

DISCOVERING AND EXPLOITING NOVEL SECURITY VULNERABILITIES IN APPLE ZEROCONF

(Xiaolong Bai, Luyi Xing) (co-first authors),

Nan Zhang , XiaoFeng Wang , Xiaojing Liao , Tongxin Li , Shi-Min Hu

Tsinghua University,
Indiana University Bloomington
Georgia Institute of Technology,
Peking University

Who are we ?

- System Security Lab, Indiana University Bloomington
 - Focus on novel problems in system security
 - High-impact publications on IEEE S&P, ACM CCS, Usenix Security, NDSS
 - <http://sit.soic.indiana.edu/en/>
- Our advisor: Prof. XiaoFeng Wang
 - Top 10 authors on leading security venues for the past 10 years
 - <http://www.informatics.indiana.edu/xw7/>



Who are we ?

- We have two talks on Black Hat USA 2016
 - Luyi Xing and Xiaolong Bai, DISCOVERING AND EXPLOITING NOVEL SECURITY VULNERABILITIES IN APPLE ZEROCONF, August 4, Jasmine Ballroom, 12:10 - 13:00
 - Nan Zhang, DANGEROUS HARE: HANGING ATTRIBUTE REFERENCES HAZARDS DUE TO VENDOR CUSTOMIZATION, August 4, South Seas GH, 17:00 - 17:25

DISCOVERING AND EXPLOITING NOVEL SECURITY VULNERABILITIES IN **APPLE ZEROCONF**



ZeroConf

- Zero Configuration Networking
- Automatically configures a usable computer network
 - No manual configuration
 - No specific configuration server
- Designed to reduce users' burden
 - Setting up a new network
 - Use a new service.

ZeroConf

- Bonjour protocol
 - zero-configuration networking over IP that Apple has submitted to the IETF.
- Goals:
 - With little or no configuration
 - to add devices/services to a local network
 - Existing devices can automatically find and connect to those new devices/services

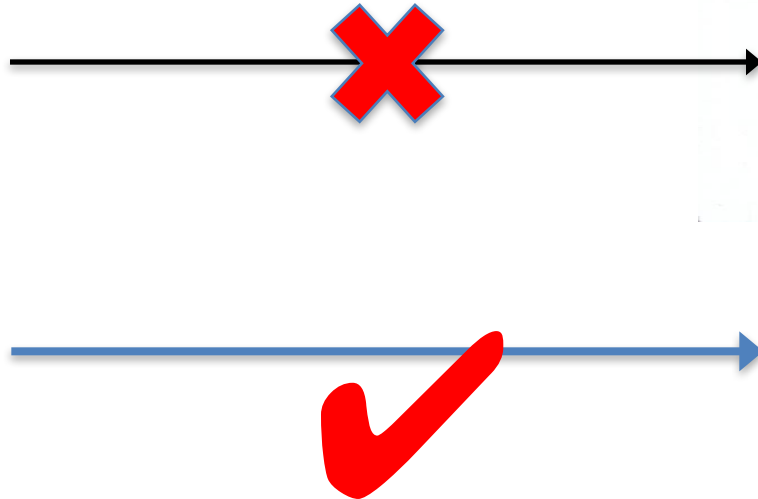


Bonjour

- Administrators
 - no need to assign IP, host names, service names to network services (e.g., printer)
- When using a service, users simply
 - ask to see what network services are available
 - and choose from the list of automatically discovered services.

How about traditional
configured network?

Traditionally



Must Configure:

- IP
- Printer name,
 - e.g., lh135-soic.ads.iu.edu
- DNS server

Traditionally



Must Configure:

- IP
- Printer name,
 - e.g., lh135-soic.ads.iu.edu
- DNS server

Features of Bonjour

1. Service configures itself
 - IP, hostname, service instance name
2. Clients automatically discover available services
 - No pre-knowledge of the service's name, hostname or IP

1. ZeroConf Concept
2. So, how?

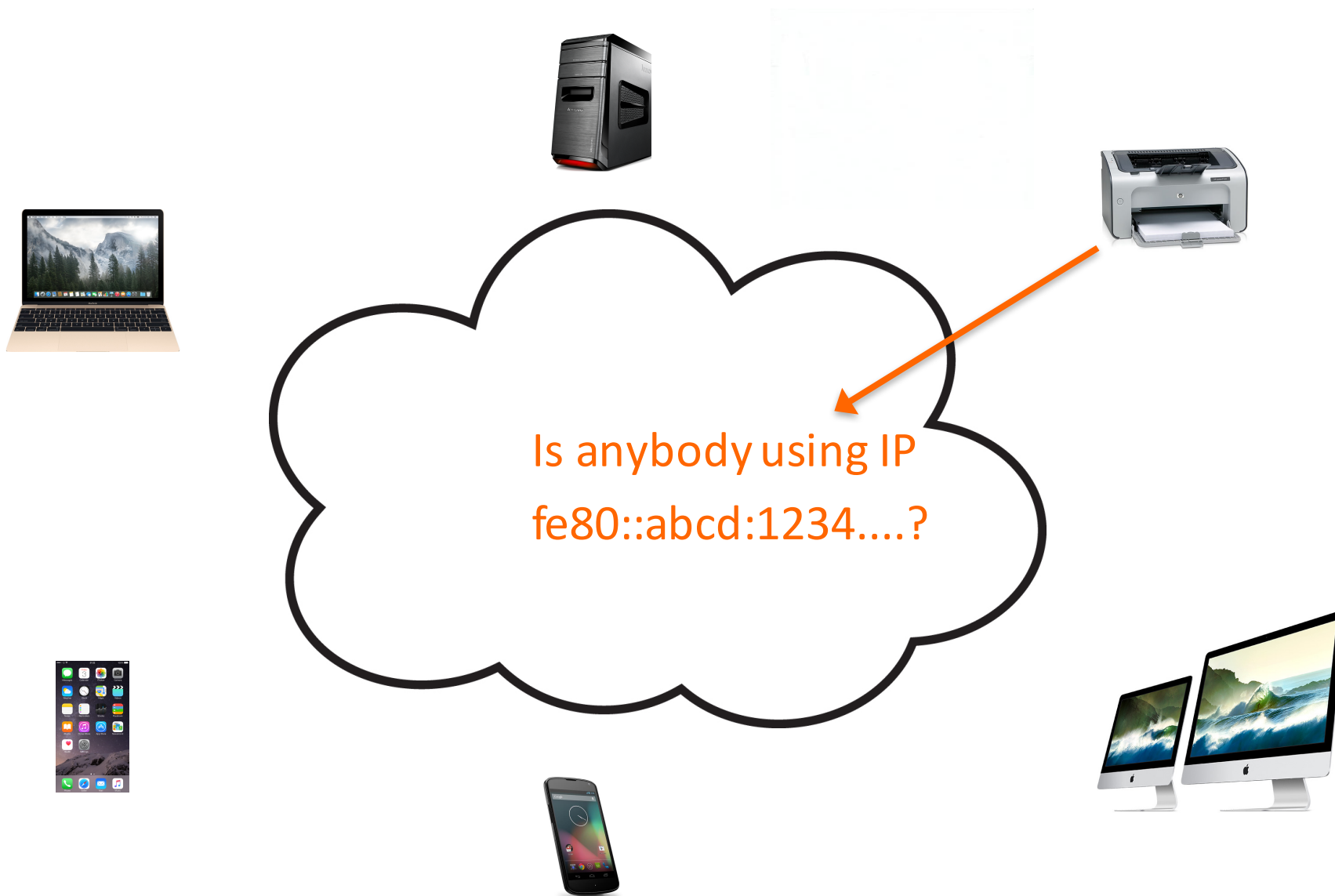
Features of Bonjour

1. Service configures itself
 - IP, hostname, service instance name
2. Clients automatically discover available services
 - No pre-knowledge of the service's name, hostname or IP

Add a new printer to a network



A printer configures itself



A printer configures itself



A printer configures itself



A printer configures itself



A printer configures itself



A printer finishes configuring itself



Features of Bonjour

1. Service configures itself

- IP, hostname, service instance name

2. Clients automatically discover available services

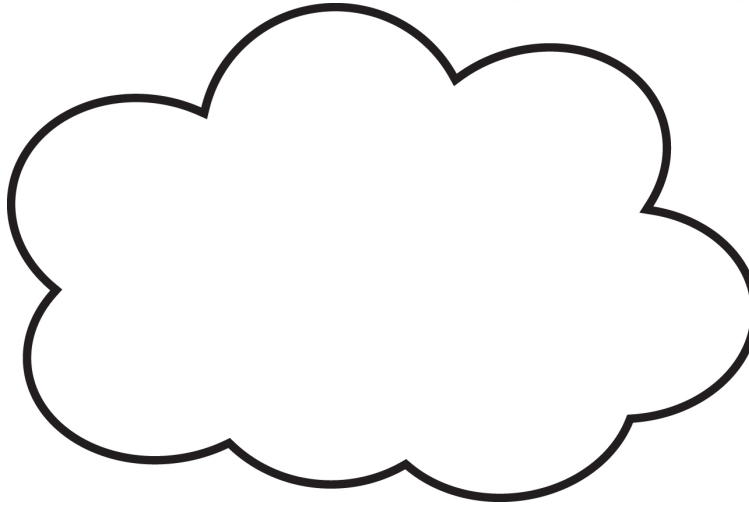
- No pre-knowledge of the service's name, hostname or IP

Two phases: Discovery and Resolution

Automatically find the printer: Discovery



Q1:
Anyone has a **printer service**?



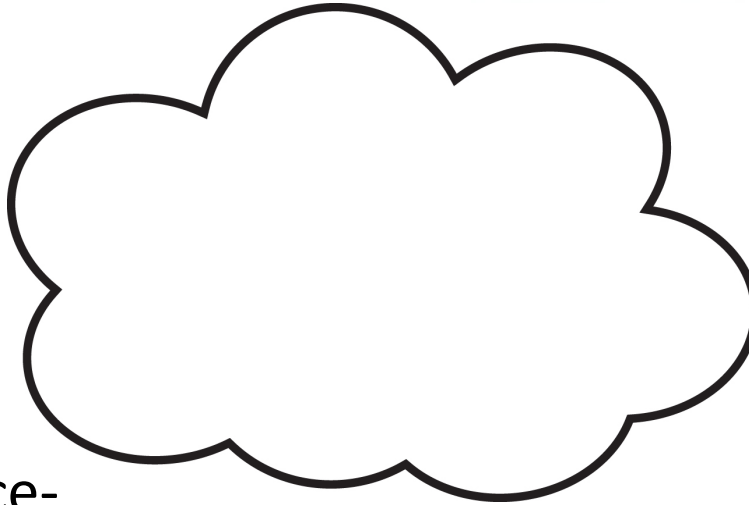
A1:
I have **HP-Service-9FE5**

Automatically find the printer: Resolution



Q1:
Anyone has a **printer service**?

Q2:
So **on which host** is this HP-Service-9FE5?



A1:
I have **HP-Service-9FE5**

A2:
It's on **host**
HP9fe5.host.local

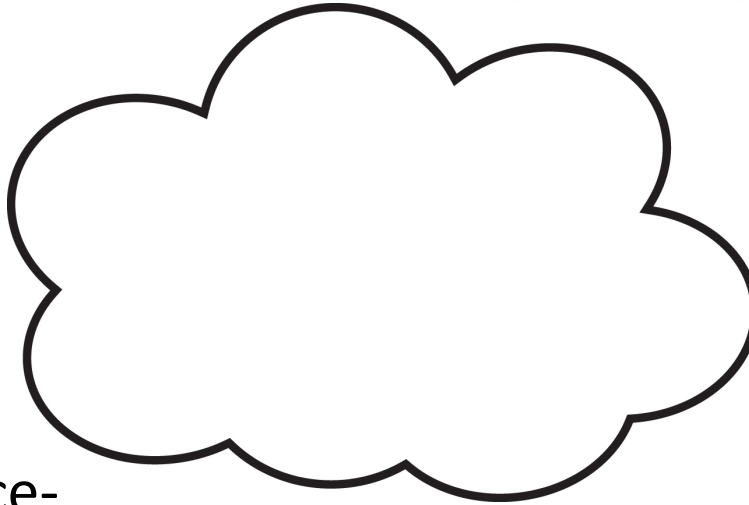
Automatically find the printer: Resolution



Q1:
Anyone has a **printer service**?

Q2:
So **on which host** is this HP-Service-9FE5?

Q3:
What is the **address** of
NPI9fe5.host.local?

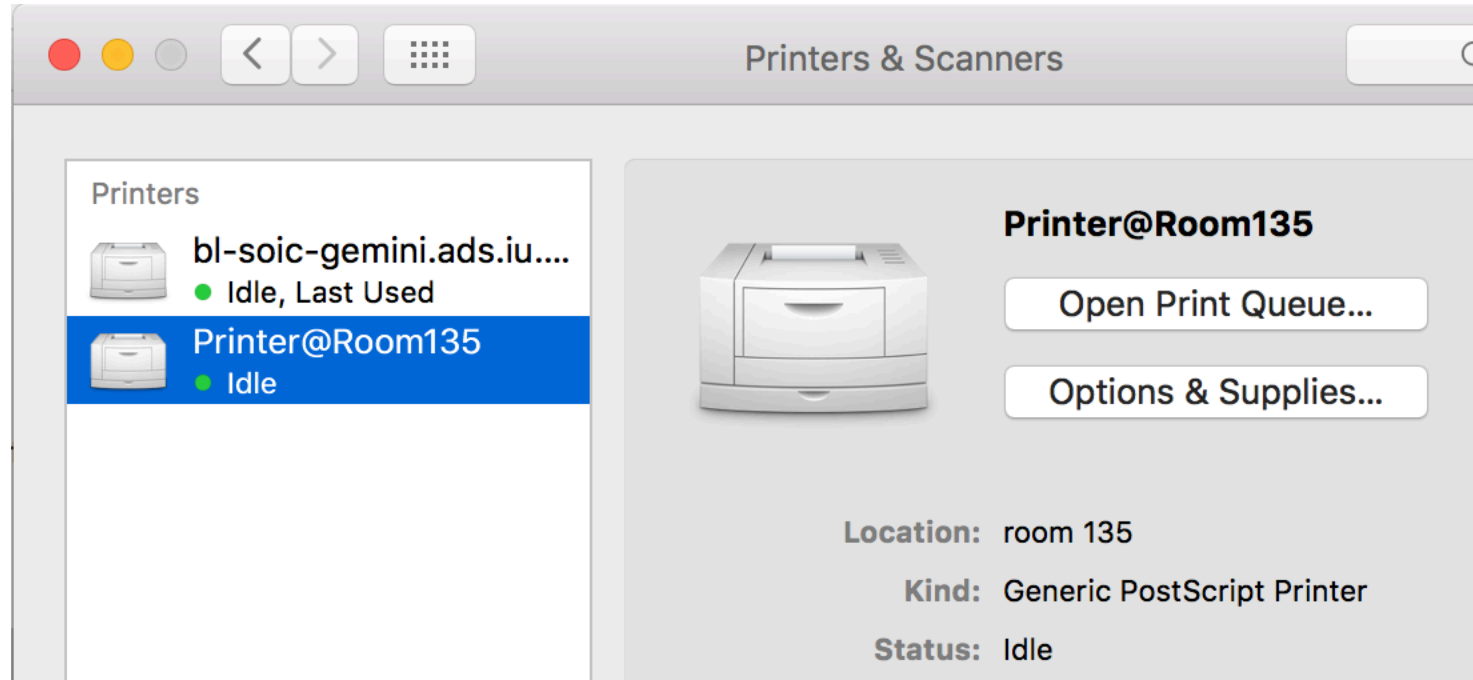


A1:
I have **HP-Service-9FE5**

A2:
It's on **host**
HP9fe5.host.local

A3:
Its **address** is
fe80::abcd:1234

Added/**Saved** the printer to your list



IP
fe80::abcd:1234

Hostname
HP9FE5.host.local

Service Instance Name
HP-Service-9FE5



Added/**Saved** the printer to your list

Apple:

*Applications store service instance names,
so if the IP, port, or host name changed, the
application can still connect.*



IP

fe80::abcd:1234

Hostname

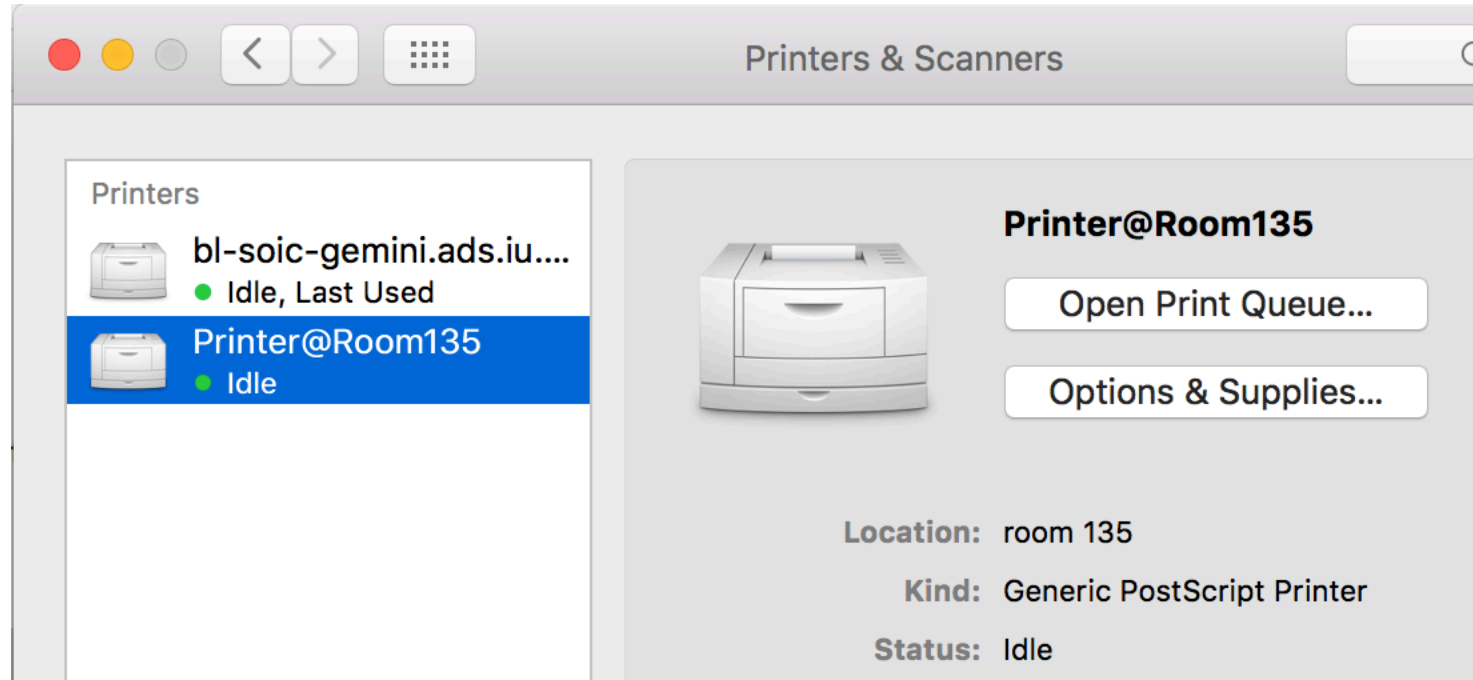
HP9FE5.host.local

Service Instance Name

HP-Service-9FE5



Service instance name HP-Service-9FE5 is saved

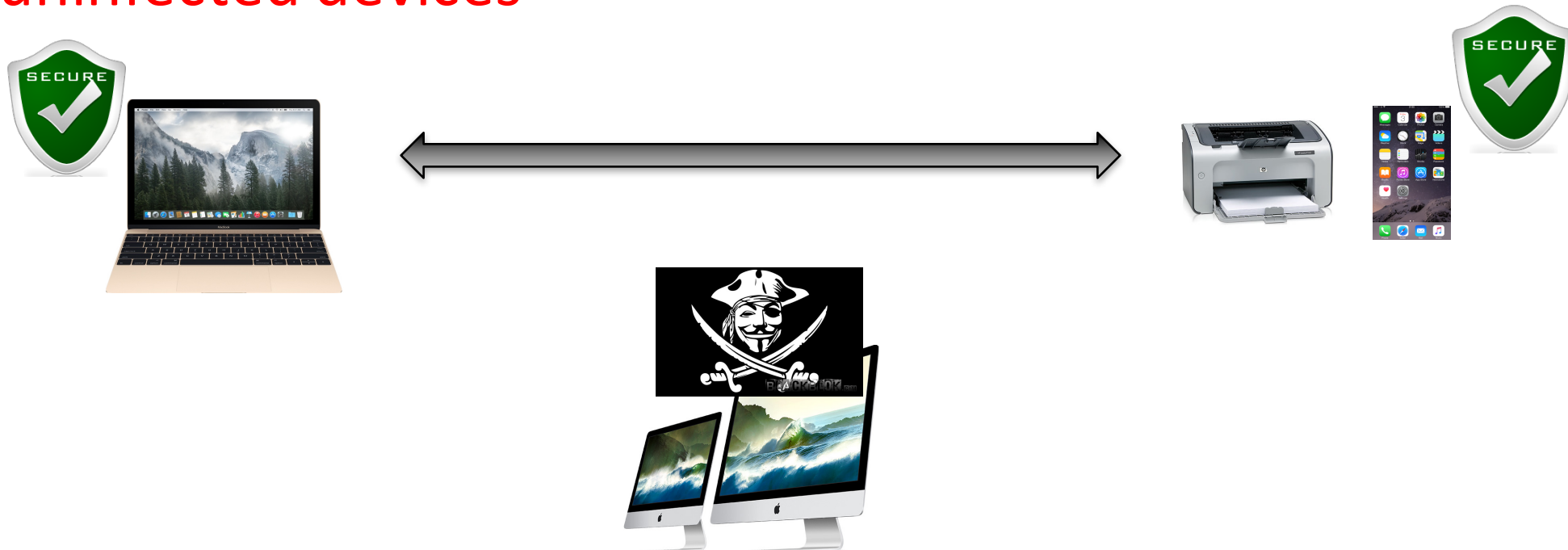


 ~~fe80::abcd:1234~~
~~Hostname~~
~~HP9FE5.host.local~~
Service Instance Name
HP-Service-9FE5

Saved printer =
A printer who owns service name HP-Service-9FE5

Adversary Model

- On a device (malware infected) in your local network
- Aims to intercept secrets/files transferred between **uninfected devices**



Adversary Model

- Your Mac/printer are un-infected
- Steal your printing documents?



1. ZeroConf Concept

2. ZeroConf How

3. ZeroConf Breaking

1. ZeroConf Concept

2. ZeroConf How

3. ZeroConf Breaking

Case 1: Attack Bonjour

Attack Bonjour

- Two examples
- Printer
 - Printers using Bonjour
- PhotoSync
 - Synchronizing photos between Mac and iPhone using Bonjour
- Not an application-specific or service-specific problem
 - Vulnerabilities in the design of Bonjour protocol

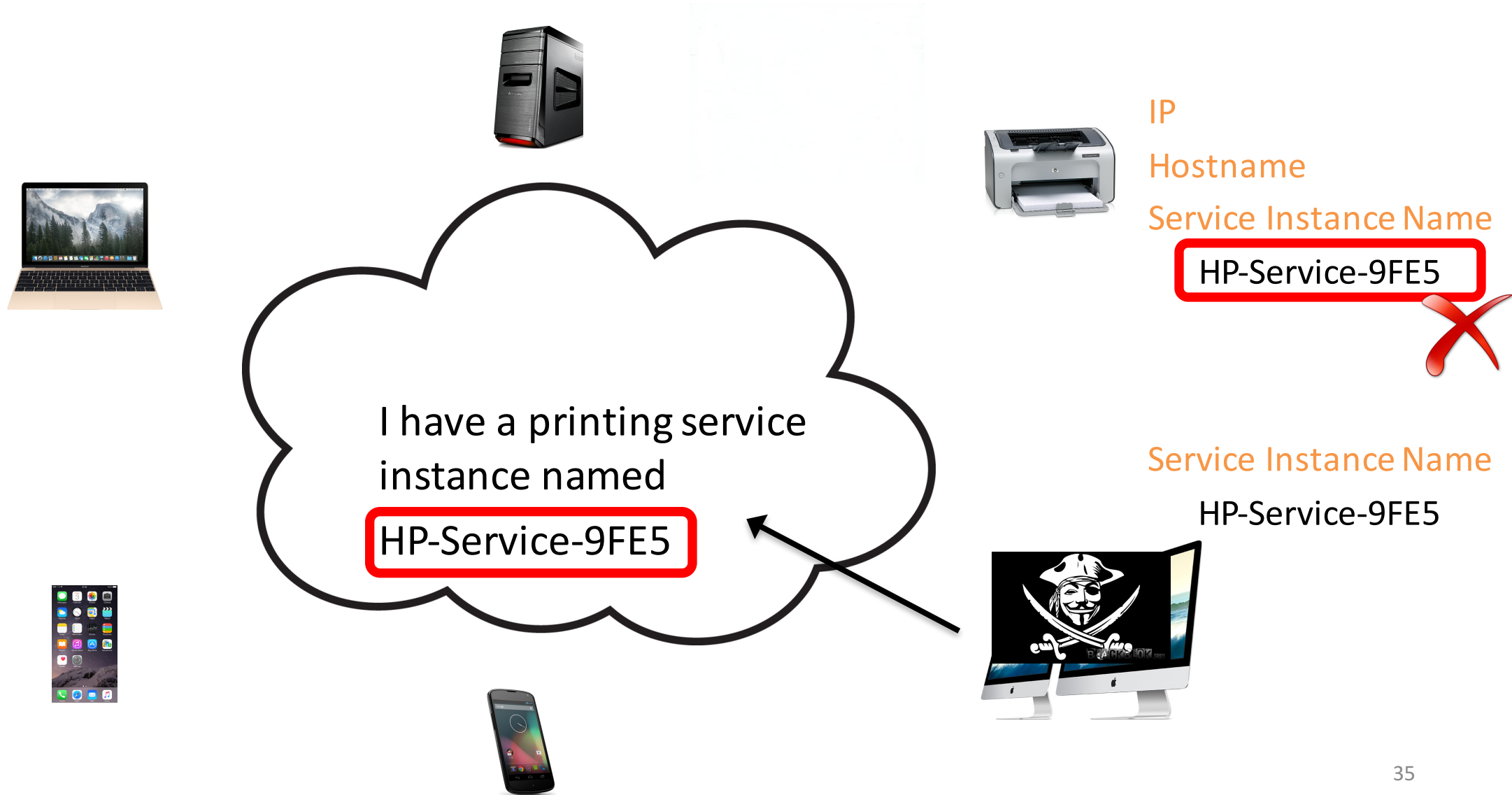
A device infected by malware



A device infected by malware



A device infected by malware



Saved printer =

A printer who owns service name **HP-Service-9FE5**



Why it happens?



Three **Changing** Attributes:

- IP
- Hostname
- Service Instance Name

Apple:

*Applications store service instance names,
so if the IP, port, or host name changed, the
application can still connect.*



Lack of authentication



Three **Changing** Attributes:

- IP
- Hostname
- Service Instance Name

- Anyone can claim any value of the three attributes
- The protocol only guarantees no duplicates.

If not saving service instance names,
is it secure enough?

No!

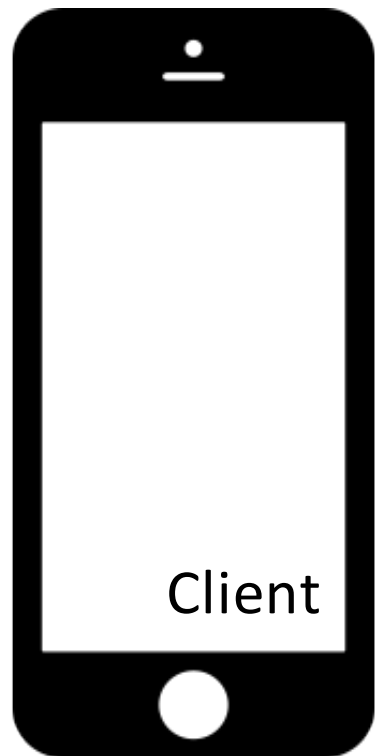
Attack Bonjour

- PhotoSync
 - Synchronizing photos between Mac and iPhone using Bonjour
- **Not saving service instance name**
 - Client discovers and resolves the server each time



Normally

- Discovery: Client browses for server



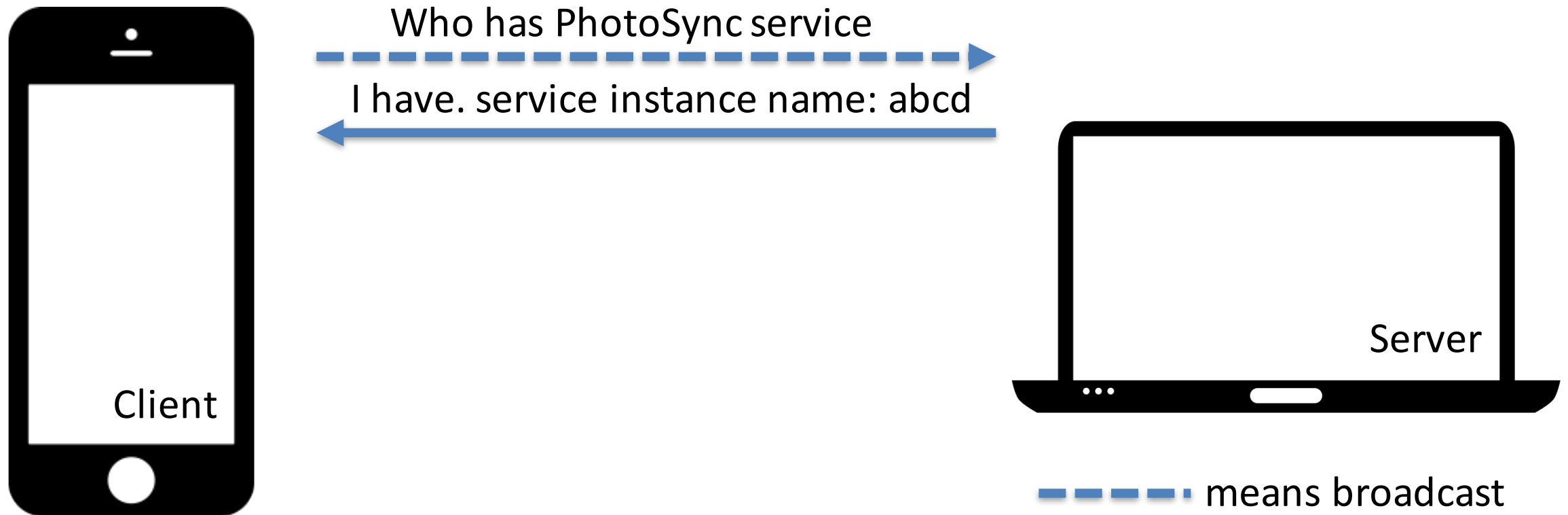
Who has PhotoSync service



— — — — means broadcast

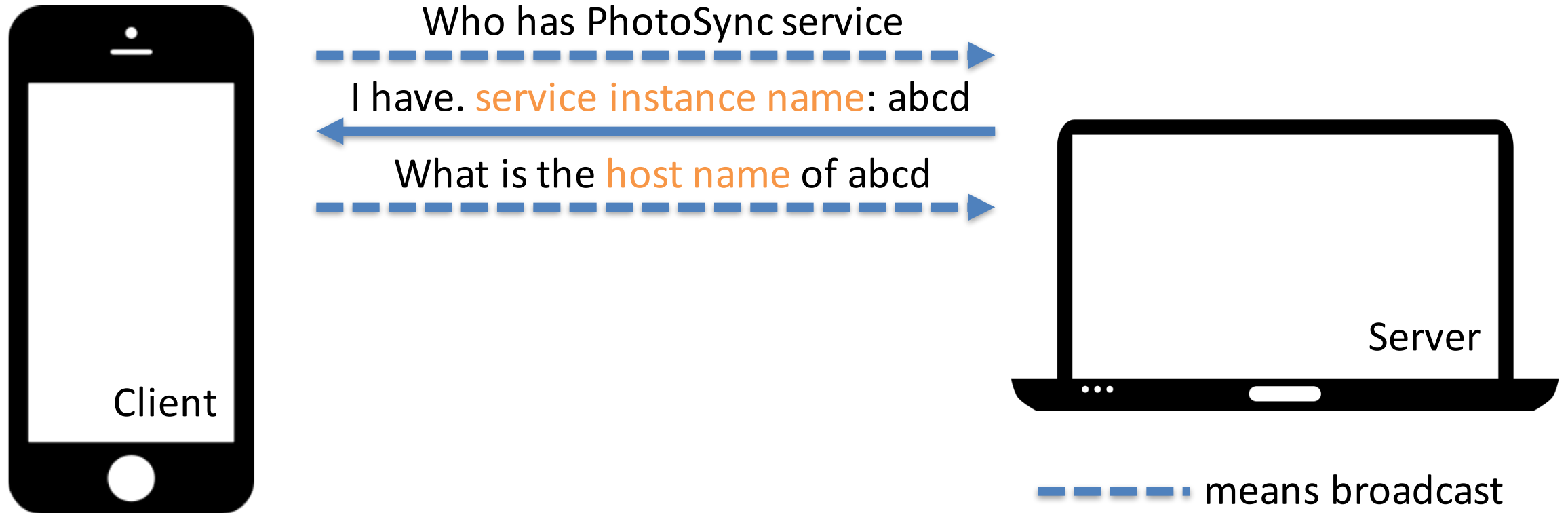
Normally

- Discovery: Server responds with service instance name



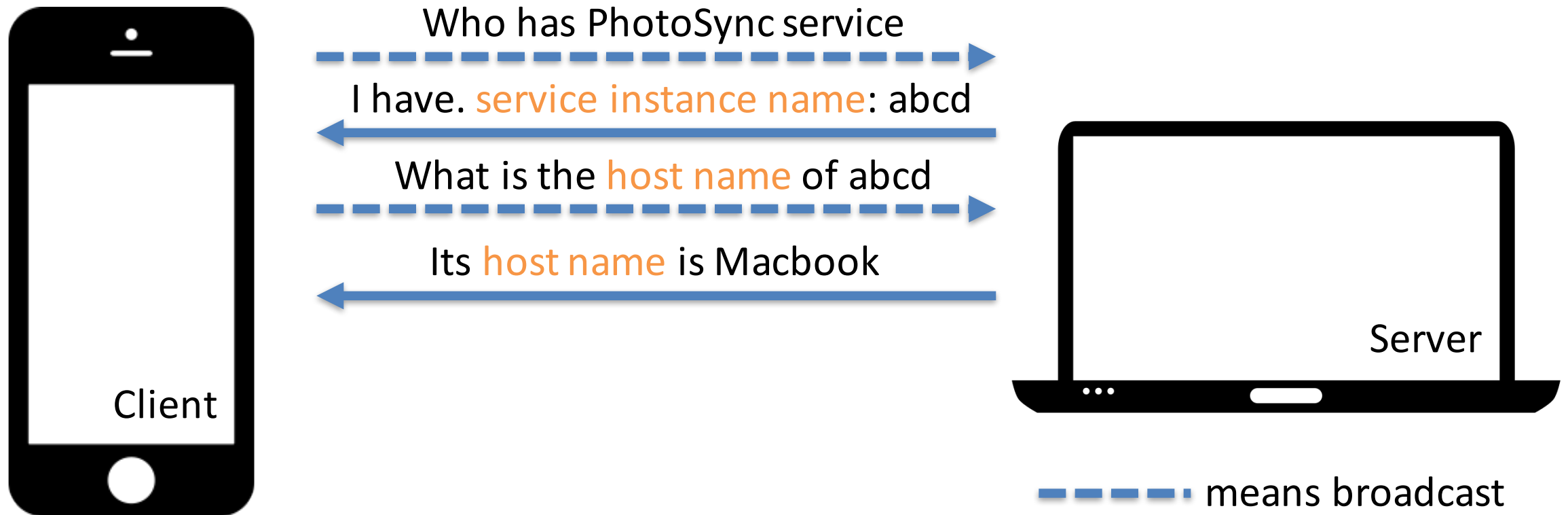
Normally

- Resolution 1: Client queries for the host name of the service



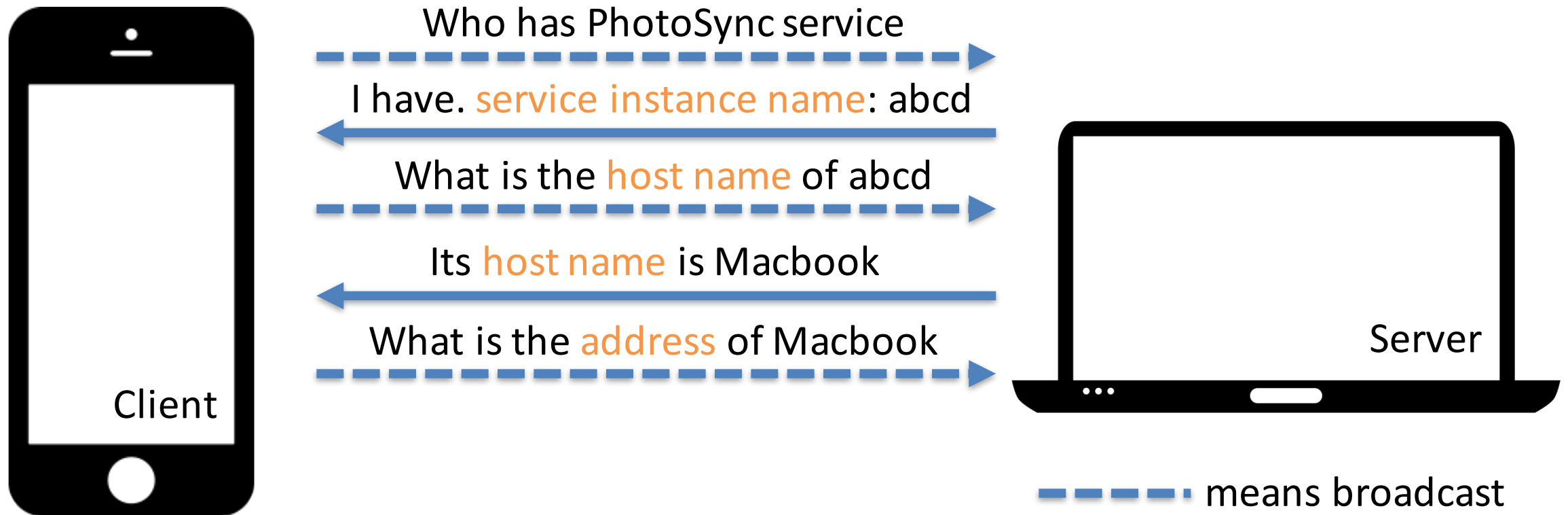
Normally

- Resolution 1: Server responds with the host name



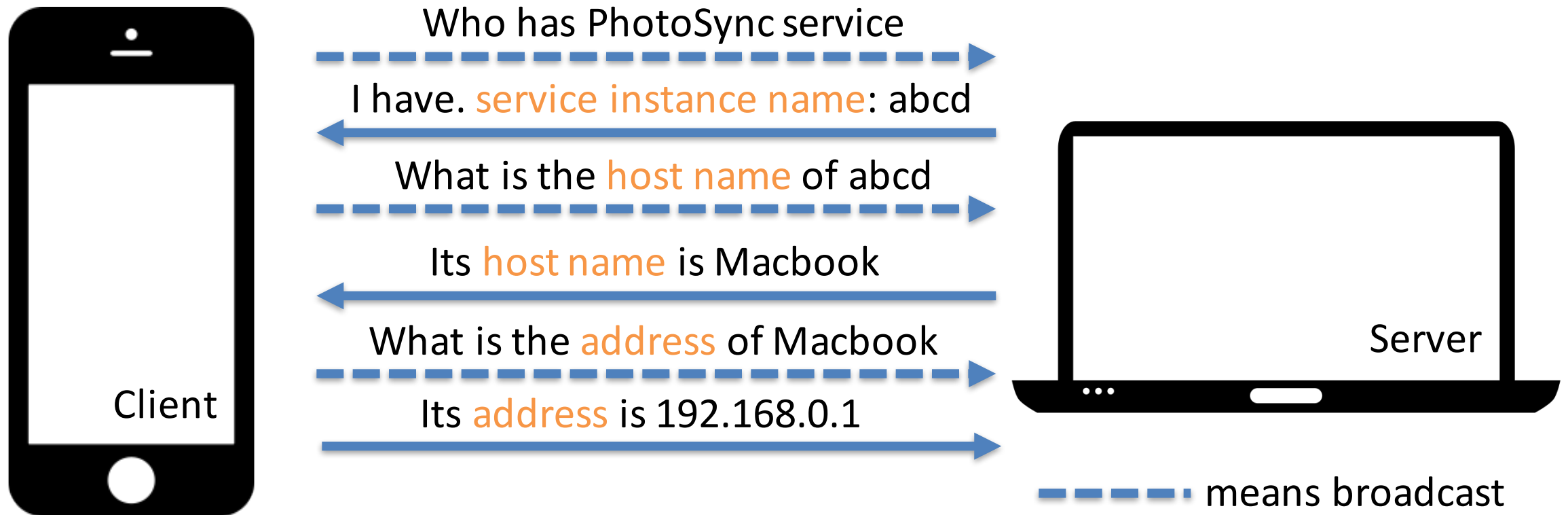
Normally

- Resolution 2: Client queries for the address of the host



Normally

- Resolution 2: Server responds with its address

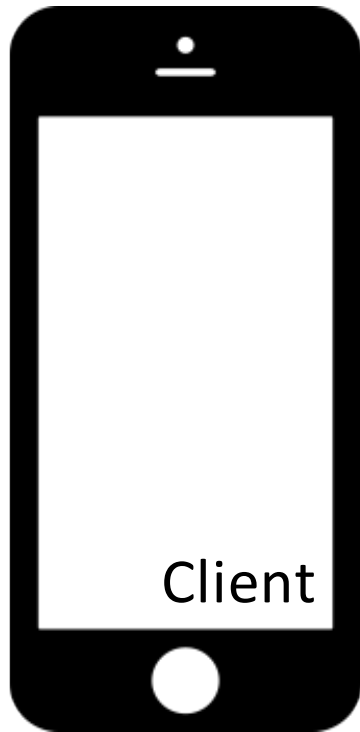


What Can Go Wrong?

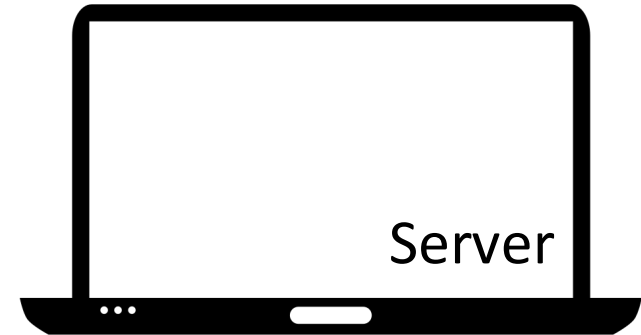
- Another malware-infected device spoofs the client
 - Successful Man-in-the-Middle
- During Resolution
 - Service instance name to host name
 - Host name to address

What Can Go Wrong?

- Attack 1: service instance name to host name

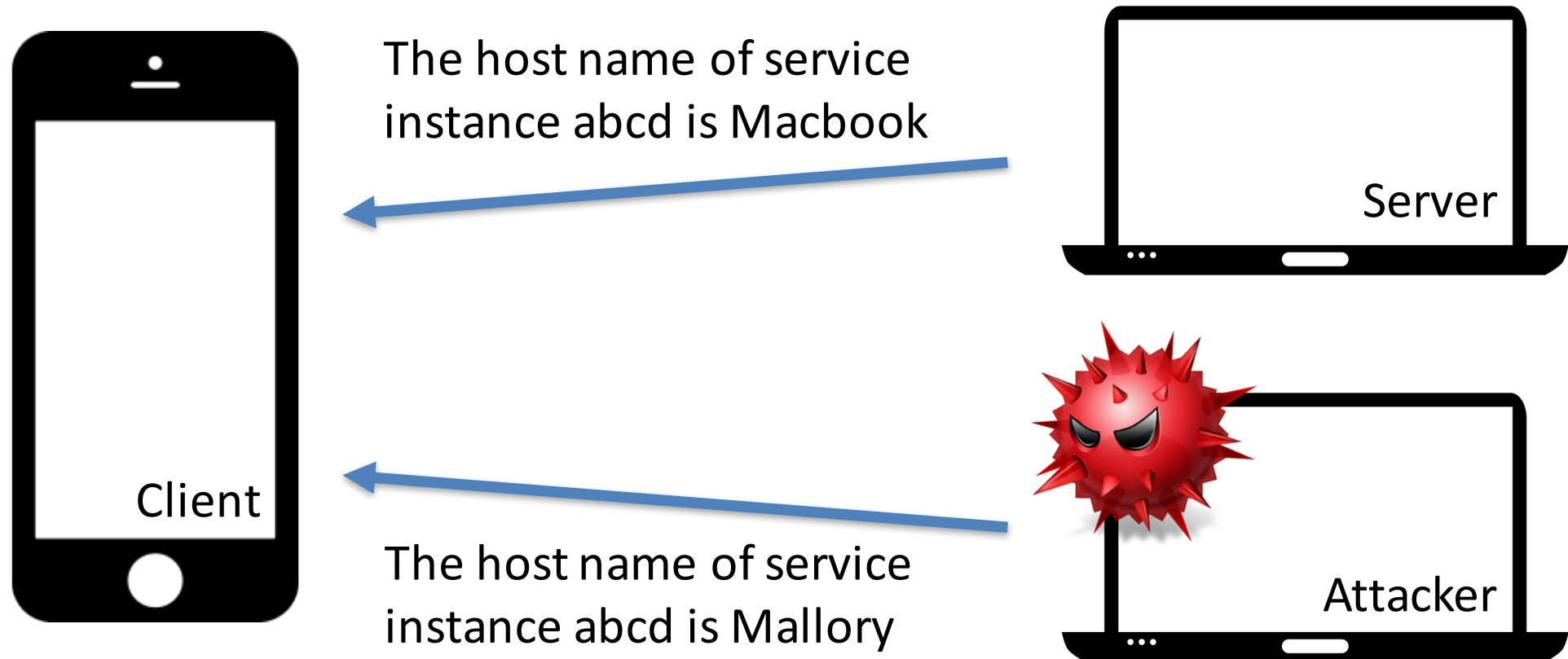


What is the **host name** of service instance abcd



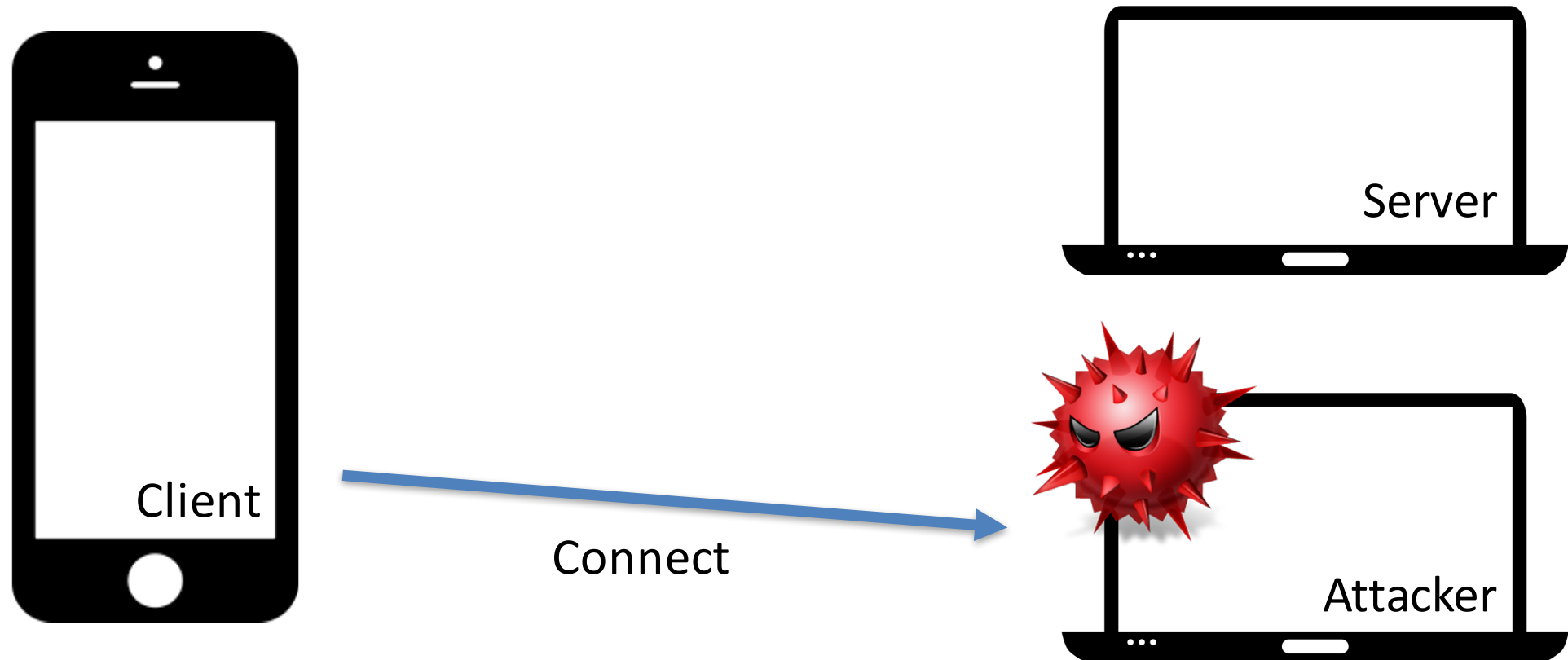
What Can Go Wrong?

- Attack 1: service instance name to host name



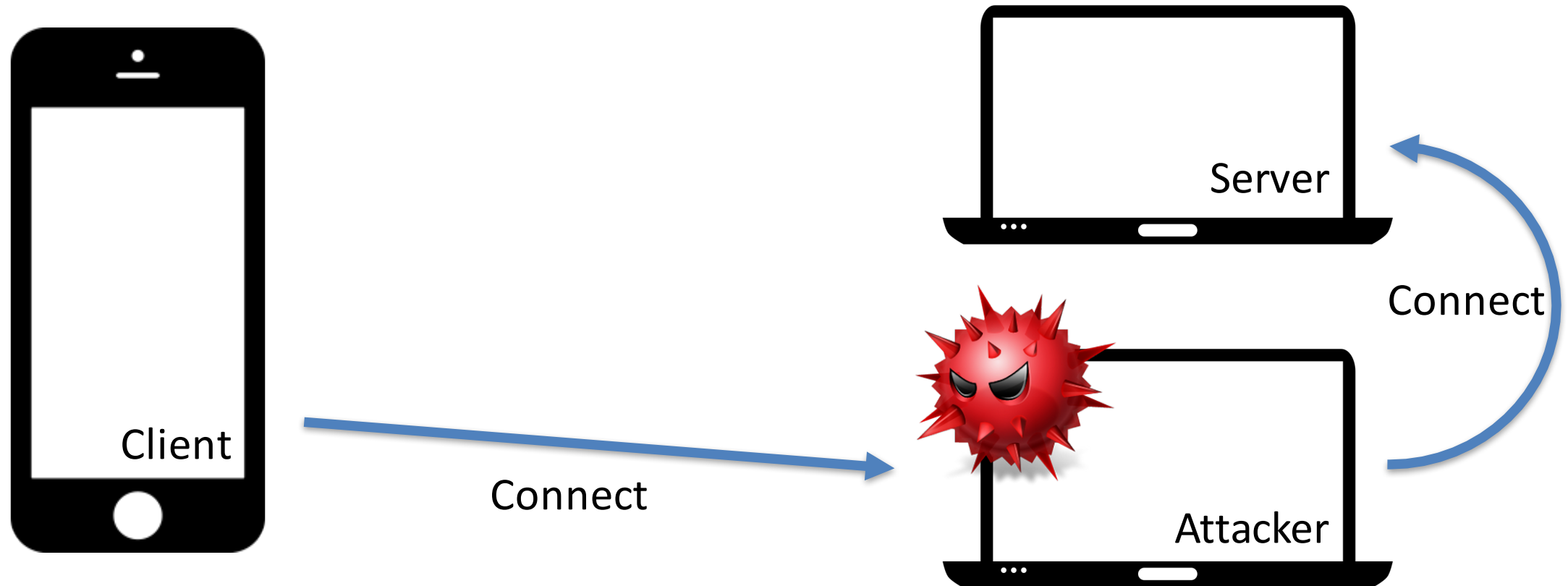
What Can Go Wrong?

- Attack 1: service instance name to host name



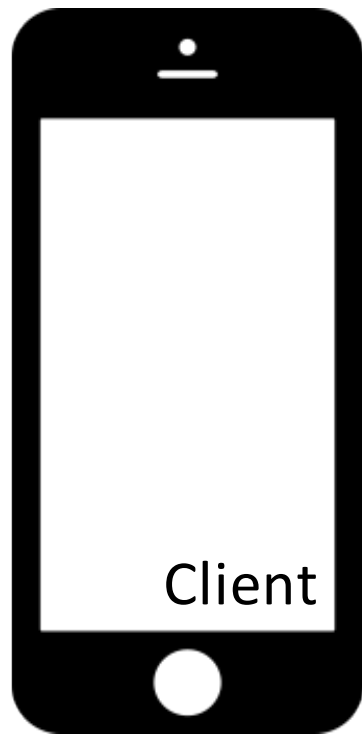
What Can Go Wrong?

- Attack 1: service instance name to host name

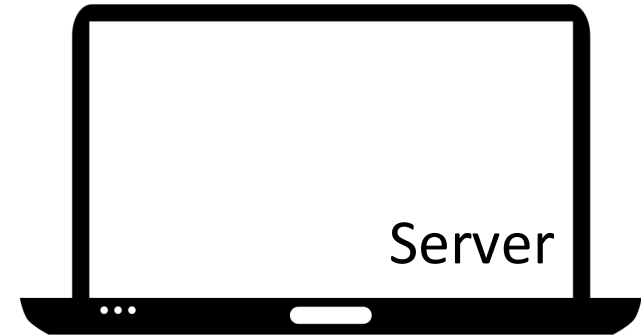


What Can Go Wrong?

- Attack 2: service instance name to host name

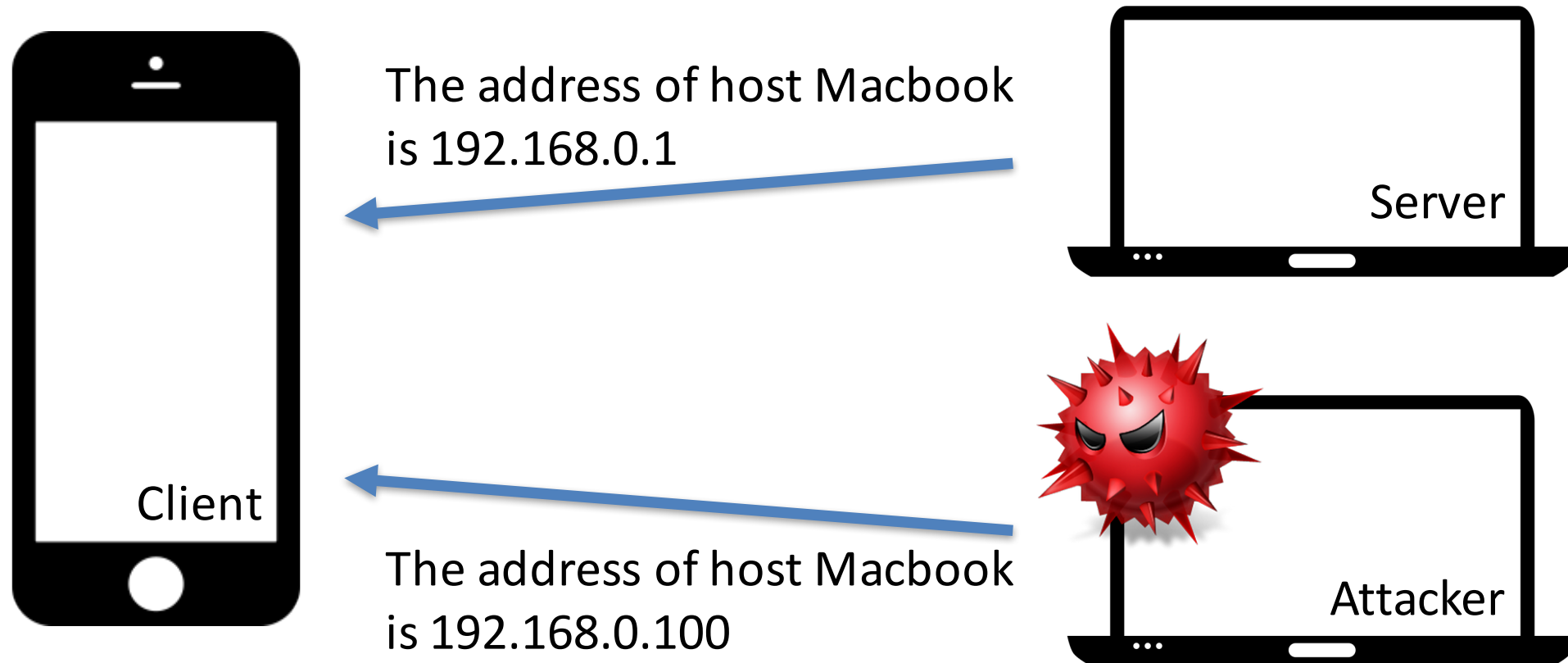


What is the **address** of
host Macbook



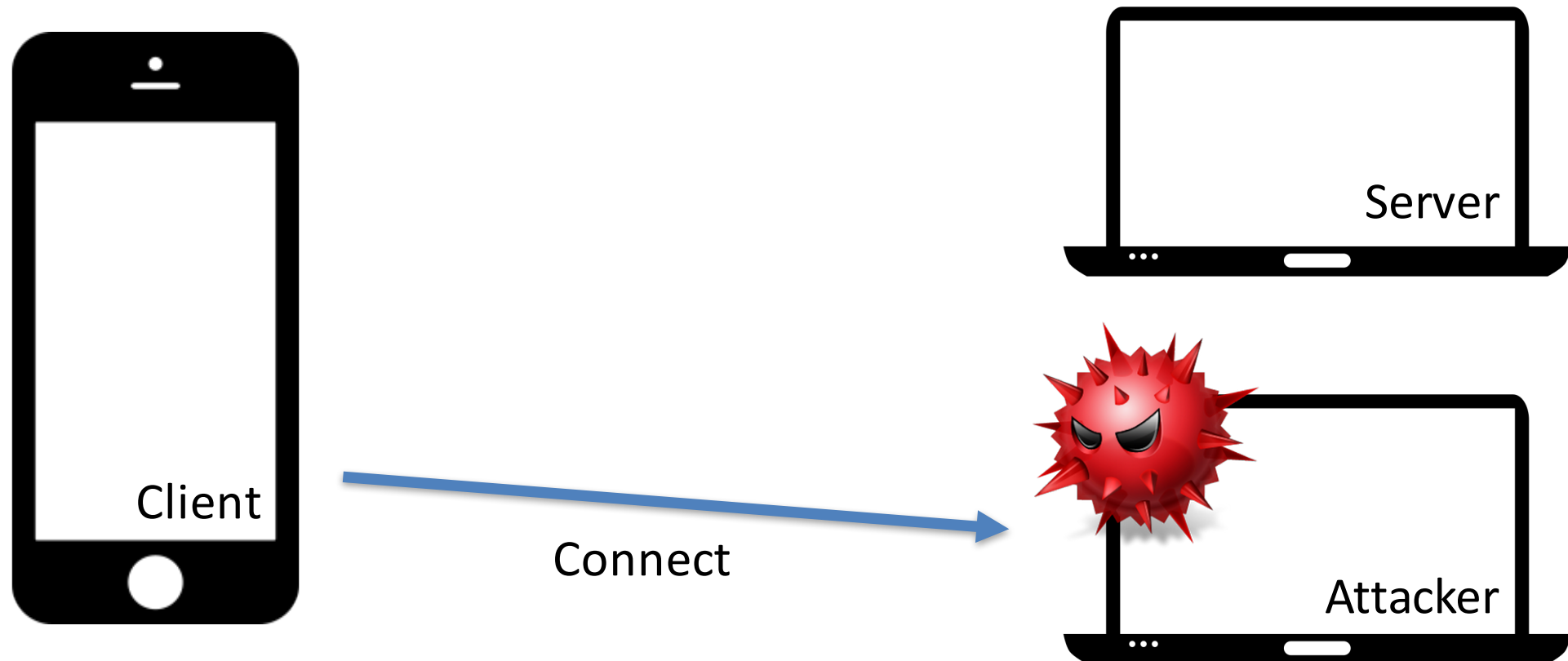
What Can Go Wrong?

- Attack 2: service instance name to host name



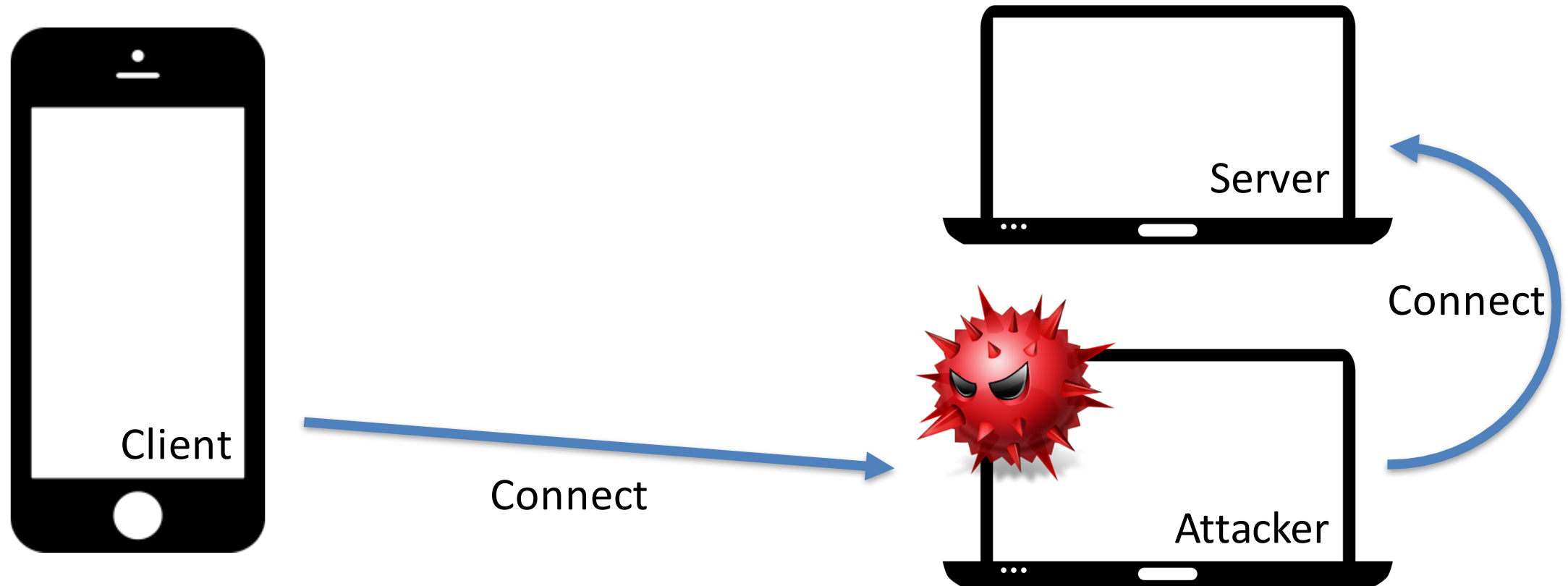
What Can Go Wrong?

- Attack 2: service instance name to host name



What Can Go Wrong?

- Attack 2: service instance name to host name



Demo

- <https://www.youtube.com/watch?v=WUWusqggqFr0&feature=youtu.be>

Fundamental Problem

- Lack of authentication
- Anyone can claim any value of the identification attributes
- The protocol only guarantees no duplicates, but not security.

Is it easy to provide authentication?

No!

1. ZeroConf Concept
2. ZeroConf How
3. ZeroConf Breaking

Case 2: Airdrop

Airdrop between Apple devices

- With AirDrop, you can share photos, videos, websites, locations, and more with people nearby with an Apple device.

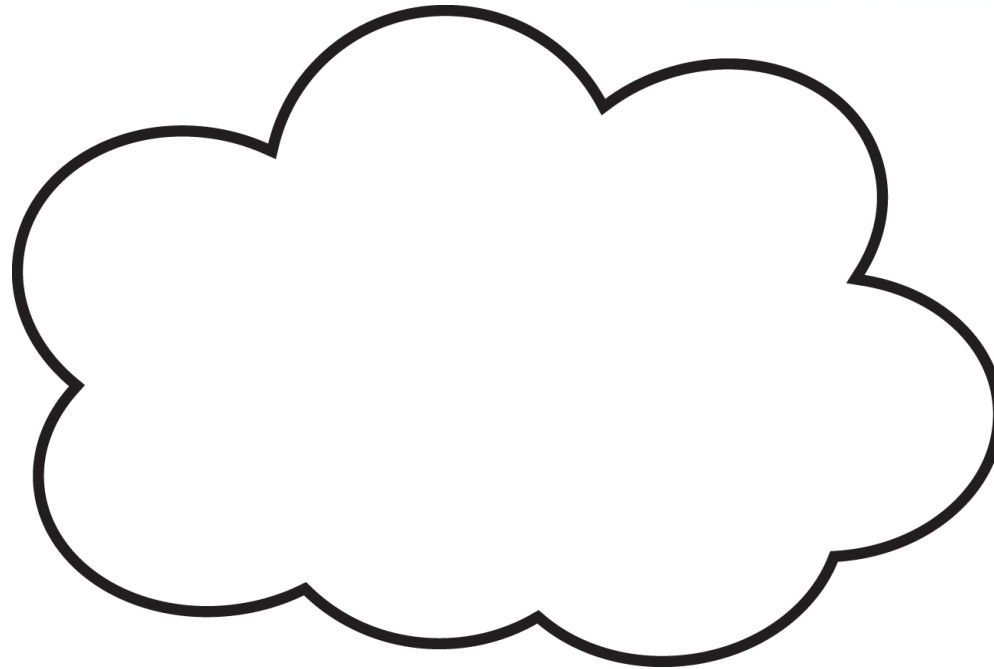


Attack Airdrop



Jeff's Macbook:
Q1: Anyone has an
airdrop service?

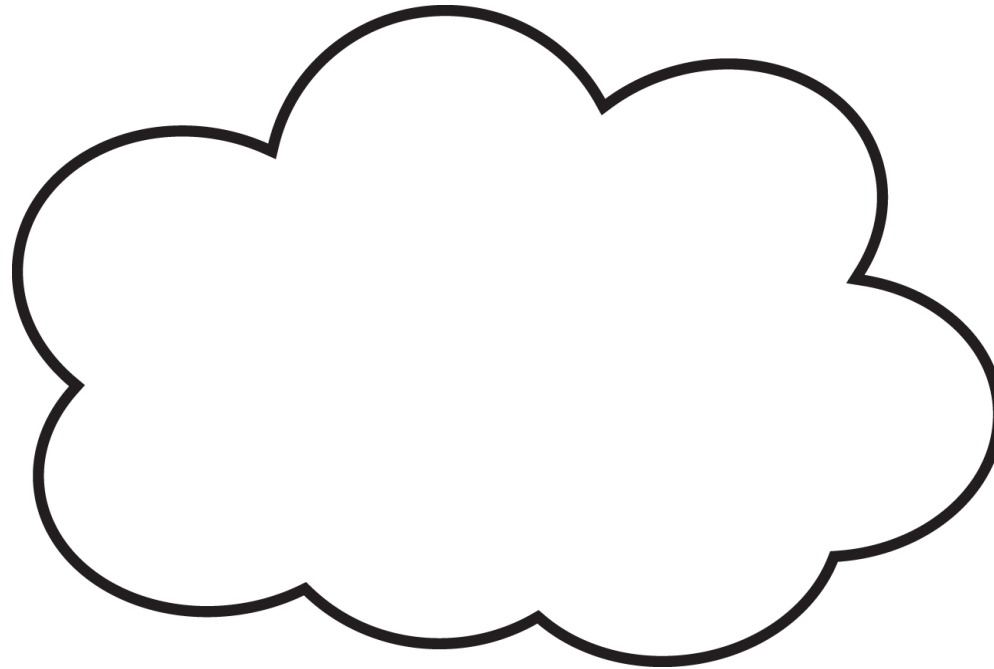
Alice's iPhone:
I have a **service** named
abcd.airdrop.service



Attack Airdrop



Jeff's Macbook:
Q2: So **on which host** is
Alice's service?



Attack Airdrop



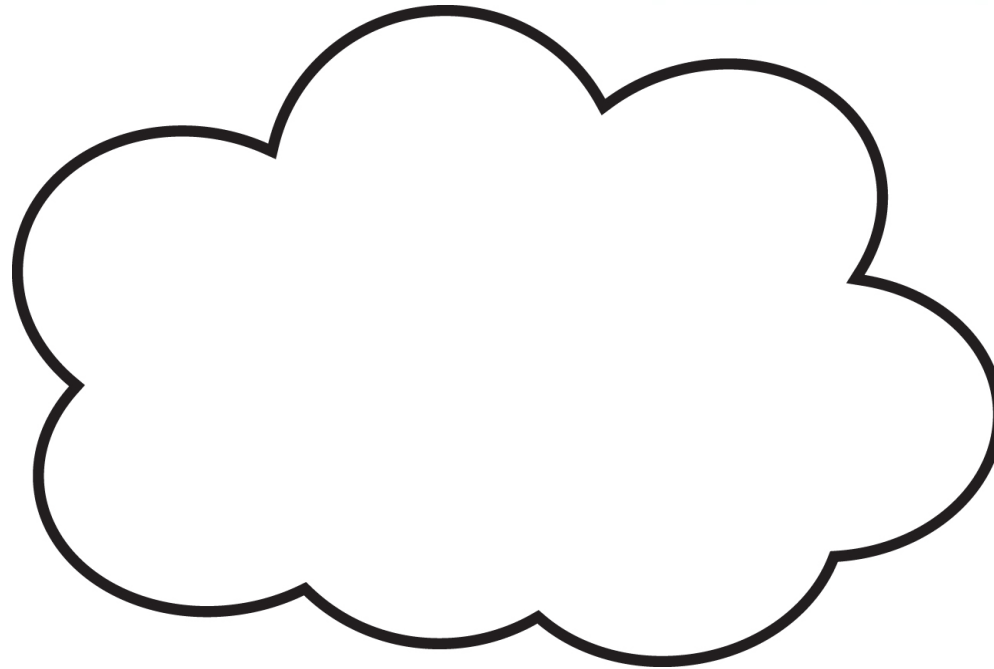
Jeff's Macbook:

Q2: So **on which host** is
Alice's service?

Alice's iPhone:

A2: It's **on host**

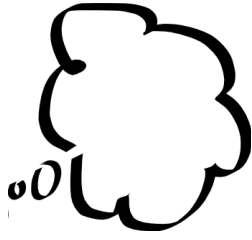
Alices.iphone.local



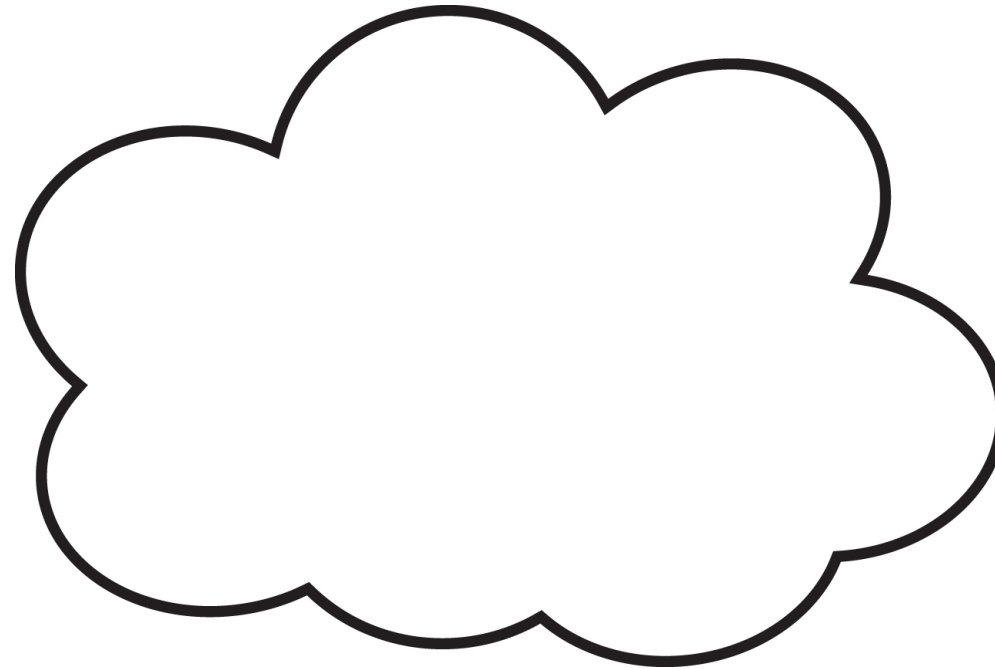
Bob's iMac:

A2: It's **on host** Bobs.imac.local





Alice's iPhone has service named abcd.airdrop.tcp,
which is on host Bobs.imac.local



Jeff's Macbook:
Q2: So on which host is
Alice's service?

Alice's iPhone:
A2: It's on host
Alices.iphone.local



Bob's iMac:
A2: It's on host Bobs.imac.local



Does TLS help?



Jeff's Macbook:
Connect

<https://Bobs.imac.local>

Alice's iPhone:

A2: It's **on host**

Alices.iphone.local



Bob's iMac:

A2: It's **on host** Bobs.imac.local



TLS in Airdrop



Jeff's Macbook

https://Bobs.imac.local

Server certificate issued to **appleid.CDEF** ...



Bob's iMac



https://Alices.iphone.local

Server certificate issued to **appleid.ABCD**...



Alice's iPhone

So the certificate in airdrop
can hardly be used for authentication.

https://Bobs.imac.local

Server certificate issued to **appleid.CDEF...**



Bob's iMac



Jeff's Macbook



https://Alices.iphone.local

Server certificate issued to **appleid.ABCD...**



Alice's iPhone

Domain should match the certificate



Jeff's Macbook

https://Bobs.imac.local

Server certificate issued to **appleid.CDEF...**



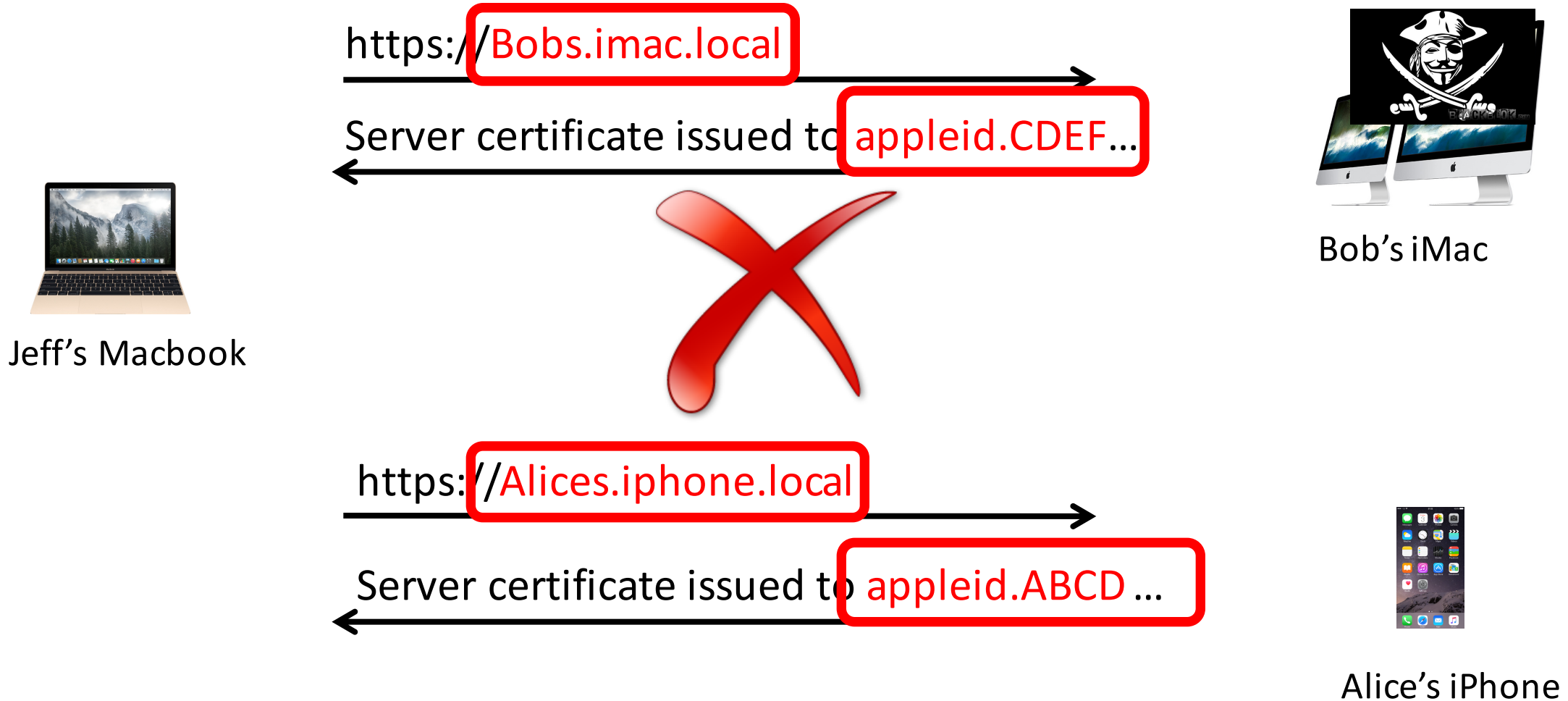
Bob's iMac

https://google.com

Certificate issued to **google.com**



Domain should match the certificate



What's wrong with TLS in Airdrop

- The certificate in airdrop cannot be used for authentication
 - E.g, certificate should be issued to Alice
 - but indeed issued to **appleid.ABCD...**
- The certificate should be issued to WHAT?

What's wrong with TLS in Airdrop

- Issue the certificate to the domain (host name)?
 - No. Host name may change and not representing a user
- Issue the certificate to the user's name?
 - No. Name can be duplicated
- Issue the certificate to the user's social security number?
 - No. social security number is too private

What's wrong with TLS in Airdrop

- Linking a human to her certificate is complicated
 - challenge in finding any identifiable information that are
 - well-known
 - no privacy implication
 - and unique

Demo

- <https://www.youtube.com/watch?v=2JEJLpvnRO4>

Technical Details

- Airdrop service daemon: `/usr/libexec/sharingd`
 - Responsible for Bonjour process and https connection
- Not ethernet interface, Apple private interface
 - `awdl0`: Apple Wireless Direct Link
 - Device-to-device direct link

Technical Details

- How to work on this interface?
 - sharingd uses an Apple-private socket option SO_RECV_ANYIF (0x1104)

```
on = 1;
status = setsockopt(handle->io_watcher.fd,
                    SOL_SOCKET,
                    0x1104,
                    &on,
                    sizeof(on));
if(status == -1){
    printf("setsockopt SO_RECV_ANYIF error\n");
}
```

Some customized ZeroConf protocols

- FileDrop
 - TCP packets for discovery
 - elliptic curve cryptography for security
 - Failed in authentication
 - challenge in linking a human to her public key

1. ZeroConf Concept

2. ZeroConf How

3. ZeroConf Breaking

Case 3: Apple's Vulnerable framework

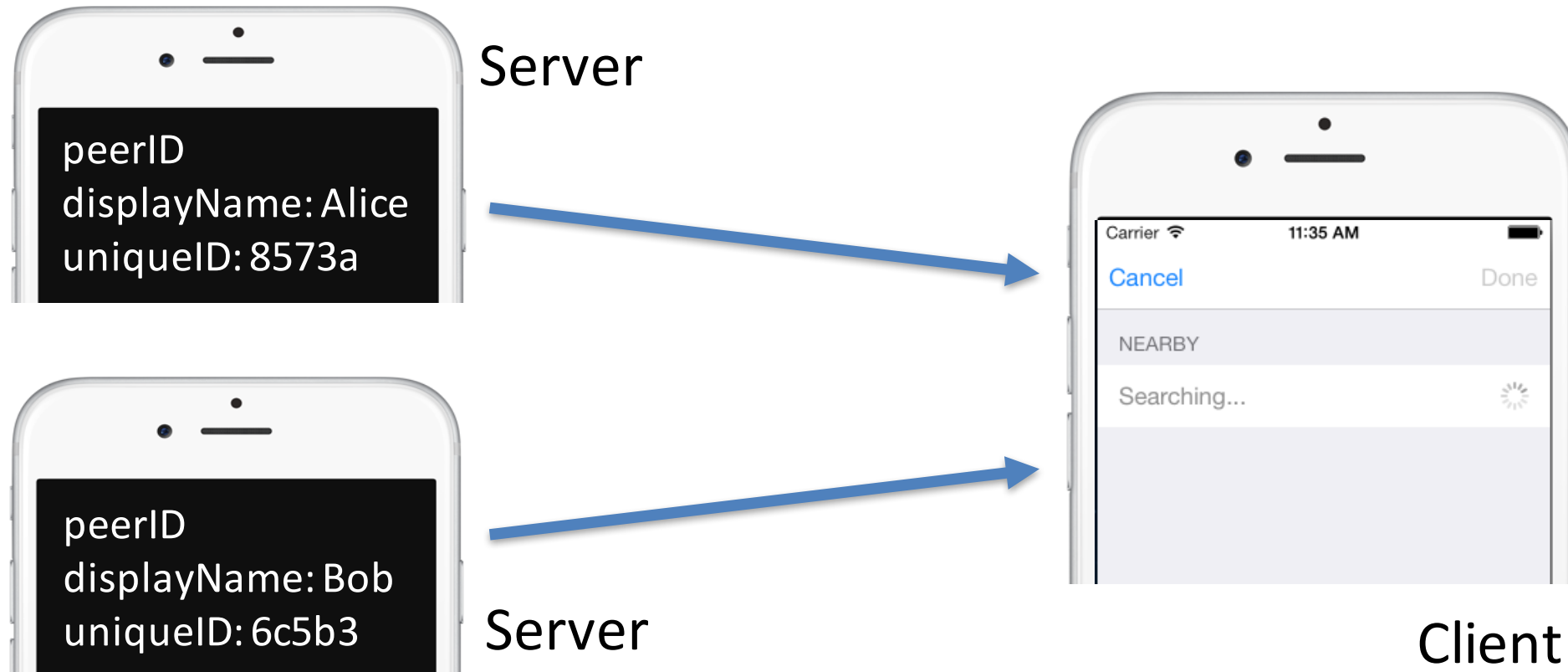
Apple's Vulnerable framework

- Multipeer Connectivity (MC)
 - A framework for automatic service discovery between nearby devices across Wi-Fi and Bluetooth without configuration
- Object to identify each app: peerID
 - displayName (public) & uniqueID (private)



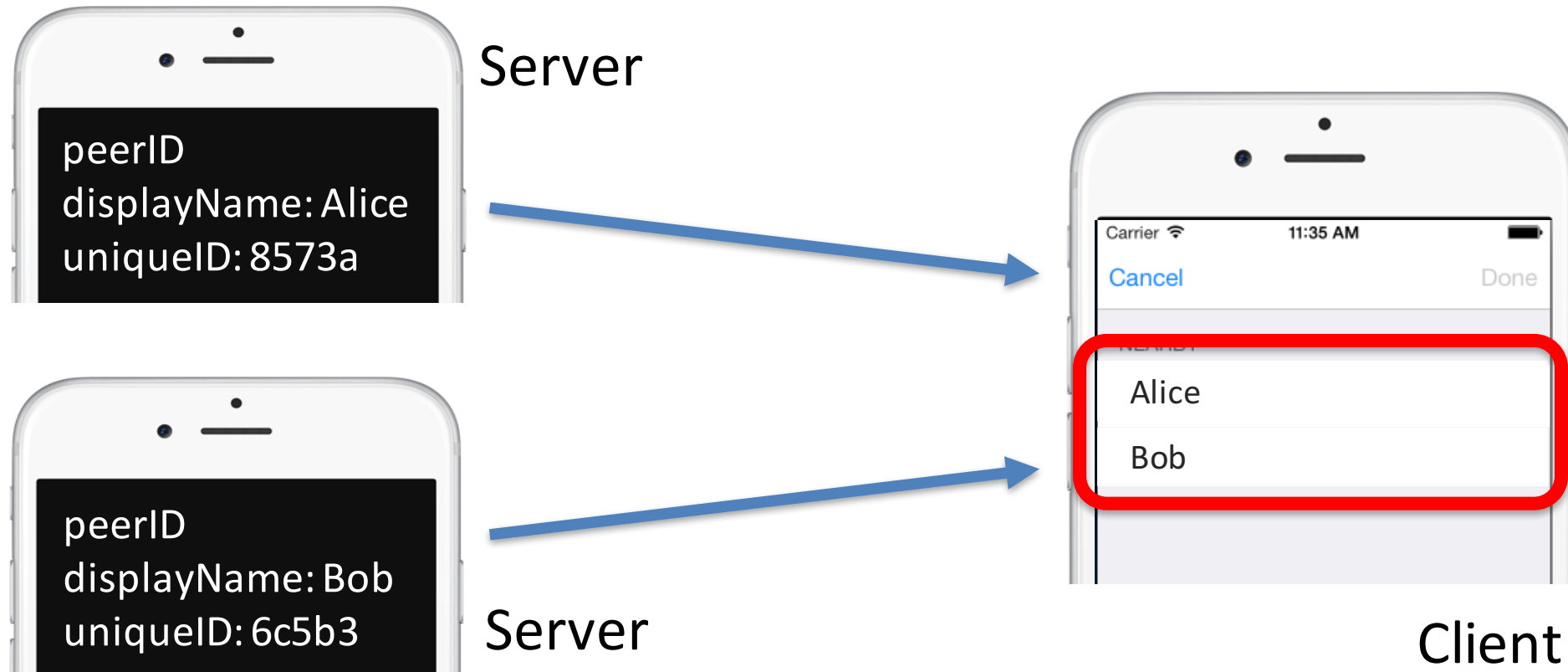
Normally

- Automatic Service Discovery Without Configuration
 - Servers advertise peerIDs



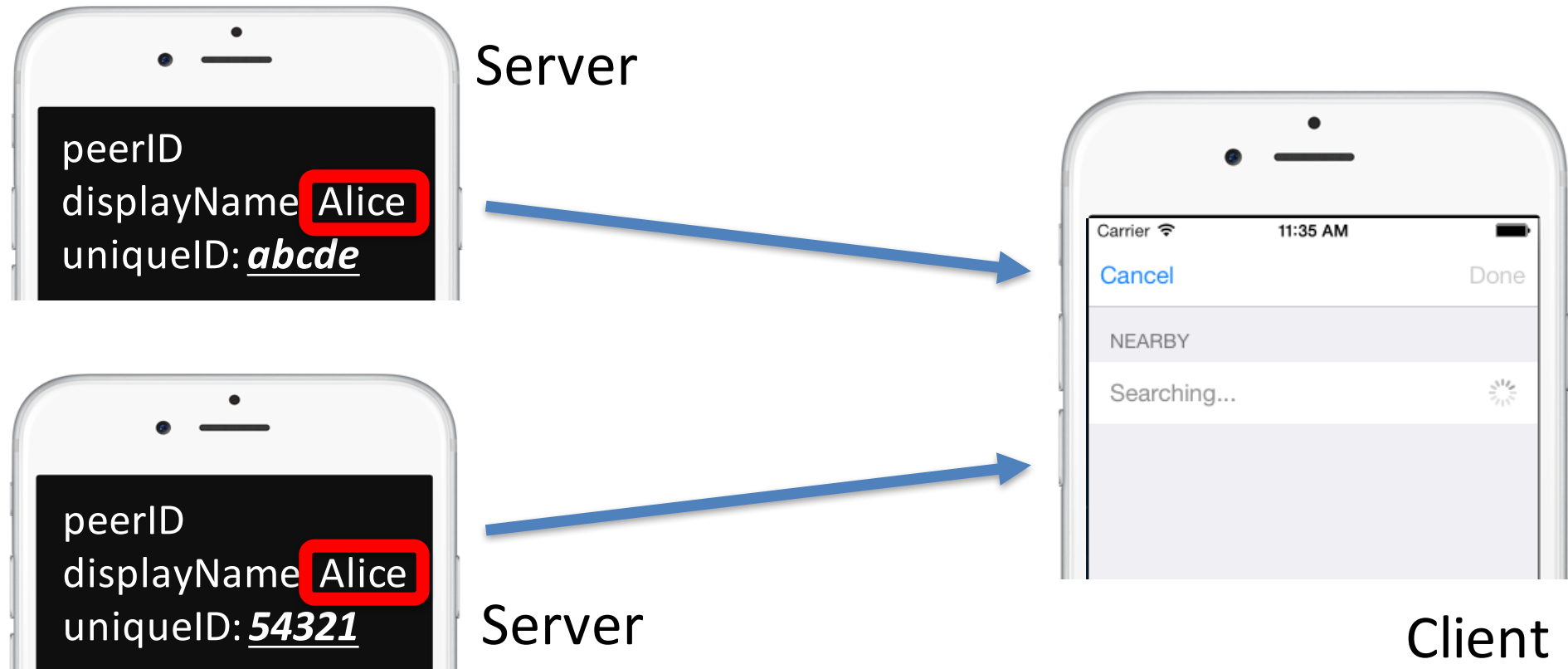
Normally

- Automatic Service Discovery Without Configuration
 - Servers advertise peerIDs, Client browse peerIDs (show displayName)



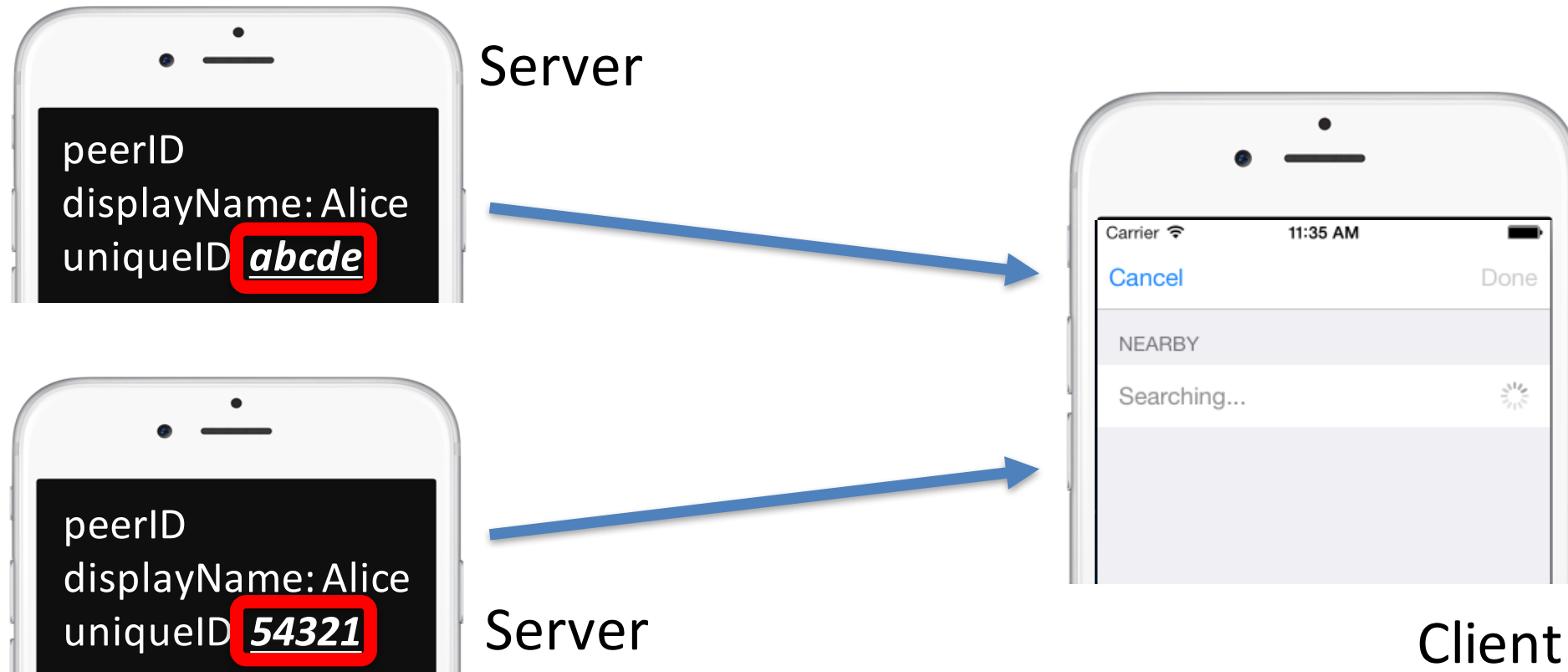
Normally

- Even if servers have the same displayName



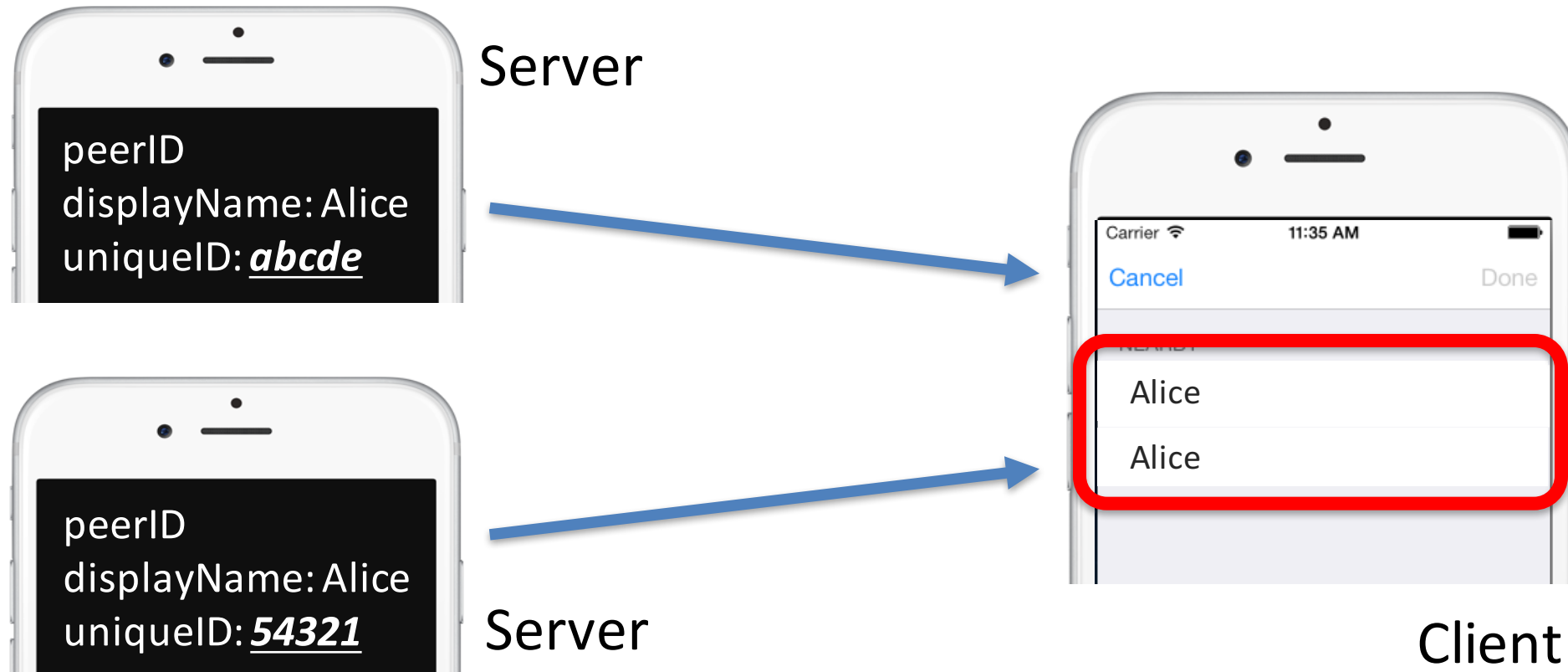
Normally

- Even if servers have the same displayName
 - uniqueIDs generated by MC will always be different



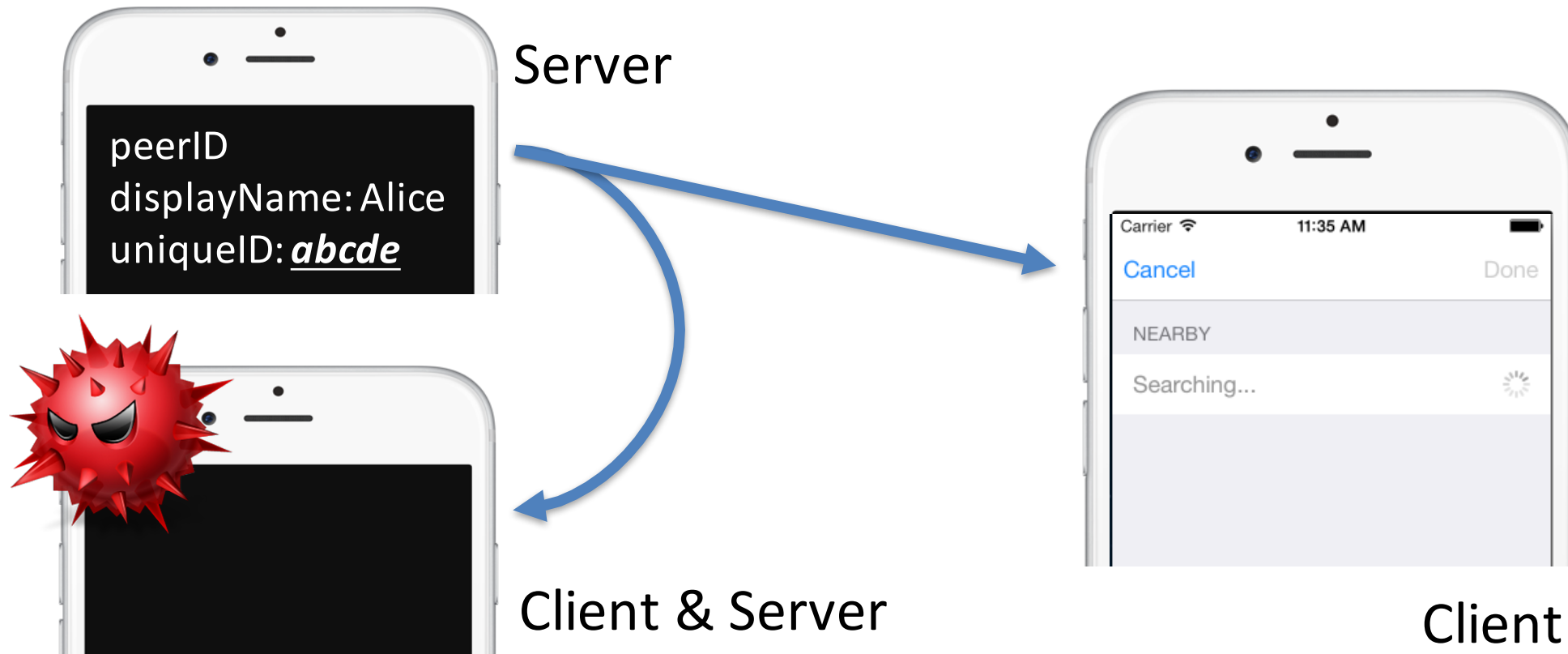
Normally

- Even if servers have the same displayName
 - uniqueIDs generated by MC will always be different



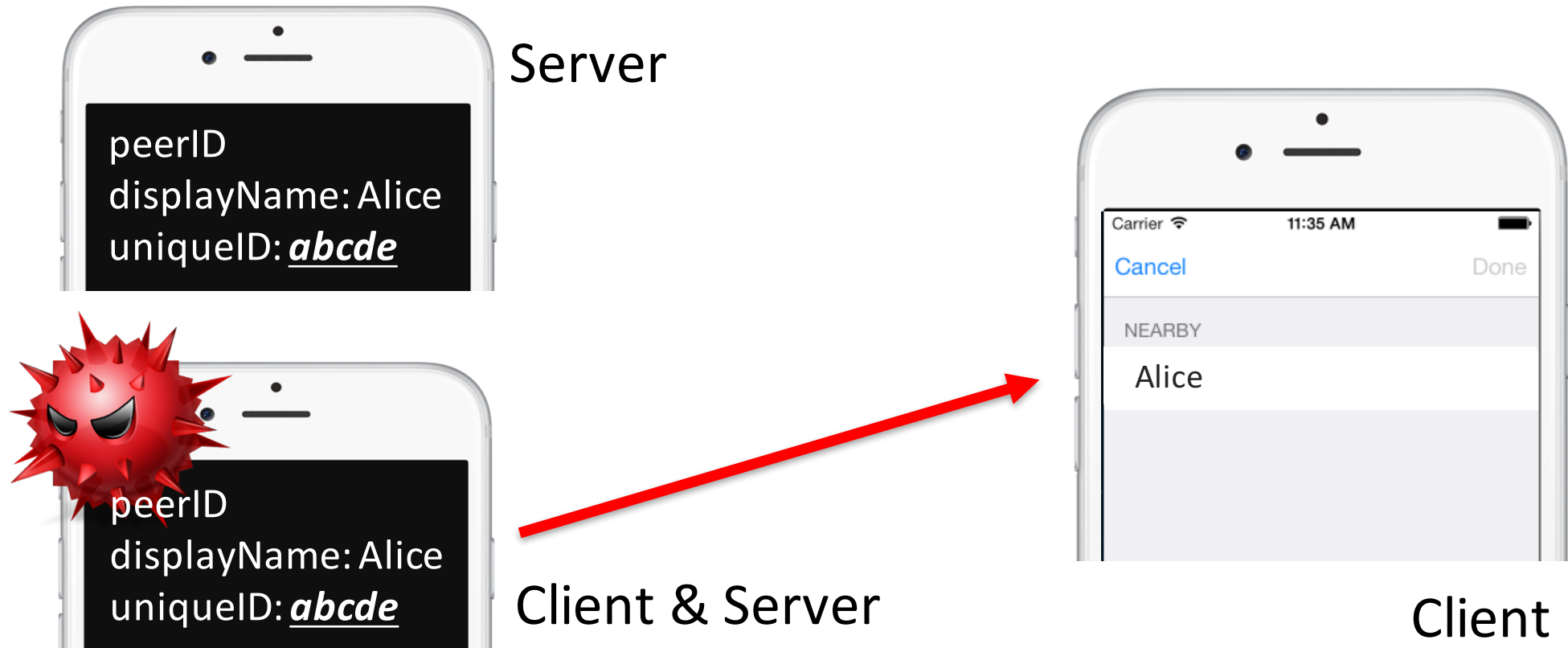
What Can Go Wrong?

- Attacker acts as both client and server
 - Browse and acquire peerID object from victim server



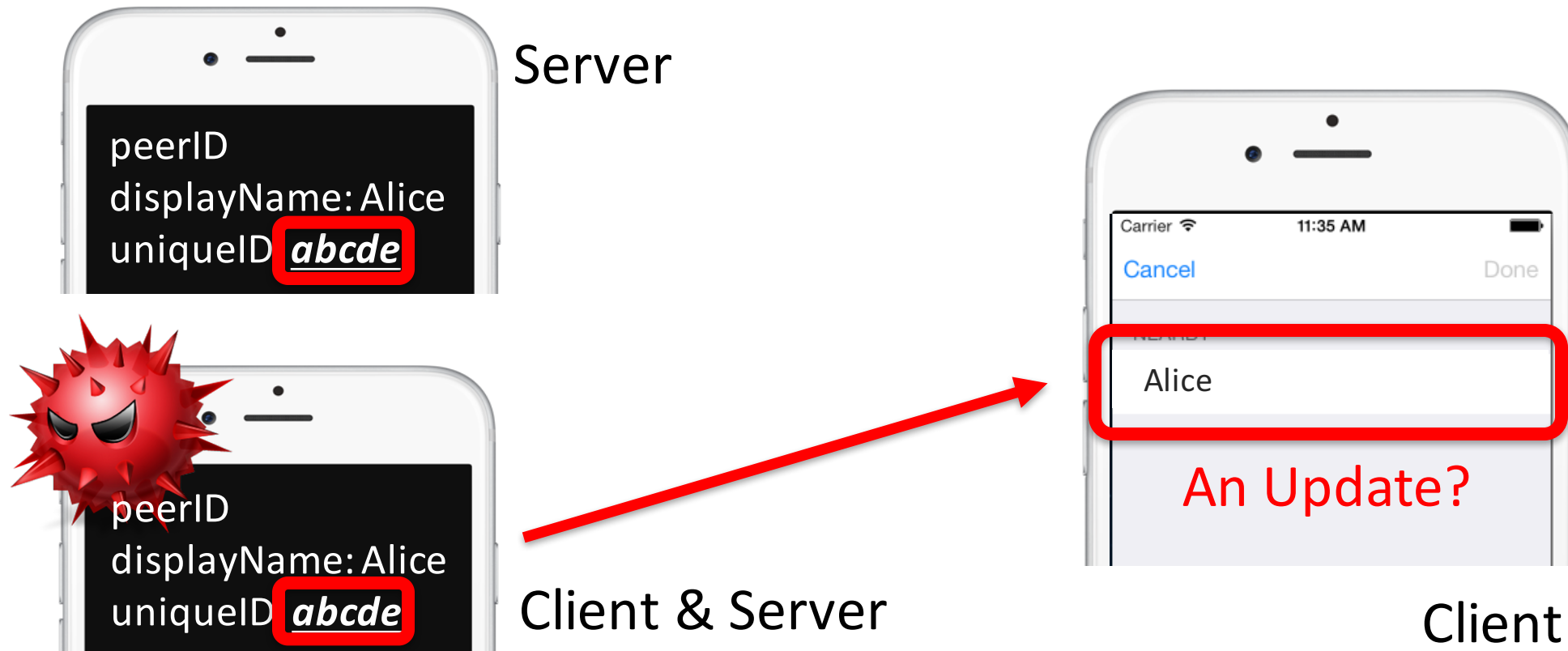
What Can Go Wrong?

- Attacker acts as both client and server
 - Advertise using the same peerID object



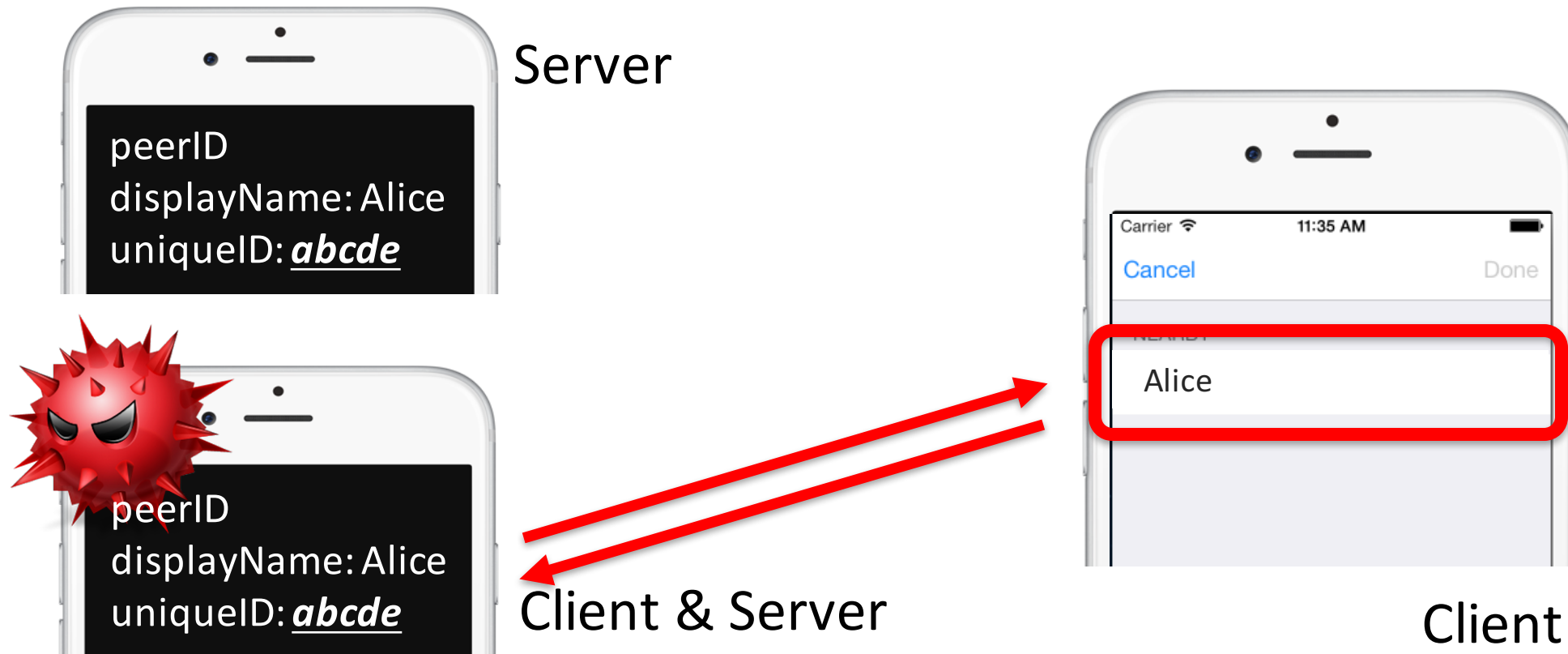
What Can Go Wrong?

- Client can not distinguish because of same uniqueID



What Can Go Wrong?

- Client can not distinguish because of same uniqueID
- Client maps the only peer to attacker's address (**MitM**)



Technical Details

- MitM attacker

- First acts as client browsing for advertising servers
- Once found a server, advertise using the same peerID

```
- (void)browser:(MCNearbyServiceBrowser *)browser foundPeer:(MCPeerID *)peerID withDiscoveryInfo:  
    (NSDictionary *)info {
```

```
    ...
```

```
    _advertiser = [[MCNearbyServiceAdvertiser alloc] initWithPeer:peerID discoveryInfo:info serviceType:  
        _serviceType];  
    _advertiser.delegate = self;  
    [_advertiser startAdvertisingPeer];
```

```
    ...
```

```
}
```

If not using peerID to for identification,
is it secure enough?

No!

1. ZeroConf Concept

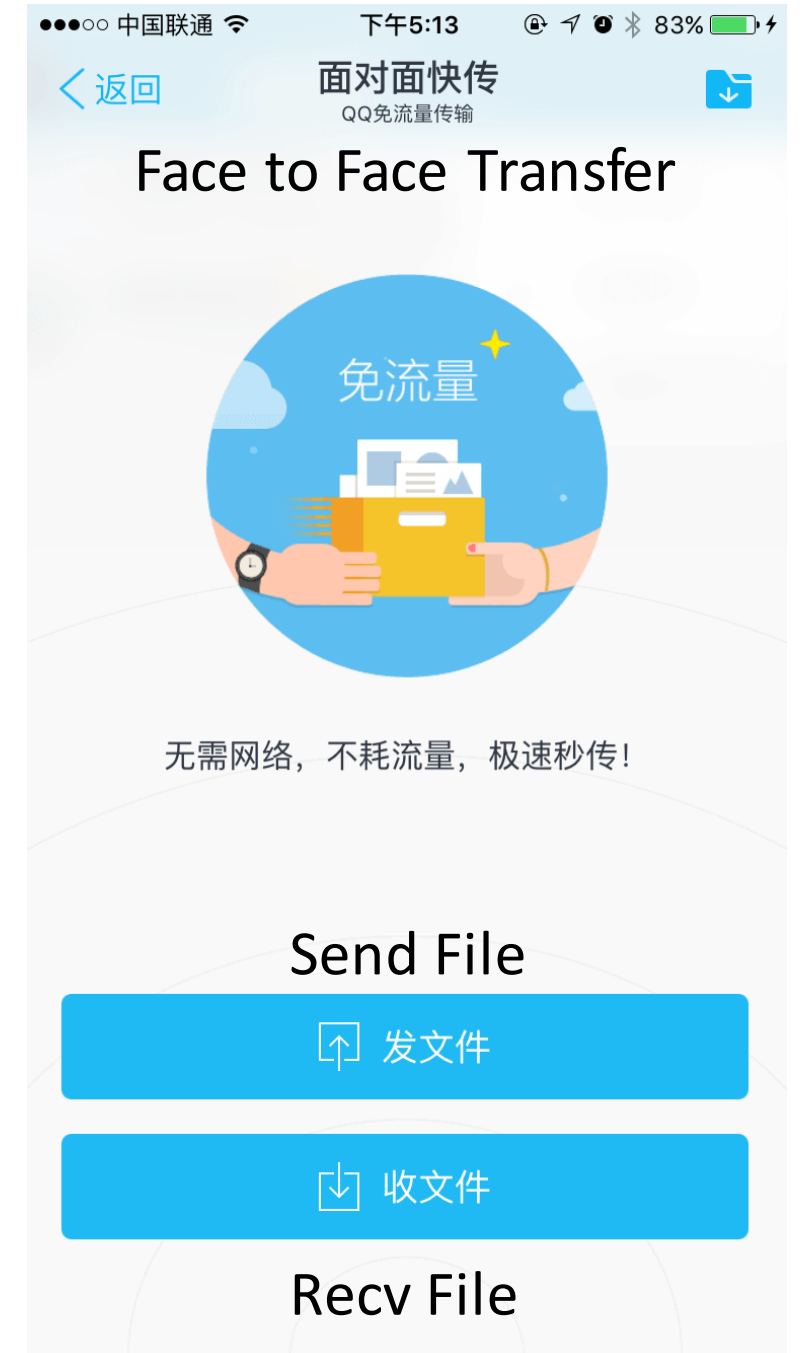
2. ZeroConf How

3. ZeroConf Breaking

Case 4: MC in QQ

MC in QQ

- Popular instant messaging software in CN
 - 829 million active accounts (Wikipedia)
- Face-To-Face Transfer
 - Transfer files between nearby peers by using Multipeer Connectivity
- Not using peerID for identification
 - Customized unique QQ ID



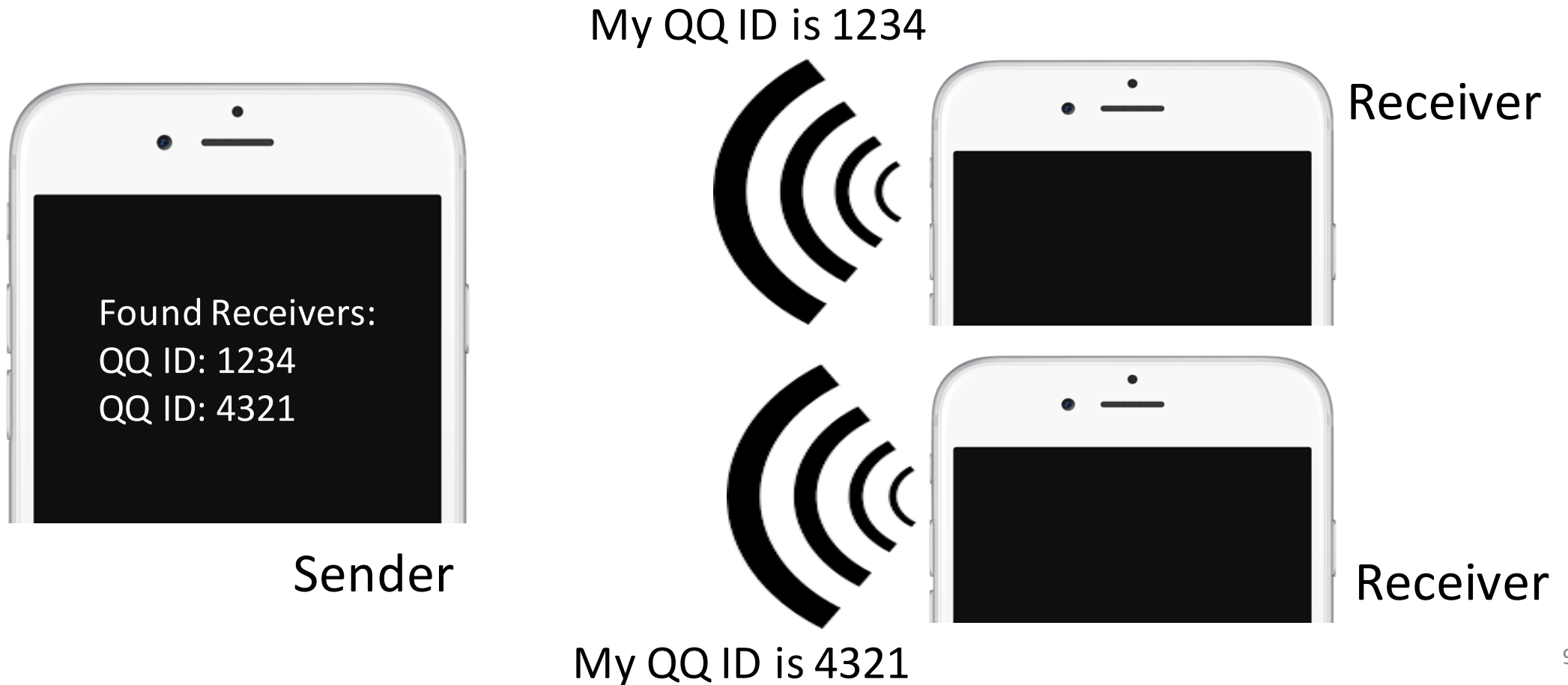
Normally

- Receiver advertises its QQ ID



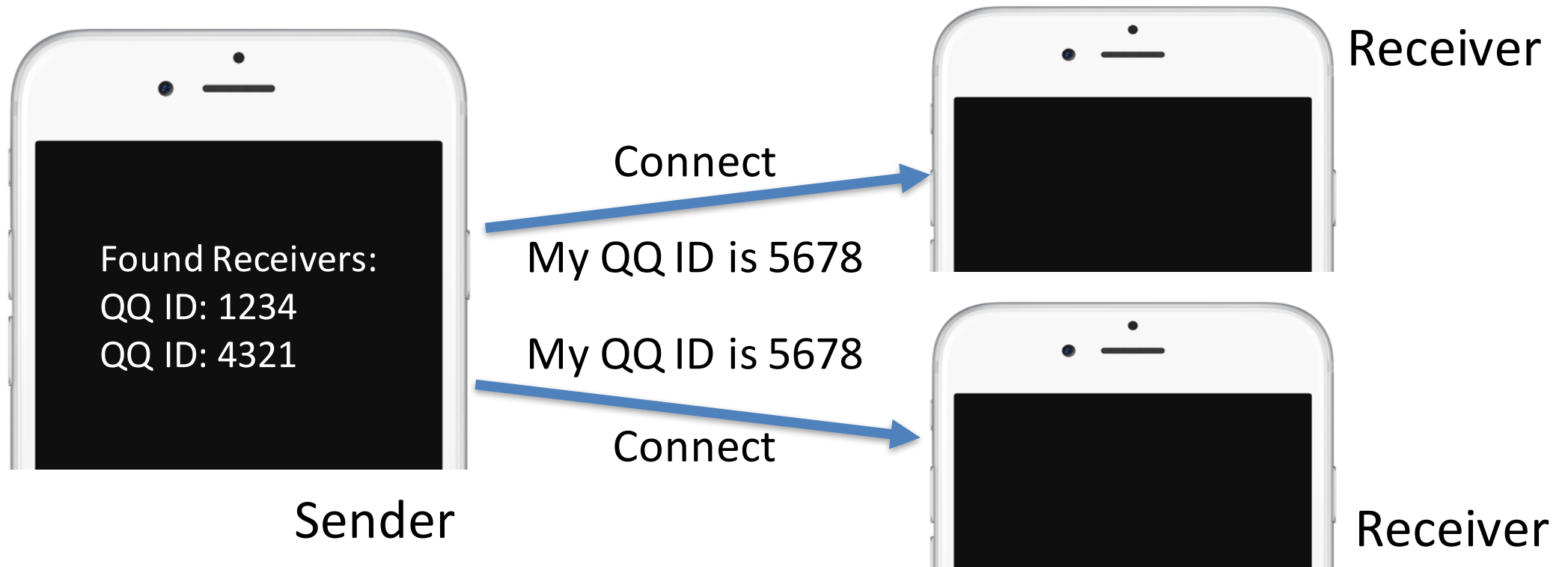
Normally

- Sender browses for receivers and found their QQ IDs



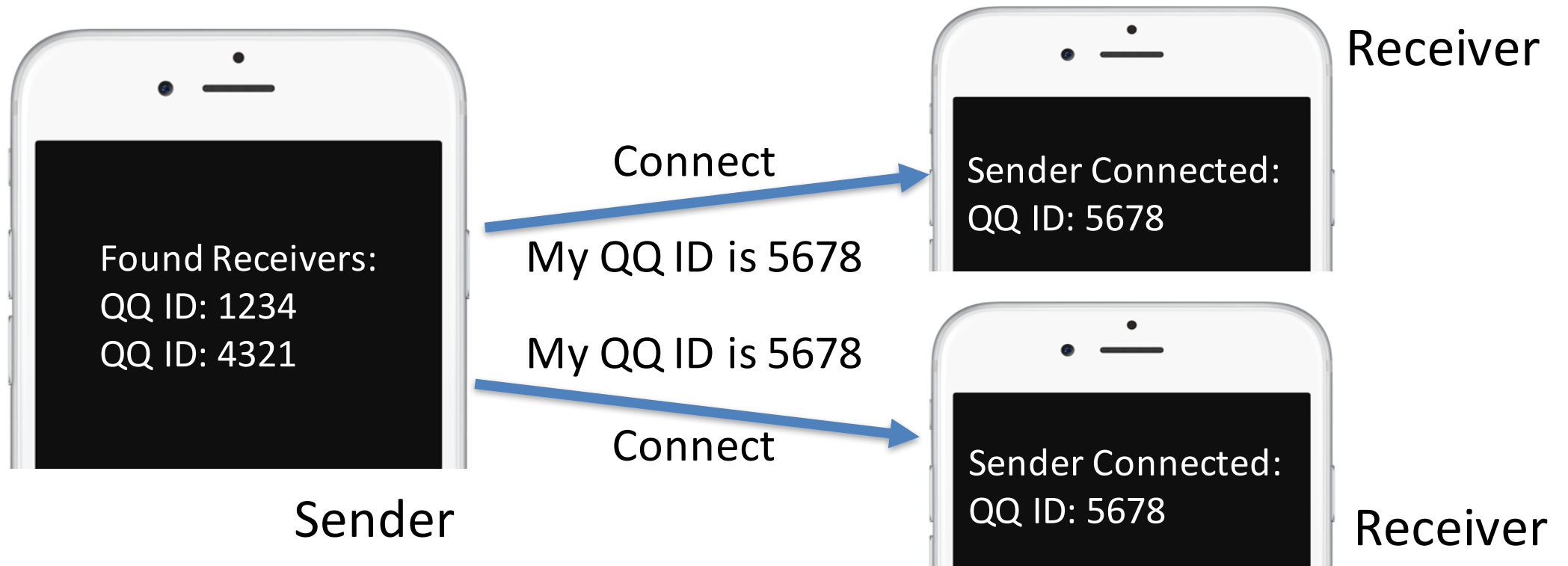
Normally

- Sender connects to receiver and gives its QQ ID



Normally

- Sender connects to receiver and gives its QQ ID

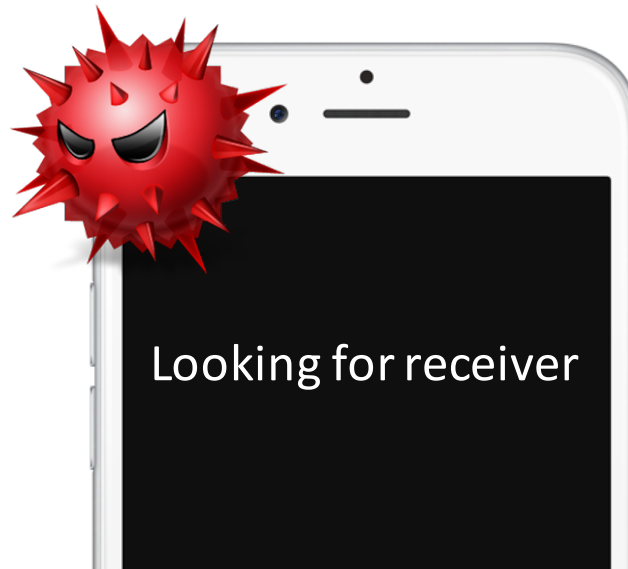


What Can Go Wrong?

- Receiver advertises its QQ ID

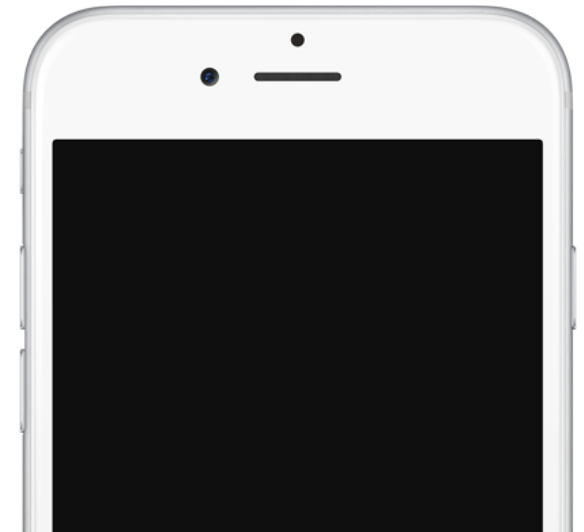


Sender



Attacker

My QQ ID
is 1234



Receiver

What Can Go Wrong?

- Attacker found victim receiver's QQ ID

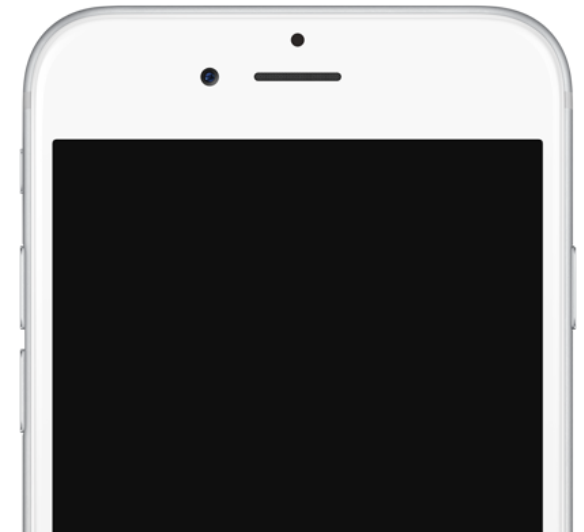


Sender



Attacker

My QQ ID
is 1234



Receiver

What Can Go Wrong?

- Attacker advertise using the same QQ ID



What Can Go Wrong?

- Sender found only one QQ ID



What Can Go Wrong?

- Sender connects to Attacker



What Can Go Wrong?

- Attacker connects to Receiver using the Sender's QQ ID



Demo

- https://www.youtube.com/watch?v=B71FID3_vrc

1. ZeroConf Concept

2. ZeroConf How

3. ZeroConf Breaking

Case 5: Bluetooth

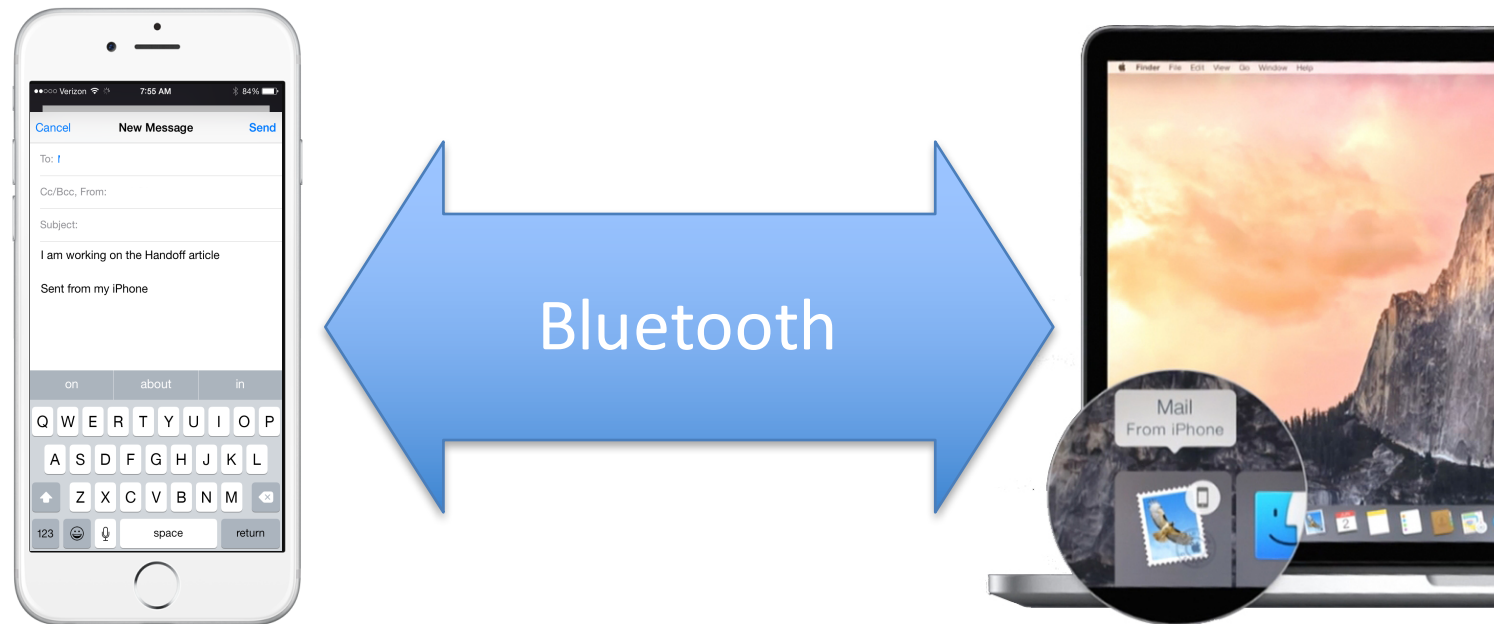
All your iOS notifications belong to me

- ZeroConf on Bluetooth: Apple Handoff
 - A service that lets iOS and OS X synchronize data through Bluetooth without configuration



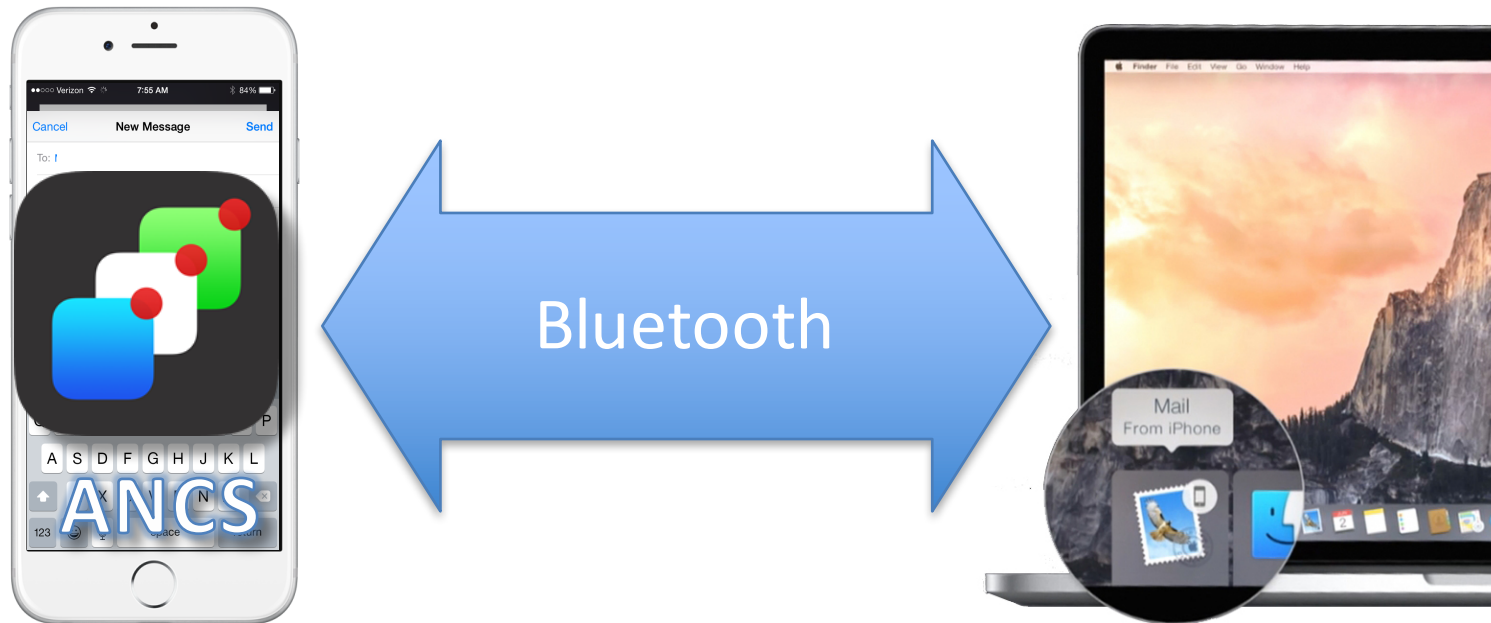
Normally

- Handoff creates Bluetooth Channel without configuration
 - Devices logged in with the same iCloud account
 - Pairing automatically through iCloud account



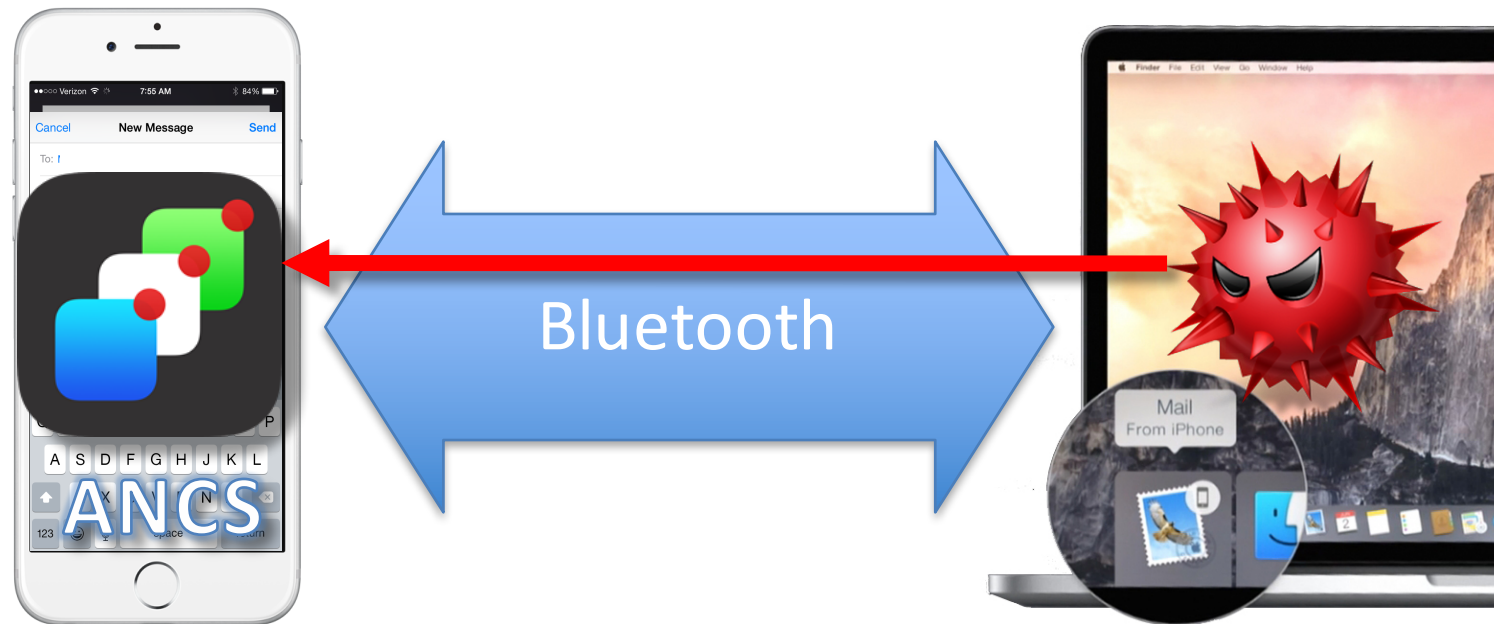
What Can Go Wrong?

- Bluetooth ZeroConf: No app-level authentication
- Apple Notification Center Service (ANCS)
 - designed for Bluetooth accessories to access notifications on iOS devices



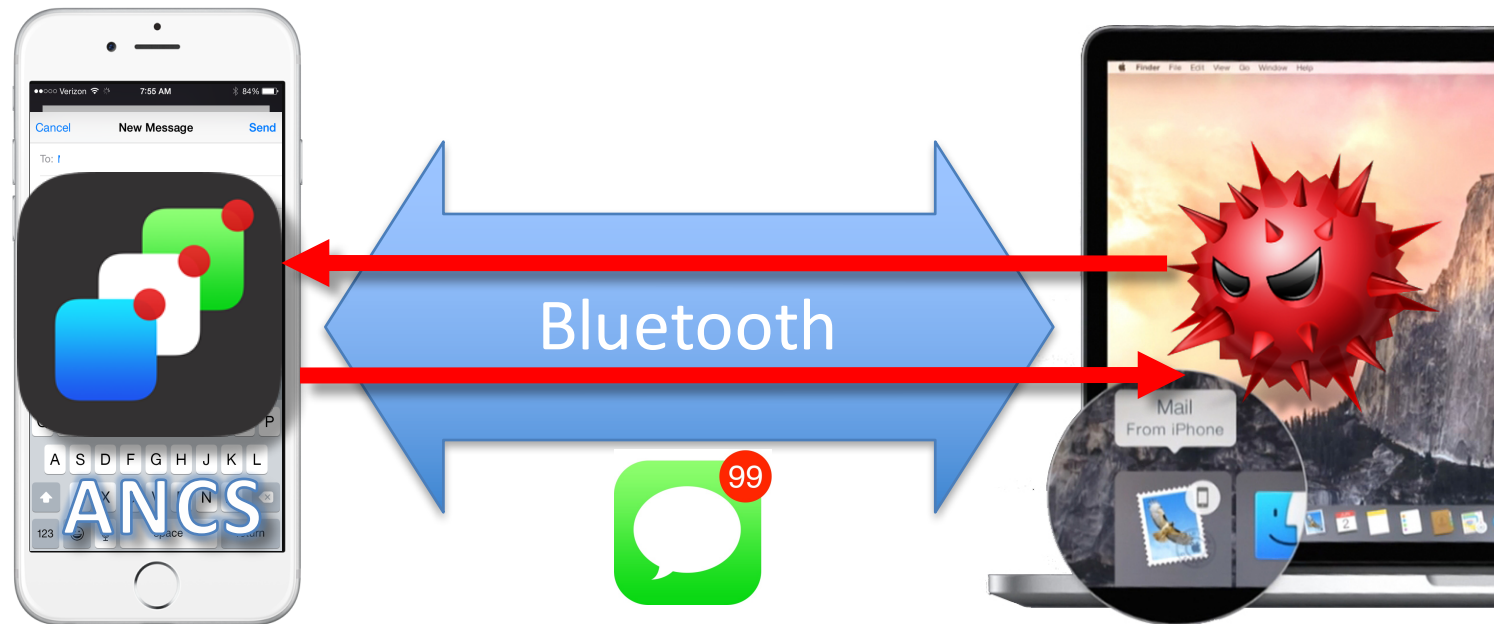
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What Can Go Wrong?

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Demo

- <https://www.youtube.com/watch?v=c5viAzAs0Uo>

Summary of attacks

- Attacks on Apple ZeroConf channels
 - Bonjour (Printer, PhotoSync)
 - Airdrop
 - Customized ZeroConf protocols (Filedrop)
 - Multipeer Connectivity (MCBrowserViewController, QQ)
 - Handoff
- All vulnerabilities were reported to vendors, acknowledged by most vendors

1. ZeroConf Concept
2. ZeroConf How
3. ZeroConf Breaking
4. Impact

Impact

- Measurement
 - We analyzed 61 popular Mac and iOS apps working with ZeroConf
 - 88.5% are vulnerable to man-in-the-middle or impersonation attacks

ZeroConf Channels	Vulnerable/ Sampled	Sensitive Information Leaked
Bonjour	18/22	files, directories and clipboard synced, documents printed, instant message
MC	24/24	files and photos transferred, instant message
BLE	10/13	User name and password for OS X
Customized protocols	2/2	remote keyboard input and files transferred

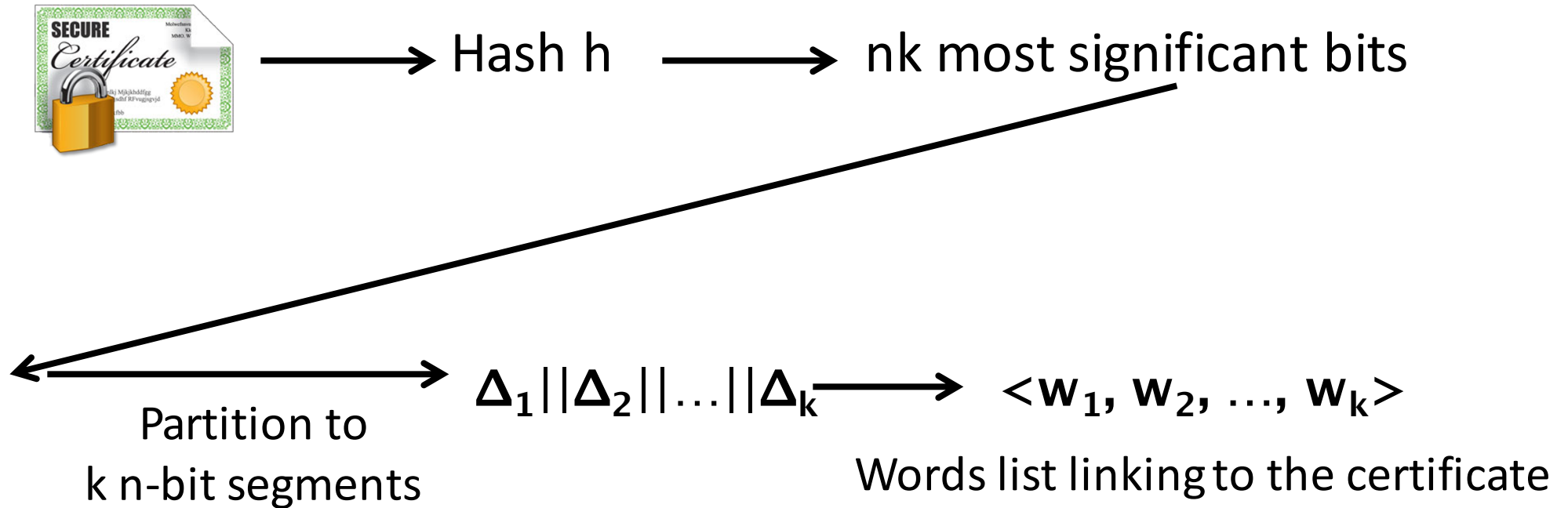
1. ZeroConf Concept
2. ZeroConf How
3. ZeroConf Breaking
4. Impact
5. Protecting ZeroConf

Protecting ZeroConf

- Problem: link a human to her certificate is complicated
- Speaking out Your Certificate (SPYC)
 - Voice biometrics ties certificate to identity



Speaking Out Your Certificate



Protecting ZeroConf

- Challenge: link a human to her certificate
- Speaking out Your Certificate (SPYC)
 - Voice biometrics ties certificate to identity
 - Human Subject Study: convenient and effective



Conclusion

- Apple's ZeroConf techniques are not secure as expected
 - The usability-oriented design affects security
- Addressing such security risks is nontrivial
 - Challenge in binding a human to her certificate
- Our Defense: SPYC
 - Voice biometrics ties certificate to identity