Privacy-Preserving 802.11 Access-Point Discovery

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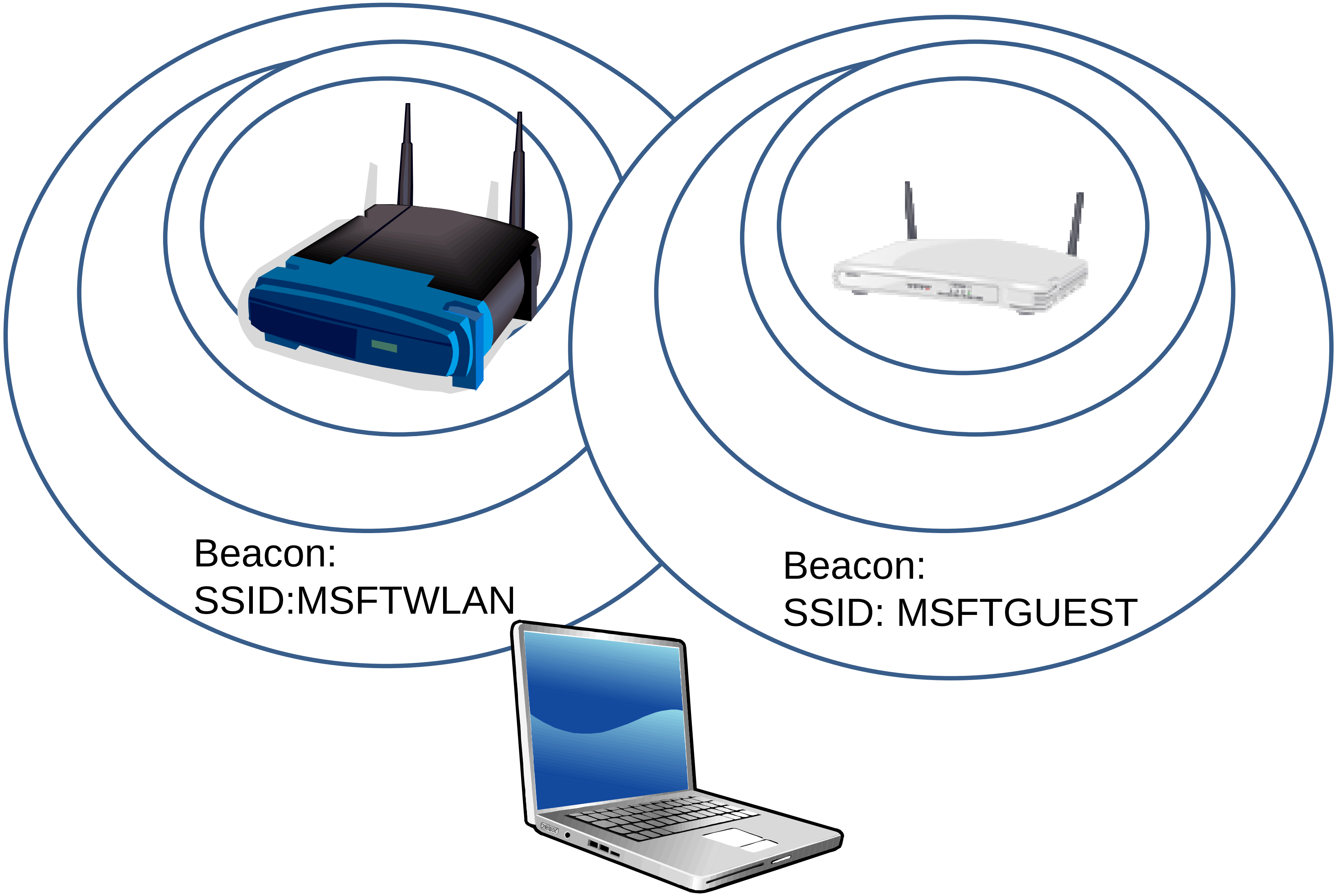
Outline

- IEEE 802.11 access-point discovery
- Privacy problem for the clients
- Possible solutions
- Privacy-preserving access-point discovery

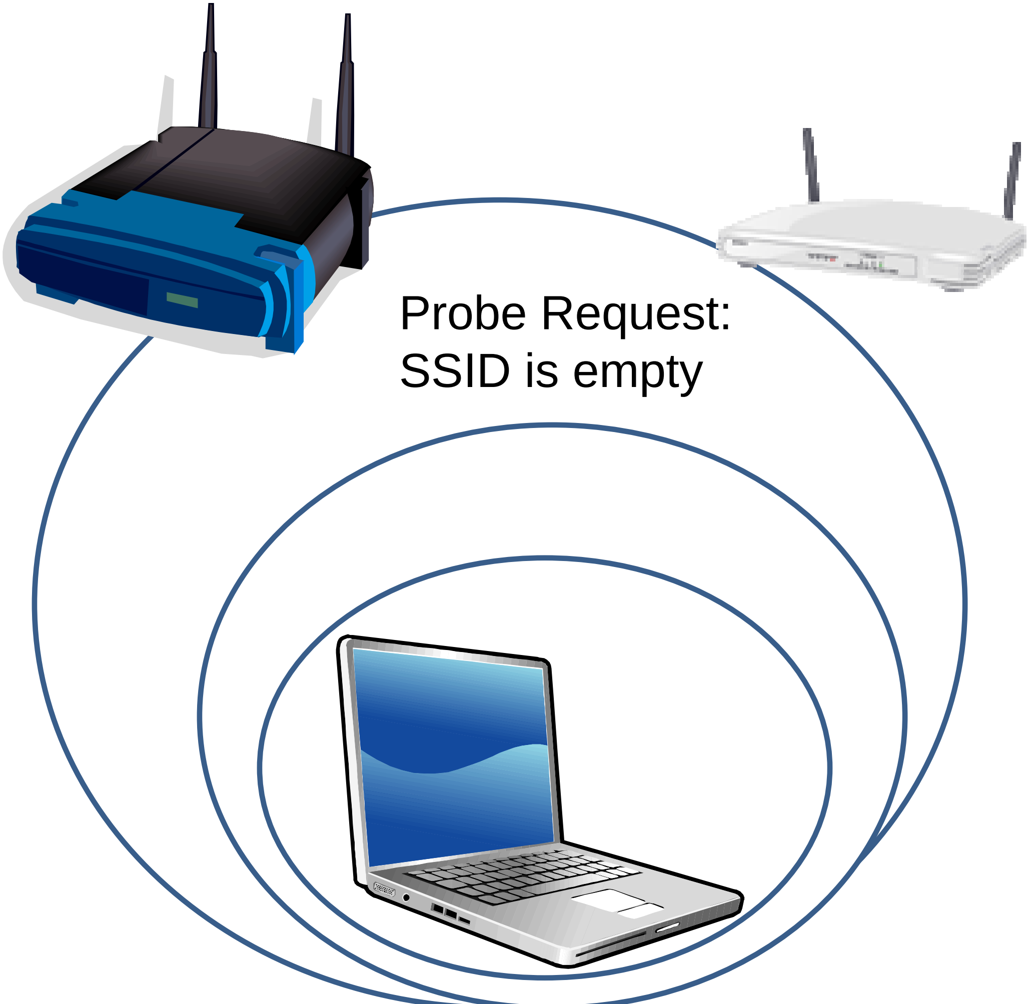
Background 802.11 AP discovery

- AP initiated
  - Beacon
- Client initiated
  - Undirected active probe
  - Directed active probe
- Beacons and probes are used to discovery the presence of a network name, the SSID.

802.11 AP discovery: *beacon*

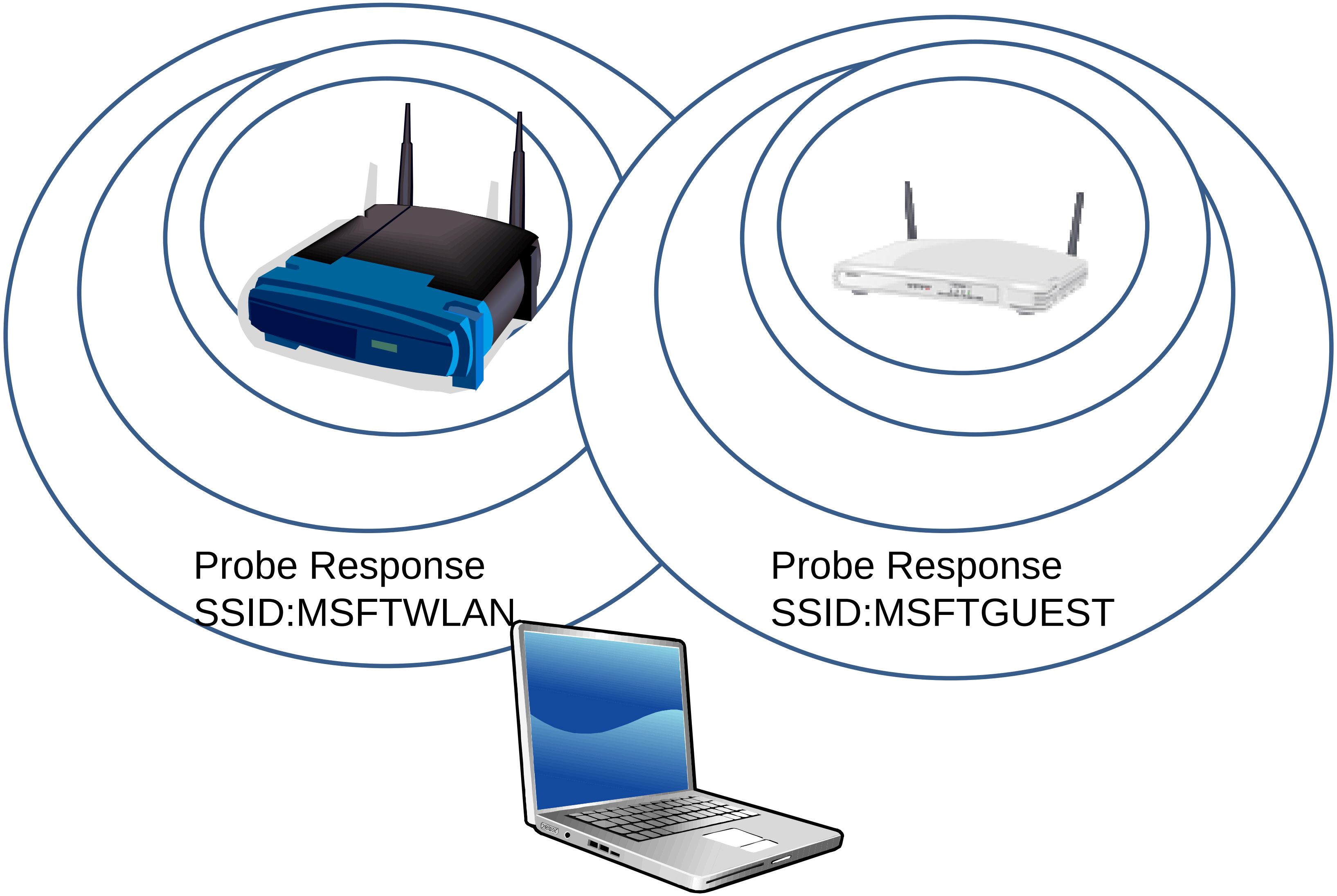


802.11 AP discovery
undirected active probe



Probe Request:
SSID is empty

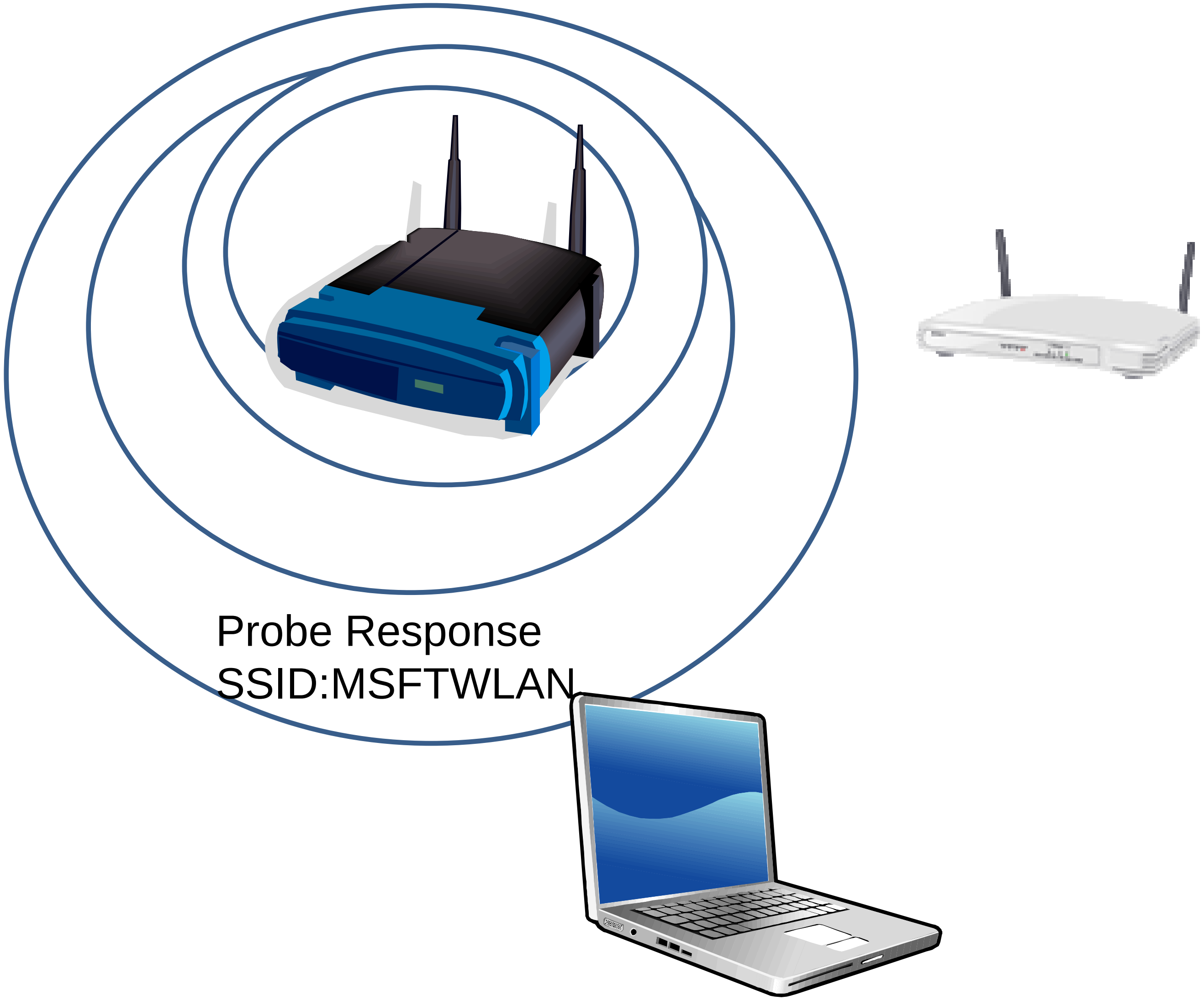
802.11 AP discovery: *undirected active probe*



802.11 AP discovery
directed active probe

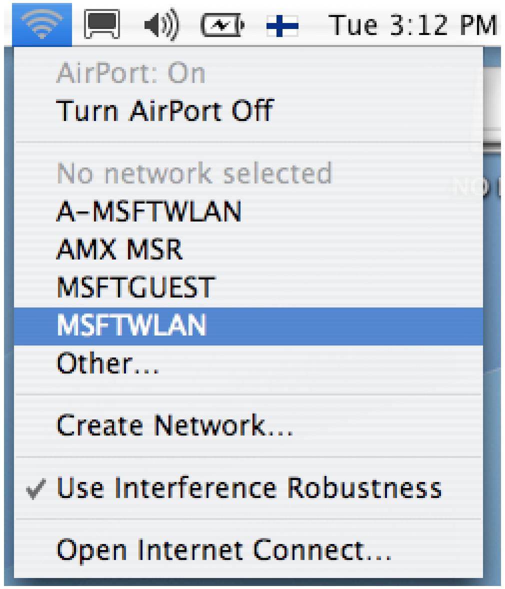
Probe Request:
SSID: MSFTWLAN

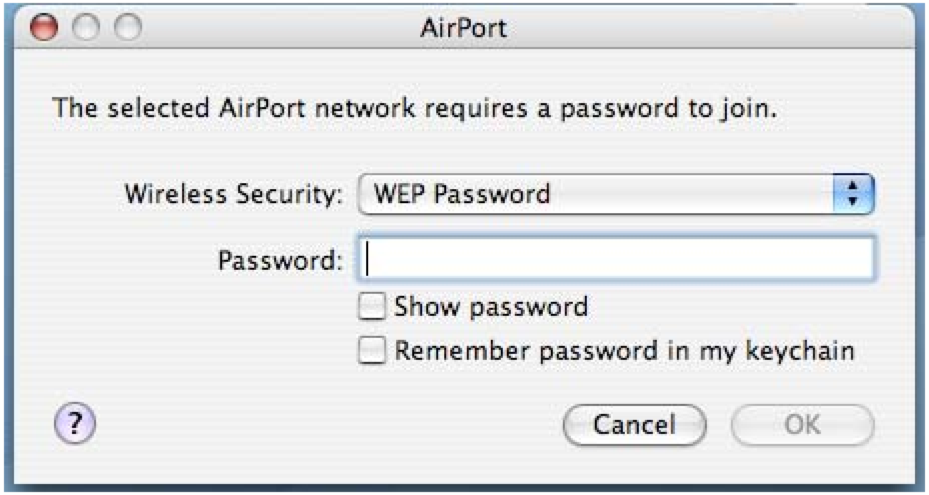
802.11 AP discovery: *directed active probe*



Probe Response
SSID:MSFTWLAN

Discovery User Experience




AirPort

The selected AirPort network requires a password to join.

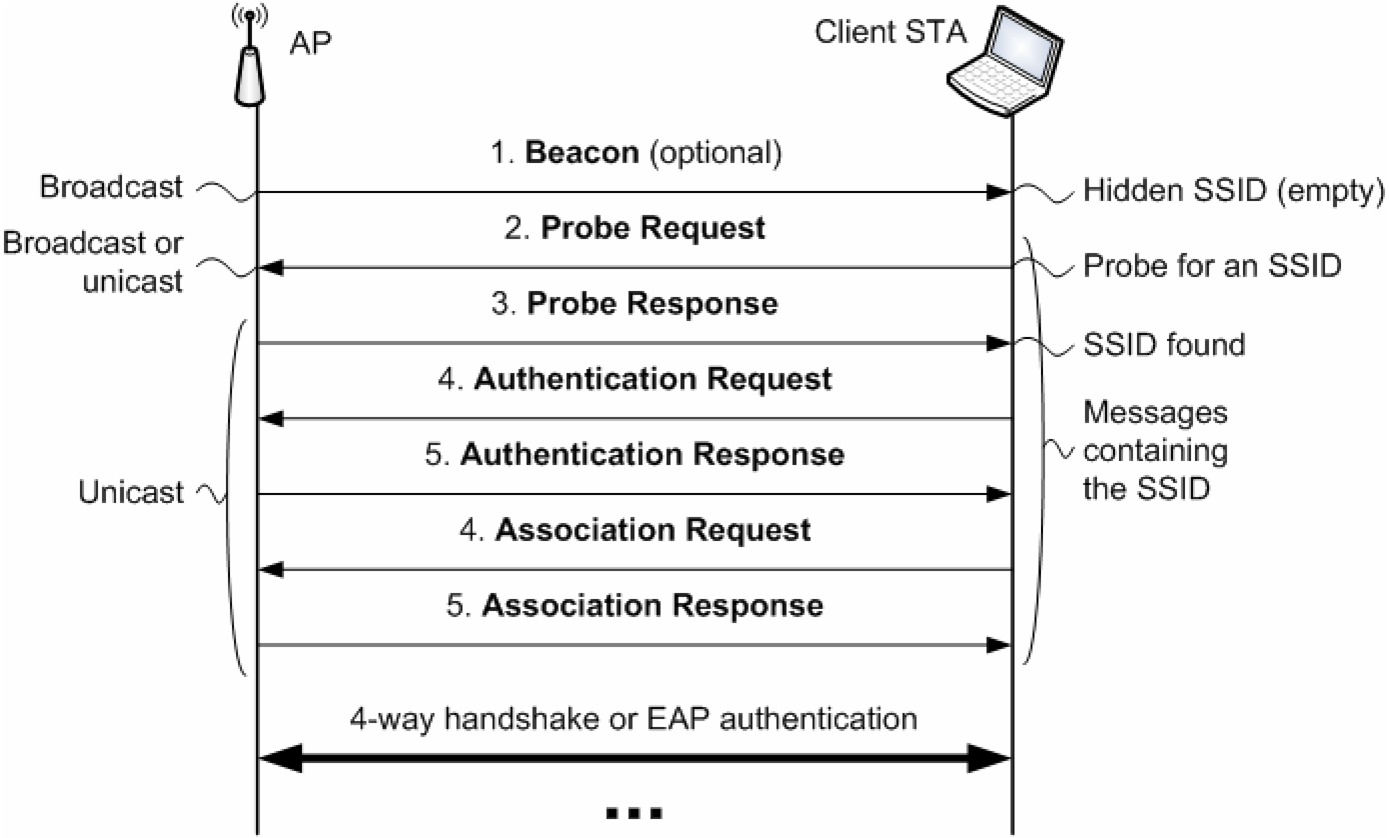
Wireless Security: WEP Password

Password:

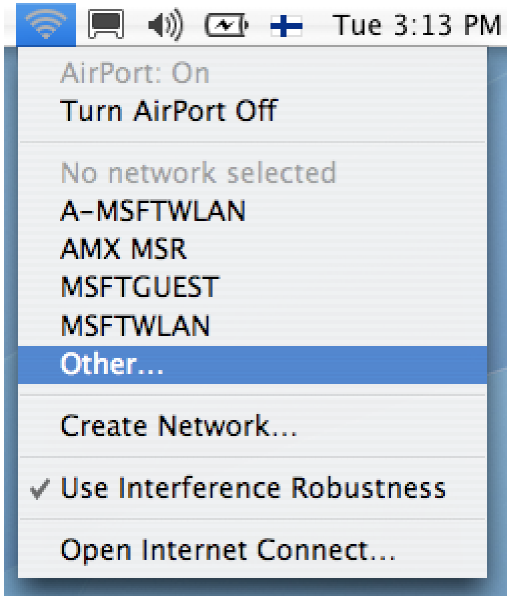
□ Show password

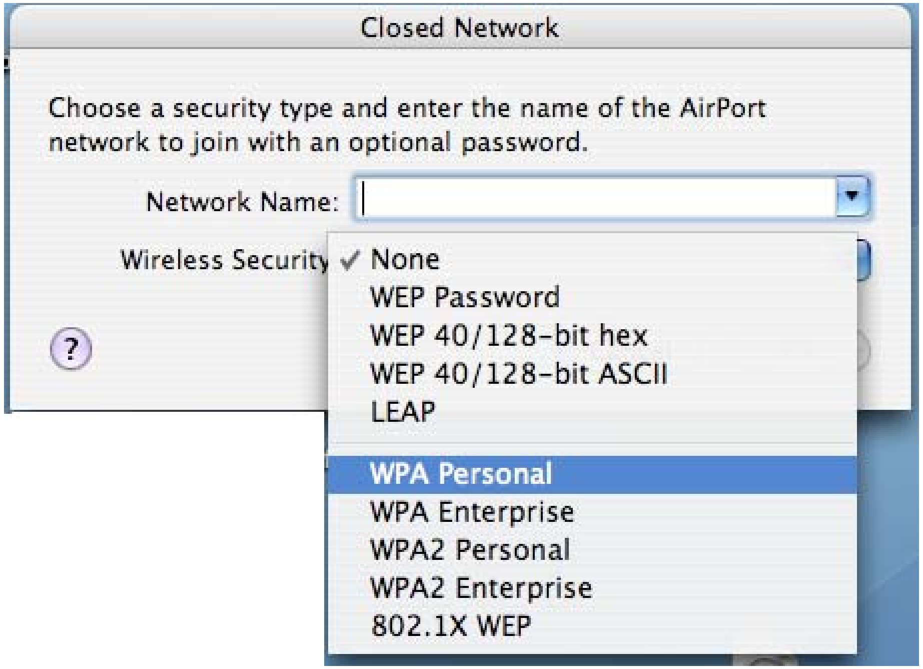
□ Remember password in my keychain

“Hidden network” discovery and association



“Hidden Network” User Experience





Choose a security type and enter the name of the AirPort network to join with an optional password.

Network Name:

Wireless Security

The Privacy Problem

- Clients keep a list of known networks, which they continuously probe.
- The SSIDs are plaintext identifiers
  - University, company, favorite Internet café
  - History of network usage
  - User fingerprinting/profiling [Pang et al., Mobicom’07)

Goal: Solving the Privacy Problem

- Protect the privacy of APs at least as well as in the current “hidden networks”
- Avoid the need for client to broadcast SSIDs when probing for “hidden networks”

  ➔ SSID not seen at all on air
- An observer can still see that some communication is taking place

Threat Model

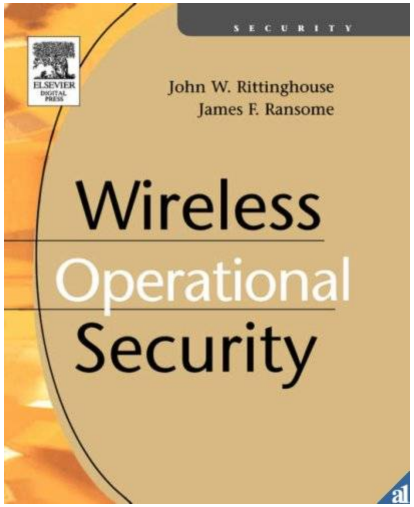
- The adversary *can*
  - Move between network locations
  - Record and replay messages
  - Mount man-in-the-middle attacks at a *single* access point at a time
- The adversary *cannot*
  - Relay messages between two network locations (wormhole attacks)

Further constraints

- Deployability
  - No changes to the user experience
  - Cannot increase handoff latency
  - Minimal changes to 802.11 standard and implementations
- Must work together WPA-PSK or WPA2-PSK authentication

Possible solutions 1/3

- Remove the “hidden network” feature and require the APs to broadcast the SSID
  - This is not going to happen, because...



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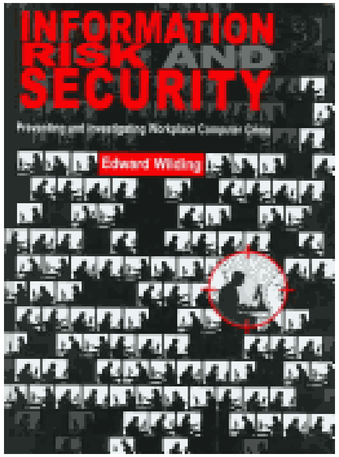
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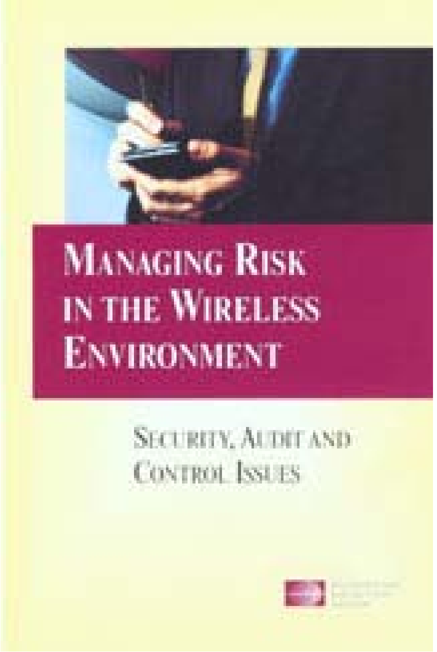

MANAGING RISK IN THE WIRELESS ENVIRONMENT
SECURITY, AUDIT AND CONTROL ISSUES

Possible solutions 2/3

- Use a random string as the SSID
  - Some implementations of WiFi Protected Setup actually do this
  - Not good for the user experience
    - SSID could be “¤#%!21%¤CXS)ASDF”
  - The user can still be profiled!
    - (possibly even better than before)

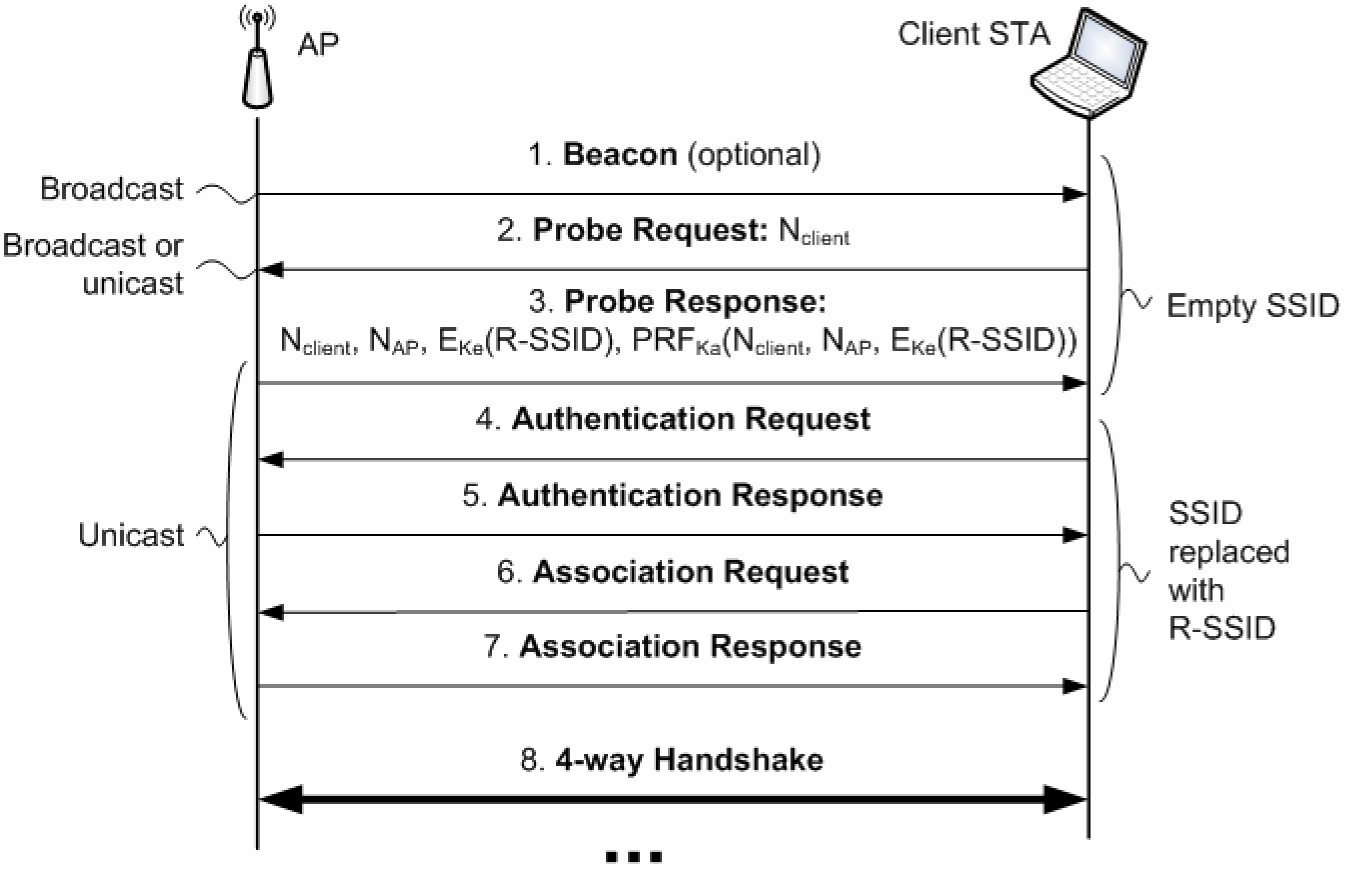
Possible solutions 3/3

- Probing not used as default, but needs to be manually enabled for each SSID
  - Windows Vista already does this
  - Users do not understand the tradeoffs
- Heuristics for reducing the number of probes
  - Heuristics often fail when the environment changes
  - Increases client implementation complexity

Our Approach

- Simple authentication protocol based on
  - cryptographic hash functions
  - symmetric key crypto
  - syntactically resembles ISO/IEC 9798-4
- Piggyback on the 802.11 undirected active probing

Privacy-preserving AP discovery


AP
Client STA
1. **Beacon** (optional)
Broadcast
2. **Probe Request:** N_{client}
Broadcast or unicast
3. **Probe Response:**
N_{client}, N_{AP}, E_{Ke}(R-SSID), PRF_{Ka}(N_{client}, N_{AP}, E_{Ke}(R-SSID))
Empty SSID
4. **Authentication Request**
5. **Authentication Response**
Unicast
6. **Association Request**
7. **Association Response**
SSID replaced with R-SSID
8. **4-way Handshake**
...

K_a = $HMAC_{PSK}$(”privacy key 1” | N_{client} | N_{AP})

K_e = $HMAC_{PSK}$(”privacy key 2” | N_{client} | N_{AP})

R-SSID = pseudorandom value

PSK = PBKDF2(Password, SSID, SSID length, 4096, 256)

User Experience

- The privacy-preserving discovery protocol does not use the SSID at any point.
- The SSID is configured as usual, so the client knows it
    - The user experience does not change
    - The name of the network is shown in the UI

Steps after Network Discovery

- WPA-PSK is privacy-preserving: continues with the 4-way handshake and encrypted connection
- Management frames need an SSID; we replace it with the R-SSID
  - new random R-SSID for each Probe Response
  - AP caches mapping between R-SSID and SSID for 60 seconds, longer if the client associates with it

Security Properties of the Protocol

- When a client probes for multiple APs, adversary cannot tell whether the APs belong to the same network or to different networks
  - (network = same SSID and PSK)
- When several clients probe for an AP, adversary cannot tell whether the clients have the same or different SSID/PSK

➔ stronger pricacy protection than in current ”hidden networks”

- No changes to WPA-PSK security; we just reuse the PSK

Limitations

- WPA-PSK is privacy-preserving, but e.g. 802.1X authentication may leak the client identity
  - e.g. EAP-TLS send client certificate as plaintext
  - Would need to change the TLS handshake to have client identity protection

Performance Measurements

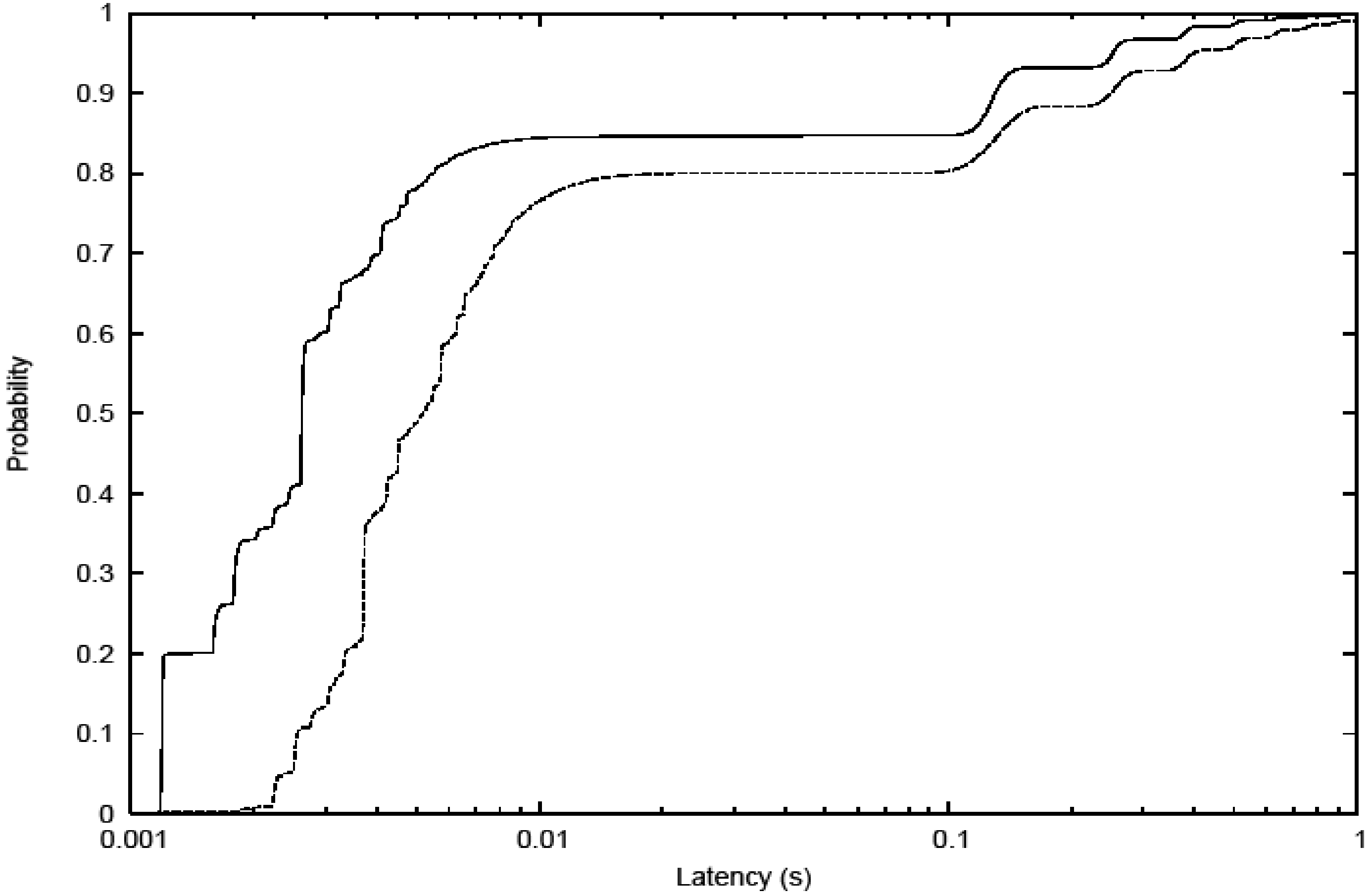
- AP implementation on Meraki Mini
  - Atheros AR2315 SoC @ 180 MHz
  - Runs Linux-based OpenWRT

- Client implementation on MadWifi drivers
- Measured also in the ORBIT testbed
  - PCs with 1 GHz VIA G3, 512 MB, Atheros AR5212 wireless interface

ORBIT Measurements

- We measured AP discovery latency
  - Compared to undirected active probing
  - Compared to hidden network discovery
- One AP
- 100 clients probed the AP every 125 ms each

ORBIT Measurements: legacy broadcast vs. our protocol



Meraki Mini Microbenchmarks

- Measured the AP discovery latency with single client probing a single AP
  - Legacy WiFi: average 1.8 ms latency and median 1.5 ms
  - Our protocol: average 3.2 ms latency and median 3.1 ms
  - Replaced the cryptographic messages with constant data
    - average 2.8 ms latency and median 2.1 ms
- Raw processing times
  - Probe response created in 0.53 ms
  - Probe response verified in 0.34 ms

  ➔ Cost of cryptographic processing not an issue

Interesting observation on hidden network discovery

- Unexpected result from ORBIT measurements
- Current “hidden network” discovery implementations probe for one SSID on all radio channels, then try the next SSID
- Our protocol probes for all SSIDs with one challenge and all APs answer

➔ Our protocol is actually *faster* when the client probes for multiple SSIDs

Related work

- Impressive clean-slate design
  - Ben Greenstein, Damon McCoy, Jeffrey Pang, Tadayoshi Kohno, Srinivasan Seshan, David Wetherall, “**Improving Wireless Privacy with an Identifier-Free Link Layer Protocol”,** in MobiSys’08.
  - Jeffrey Pang, Ben Greenstein, Damon McCoy, Srinivasan Seshan, David Wetherall, “**Tryst: The Case for Confidential Service Discovery**”, in HotNets VI, 2007.
  - Requires explicit pairing
  - Needs to consider clock skew

Further Information

- ACM WiSec’09 paper

  http://www.tml.tkk.fi/~jklindqv/wisec09web.pdf
- Further details in Microsoft Research Tech Report – MSR-TR-2009-07
- Source and patches coming to the web near you shortly.

Conclusions

- Small modifications to the standard WLAN
  - Co-exists with the current protocols and APs
  - Easy to deploy
- No changes to user experience
  - Configure like you would configure today
- *Enabler* for more complex privacy solutions such as MAC address randomization and other privacy mechanisms on upper layers.