Physical Layer Security

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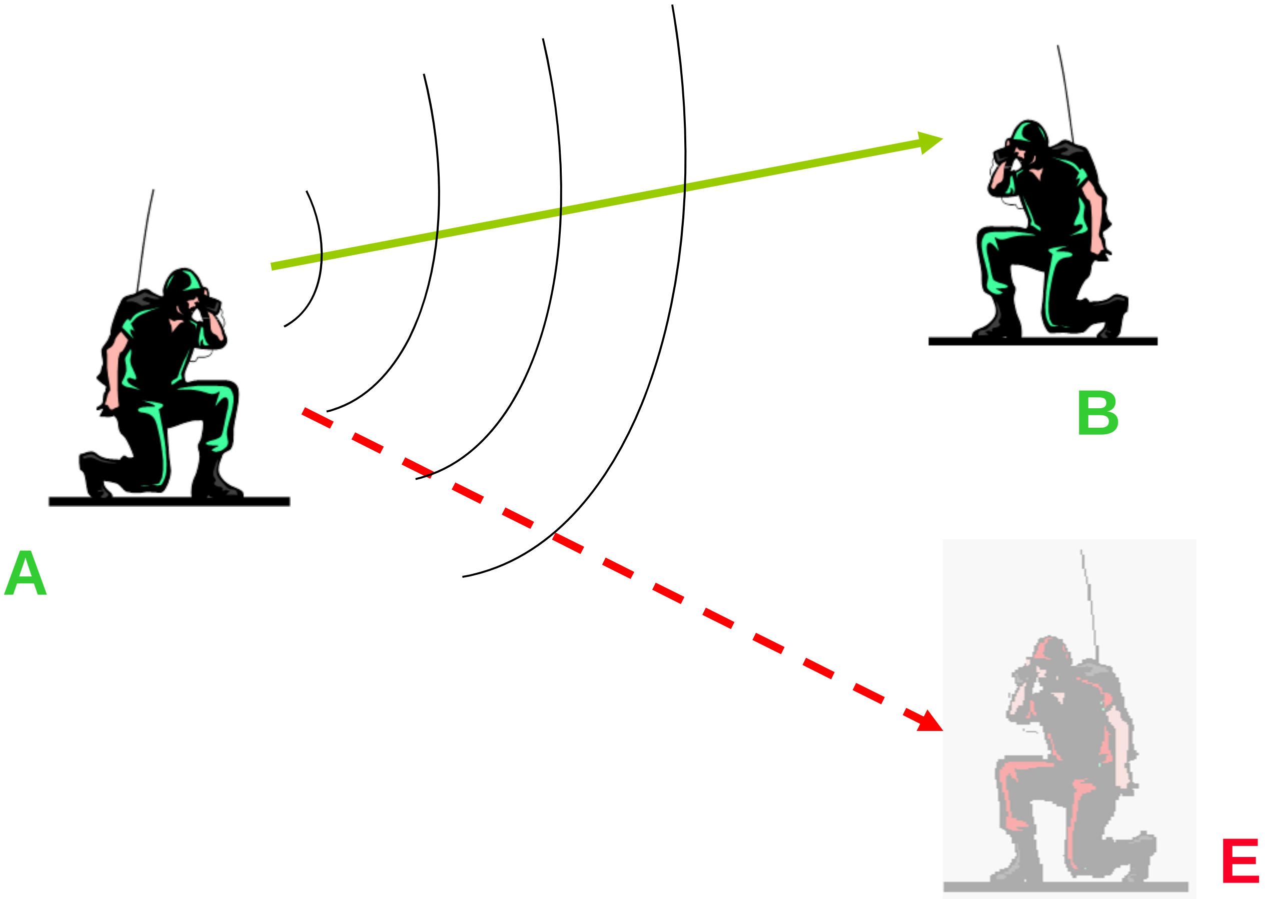
Security in Wireless Systems

Inherent openness in the wireless communications channel:

eavesdropping and **jamming** attacks



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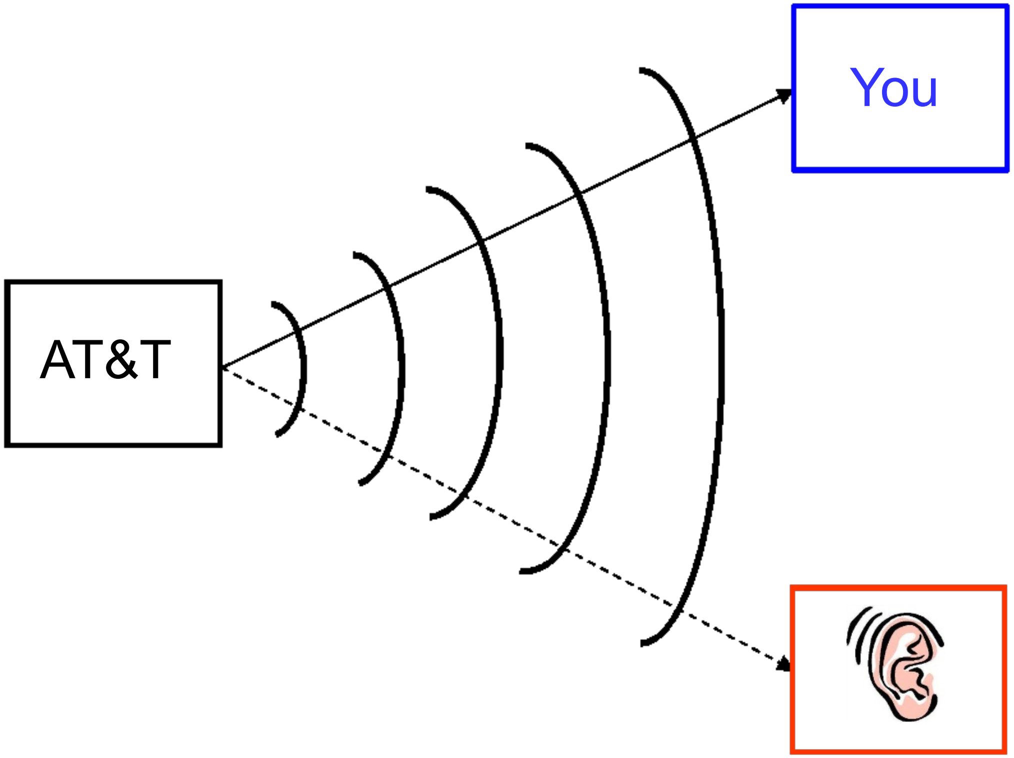

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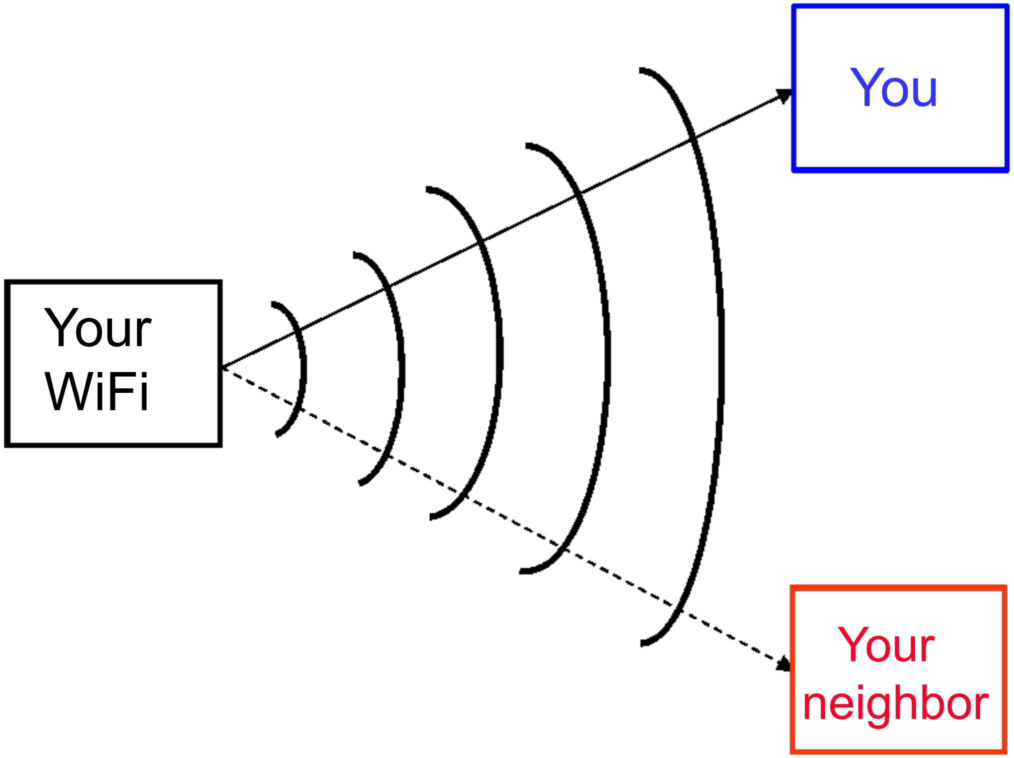

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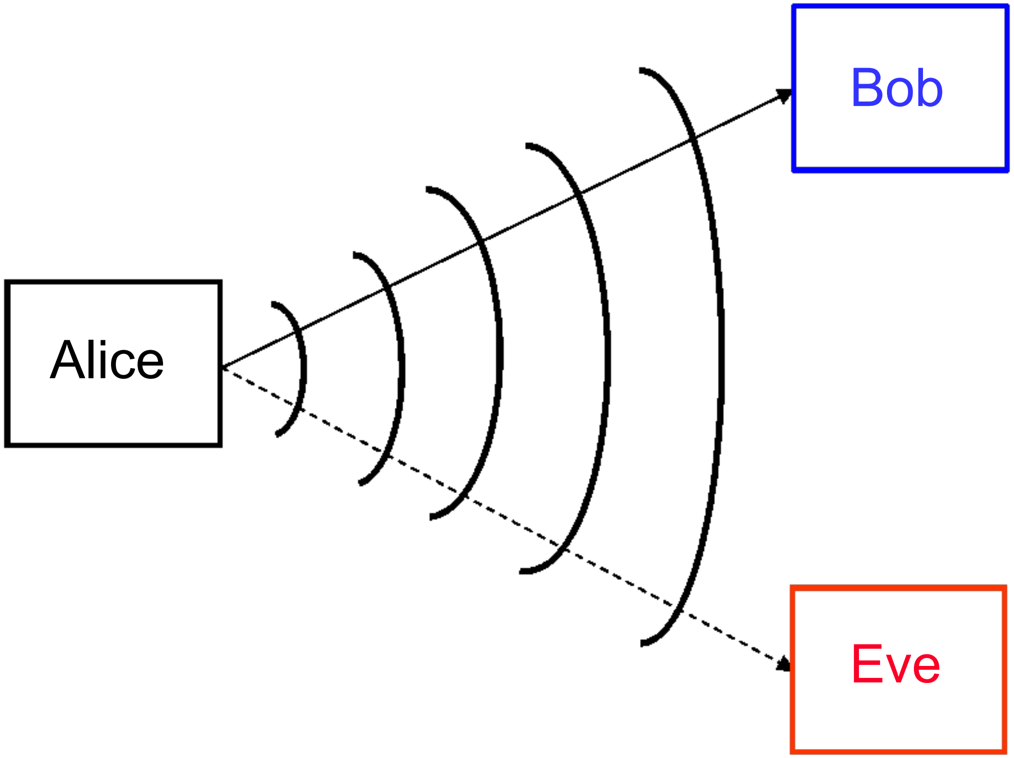

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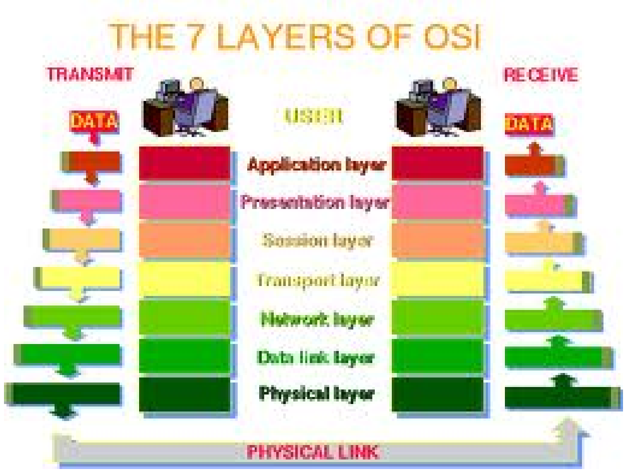
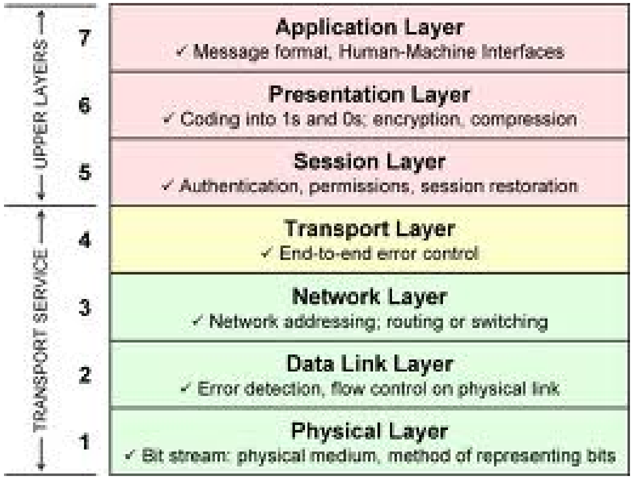
What is the Physical Layer?

The **lowest layer** of the 7-layer OSI protocol stack.

The level at which **bits** are transmitted/received.





UPPER LAYERS	7	**Application Layer** ✓ Message format, Human-Machine Interfaces
	6	**Presentation Layer** ✓ Coding into 1s and 0s; encryption, compression
	5	**Session Layer** ✓ Authentication, permissions, session restoration
TRANSPORT SERVICE	4	**Transport Layer** ✓ End-to-end error control
	3	**Network Layer** ✓ Network addressing; routing or switching
	2	**Data Link Layer** ✓ Error detection, flow control on physical link
	1	**Physical Layer** ✓ Bit stream: physical medium, method of representing bits

Countering Security Threats: Current State-of-the-Art

Cryptography:

- at higher layers of the protocol stack
- based on **limited computational power** at the adversary

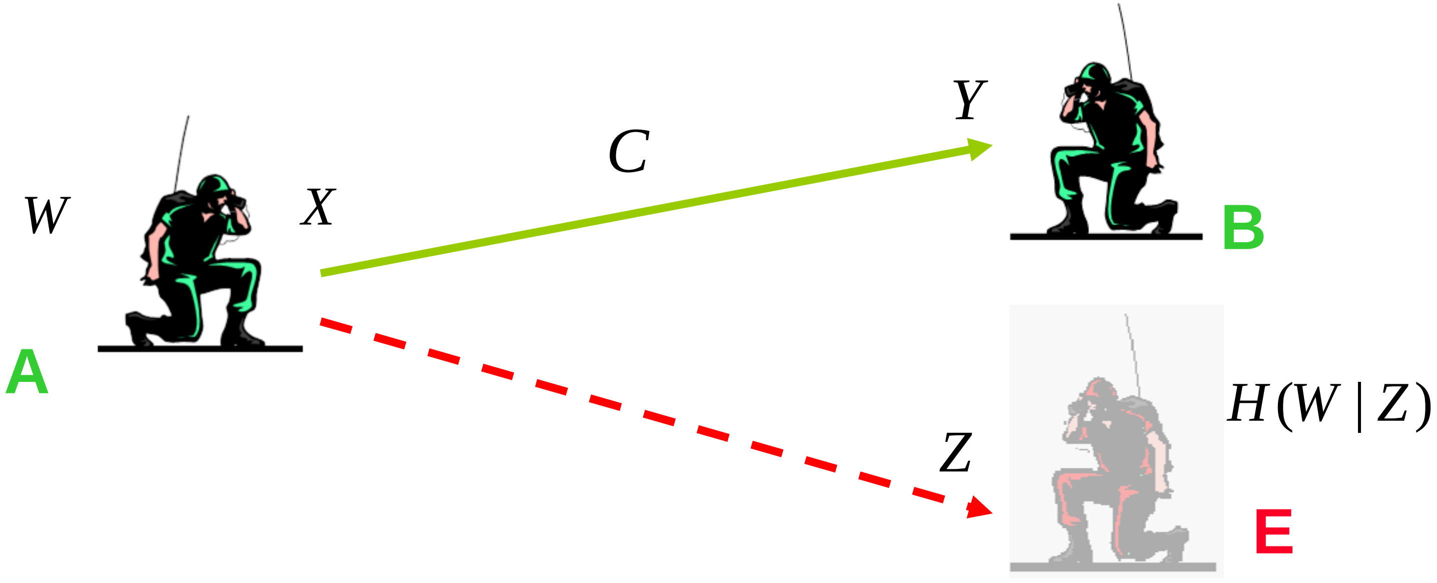
Spread spectrum, e.g., frequency hopping and CDMA:

- at the physical layer
- based on **limited knowledge** at the adversary

Physical layer security:

- at the physical layer
- no assumption on adversary’s computational power
- no assumption on adversary’s available information
- **provable** and **quantifiable** (in bits/sec/hertz)
- **implementable** using signal proc, comm and coding techniques

Wireless Wiretap Channel



- Perfect secrecy: $H(W|Z) = H(W)$
- Perfect secrecy capacity: $C = \max\ I(X;Y) - I(X;Z)$
- For certain channels (but not always): $C = C_B - C_E$

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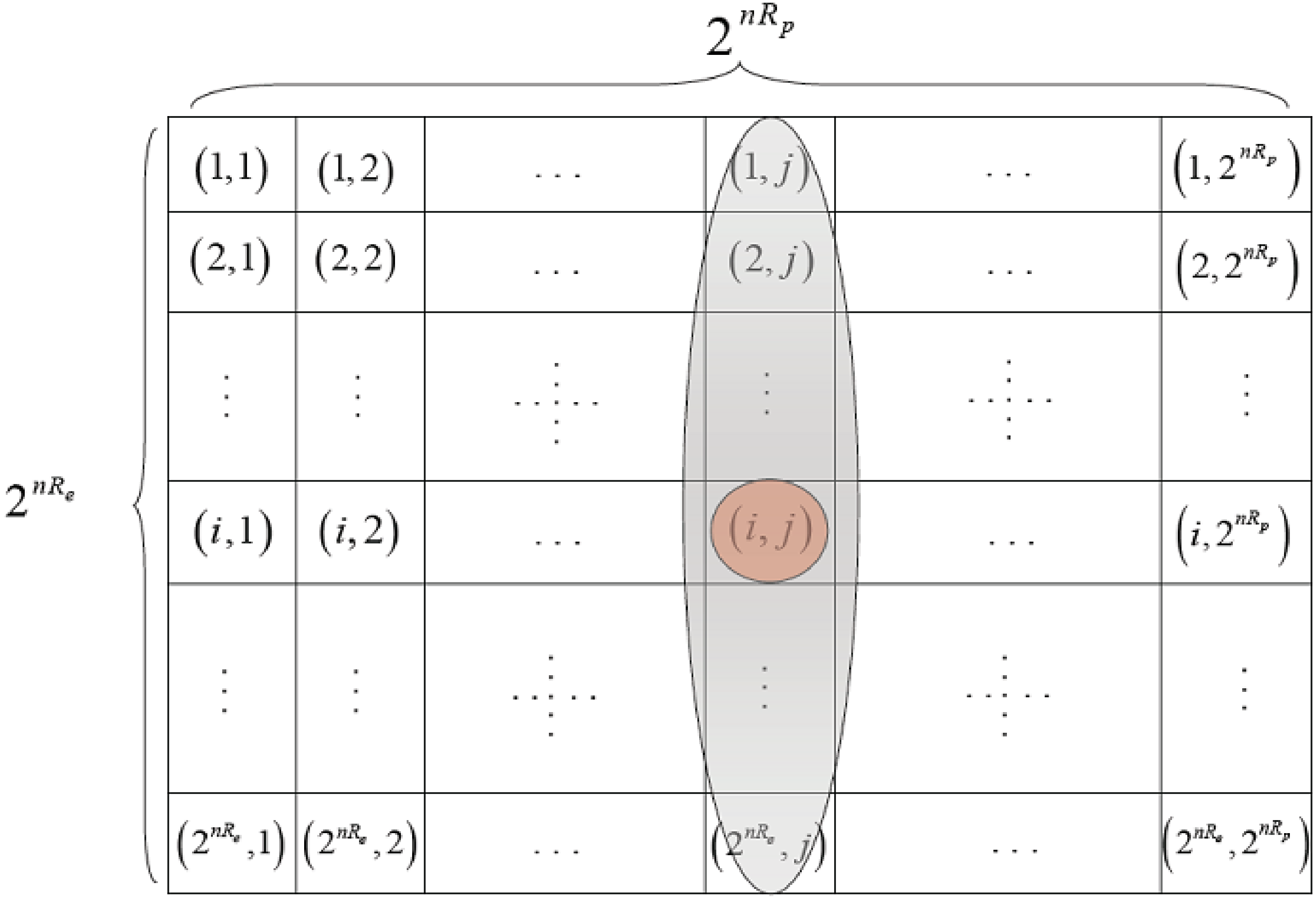
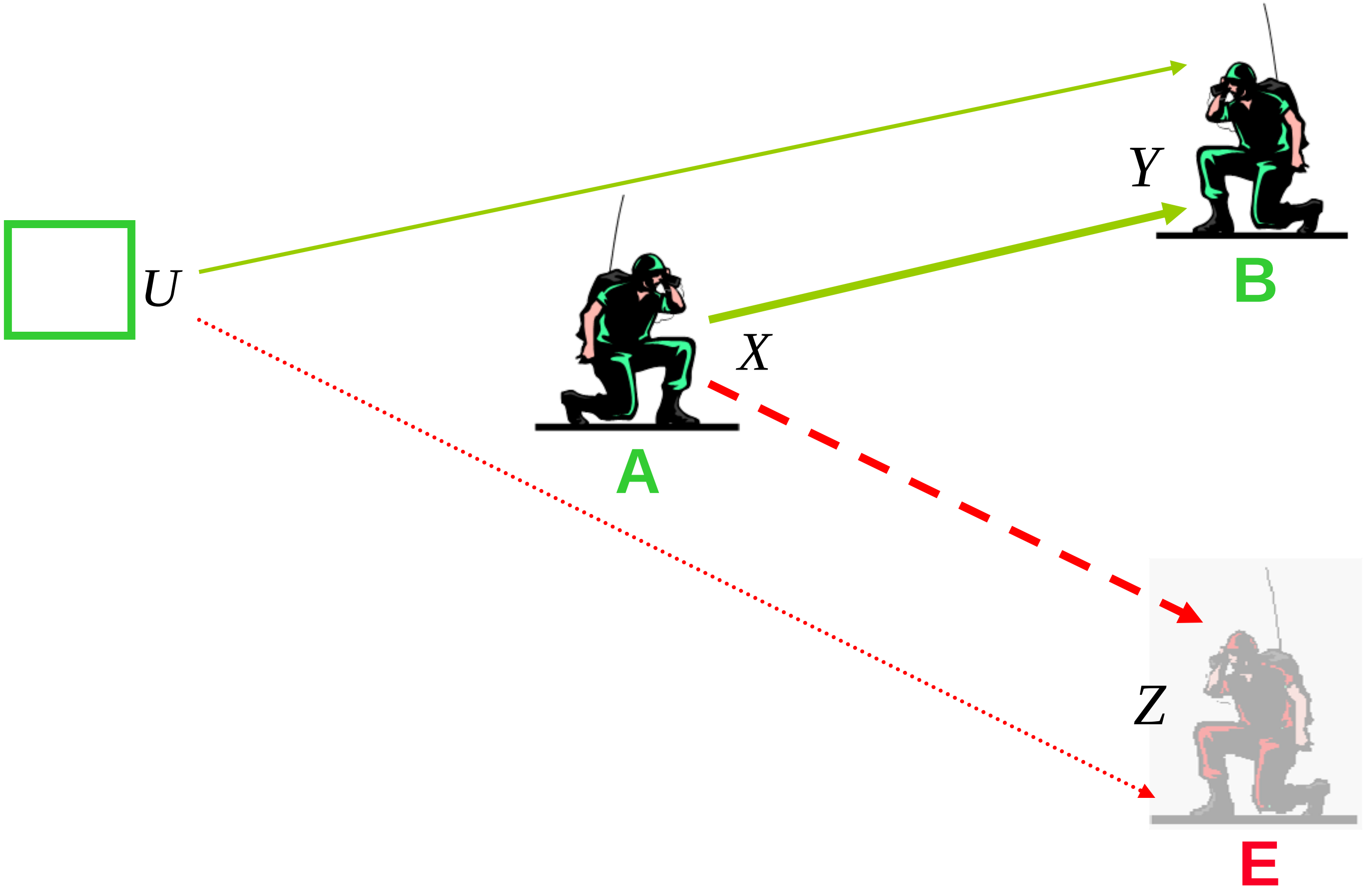
Main Tools: Stochastic Encoding



$(1,1)$	$(1,2)$	$\cdots$	$(1,j)$	$\cdots$	$(1,2^{nR_p})$
$(2,1)$	$(2,2)$	$\cdots$	$(2,j)$	$\cdots$	$(2,2^{nR_p})$
$\vdots$	$\vdots$	$\cdots\vdots\cdots$	$\vdots$	$\cdots\vdots\cdots$	$\vdots$
$(i,1)$	$(i,2)$	$\cdots$	(i,j)	$\cdots$	$(i,2^{nR_p})$
$\vdots$	$\vdots$	$\cdots\vdots\cdots$	$\vdots$	$\cdots\vdots\cdots$	$\vdots$
$(2^{nR_e},1)$	$(2^{nR_e},2)$	$\cdots$	$(2^{nR_e},j)$	$\cdots$	$(2^{nR_e},2^{nR_p})$

$$R_e = I(X;Y) - I(X;Z), \quad R_p = I(X;Z)$$

Main Tools: Channel Pre-fixing



- Perfect secrecy capacity: $C = \max \; I(U;Y) - I(U;Z)$

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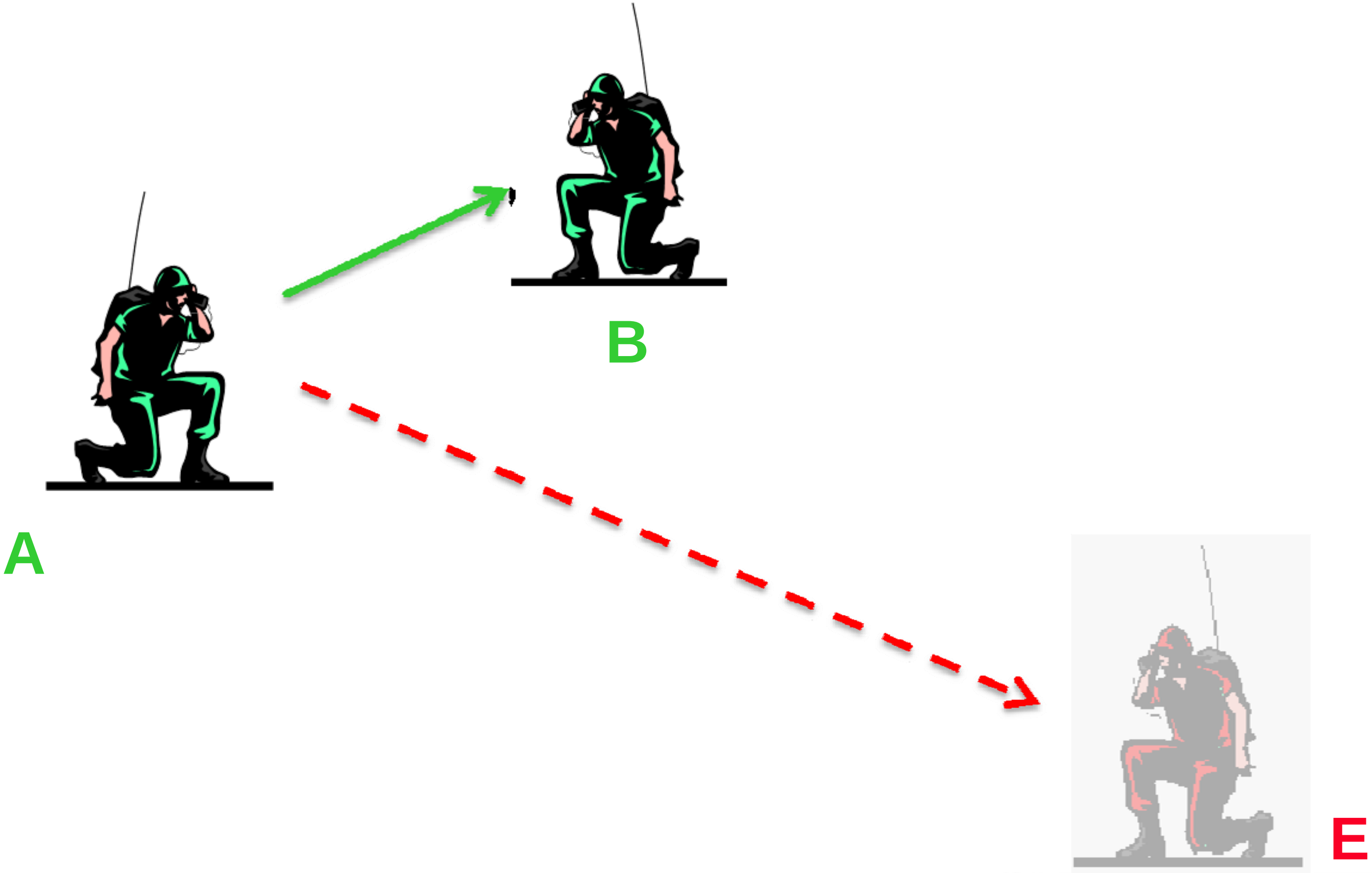
Simple Illustrative Example: Stochastic Encoding

Bob has a better (less noisy) channel than Eve.



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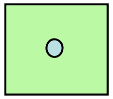
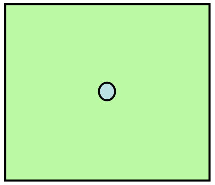
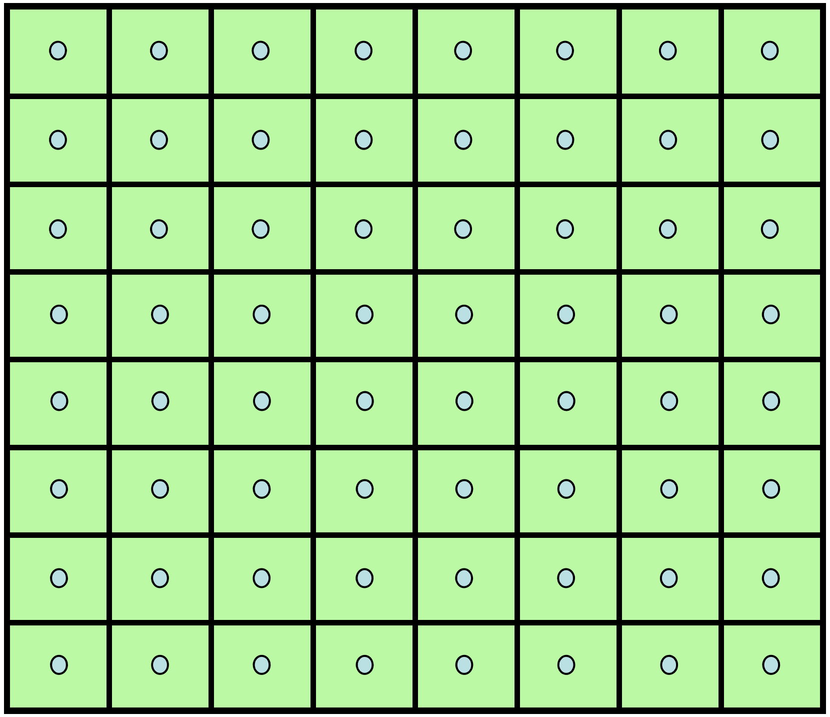
Bob’s noise



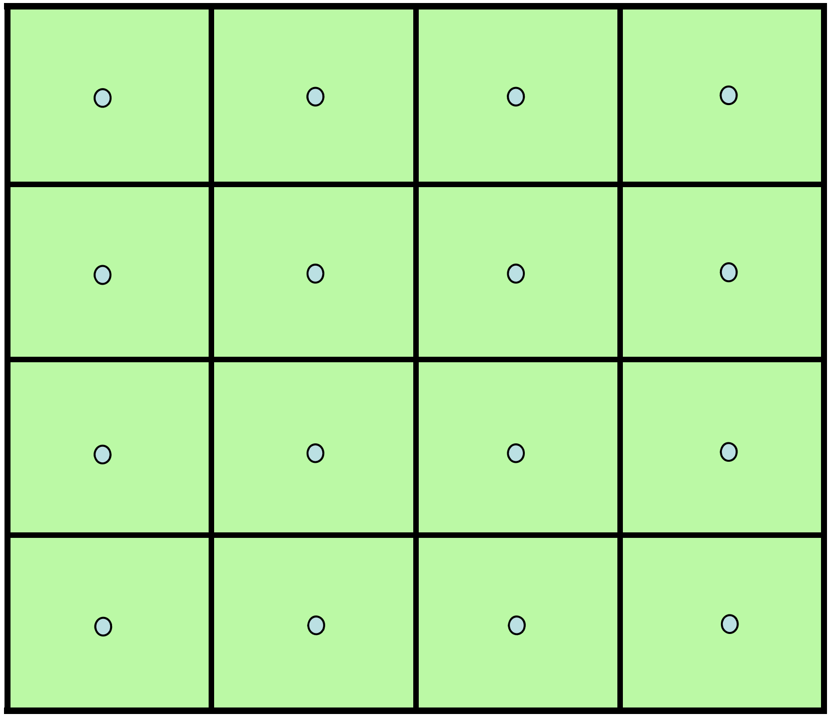
Eve’s noise



Bob’s constellation



Eve’s constellation

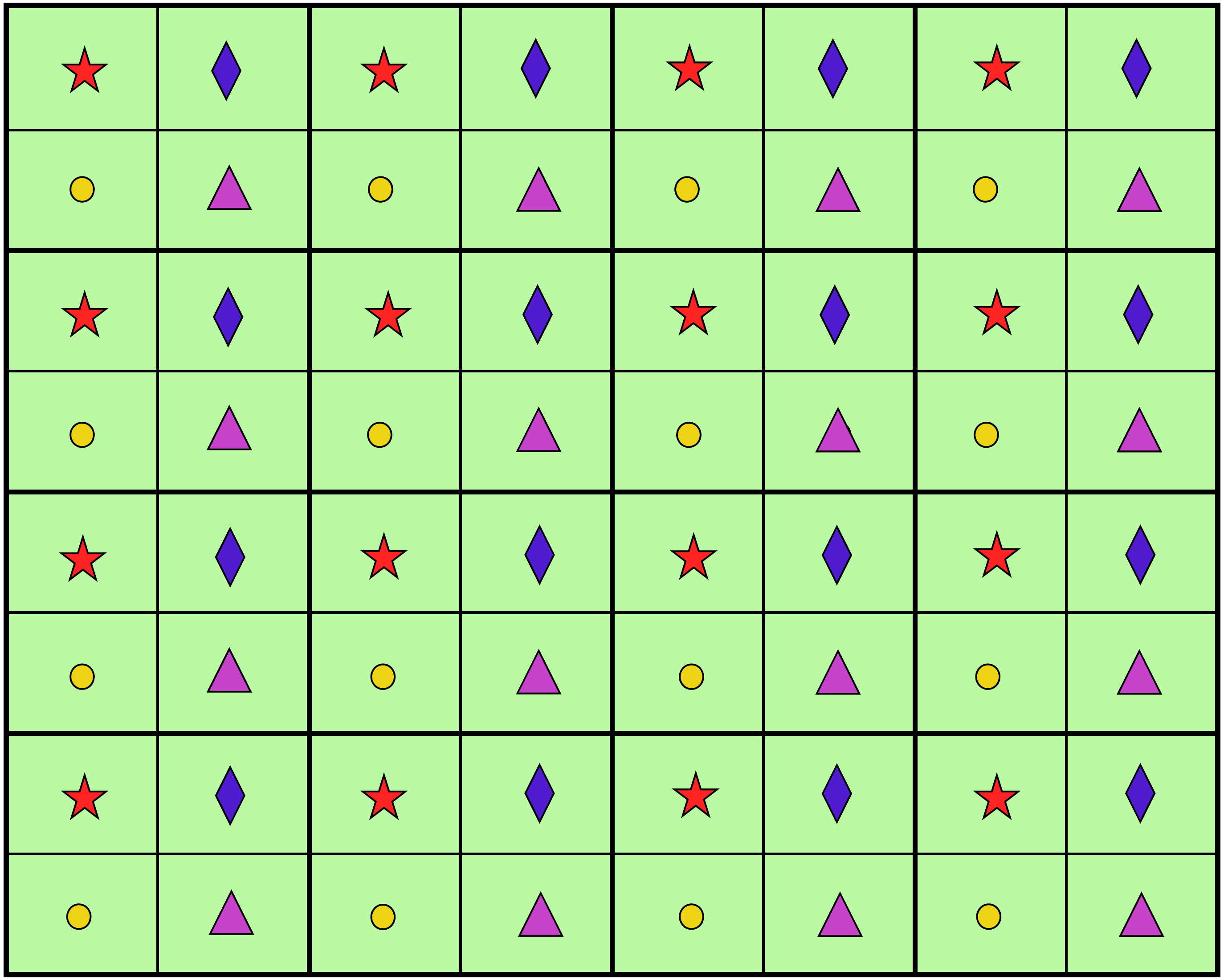


$$C_B = \log_2 64 = 6 \text{ b/s}$$

$$C_E = \log_2 16 = 4 \text{ b/s}$$

$$C_s = C_B - C_E = 2 \text{ b/s}$$

Divide Bob’s constellation into 4 subsets.



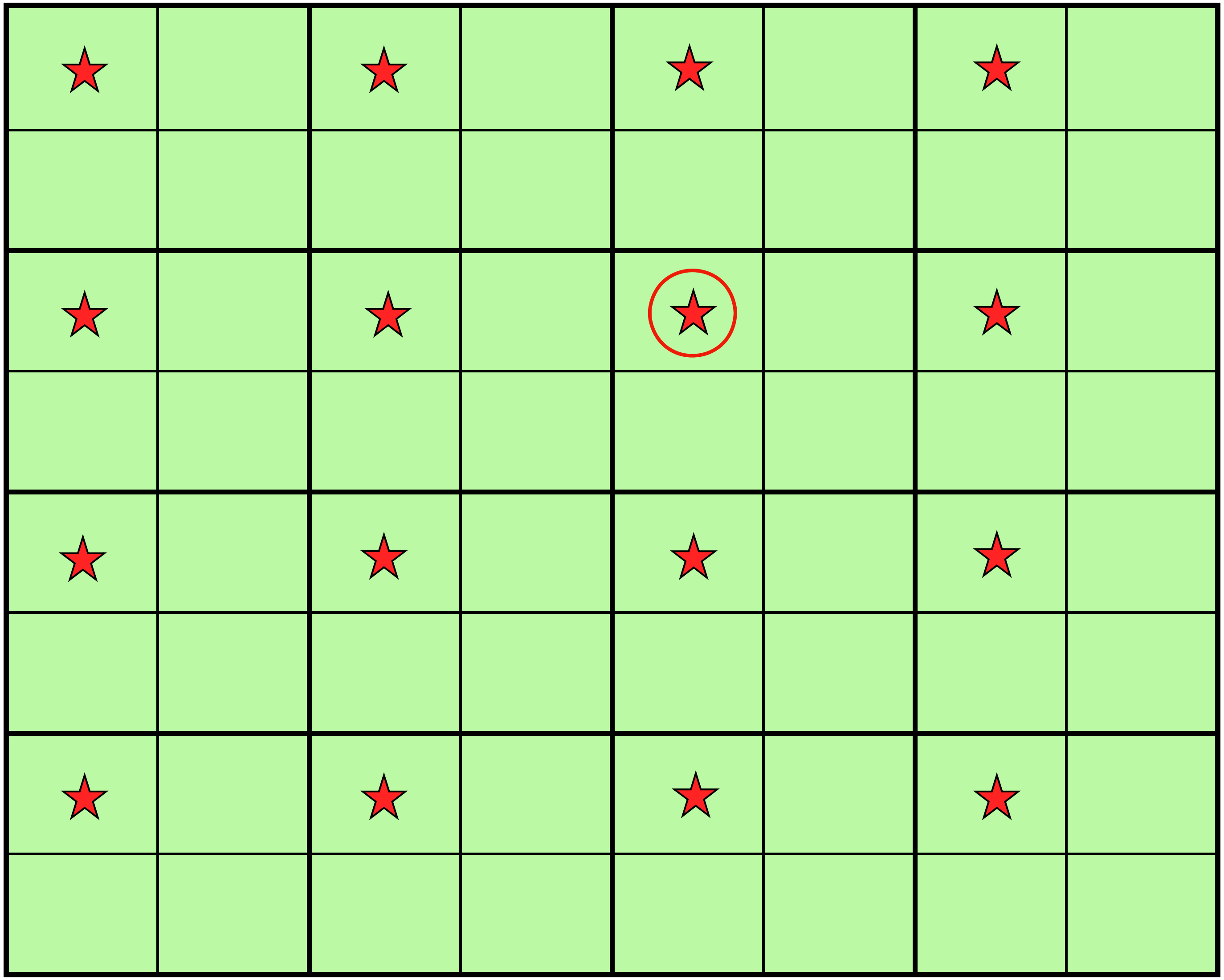
● Message 1

▲ Message 2

◆ Message 3

★ Message 4

All red stars denote the same message. Pick one randomly.



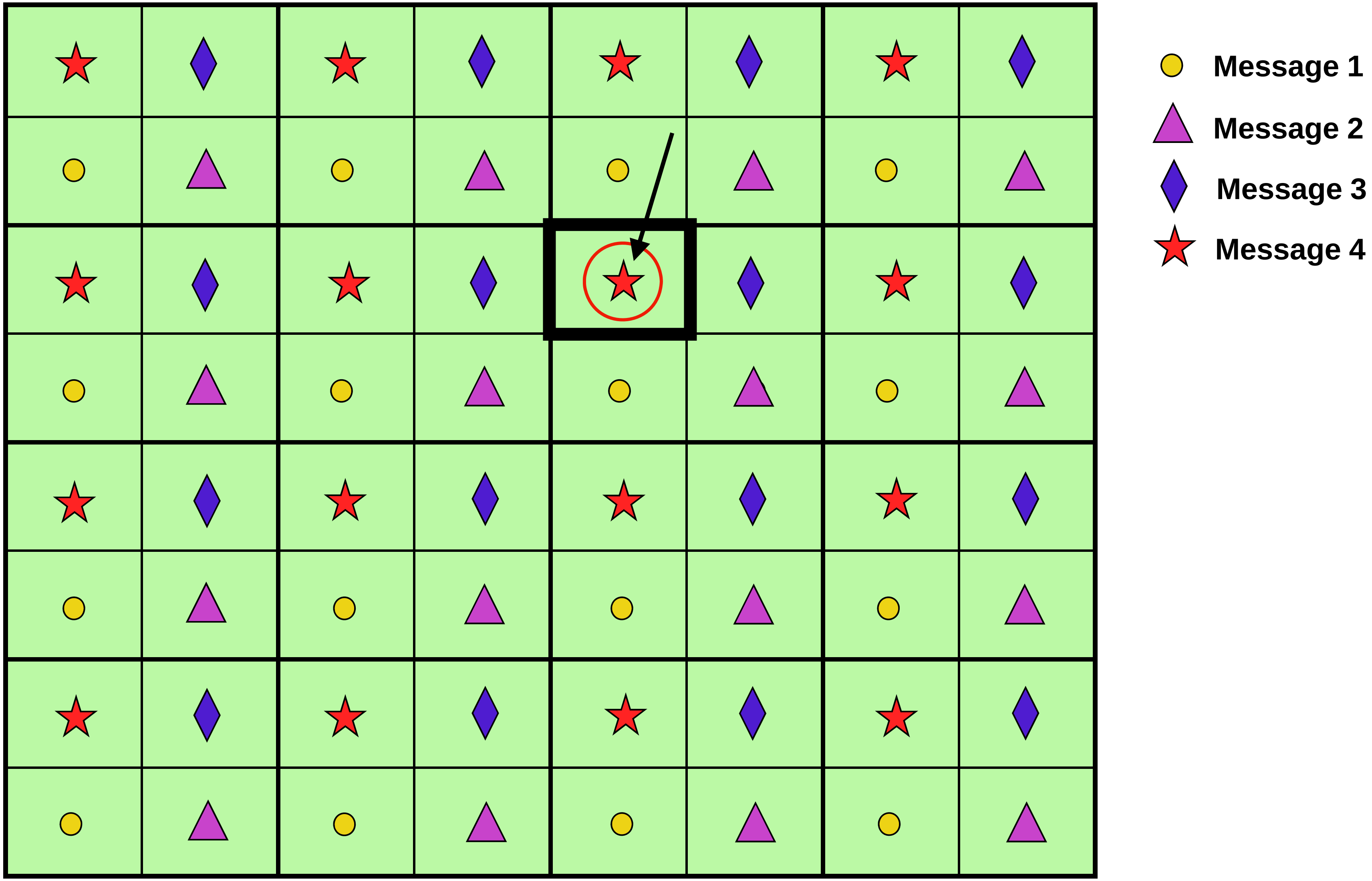
● Message 1

▲ Message 2

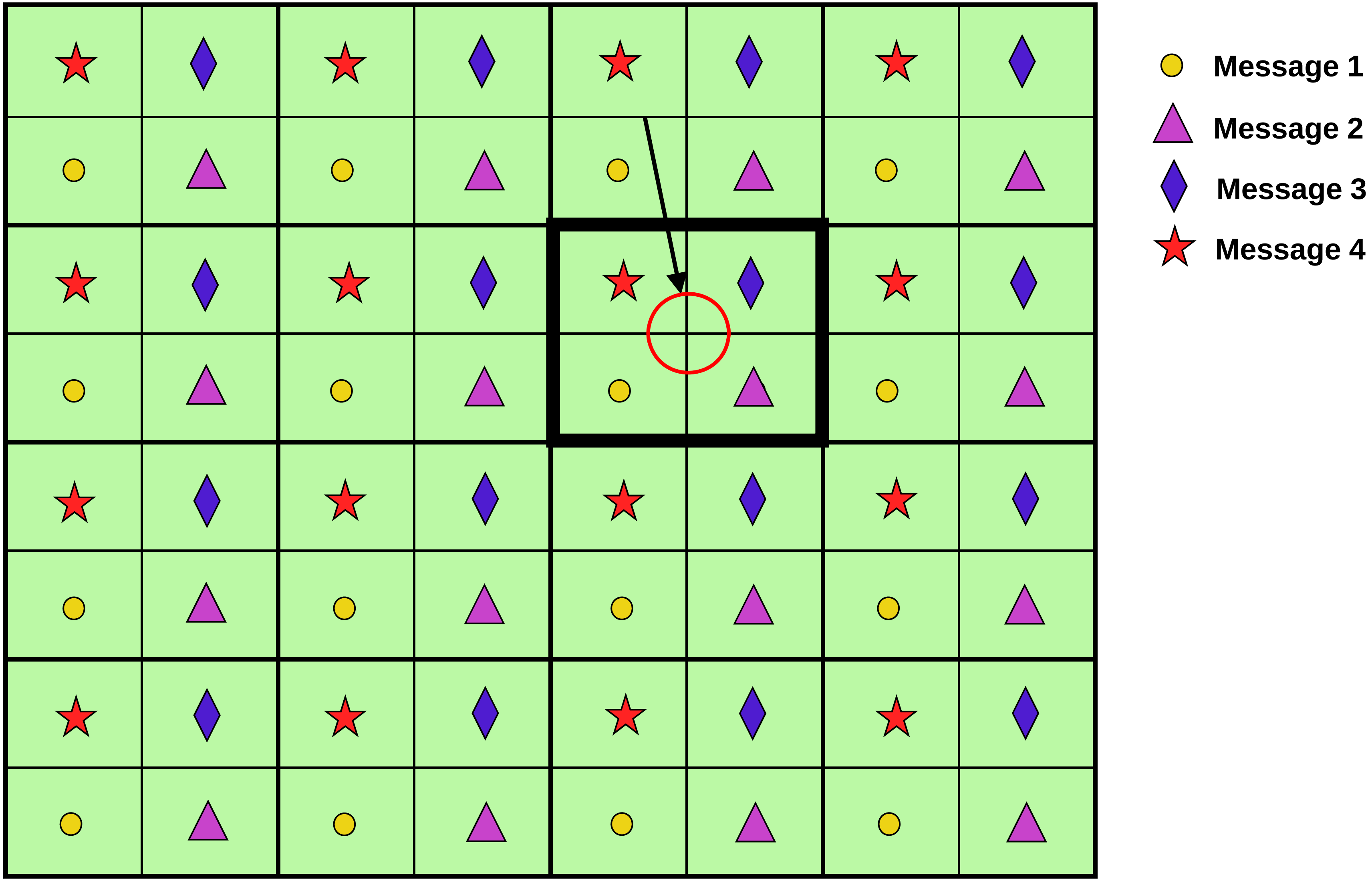
◆ Message 3

★ Message 4

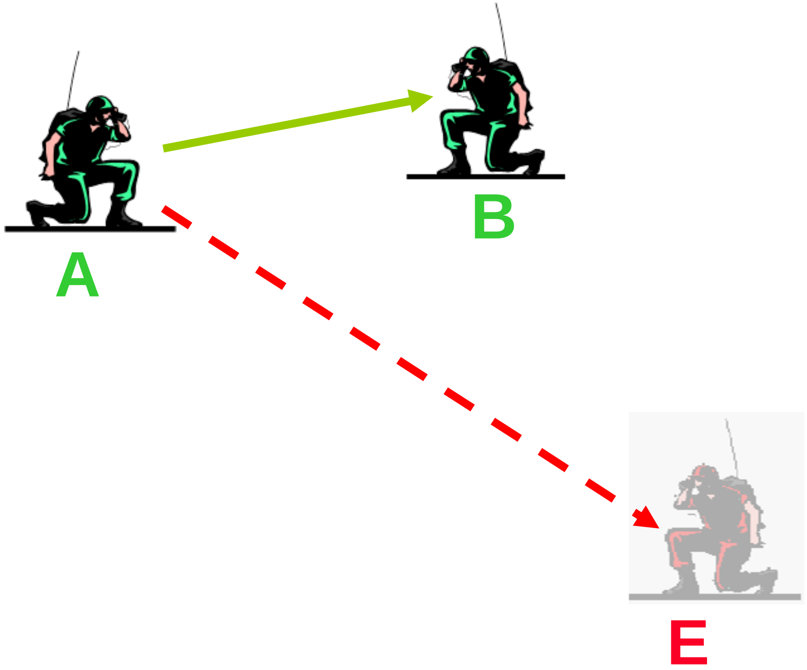
Bob can decode the message reliably.



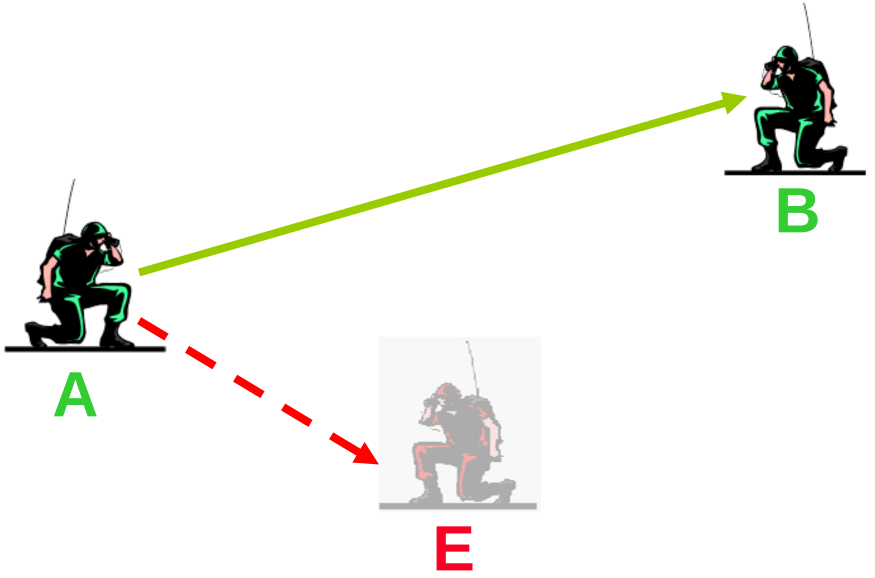
For Eve, all 4 messages are equally-likely.



Caveat: Need Channel Advantage



positive secure capacity



zero secure capacity

Two Recurring Themes:

1) Creating advantage for the good guys:

- □ computational advantage (crypto)
- □ knowledge advantage (spread spectrum)
- □ channel advantage (physical layer security)

2) Exhausting the capabilities of the bad guys:

- □ exhausting computational power (crypto)
- □ exhausting searching power (spread spectrum)
- □ exhausting decoding capability (physical layer security)

Obvious Applications with Natural Channel Advantage:

1) Near Field Communications

2) Medical Communications

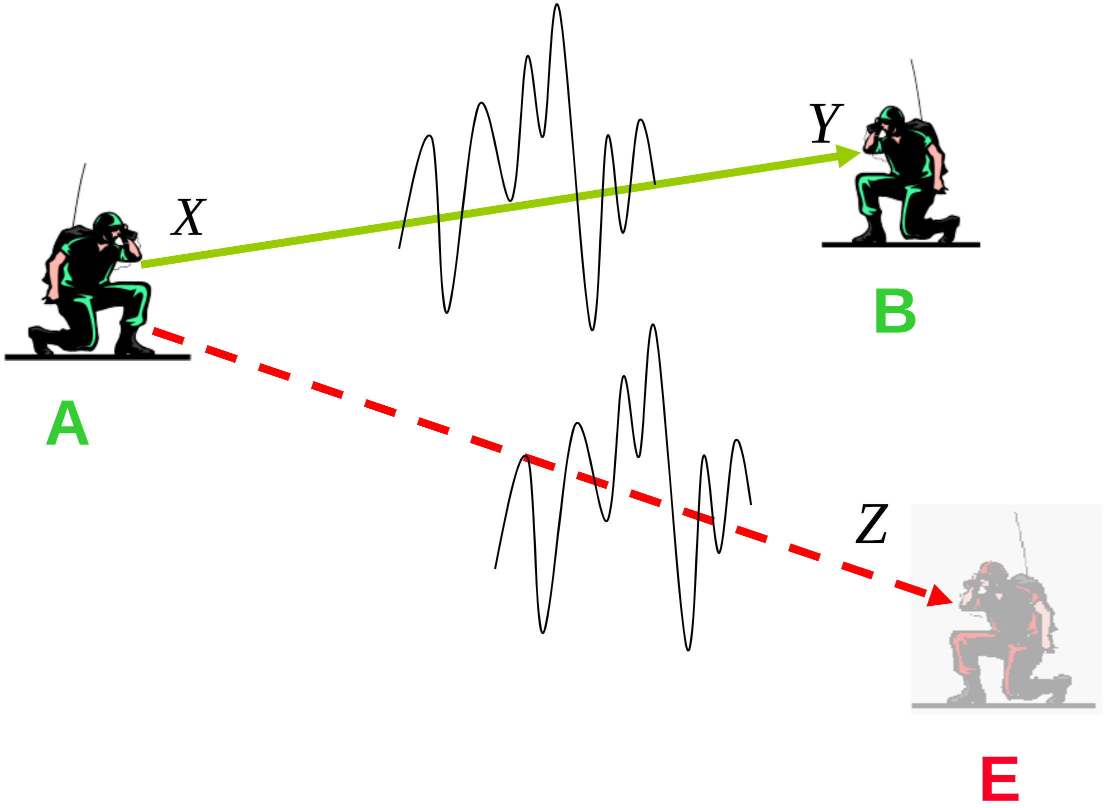
3) Military/Civilian Green Zones

Former Republican Palace, Bagdad, Iraq

Creating Channel Advantage

Exploiting channel variations (fading)

Opportunistic transmissions



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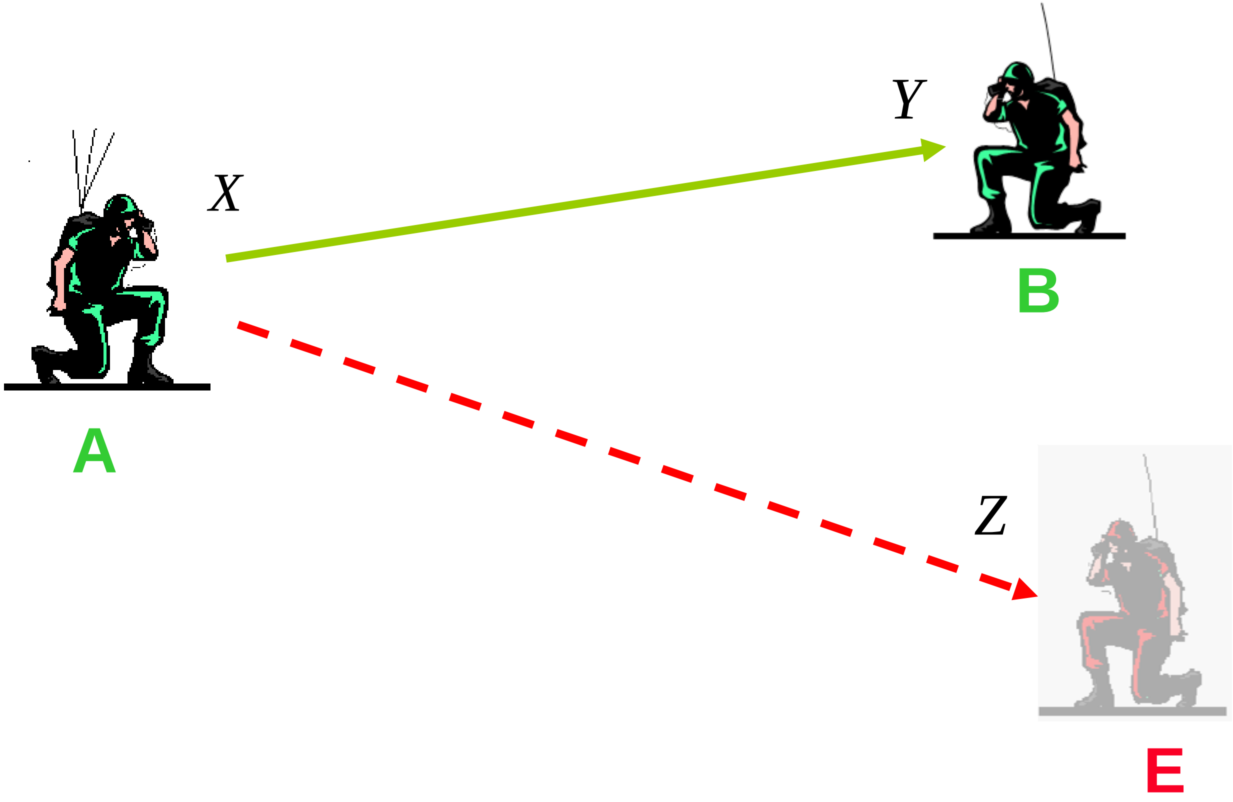
Creating Channel Advantage

Use of multiple antennas

Spatial diversity



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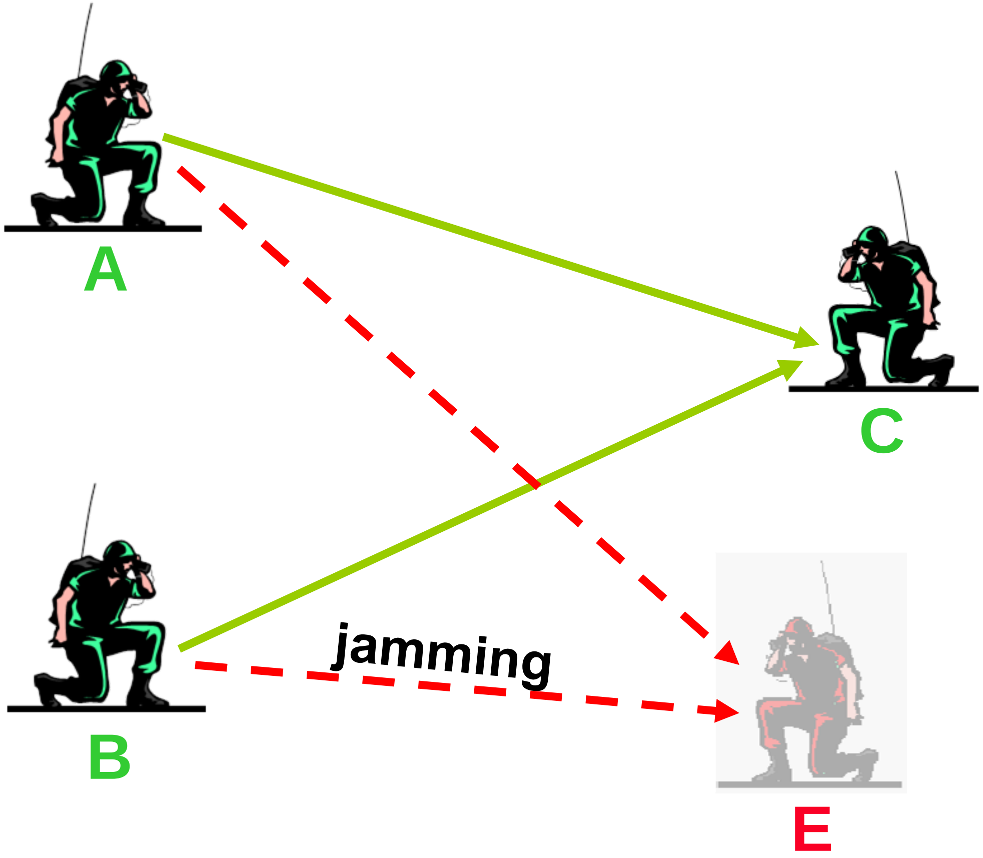
Cooperation for Security

Cooperation using (or without using) overheard signals.



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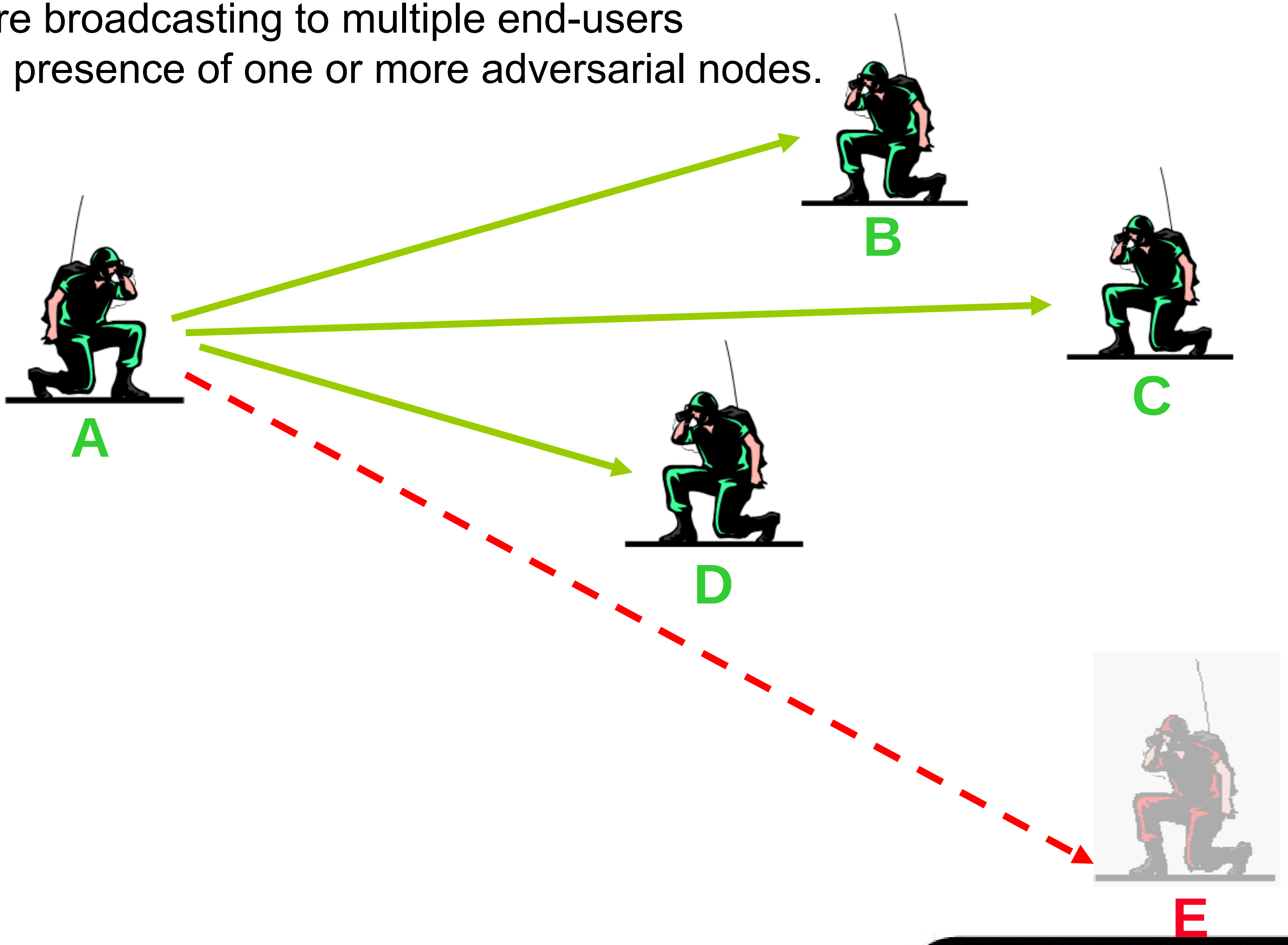
Secure Broadcasting

Secure broadcasting to multiple end-users
in the presence of one or more adversarial nodes.



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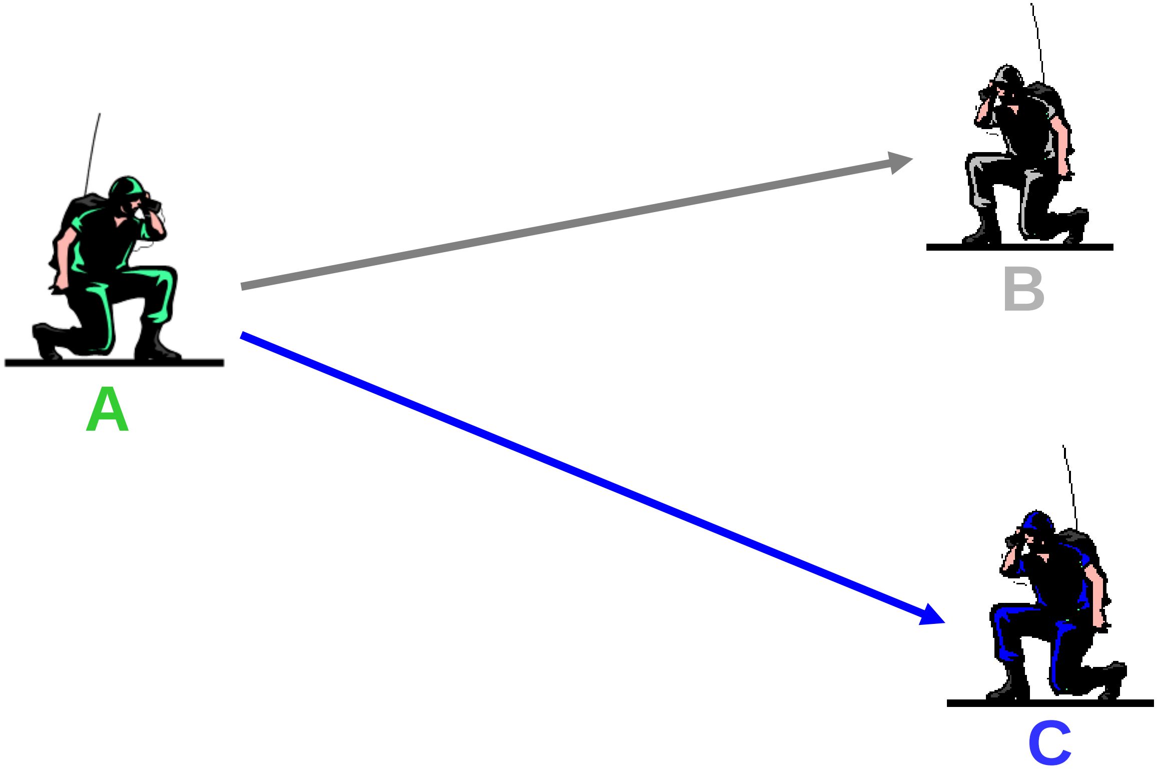
Varying Security Clearance Levels

Both B and C are friendly nodes, but they have different security clearances.

We can send secure information to B (un-decodable by C), and visa versa.



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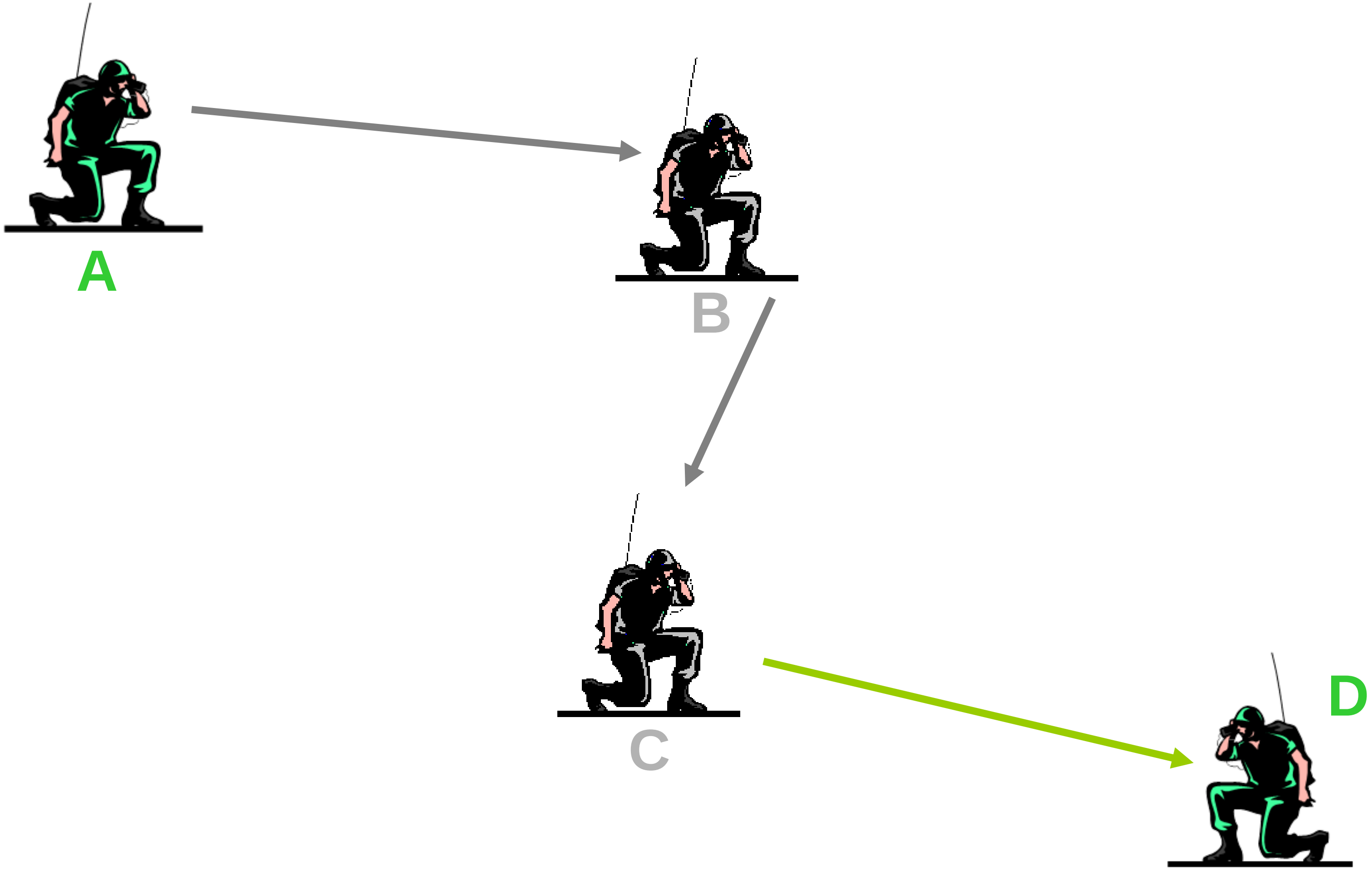
Untrusted (but Friendly) Relays

Nodes B and C relay information without being able to decode its content.



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Conclusions

Physical-layer security is powerful:

- ❑ no limitation on adversary’s computation power or available information
- ❑ **provable, quantifiable** (bits/sec/hertz) and **implementable**

Many open problems:

- ❑ explicit code constructions
- ❑ implementing in the existing infrastructure
- ❑ better modeling adversary – e.g., active adversaries
- ❑ robust modeling of adversary – e.g., no CSI
- ❑ combining with cryptography
- ❑ …

Contact me with questions/comments/ideas:

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