Wireless Security gets Physical

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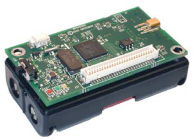
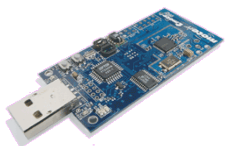
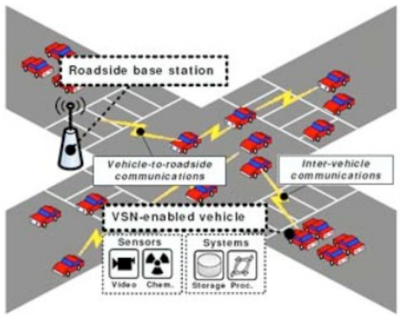
Age of wireless communication ...

- Mesh Networks (Inter and Inter-home)
- Vehicular Networks
- Sensor/Actuator Networks
- Networks of Robots
- Underwater Networks
- Personal Area (body) Networks
- Satellite Networks (NASA 2007)
- Cellular, WiFi, ..

- Digitalization of the physical world: every physical object will have a digital representation
- "Internet of things" communication with every object/device

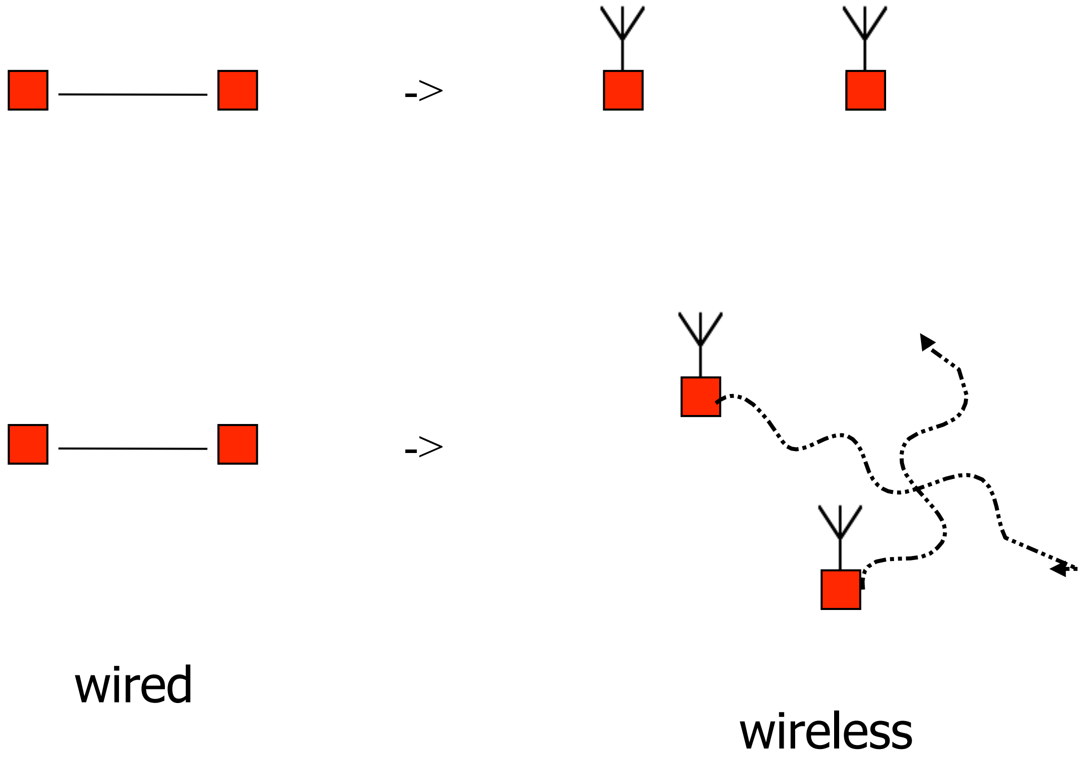






What changed?

- Physical layer
- Physical locations of devices

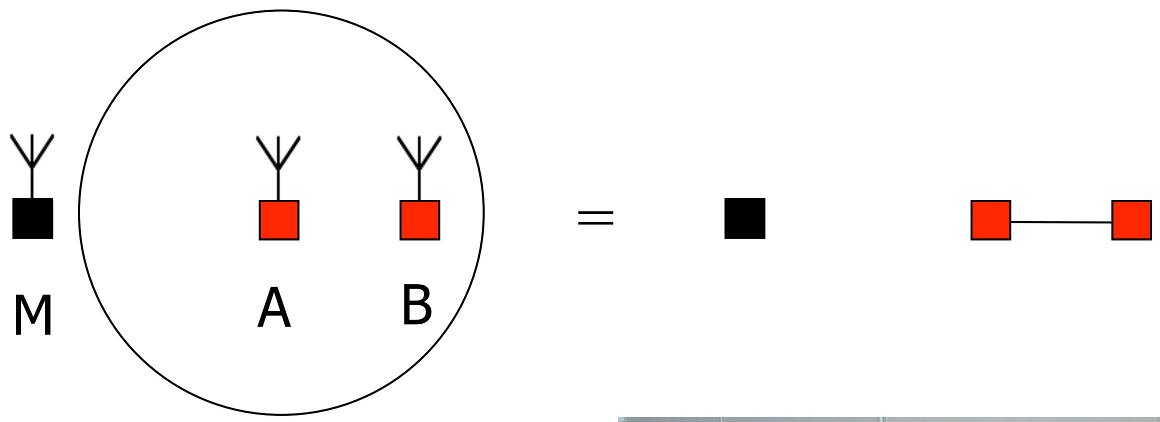


The change for worse or for better?

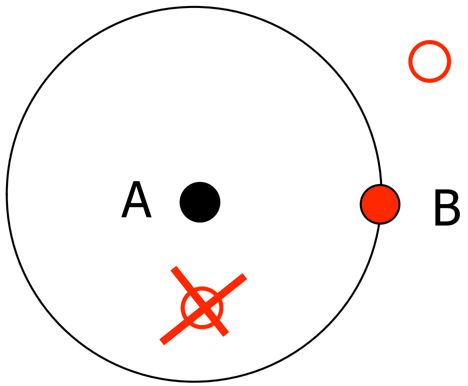
- Physical layer
  - "New" risks: insertion, jamming, eavesdropping, ...
  - Opportunities: broadcast, localization, device identification, ...

- Physical locations of devices
  - New problems: how do we (securely) localize devices,
    track
    them, how do we verify their claimed locations?, location privacy, ..
  - Opportunities: using location information to secure even basic
    net
    w
    ork services (key establishment), access control, data gathering ...

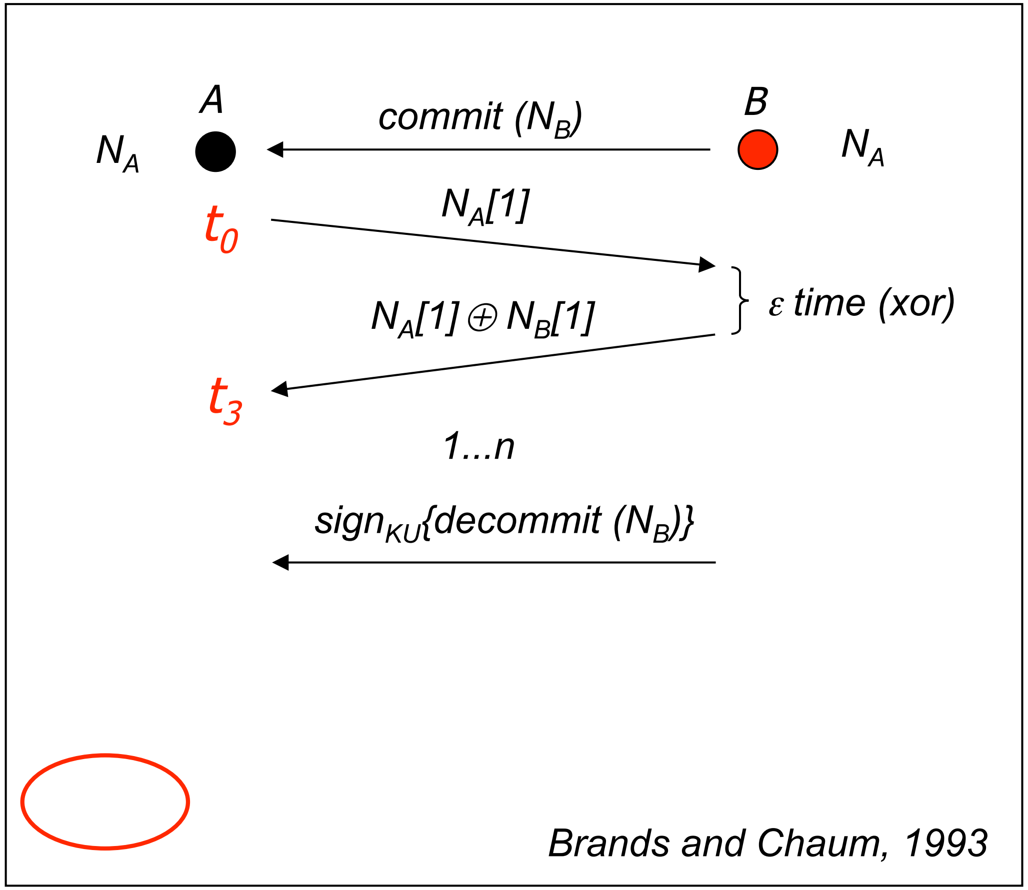
A simple example



Example: Distance bounding (Verification)



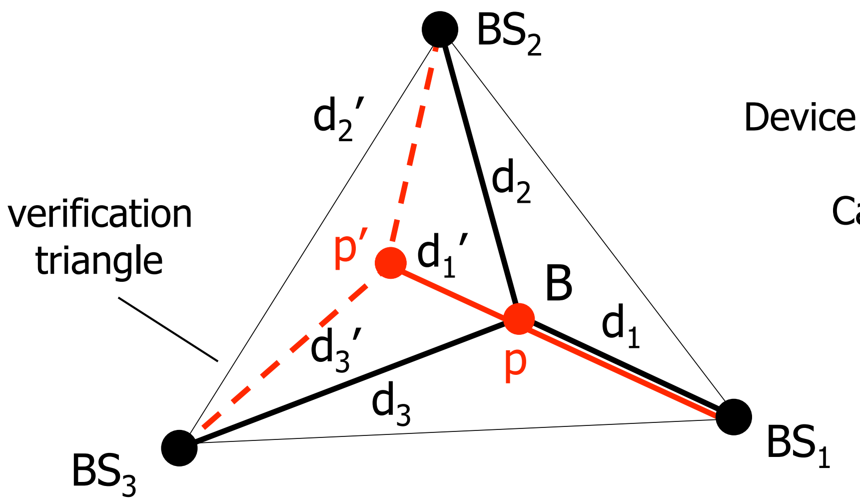
B node cannot pretend to be closer than it really is, only further !!!



Many variants and implementations followed.

From Distance to Location Verification

- Verifiable Multilateration
  - prevent distance reduction attacks (distance bounding)
  - multilateration using distance bounding within a verification triangle



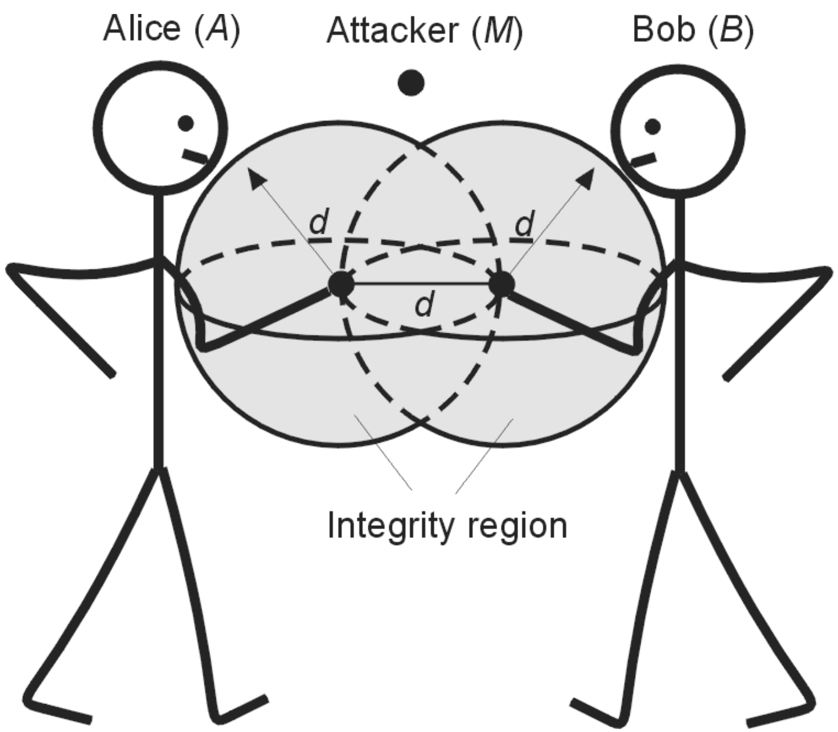
d = distance bound from BS to B

Device cannot cheat on its location within the triangle !!!

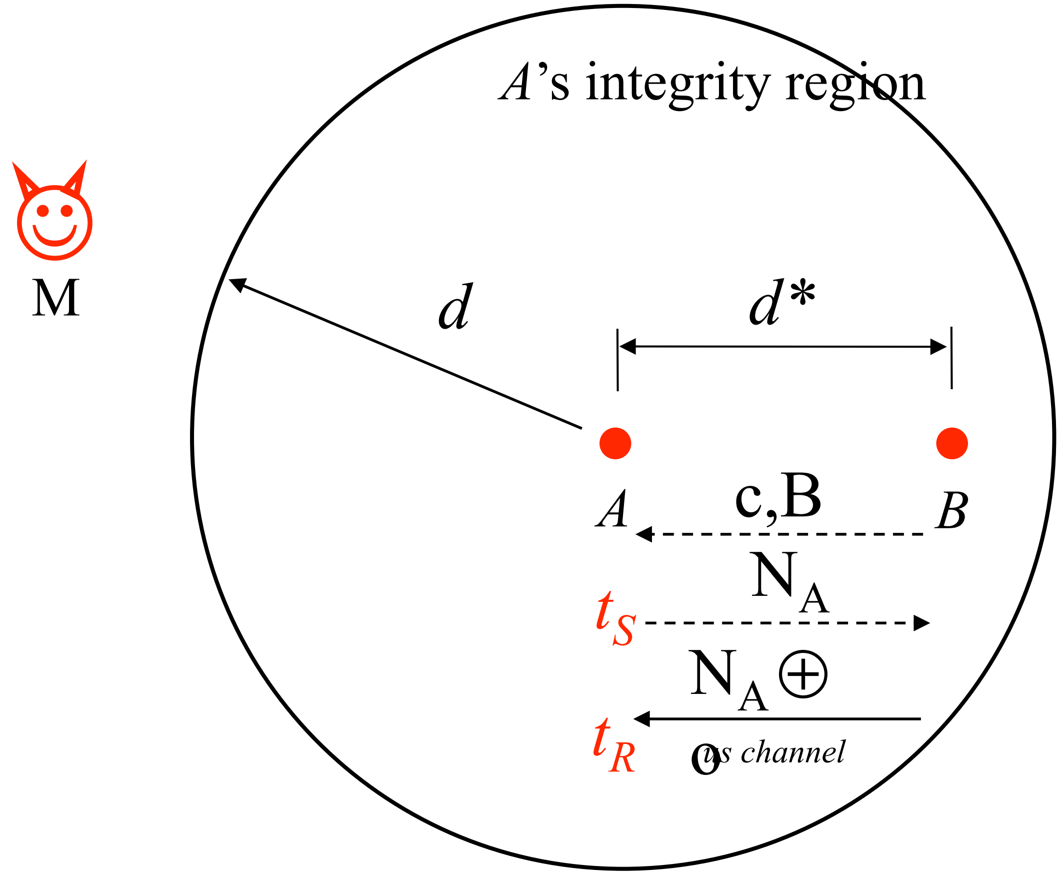
Can only pretend to be outside of the triangle.

From Distance Verification to Message Auth. (I)

- Main idea:
  - bind messages to distances &
  - keep your friends close
- Authentication through (attacker) absence awareness
  - No reliance on propagation assumptions



From Distance Verification to Message Auth. (II)



$(c,o) = commit(m=g^b)$

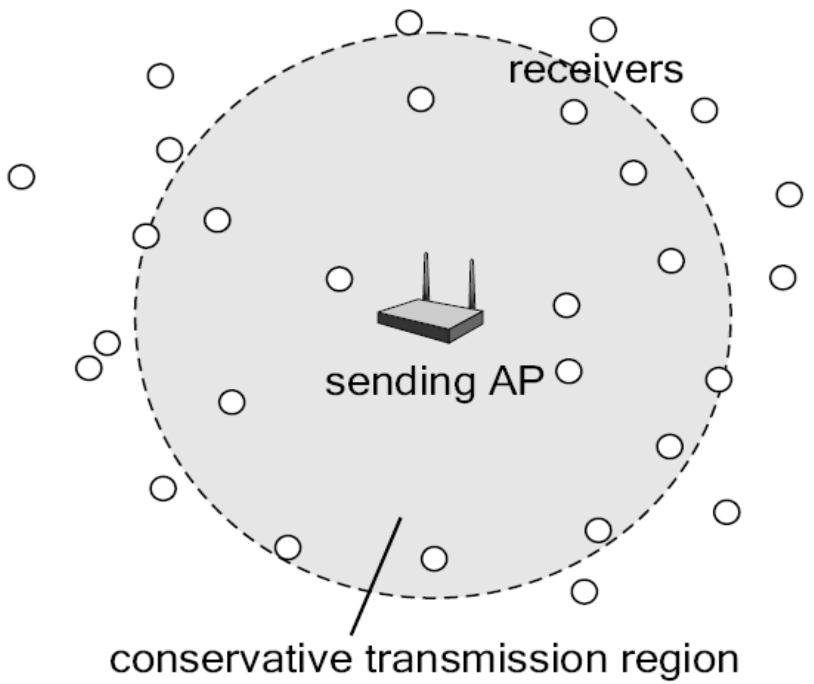
A: $d^*=(t_R-t_S)v_{sound}$

verify that there are no devices at any distance *d** << d**

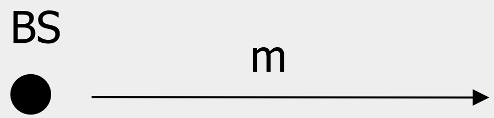
Integrity regions prevent MITM attacks e.g.,on DH protocol.

Authentication through presence awareness

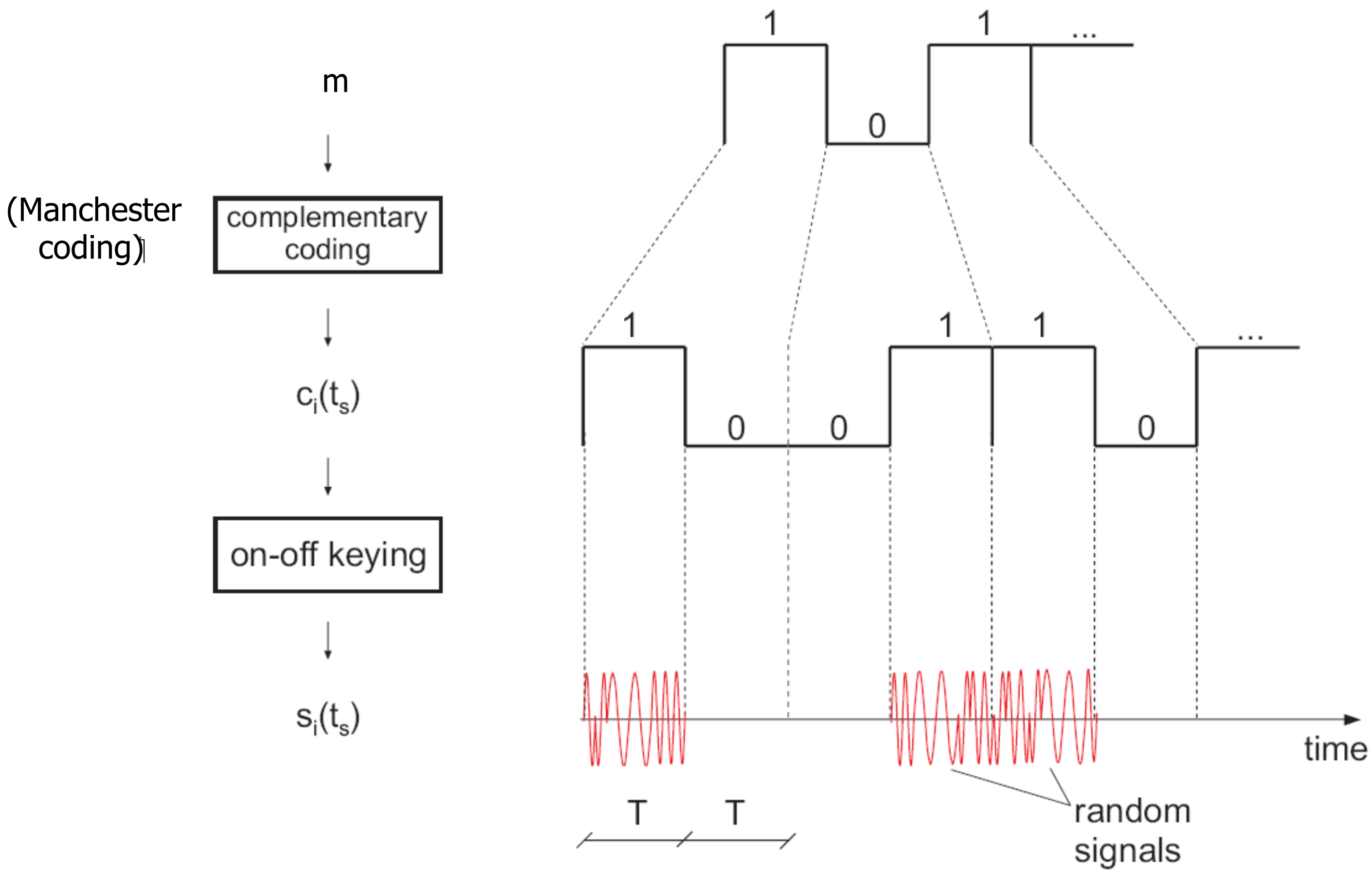
- Main idea:
  - Use special message encoding (Integrity coding)
  - Receiver(s) know that they are in range of the sender (presence awareness)



Integrity Coding



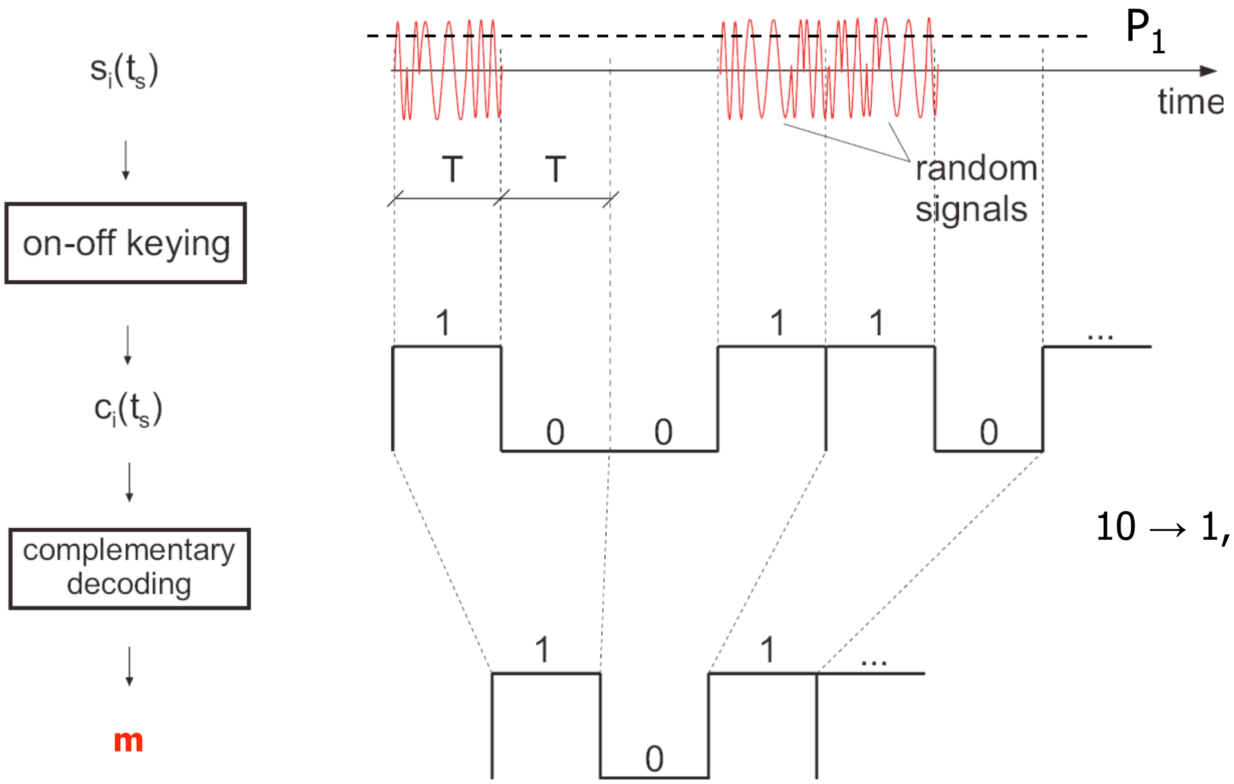
- k-bit Beacon1 spread to 2k bits (1->10, 0->01) (H(m) = k/2)
- transmitted using on-off keying (each "1" is a fresh random signal)



H(m) = the number of bits "1" in m (Hamming weight)

Integrity Decoding

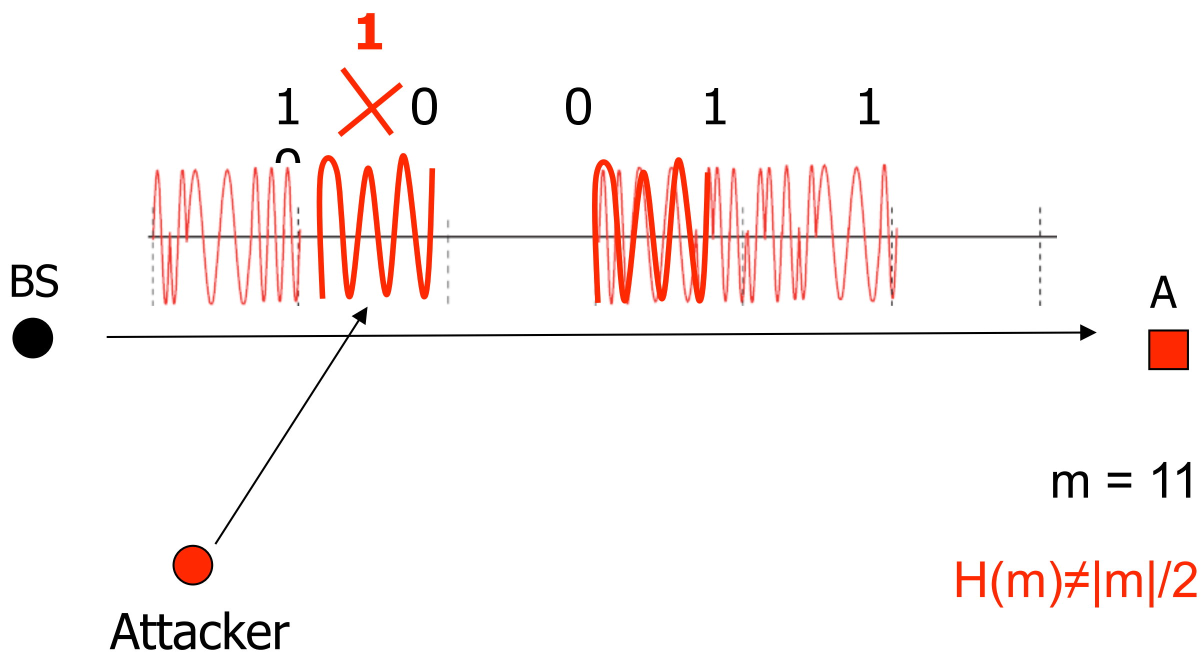
- Beacon detection:
  - presence of signal ($>P_1$) during T on CH1 interpreted as "1"
  - absence of signal ($<P_0$) during T on CH1 interpreted as "0"
- Beacon integrity and authenticity verification
  - IF H(m)=|m|/2 THEN "m" was not modified in transmission



10 → 1, 01 → 0 (Manchester)

Integrity Coding Analysis

- Message Hamming weight is a public parameter H(m)=|m|/2=2
- Attacker can change 0 → 1 and NOT 1 → 0 (except with ε)
- A can detect all modifications of the message on channel CH1
- A knows that BS is transmitting on CH1



m = 110110

H(m)≠|m|/2 => m is invalid

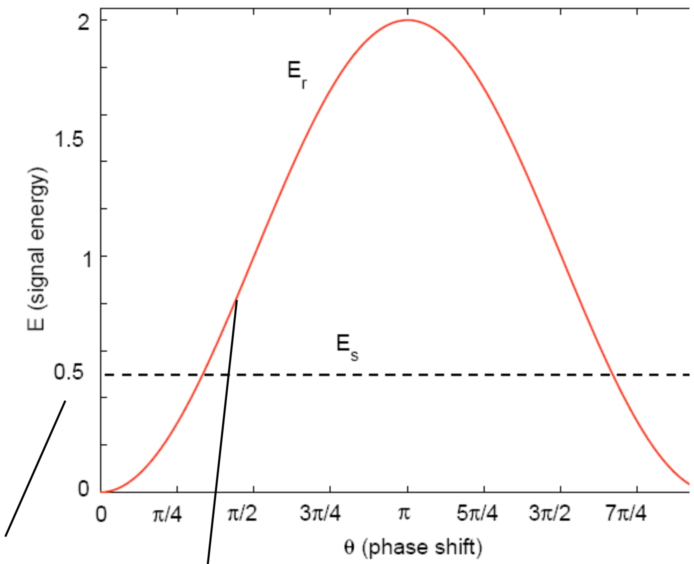
IC: Anti-blocking property of the wireless channel

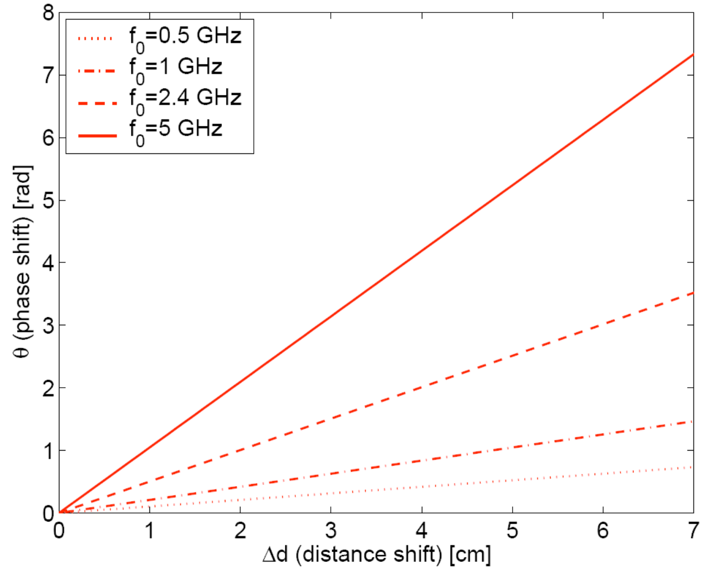
$0 \rightarrow 1$

- phase shift

$$\underbrace{r(t)}_{\text{receiver}} = \underbrace{\cos(\omega_0 t)}_{\text{sender}} - \underbrace{\cos(\omega_0 t - \theta)}_{\text{adversary}}, \text{ where } \theta \in [0, 2\pi)$$

$$E_r = \int_0^{T_s} r^2(t)dt$$
$$\approx 2T_s \sin^2\left(\frac{\theta}{2}\right)$$





original signal energy

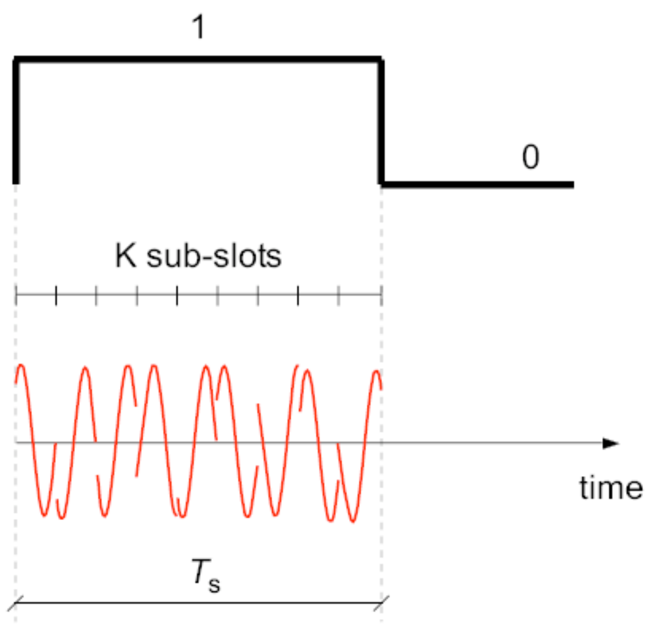
signal energy of the cumulative sender + attacker signal

error in distance estimation (by the attacker)

IC: Randomization At the Sender

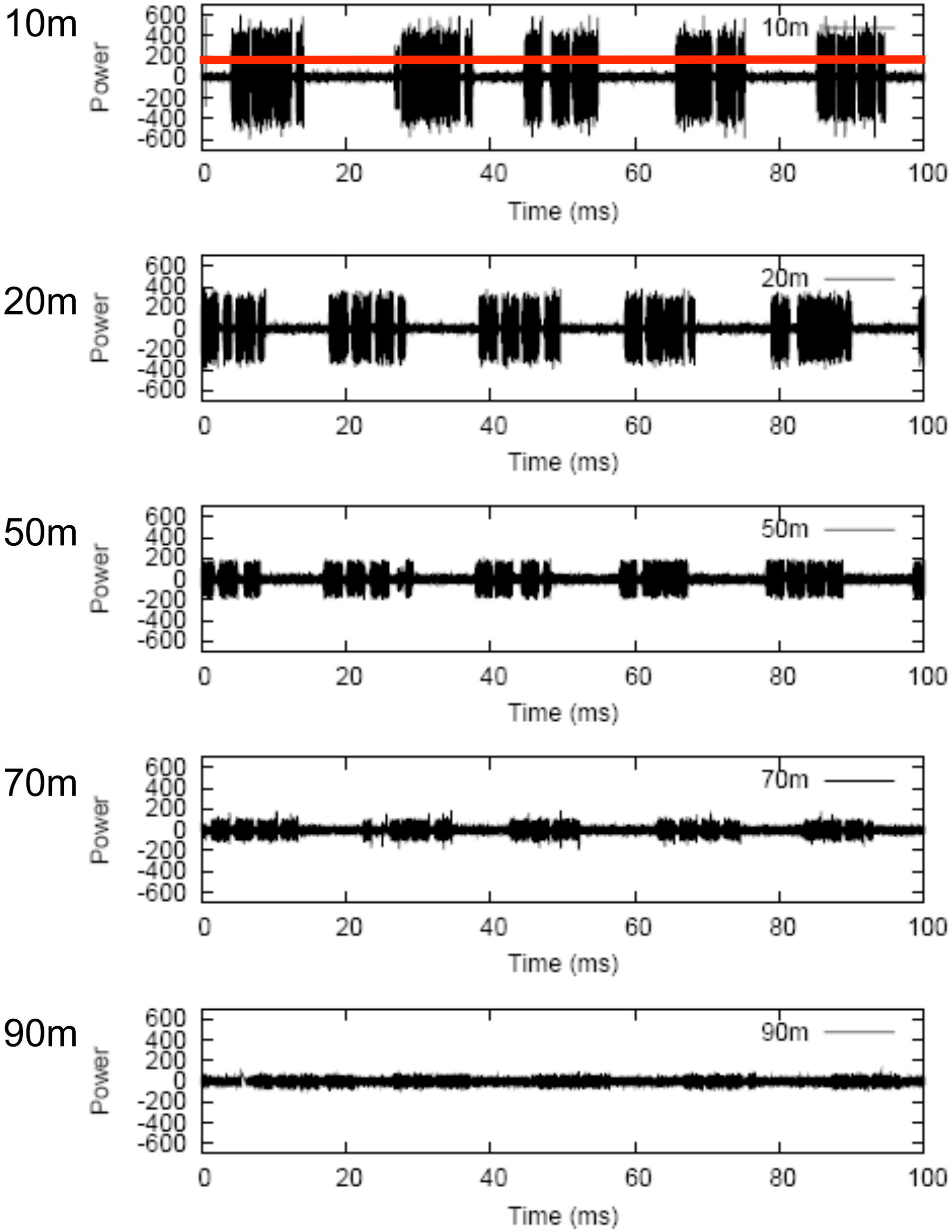
- K-slotted signal (spreading)
- Φ random (e.g., choosen uniformly from $[0,2\pi)$)

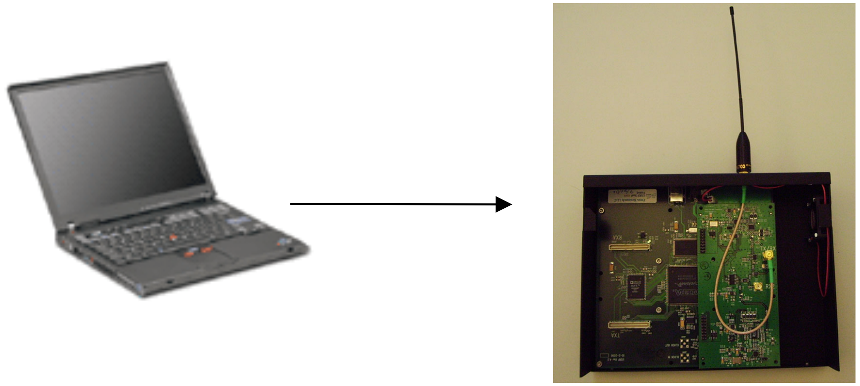
$$\underbrace{R(t)}_{\text{receiver}} = \underbrace{\cos(\omega_0 t + \Phi)}_{\text{sender}} - \underbrace{\cos(\omega_0 t - \Theta)}_{\text{adversary}}, \quad \Phi \in_U [0, 2\pi)$$



$$\mathbb{P}[K_{\text{attenuated}} \leq K_\varepsilon] \geq 1 - \varepsilon$$

Implementation





Integrity Coding: Summary

BS

- sends Integrity-coded messages (e.g., localization beacons or time-synchronization timestamps) on a designated channel

Node/User

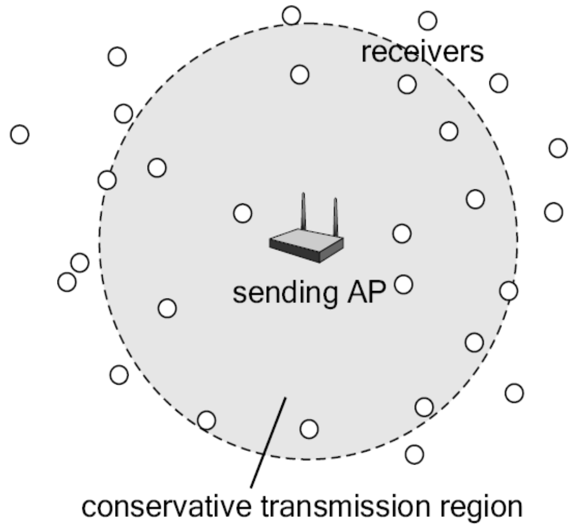
- knows the coverage area
- is aware of its presence in the covered area (e.g., ETHZ campus)

Attacks

- Overshadowing results in all 1s being received => incorrect H(m)
- Jamming results in all 1s being received => incorrect H(m)
- Replay results in an incorrect H(m)

Benefit

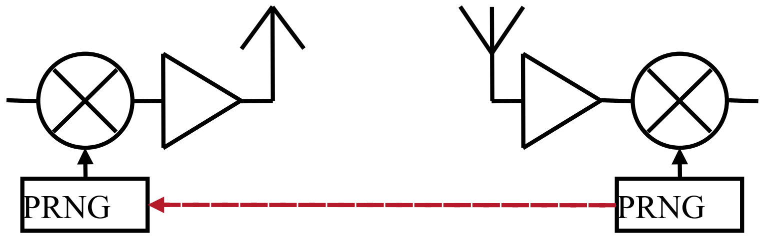
- Broadcast authentication and message integrity protection through presence awareness

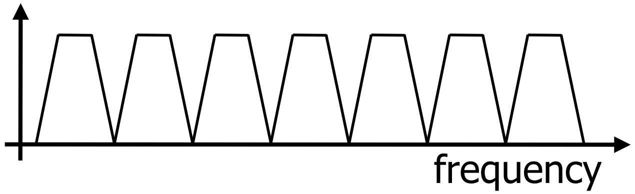


Anti-Jamming Broadcast and Key Establishment

Anti-jamming Techniques

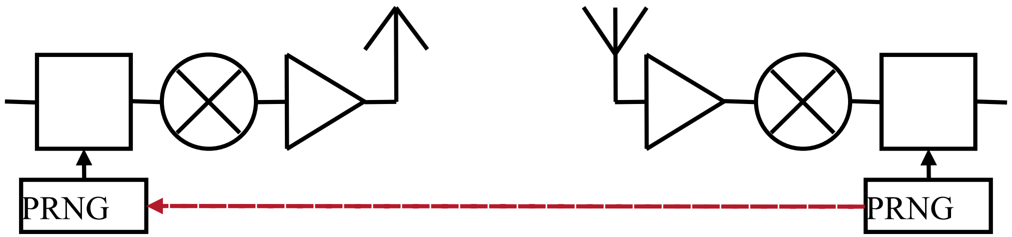
- FHSS: Frequency Hopping Spread Spectrum

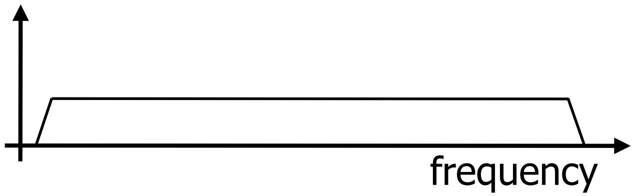




Hopping sequence (PRNG seed) must be known to the sender and receiver but not the jammer

- DSSS: Direct Sequence Spread Spectrum



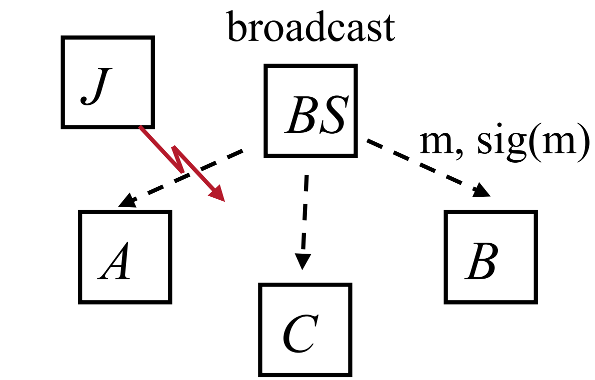


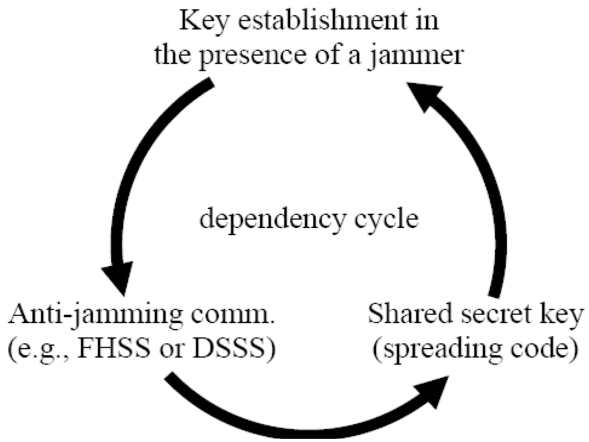
Spreading code (PRNG seed) must be known to the sender and receiver but not the jammer

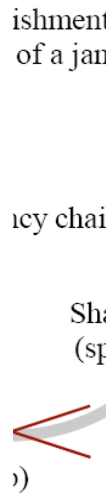
- **Common anti-jamming techniques rely on pre-shared secret codes (keys)**

Anti-jamming broadcast and key establishment

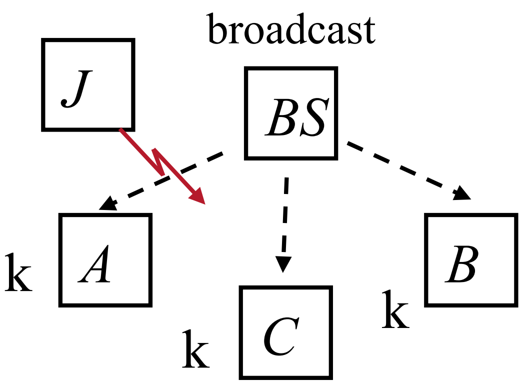
Problem: BS needs to broadcast a message to a large number of unknown receivers in an anti-jamming manner







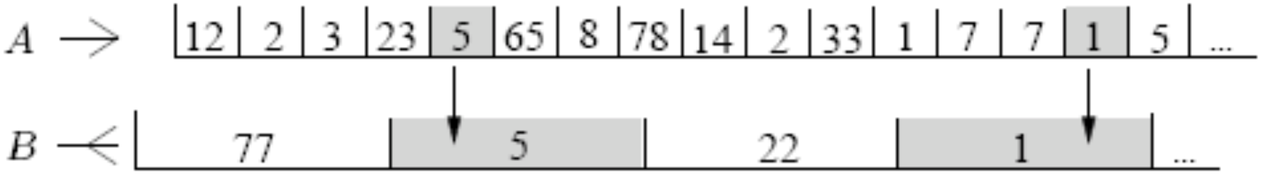
Anti-Jamming techniques rely on shared keys, but broadcasting node cannot share the same key with all recipients => dependency



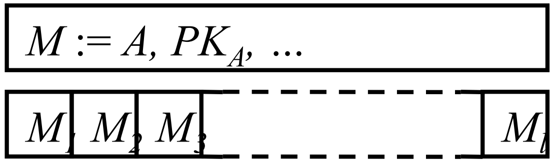
The receivers might be untrusted and/or unknown!

Jamming in Wireless networks pushes us back to pre-PK era!

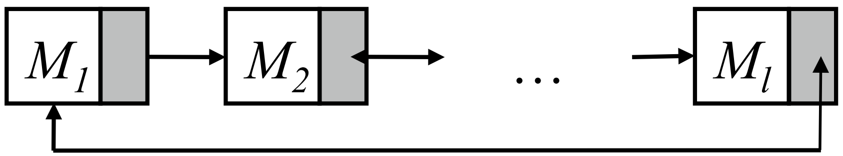
Solution: Uncoordinated Frequency Hopping



Problem: A message might be too long (contains a signature as well)
Solution: Fragment message and transmit each fragment in one slot

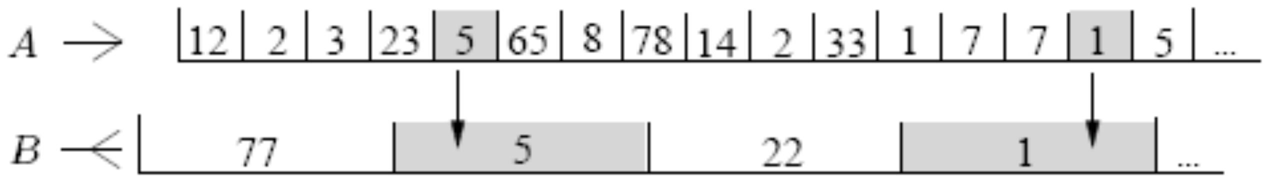


Problem: Fragments are not individually authenticated (poisoning attack)
Attacker might insert its own fragments => computationally infeasible message reconstruction.
Solution: Link fragments (e.g., using hash-links)

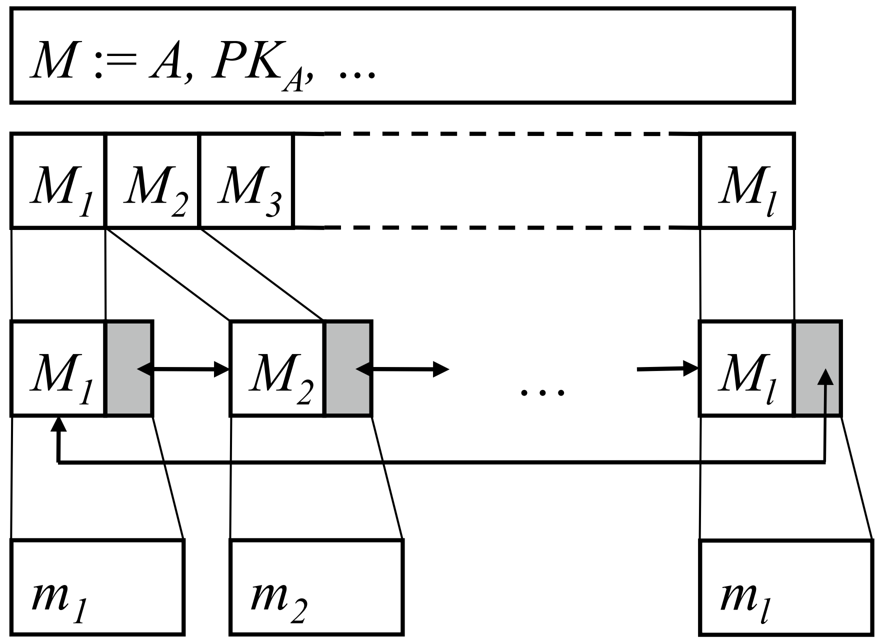


$$h_l := h(m_l),\ h_i := h(m_{i+1} || h_{i+1})$$

Solution: Uncoordinated Frequency Hopping



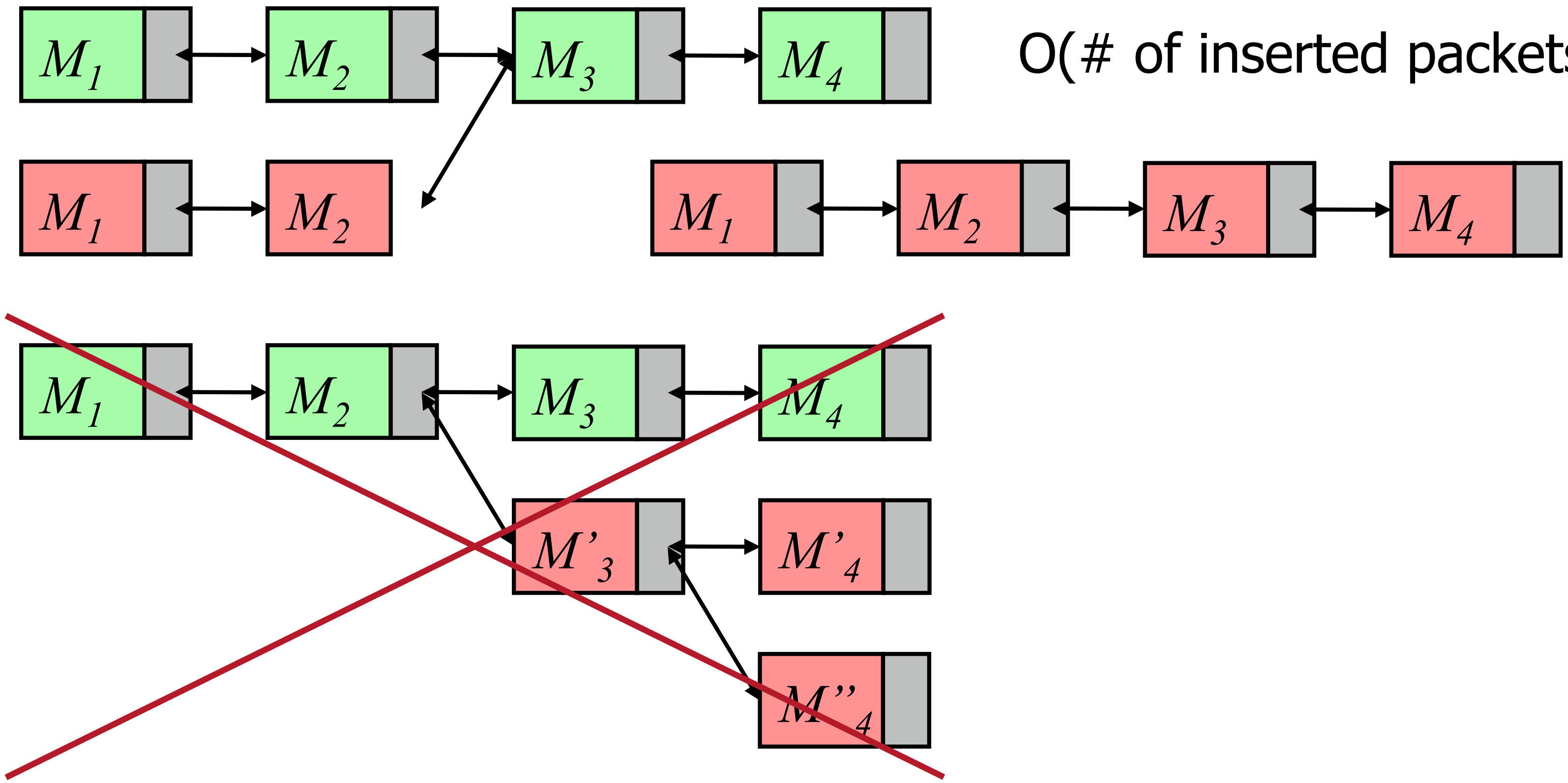
- Fragmentation
- Hash linking
  $h_l := h(m_l),\ h_i := h(m_{i+1} || h_{i+1})$
- Bit coding/interleaving



Other approaches: accumulators, turbo-codes, short signatures, Merkle trees …

UFH: analysis

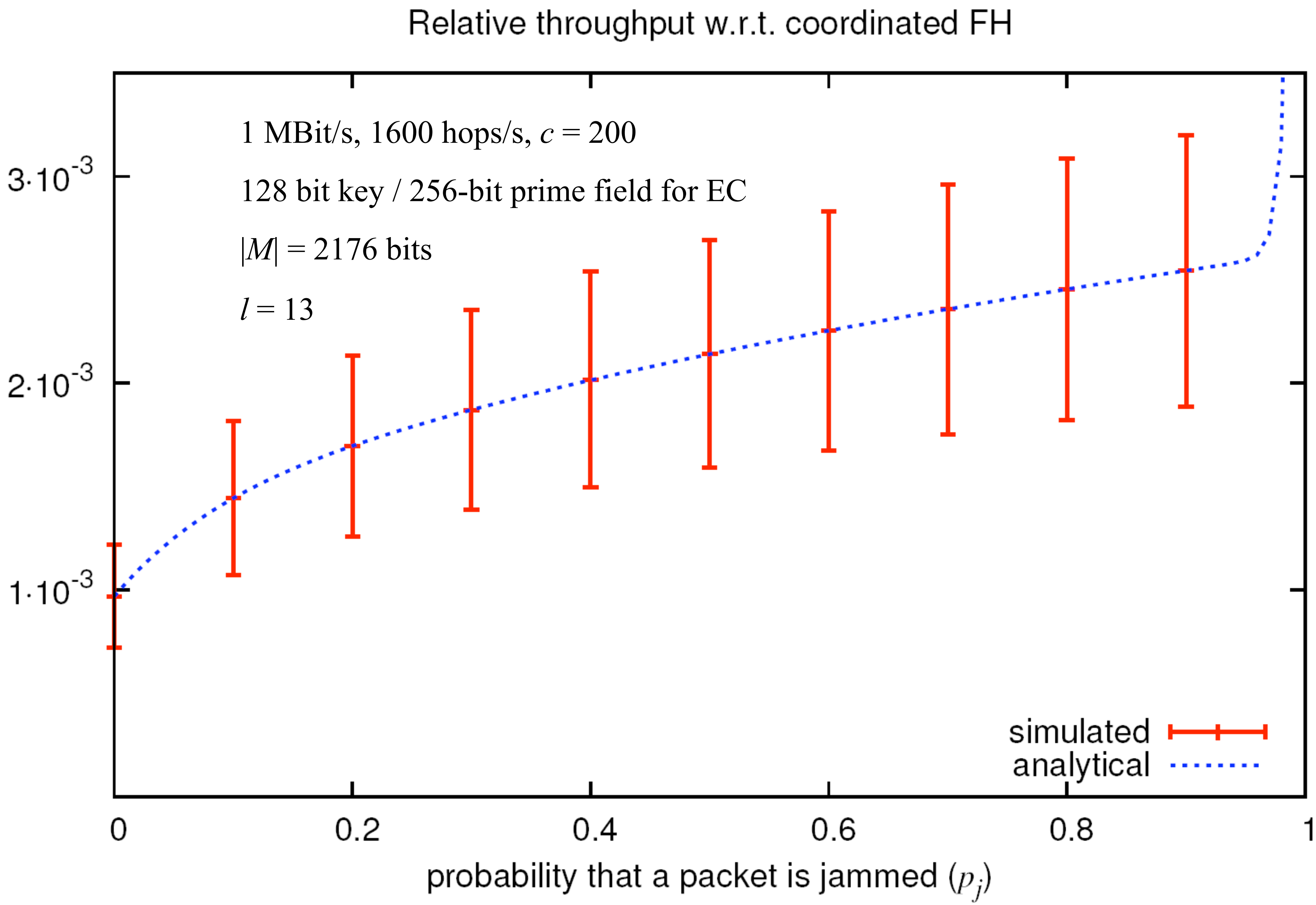
Uncoordinated Frequency Hopping: brief analysis
insertion/poisoning



O(# of inserted packets)

Cross-layer (DoS on communication and on computation)

Performance Evaluation: Illustrative Example



Broadcast Anti-jamming Communication: Summary

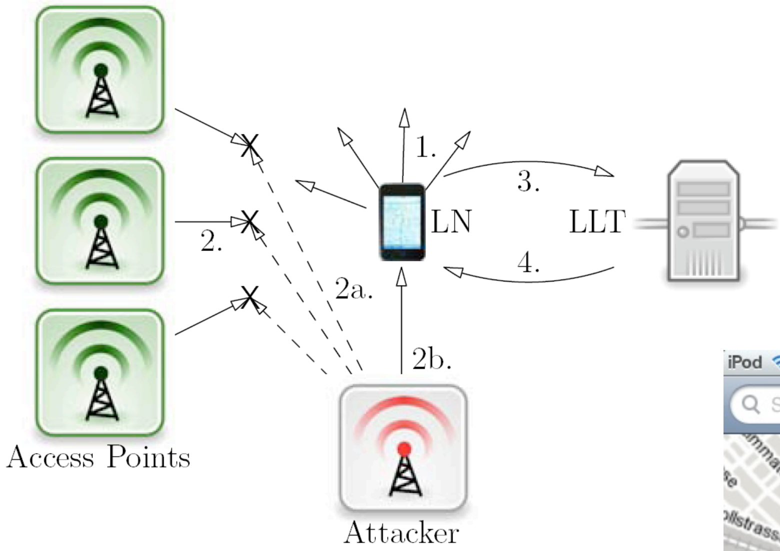
- Key establishment-anti-jamming dependency cycle
- New solutions break this dependency

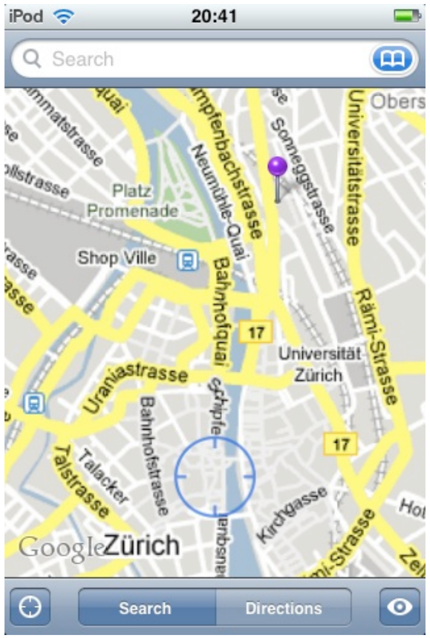
- UFH
- Other ideas:
    - Yvo Desmedt (pre-shared sets of hopping sequences)
    - UDSSS (Uncoordinated Direct Sequence Spread Spectrum)
- Implementations using SDR (0.2-300s latency)

UFH and UDSSS achieve broadcast anti-jamming communication but reduce communication throughput.

Example: Attacks on iPhone localization system

- Attack goal: device displays an incorrect location
- Attack: Jam signals from legitimate APs
  insert messages with MACs corresponding to other APs





- More attacks:
  database poisoning, ...

Summary/Conclusion

- We should not abstract-away the physical layer
  - When reasoning about the security of Wireless Networks we need to consider:
    - Their physical layer
    - Physical node locations and how they are obtained
- ... and make use of the physical layer and the locations

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Misc

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