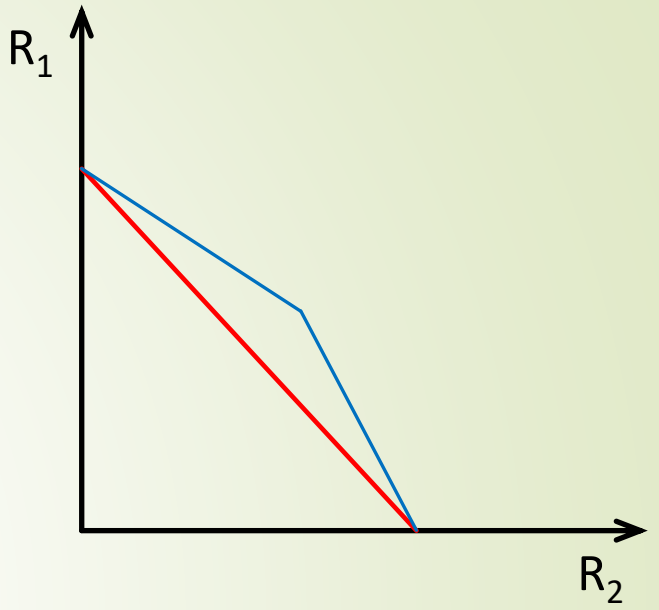


Protocol with no attack





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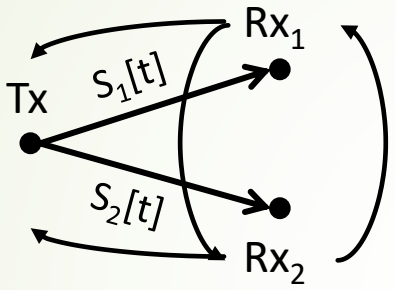
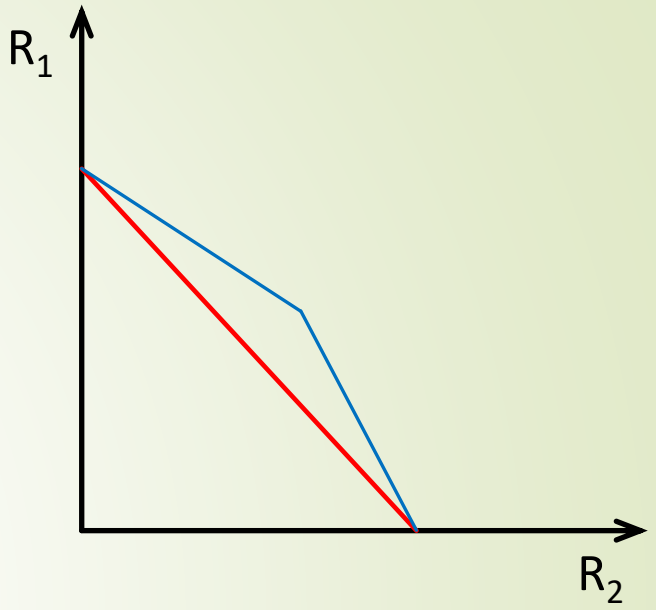
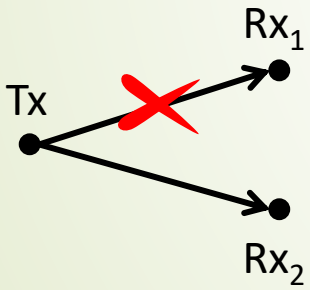


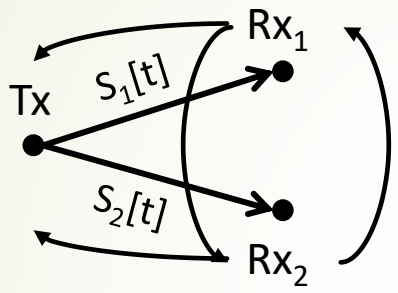


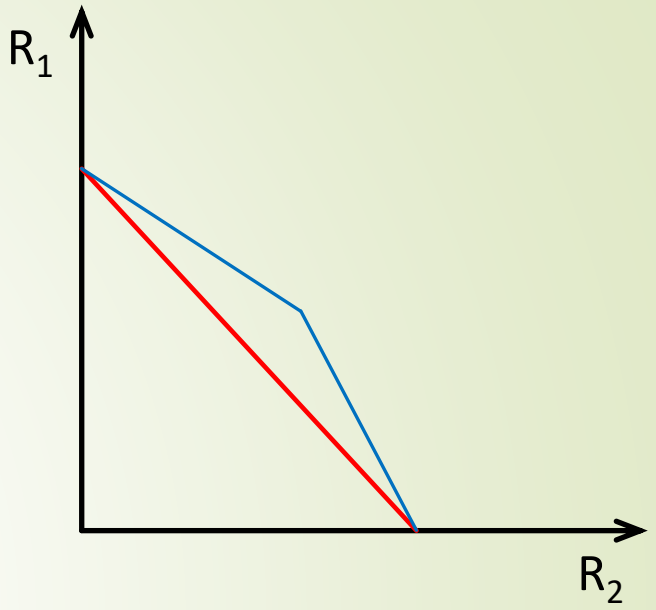
Send user 1's packets



v_1

Protocol with no attack





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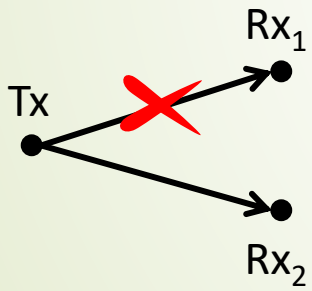
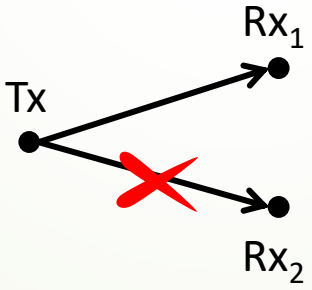


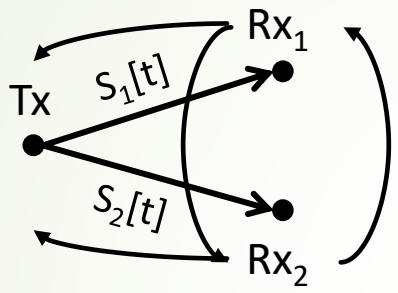
v_1

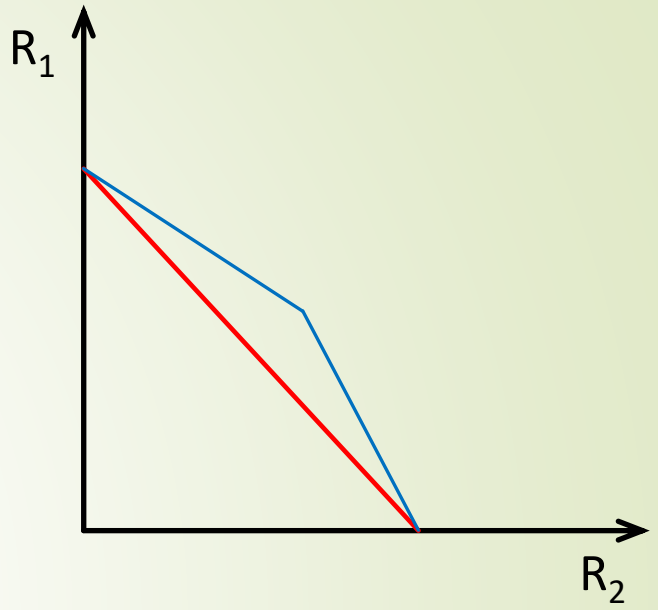
Send user 2's packets



v_2

Protocol with no attack





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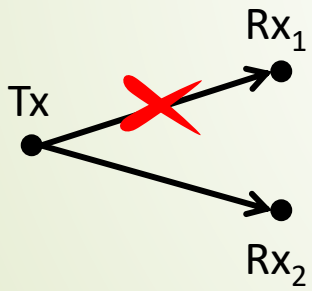

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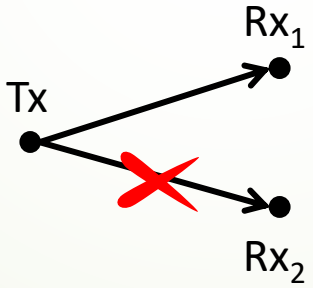
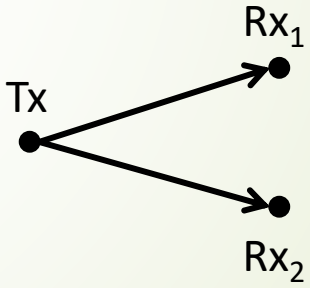


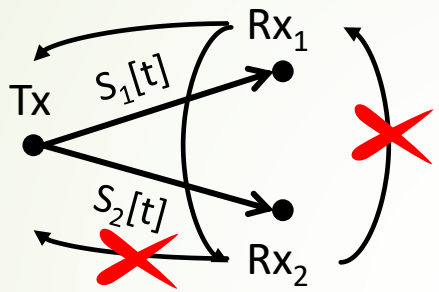
v_2

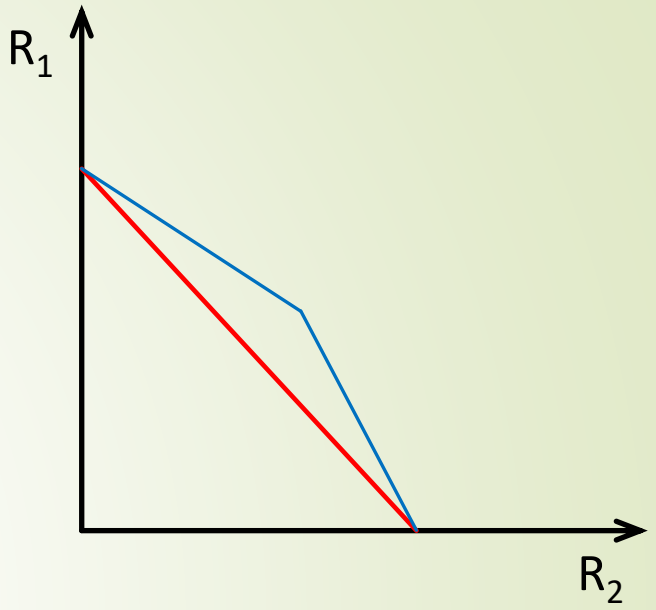
benefit from multicast



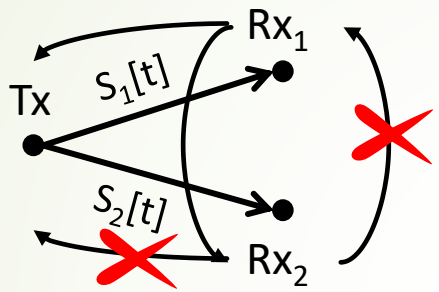
$v_1 + v_2$

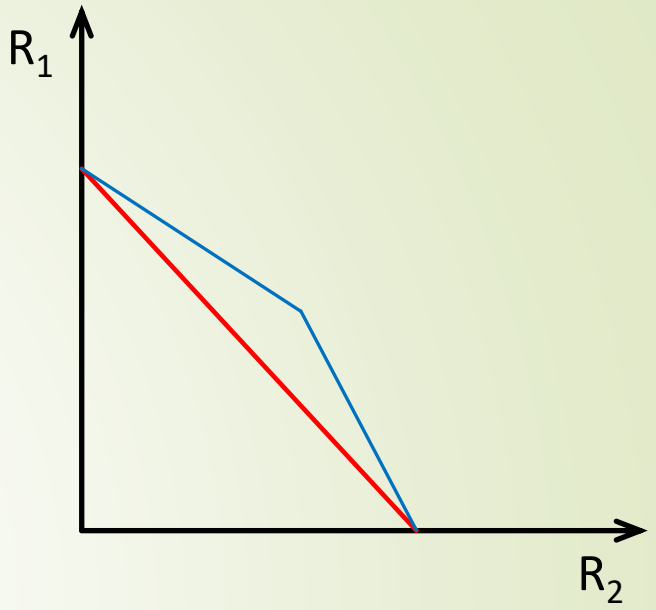
Denial-of-service attack





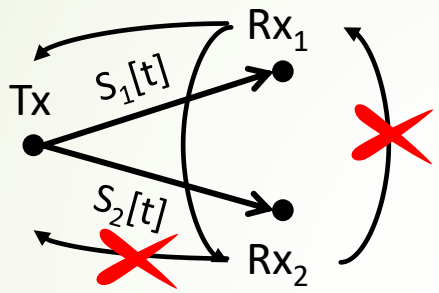
Denial-of-service attack

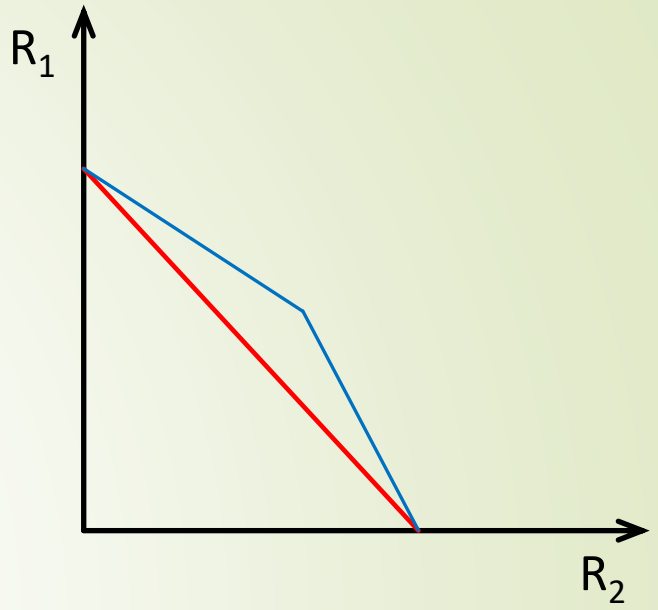




- Is this single-user knowledge still useful?

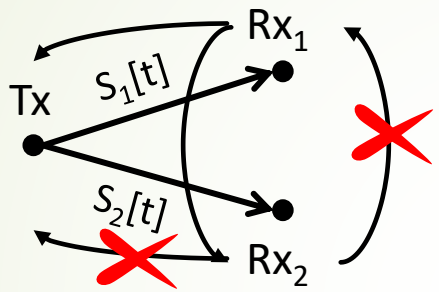
Denial-of-service attack

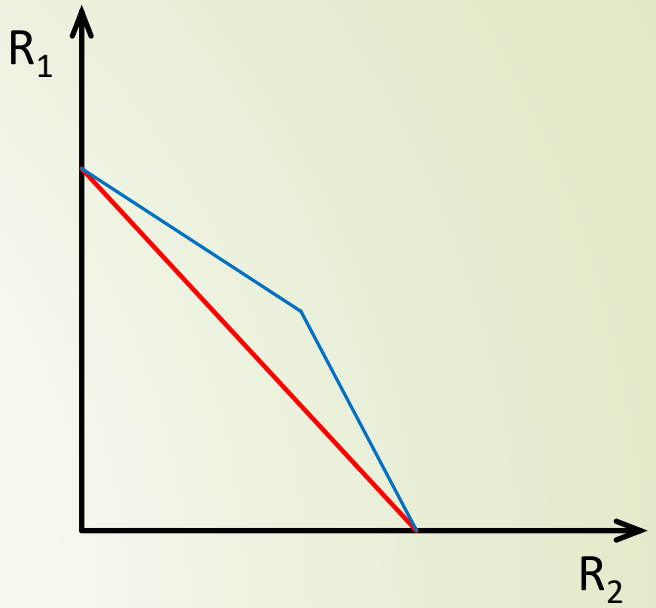




- Is this single-user knowledge still useful?
  - For MISO BC with continuous feedback, the answer is no!

Denial-of-service attack

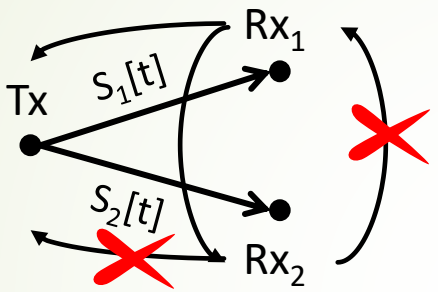




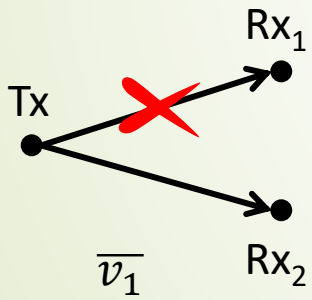
- Is this single-user knowledge still useful?
  - For MISO BC with continuous feedback, the answer is no!
  - We have a much brighter picture in packet networks!

Vahid et. al, "Capacity of broadcast packet erasure channels with single-user delayed CSI," Trans. IT, 2021.

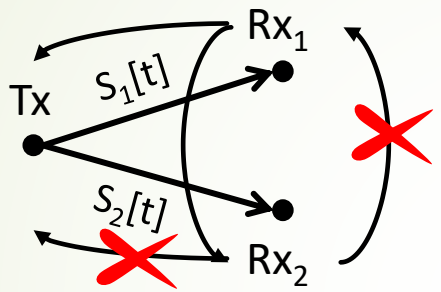
Protocol under strong denial-of-attack



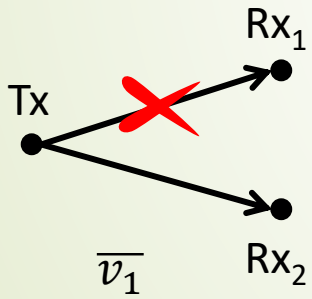
Send user 1's packets



Protocol under strong denial-of-attack

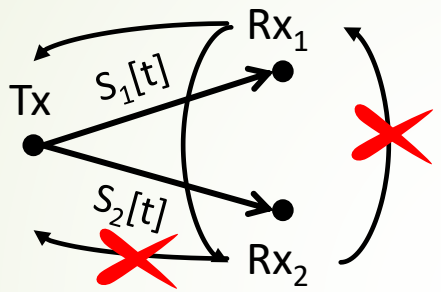


Send user 1's packets

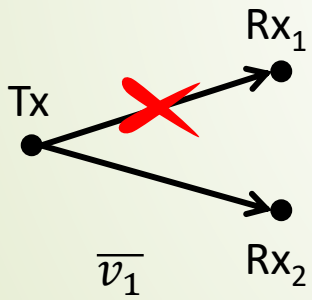


I know what user 1 is missing; and statistically what user 2 gets,

Protocol under strong denial-of-attack

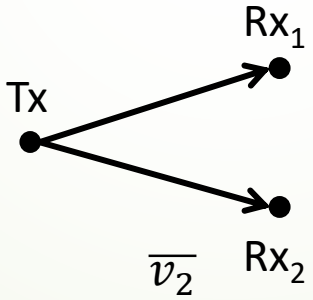


Send user 1's packets

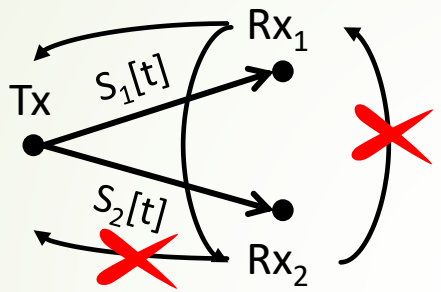


I know what user 1 is missing; and statistically what user 2 gets,

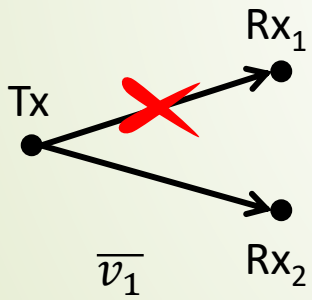
Send user 2's packets



Protocol under strong denial-of-attack

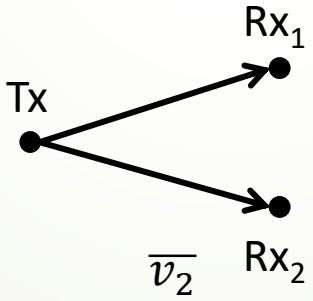


Send user 1's packets



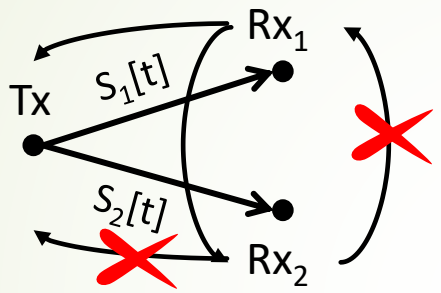
I know what user 1 is missing; and statistically what user 2 gets,

Send user 2's packets

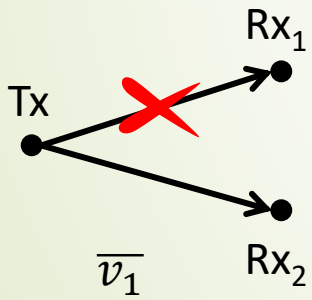


We don't know when user 2 was off! But we know what user 1 receives.

Protocol under strong denial-of-attack

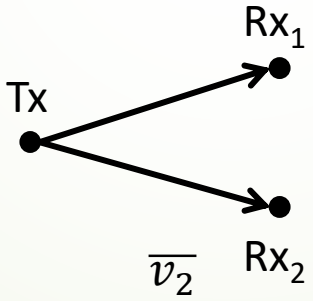


Send user 1's packets



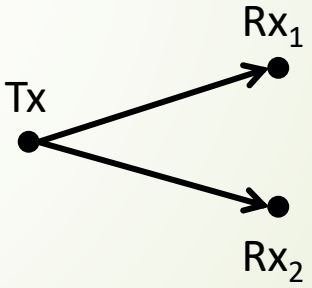
I know what user 1 is missing; and statistically what user 2 gets,

Send user 2's packets

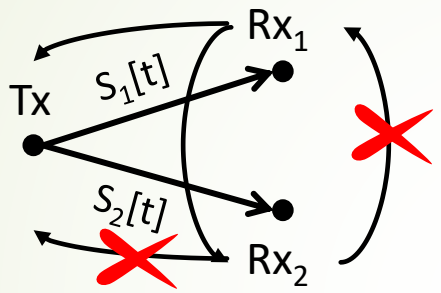


We don't know when user 2 was off! But we know what user 1 receives.

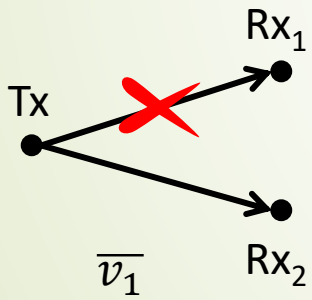
benefit from **feedback**



Protocol under strong denial-of-attack

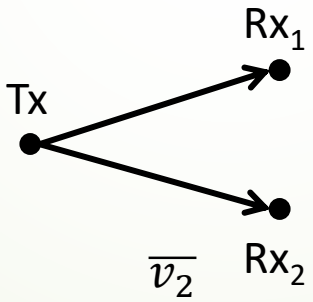


Send user 1's packets



I know what user 1 is missing; and statistically what user 2 gets,

Send user 2's packets



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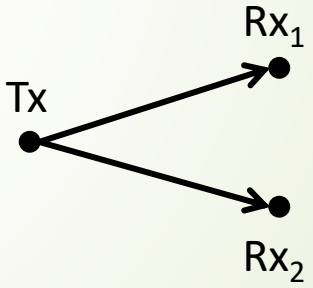
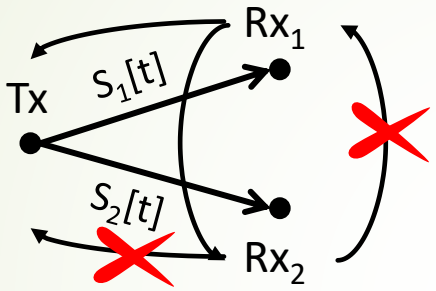
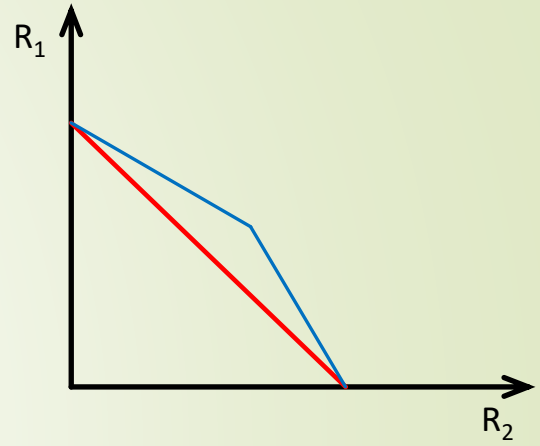


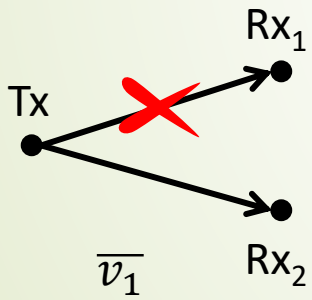
Resend $\overline{v_1}$ until ACK
+
Linearly coded $\overline{v_2}$

Protocol under strong denial-of-attack



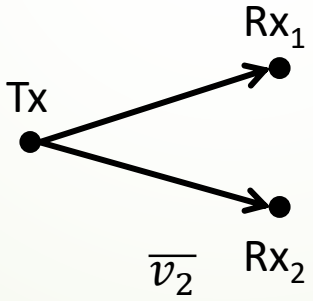


Send user 1's packets



I know what user 1 is missing; and statistically what user 2 gets,

Send user 2's packets



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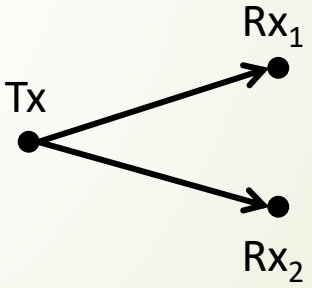
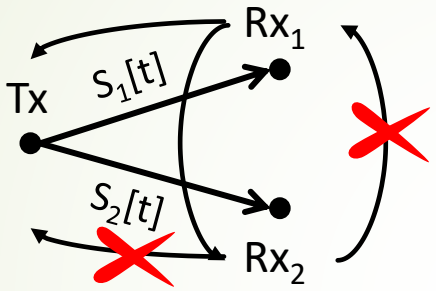
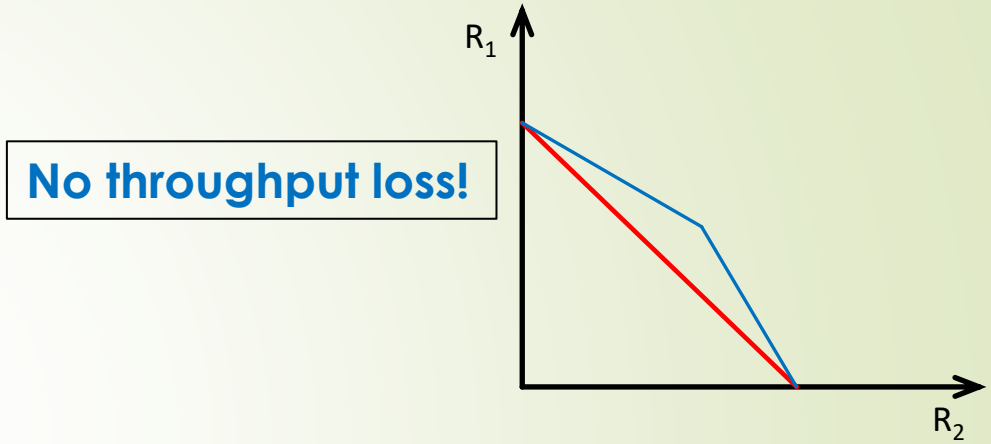


Resend $\overline{v_1}$ until ACK
+
Linearly coded $\overline{v_2}$

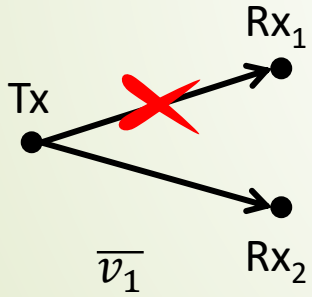
Protocol under strong denial-of-attack





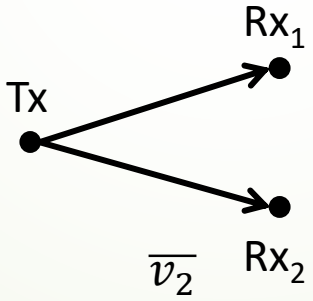
No throughput loss!

Send user 1's packets



I know what user 1 is missing; and statistically what user 2 gets,

Send user 2's packets



We don't know when user 2 was off! But we know what user 1 receives.

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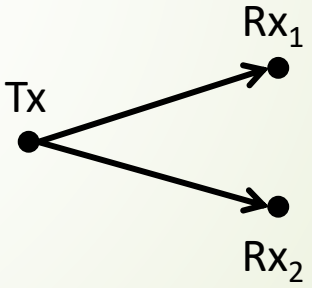
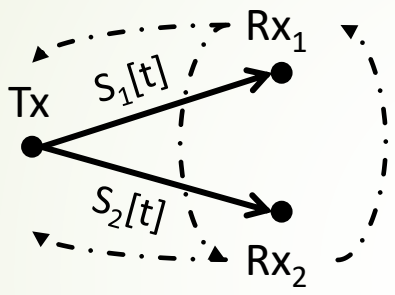
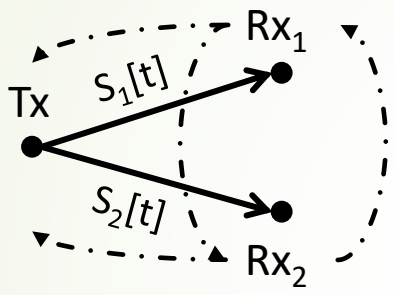


Resend $\overline{v_1}$ until ACK
+
Linearly coded $\overline{v_2}$

General denial-of-attack on control channels



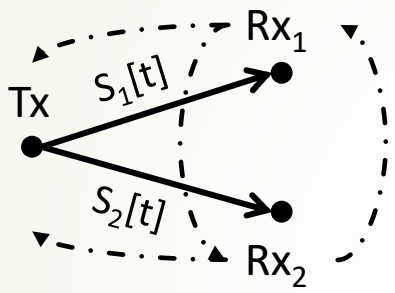
General denial-of-attack on control channels



Each Rx simply broadcasts its control packet.

All control channels have some probability of failure.

General denial-of-attack on control channels



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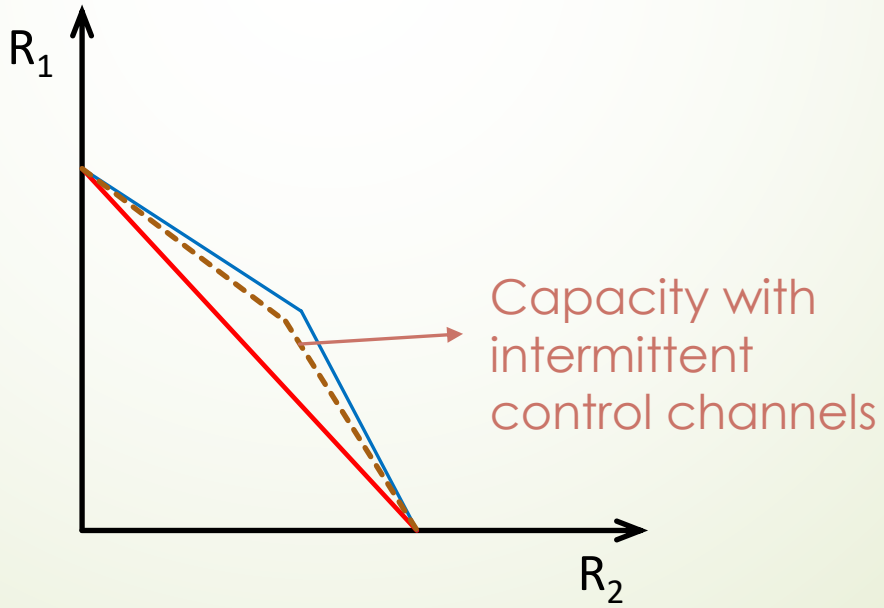
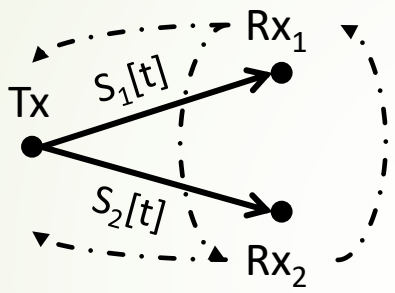


General denial-of-attack on control channels



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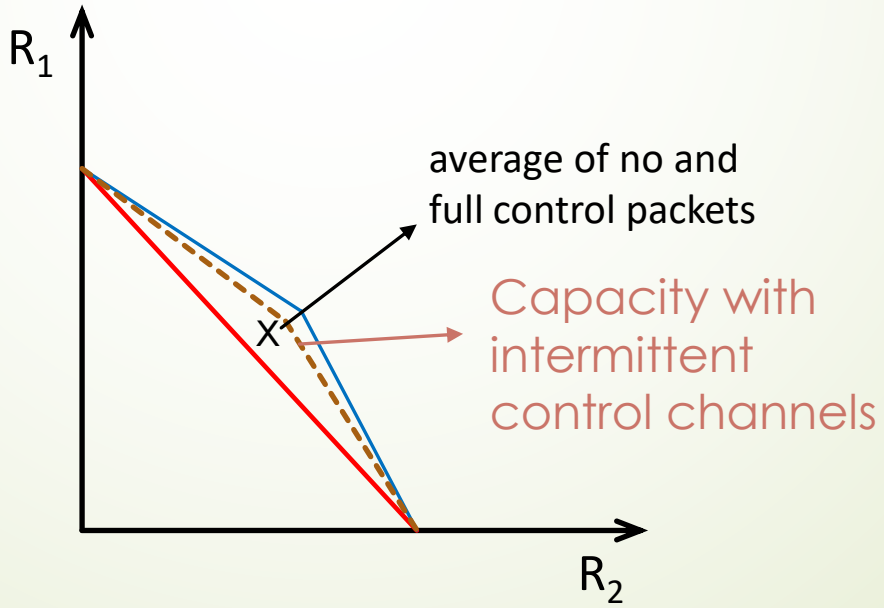
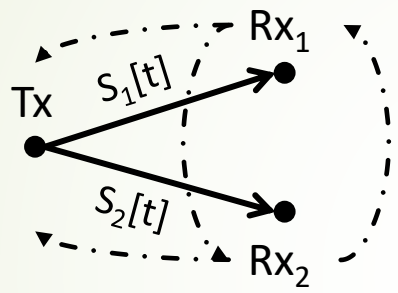


Vahid et. al, "Erasure broadcast channels with intermittent feedback," Trans. Comm, 2021.

General denial-of-attack on control channels

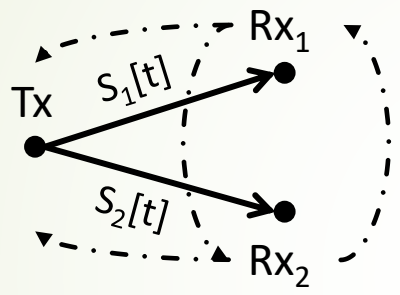


Each Rx simply broadcasts its control packet.

All control channels have some probability of failure.

- Phase 1: Send bits for user 1.

General denial-of-attack on control channels

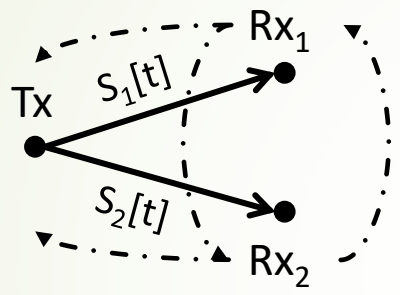


Each Rx simply broadcasts its control packet.

All control channels have some probability of failure.

- Phase 1: Send bits for user 1.
  - when there is FB: v_1 are the bits at Rx_2 needed at Rx_1
  - when no FB: $\bar{v}_1$ are statistical equations needed at Rx_1

General denial-of-attack on control channels

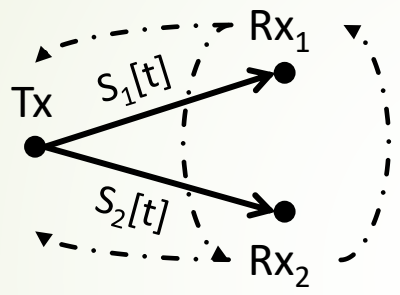


Each Rx simply broadcasts its control packet.

All control channels have some probability of failure.

- Phase 1: Send bits for user 1.
  - when there is FB: v_1 are the bits at Rx_2 needed at Rx_1
  - when no FB: $\bar{v}_1$ are statistical equations needed at Rx_1
- Phase 2: Send bits for user 2. Create $\bar{v}_2$ and v_2.

General denial-of-attack on control channels



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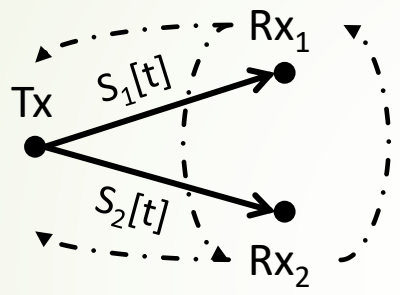
- Phase 2: Send bits for user 2. Create $\bar{v}_2$ and v_2.
- Phase 3: send the summation of v_1 & v_2.

General denial-of-attack on control channels



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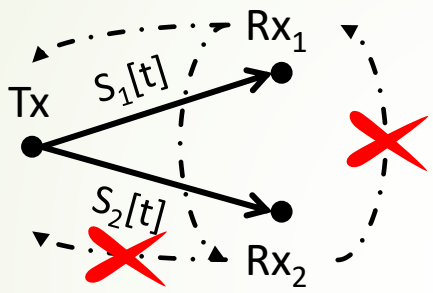
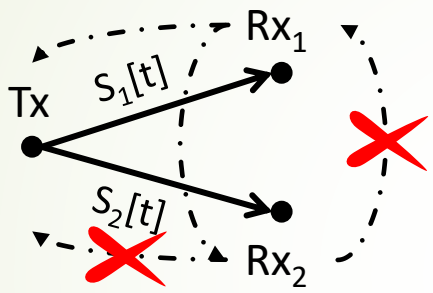
- Phase 1: Send bits for user 1.
  - when there is FB: v_1 are the bits at Rx_2 needed at Rx_1
  - when no FB: $\bar{v}_1$ are statistical equations needed at Rx_1
- Phase 2: Send bits for user 2. Create $\bar{v}_2$ and v_2.
- Phase 3: send the summation of v_1 & v_2.
- Recursion: Use $\bar{v}_1$ & $\bar{v}_2$ as inputs to Phase 1.

Extreme environment



The available control channels have sub-bit capacity!

Extreme environment



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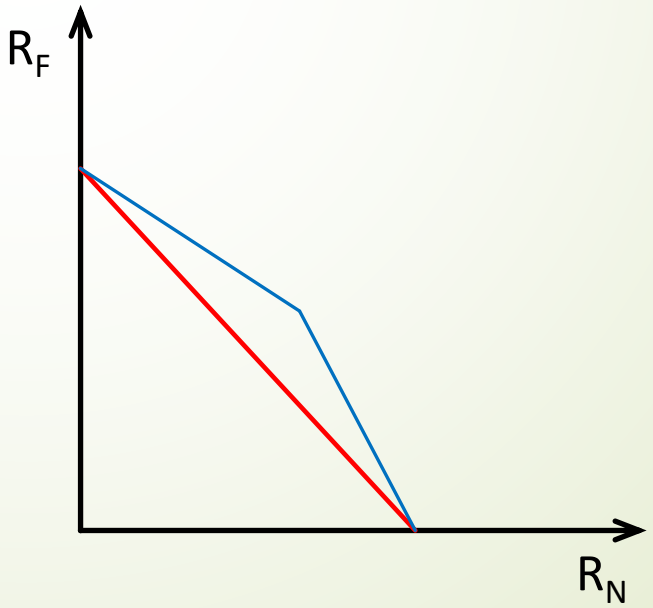
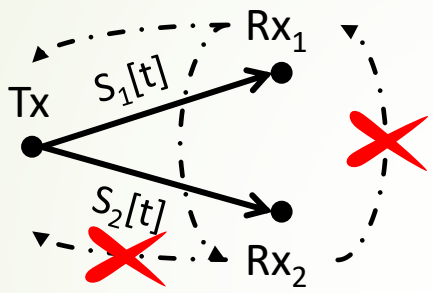
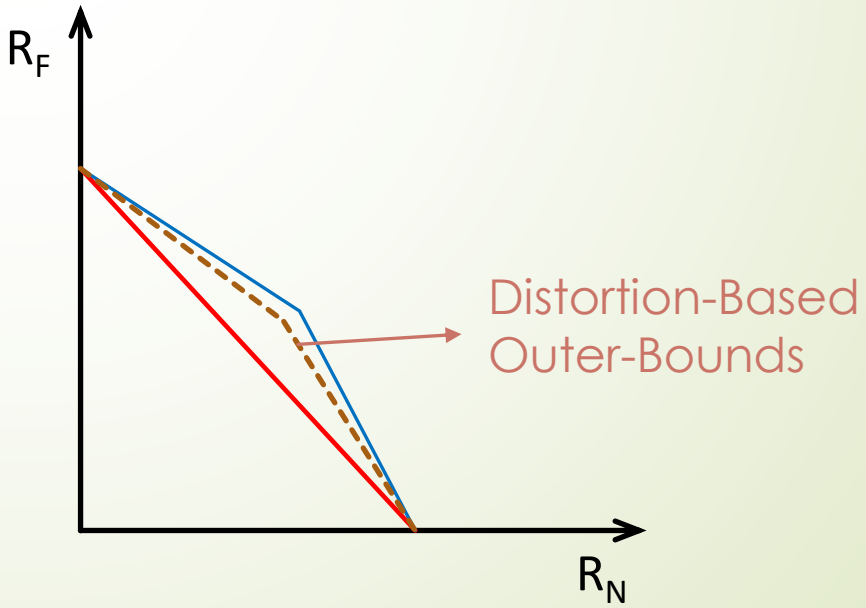


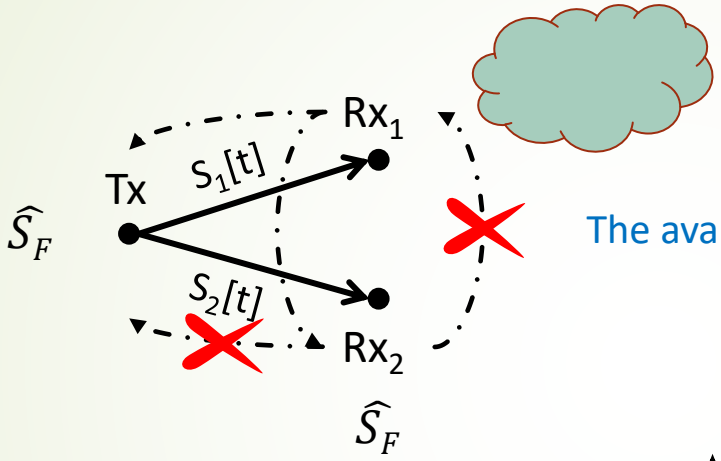
Extreme environment



The available control channels have sub-bit capacity!



Extreme environment



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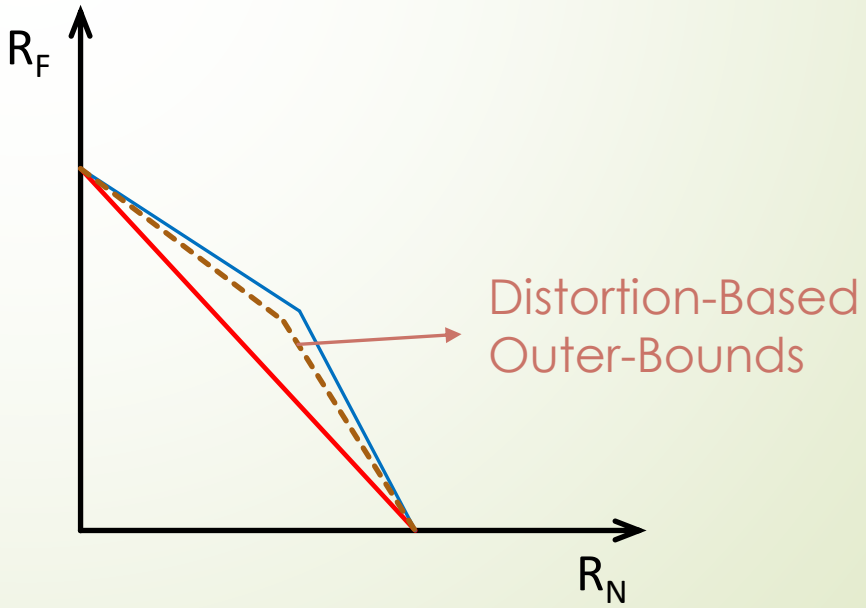

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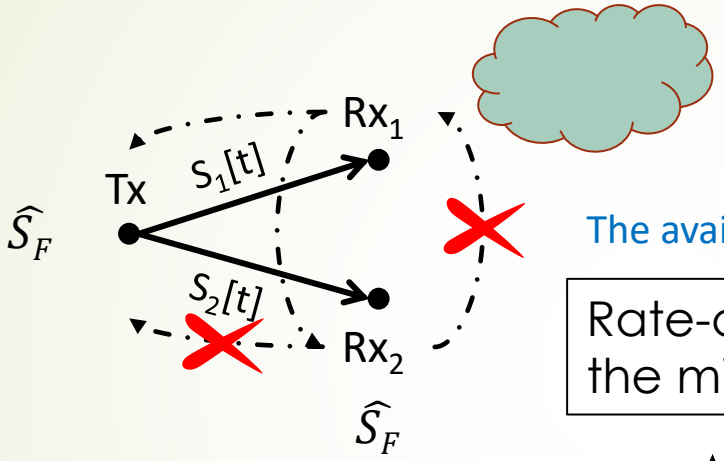
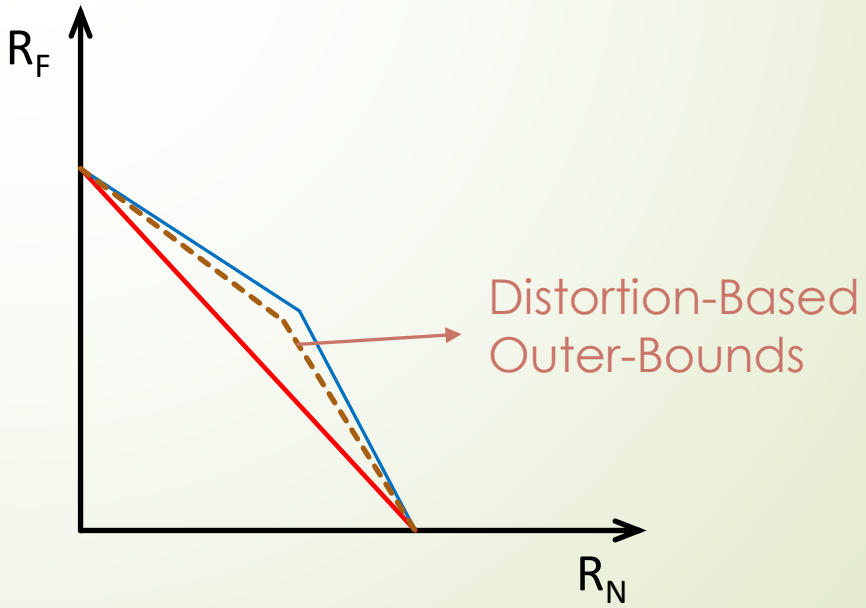
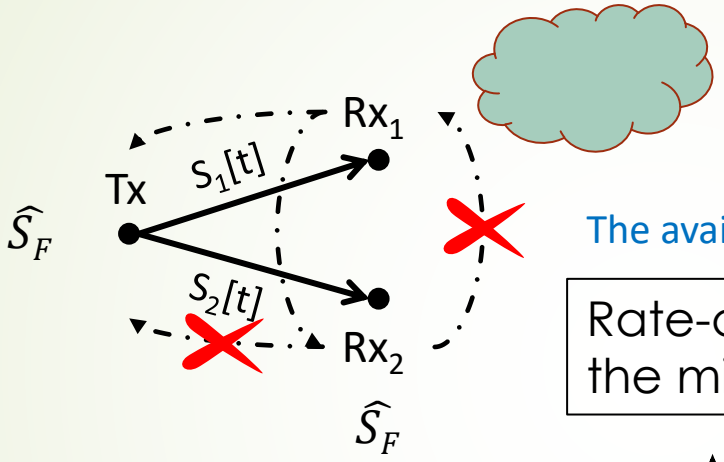


The available control channels have sub-bit capacity!

Rate-distortion theory gives us the minimum attainable distortion.



Extreme environment



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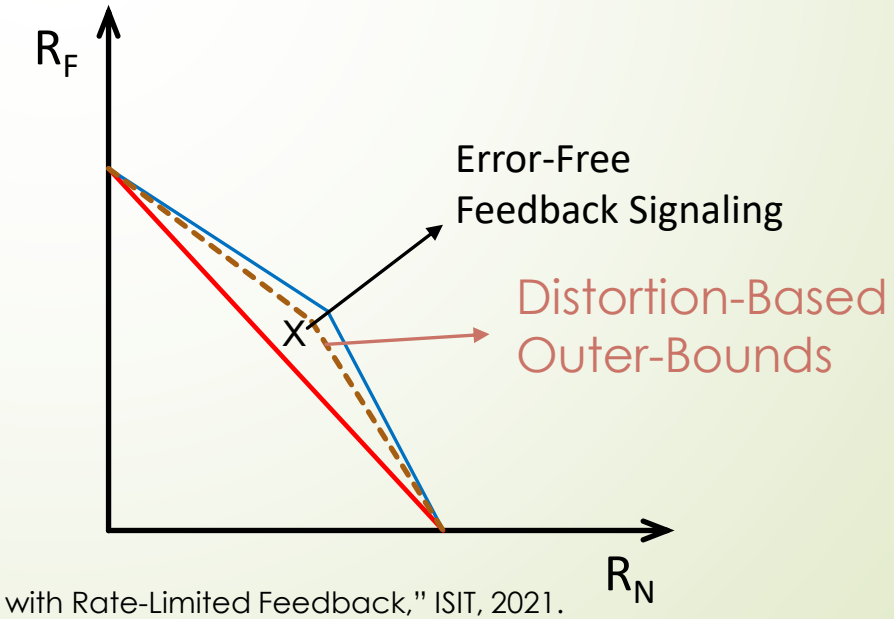
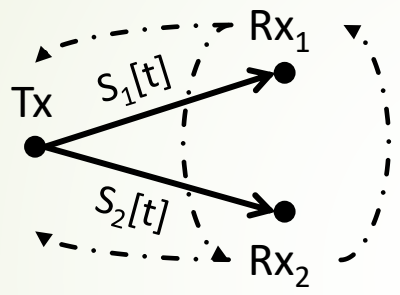


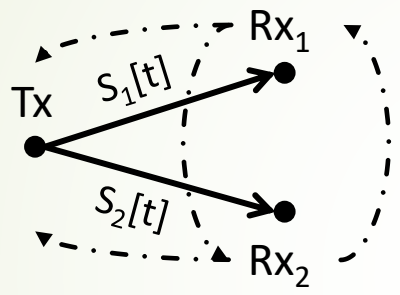
Vahid, "Distortion-Based Outer-Bounds for Channels with Rate-Limited Feedback," ISIT, 2021.

Remaining theoretical questions



- How do the results scale?

Remaining theoretical questions



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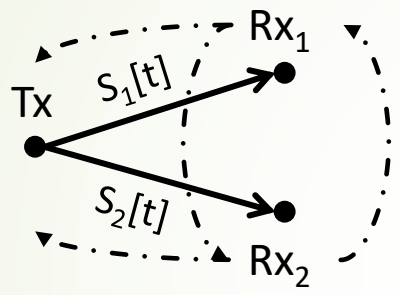

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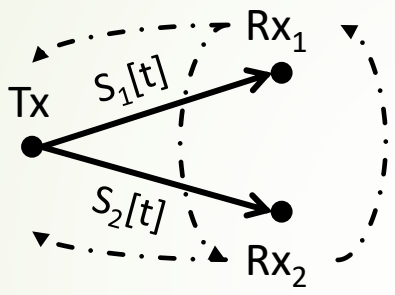

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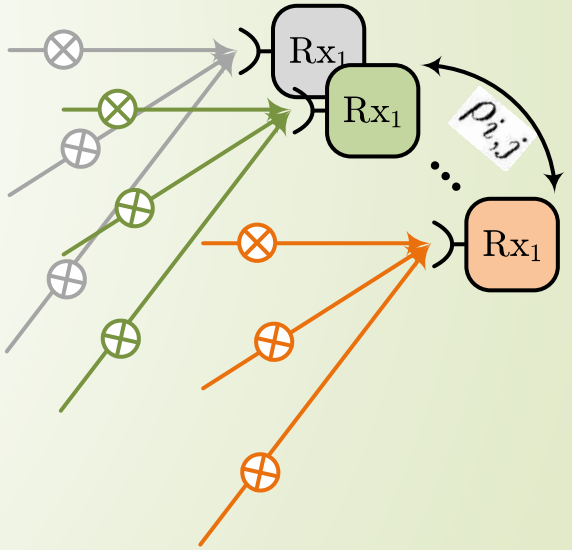

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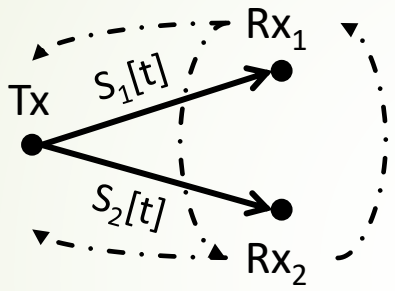
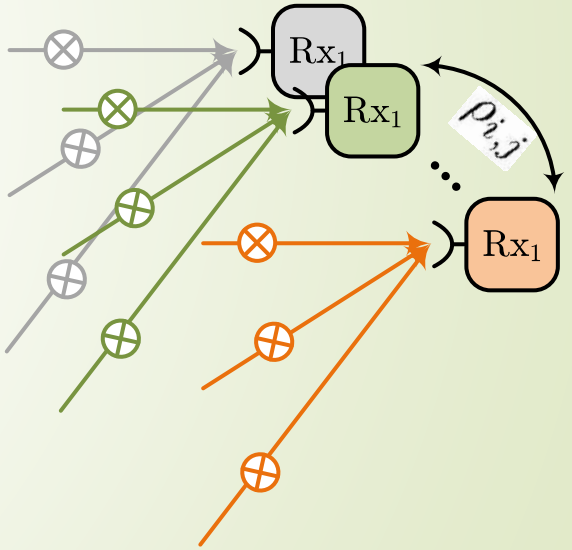
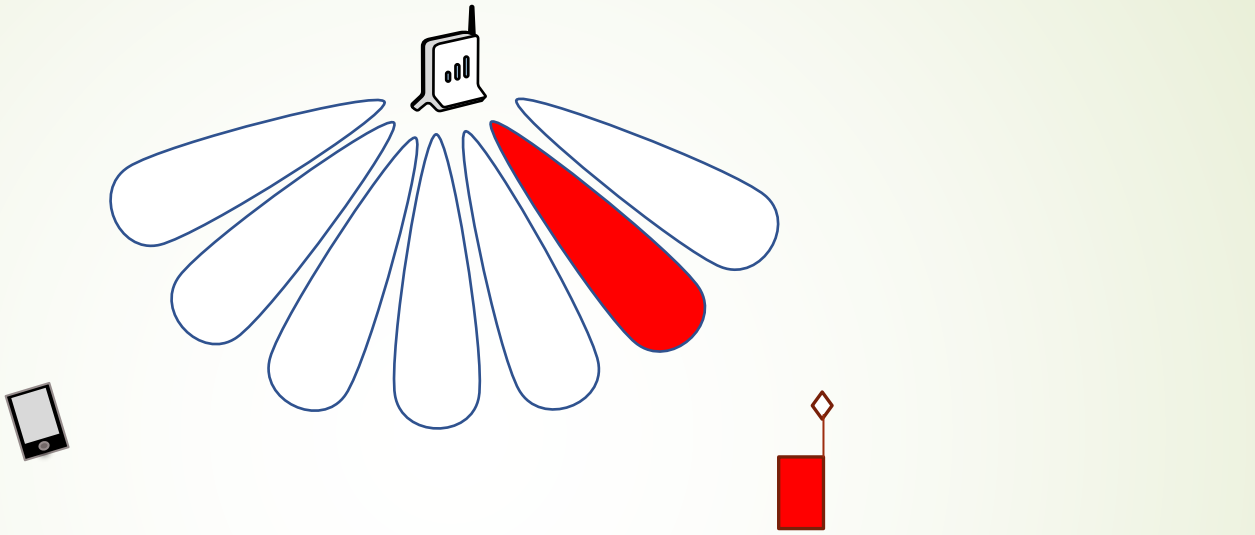
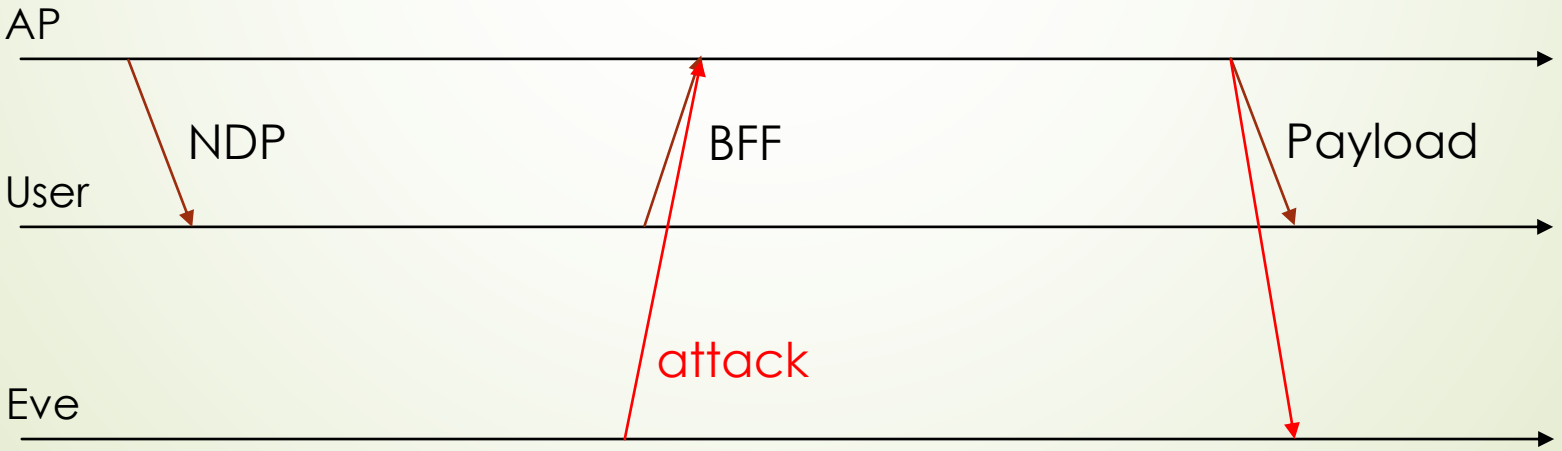




- How do the results scale?
- What is the delay implications of the protocols?
- The extreme sub-bit regime remains open.
- Spectrum sharing
- Can these ideas be incorporated in existing protocols?

Back to WiFi-6 (-7)





Defending WiFi against Control Ch. Attacks

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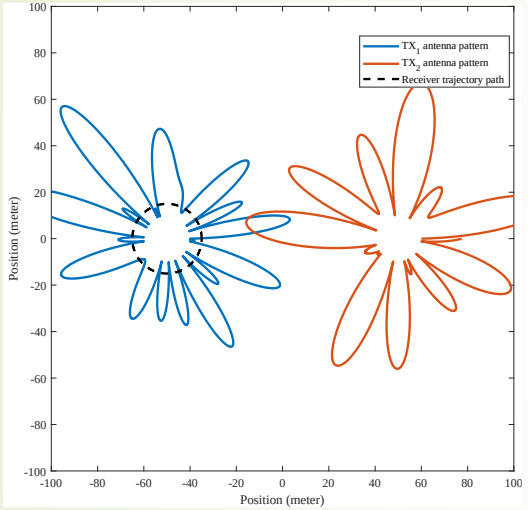

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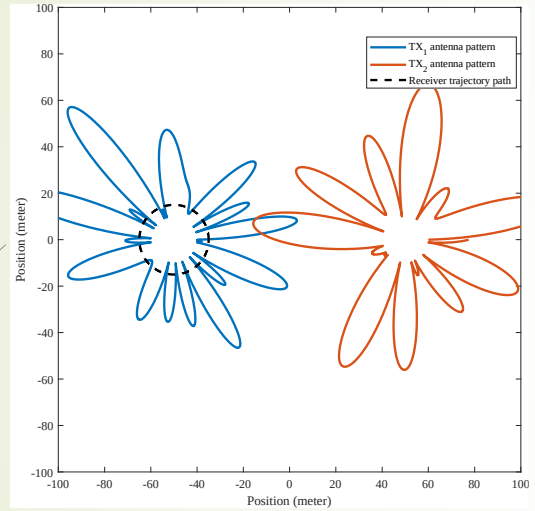

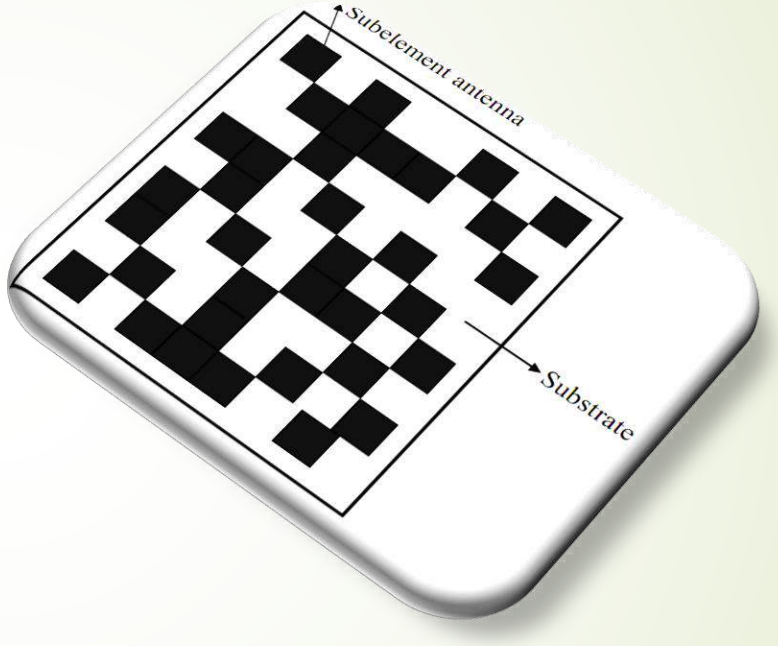

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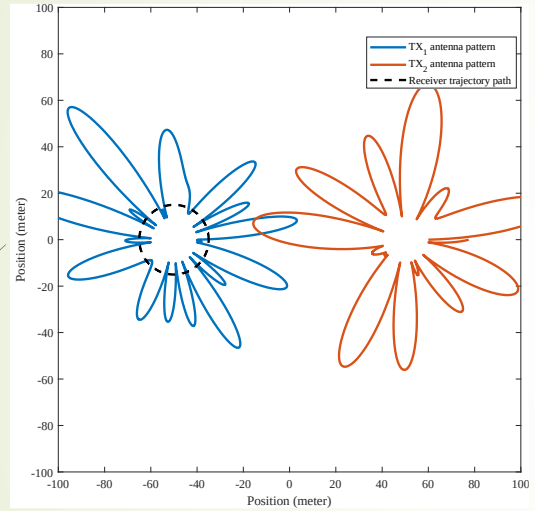

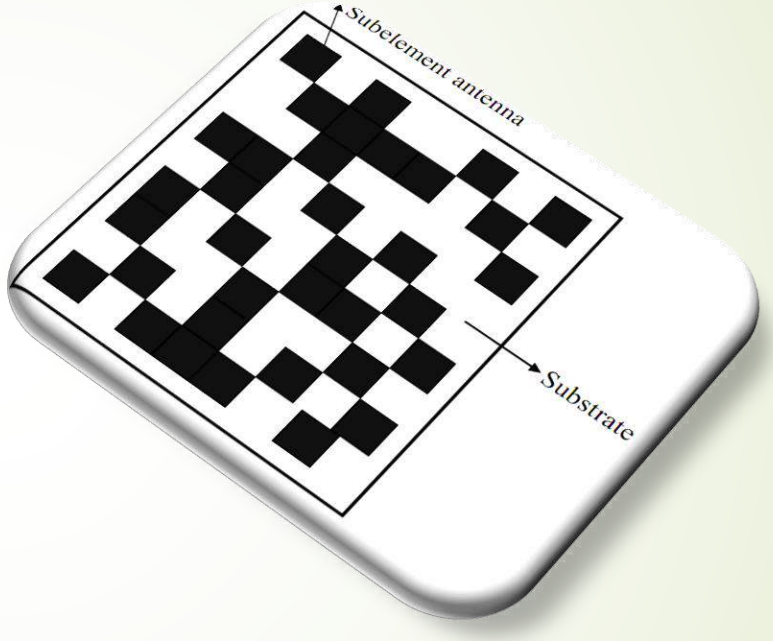

- Desired user will always be at 0° phase, while others see varying phases. (rel. to antenna-selection mod.)

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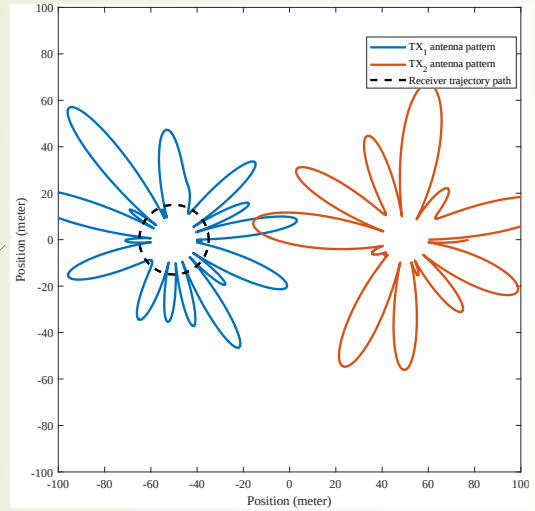
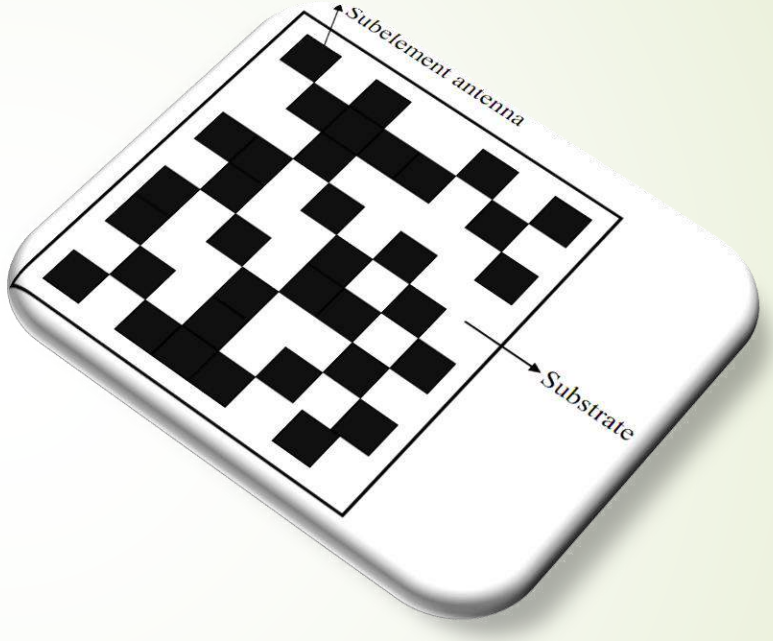
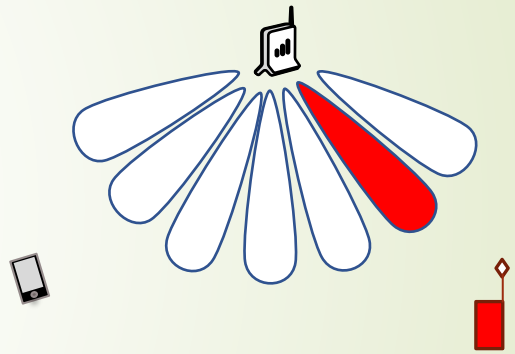




- Desired user will always be at 0° phase, while others see varying phases. (rel. to antenna-selection mod.)
- Embedding information in radiation pattern fluctuations is itself a worthy direction.

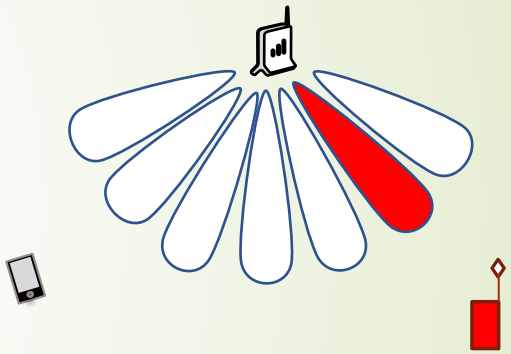
Vahid et al, "Exploiting coherence time variations for opportunistic blind interference alignment," Trans. Comm, 2020.

Defending WiFi against Control Ch. Attacks



Defending WiFi against Control Ch. Attacks

- Radiation pattern fluctuations.
- WiFi localization (e.g., time of flight).
- Channel signatures.



Vahid et al, "A Game-Theoretically Optimal Defense Paradigm against Traffic Analysis Attacks Using Multipath Routing and Deception," SACMAT, 2022.

Vahid et al, "Toward practical defense against traffic analysis attacks on encrypted DNS traffic," Computers & Security, 2022.


Higher frequency bands?

Thank you!