## Overview

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   - b. Denial of Service - SecureArray
3. Current Security Measures
   - a. Key Sharing - SafeSlinger
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### Why Wireless Security?

- The world will have 30 billion wirelessly connected devices by 2020
- An increasing number of our systems are connected wirelessly
  - Energy Grid
  - Planes
  - Door locks!
- Wireless communications are public in nature

<table>
<thead>
<tr>
<th>Wired Security</th>
<th>Wireless Security</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication travels within a shielded copper cable</td>
<td>Wireless radio frequency communication travels through open air</td>
</tr>
<tr>
<td>Network is completely contained</td>
<td>Anyone can capture and record information travelling through a wireless network</td>
</tr>
<tr>
<td>Must physically connect to the network to obtain information</td>
<td>A single compromised node in the network can compromise the entire network</td>
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Types of Attacks

- Man in the Middle (MitM)
- MAC Spoofing
- Denial of Service (DoS)

Man in the Middle

Definition: the attacker poses as an access point and forwards packets to/from the user

Purpose: allows attackers to intercept and modify information sent in the network

MAC Spoofing

Definition: transmission of packets with the MAC address of a different user

Purpose: allows attackers to transmit packets over a network with the address information of an authorized user

Clock Skew Estimation: Problem Summary

- AP selection algorithms use signal strength as the only criteria
- Attacker can set up fake APs with the same MAC address as the real AP, but with different physical characteristics
On Fast and Accurate Detection of Unauthorized Wireless Access Points Using Clock Skews

Suman Jana, University of Utah
Sneha K. Kasera, University of Utah

Clock Skew Estimation: How it Works

- Microsecond resolution clock records times received
- Assumes linear offset times
- Uses least square fitting to find line of best fit - slope of line is clock skew estimate

Clock Skew Estimation: How it Works

- Proposed solution - use clock skew to fingerprint APs
  - Beacons transmit packets from APs regularly
  - User records offsets between TSF timestamps of received packets to estimate clock skew

Clock Skew Estimation: How it Works

- Estimates require 50-100 packets to stabilize
- Clock skew is consistent for a particular AP
- Clock skew varies greatly across APs

<table>
<thead>
<tr>
<th>AP</th>
<th>1st Measurement (LSFR)</th>
<th>2nd Measurement (LSFR)</th>
<th>3rd Measurement (LSFR)</th>
<th>4th Measurement (LSFR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminea</td>
<td>-61.80 ppm</td>
<td>-61.80 ppm</td>
<td>-61.90 ppm</td>
<td>-61.77 ppm</td>
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<td>Linksys</td>
<td>-61.03 ppm</td>
<td>-61.03 ppm</td>
<td>-61.54 ppm</td>
<td>-61.37 ppm</td>
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<tr>
<td>Linksys</td>
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<td>-61.84 ppm</td>
<td>-62.77 ppm</td>
<td>-62.84 ppm</td>
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<tr>
<td>Belkin</td>
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<td>-64.08 ppm</td>
<td>-56.05 ppm</td>
<td>-56.85 ppm</td>
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<td>-27.50 ppm</td>
<td>-45.46 ppm</td>
<td>-48.30 ppm</td>
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<tr>
<td>Unitekn</td>
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<td>-47.13 ppm</td>
<td>-47.80 ppm</td>
<td>-48.14 ppm</td>
</tr>
<tr>
<td>Universal</td>
<td>-60.00 ppm</td>
<td>-60.00 ppm</td>
<td>-61.84 ppm</td>
<td>-61.87 ppm</td>
</tr>
</tbody>
</table>
Limitations of Clock Skew Estimation

- Assumes constant data rate and clock skew for the receiving device
- Assumes that the fake AP cannot forge timestamps to align with the real AP’s clock skew

Denial of Service

Definition: the flooding of a network with packets, preventing authorized users from transmitting

Purpose: allows attackers to observe handshake codes on network restart, could relay packets from jammed users

SecureArray: Problem Summary

- WPA allows for injection attacks - attacker injects a frame into the network, leading to Denial of Service
- Security protocols can be compromised when shared secrets can be exposed
- Users need a procedure to uniquely identify other network participants

SecureArray: Improving Wifi Security with Fine-grained Physical Layer

Jie Xiong, Singapore Management University
Kyle Jamieson, University College London
SecureArray: How it Works

- SecureArray leverages modern access points that exploit MIMO through the use of multiple antennas and spatial division multiplexing.
- An Angle of Arrival signature is established between a client and an Access Point to profile direction of signal received.
  - AoA signature is detailed due to multipath effects.

SecureArray: Mitigating Attacks

Authenticated Mac Address Spoofing

- Attacker manages to be authenticated with AP, and can sniff Mac Address of another authenticated client and spoof it.
- Uses DataCheck protocol to mitigate authenticated spoofing.
  - Client detects unexpected ACK frame and challenges AP.

SecureArray: Mitigating Attacks

Deauthentication Deadlock

- Attacker leverages WPA weaknesses.
- AP engages in AoA signature comparisons of local maxima when attack is suspected.

SecureArray: Results

- 100% attack detection rate of WiFi spoofing attack and 0.6% false alarm rate in noisy office environment.
Limitations of SecureArray

- Increased latency of the protocol with added overhead of the Angle of Arrival signatures
- Attacker can replicate Angle of Arrival signature by being in close proximity to the client (~ 5cm)

Current Security Measures

- SSID Hiding
- MAC Address Filtering
- Key Exchange Protocols: WPA

SSID Hiding

- Service Set Identifier (SSID) - 32 character sequence that uniquely identifies a WLAN
- APs broadcast their SSIDs by default
- SSID Hiding - SSID broadcasting is disabled, mandating clients to know SSID
- Cons: Does not prevent malicious attackers from sniffing packets containing SSIDs

MAC Address Filtering

- Defines a list of devices that are allowed on your WiFi network
- Cons: Can easily be breached by MAC address spoofing
**Key Exchange Protocols: WPA**

*Wi-Fi Protected Access*

- Four-way handshake with the Access Point to exchange shared key
- Uses Temporal Key Integrity Protocol
  - Uses **Dynamic Key Generation** - separate 128 bit key is generated for each packet transmission
  - **Message Integrity Code** - inserted to validate the message
- Uses the **Advanced Encryption Scheme** - advanced symmetric key generation algorithm

**Key Exchange Protocols: WPA Weaknesses**

- Injection Attacks - malicious code can be inserted into WPA protocol stack
- WPA lacks a **forward secrecy system**
  - Compromised keys can decrypt all subsequent packets
  - Key generation process is pseudorandom - brute-force testing

**SafeSlinger: Easy-to-Use and Secure Public-Key Exchange**

Michael Farb, CyLab / CMU  
Yue-Hsun Lin, CyLab / CMU  
Tiffany Hyun-Jin Kim, CyLab / CMU  
Jonathan McCune, Google Inc.  
Adrian Perrig ETH Zürich, CyLab / CMU

**SafeSlinger: How it Works**

- **iOS and Android** application
- Enables secure communications between pairs or groups of users
Diffie-Hellman Key Exchange

- Prime numbers \( p \) and \( g \) known
- Alice - makes private key \( a \)
- Alice - sends \((X = g^a \mod p)\) to Bob
- Bob - makes private key \( b \)
- Bob - sends \((Y = g^b \mod p)\) to Alice
- Alice - computes \( Y^a \mod p \)
- Bob - computes \( X^b \mod p \)
- Alice and Bob now have a shared secret key

SafeSlinger: How it Works

- Step 1: Multi-Commitment Generation
  - Each user creates a Diffie-Hellman private key
  - Key is encrypted and sent to the server

SafeSlinger: How it Works

- Step 2: Authenticity Verification
  - Server assigns IDs to each user
  - Users receive IDs and commitments from all other users
  - Each user must sort the decommitments by ID to generate 24-bit hash value
  - Hash value is inputted into the PGP word list to generate the correct 3-word phrase

SafeSlinger: How it Works

- Step 3: Secret Sharing Round
  - Once all users have sent in the correct phrase, users can send their contact information encrypted with the shared group key
  - Users decrypt contact information and store it on their phones for future use
SafeSlinger: How it Works

- Includes an API to import specific user public keys from contacts on phone

Limitations of SafeSlinger

- Scalability - Key management between many groups of connections is logistically difficult
- Difficult to verify effectiveness - paper asked users how secure they felt using the application

What Does the Future Hold?

- The number of connected devices and communication paths will increase rapidly in the coming decades
- How do we secure networks against future attacks?
  - Restrict access
  - Isolate the network
  - End-to-end encryption

QUESTIONS?
References

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