

# DISCOVERING AND EXPLOITING NOVEL SECURITY VULNERABILITIES IN APPLE ZEROCONF

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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

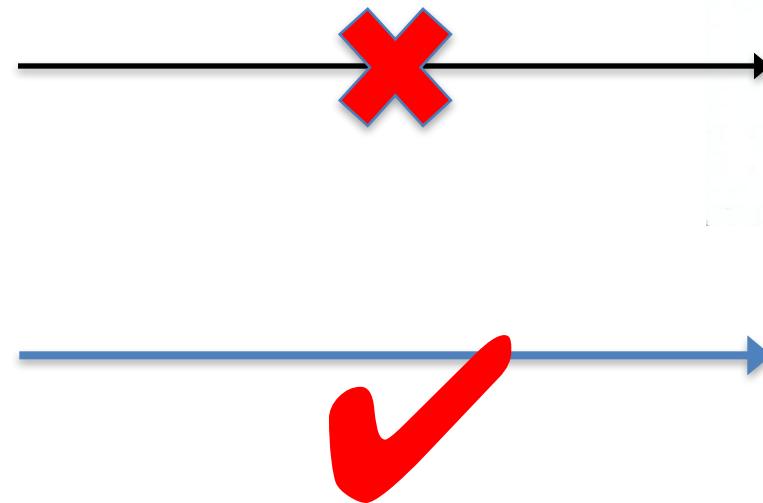


# Bonjour

- 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?

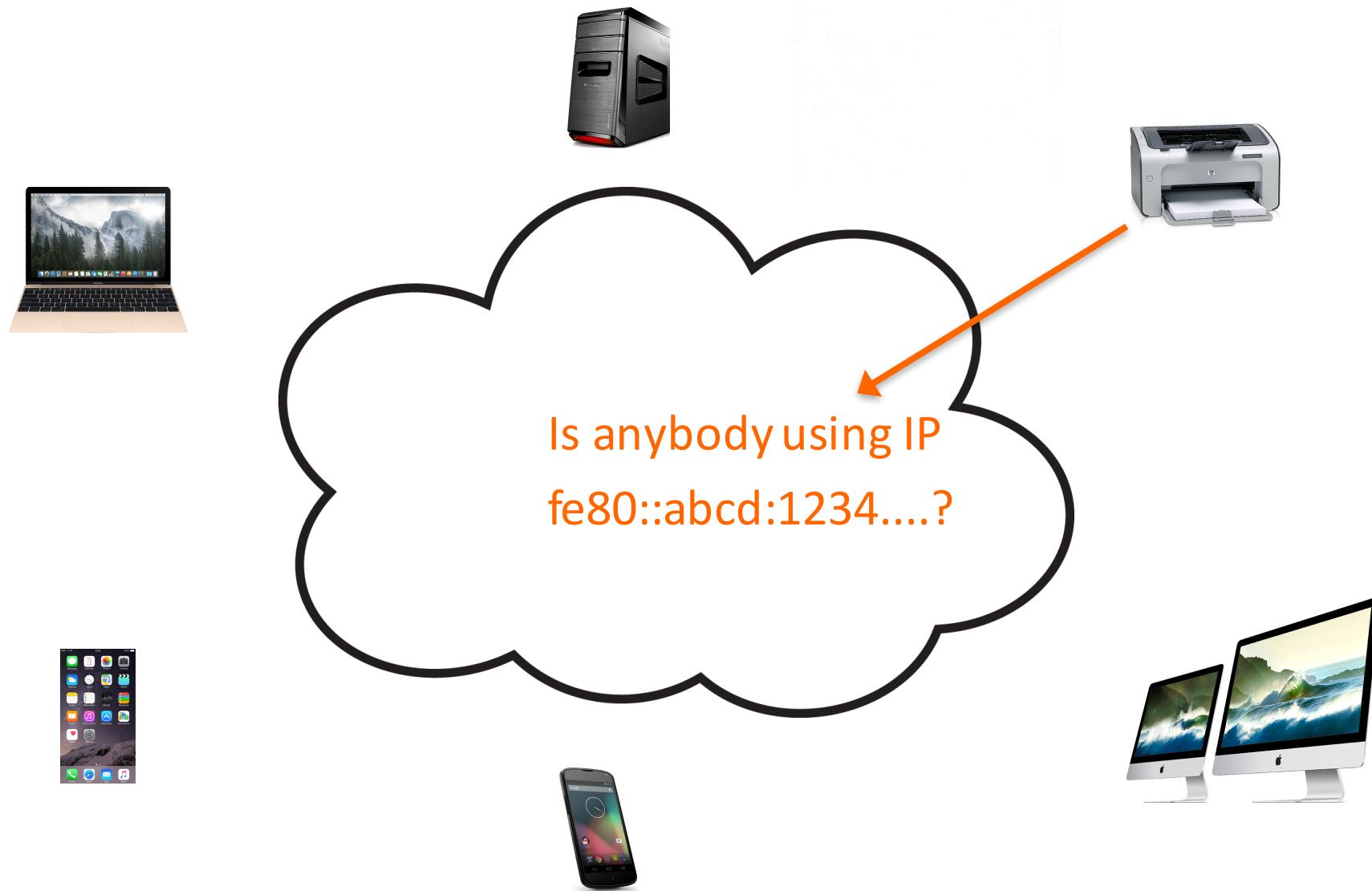
# Features of Bonjour

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

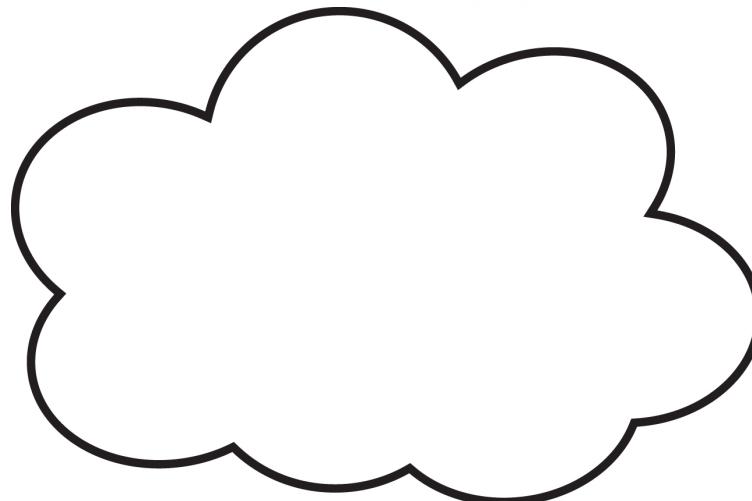
Two phases: Discovery and Resolution

# Automatically find the printer: Discovery



Q1:

Anyone has a **printer service**?



A1:

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

# Automatically find the printer: Resolution

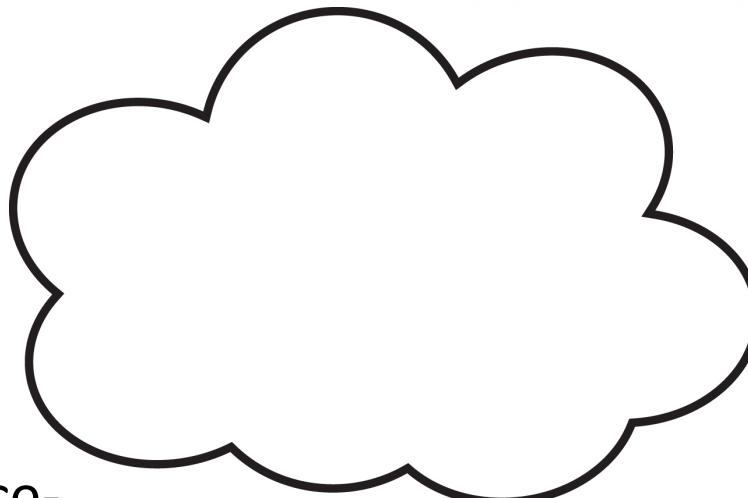


Q1:

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:

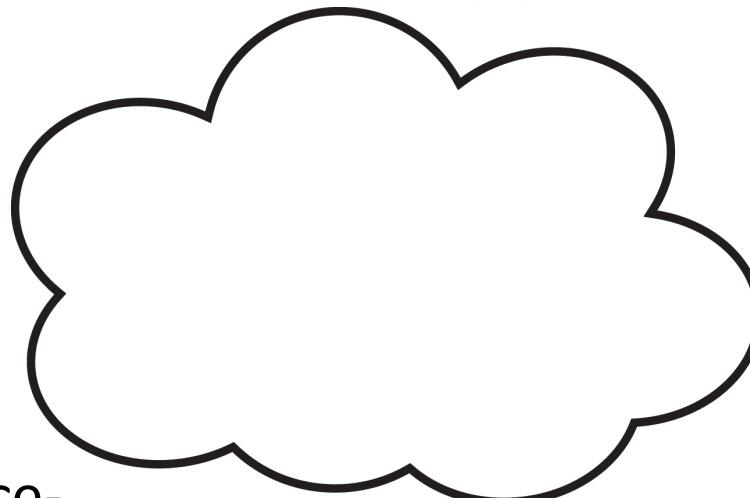
Anyone has a **printer service**?

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:

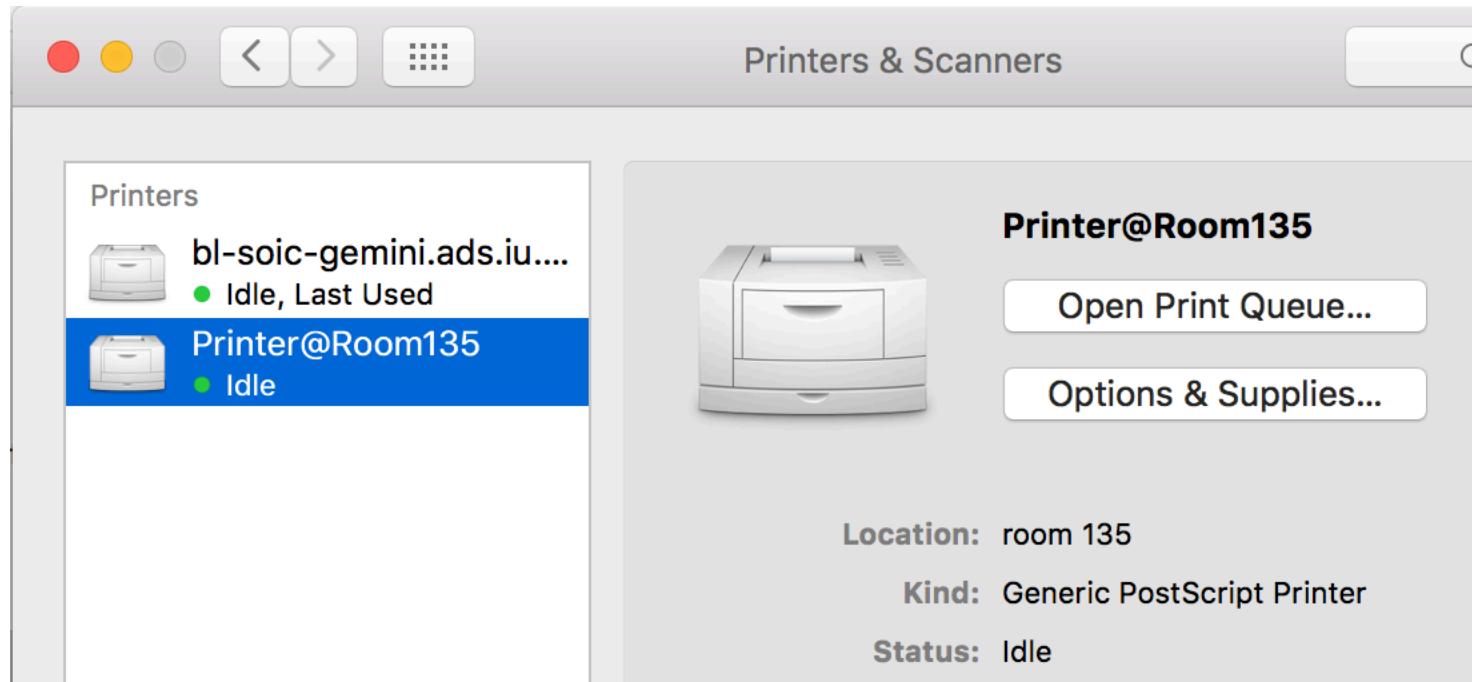
It's on **host**

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

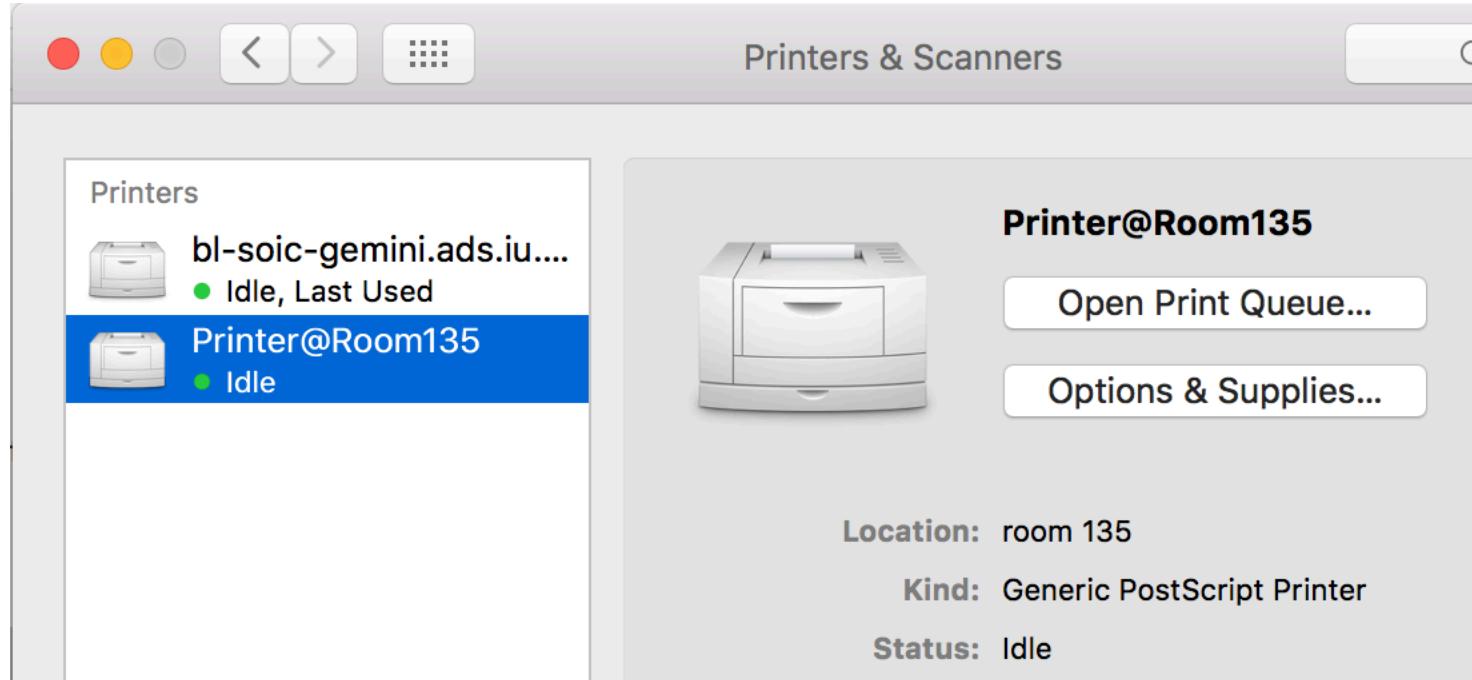
HP-Service-9FE5

?

?

?

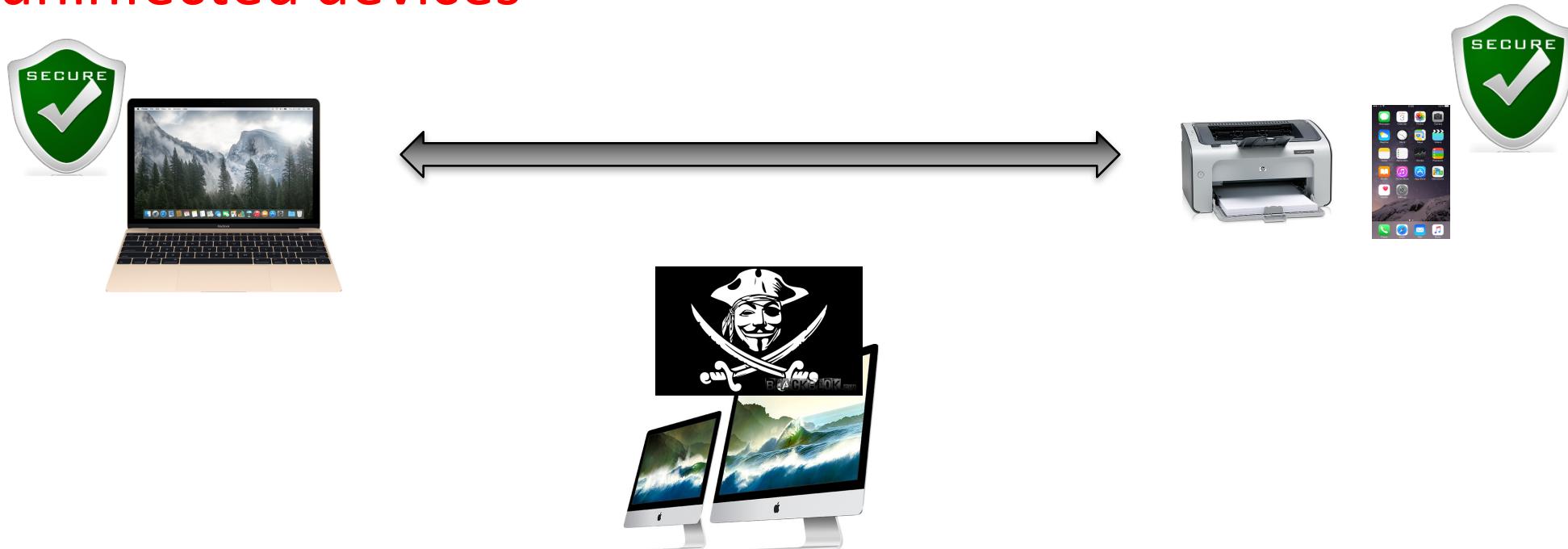
# Service instance name HP-Service-9FE5 is saved



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

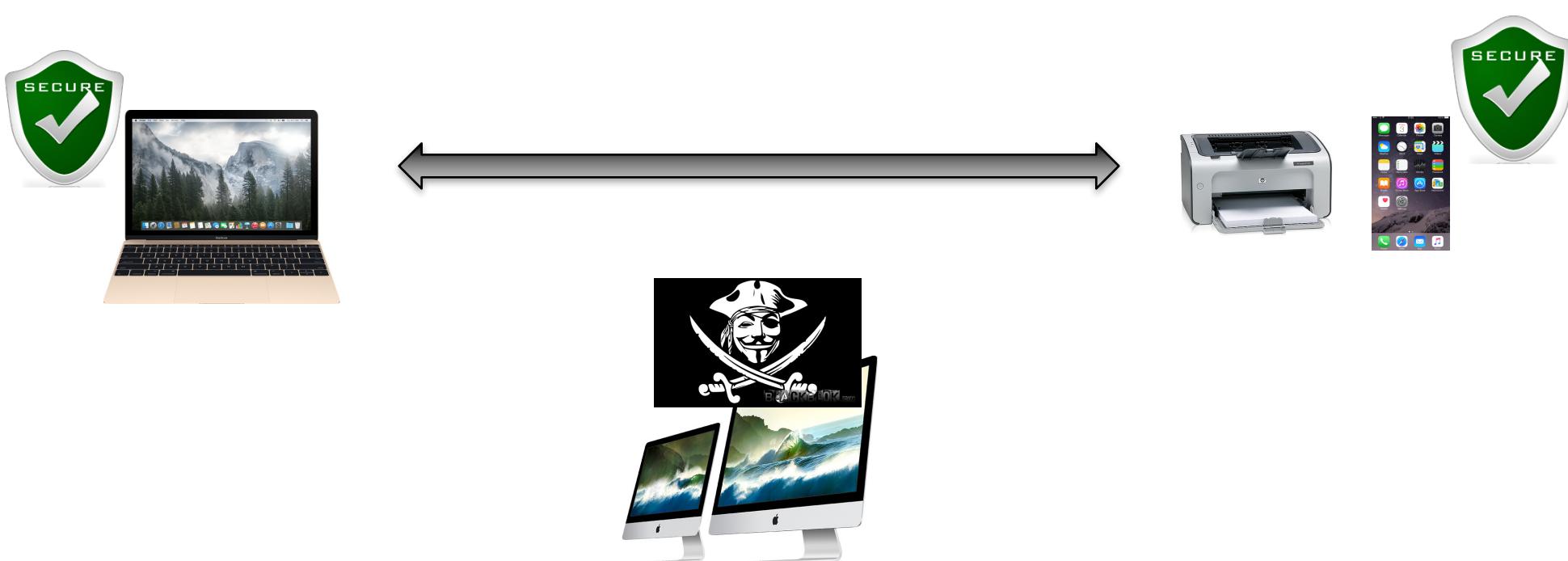
# Adversary Model

- 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

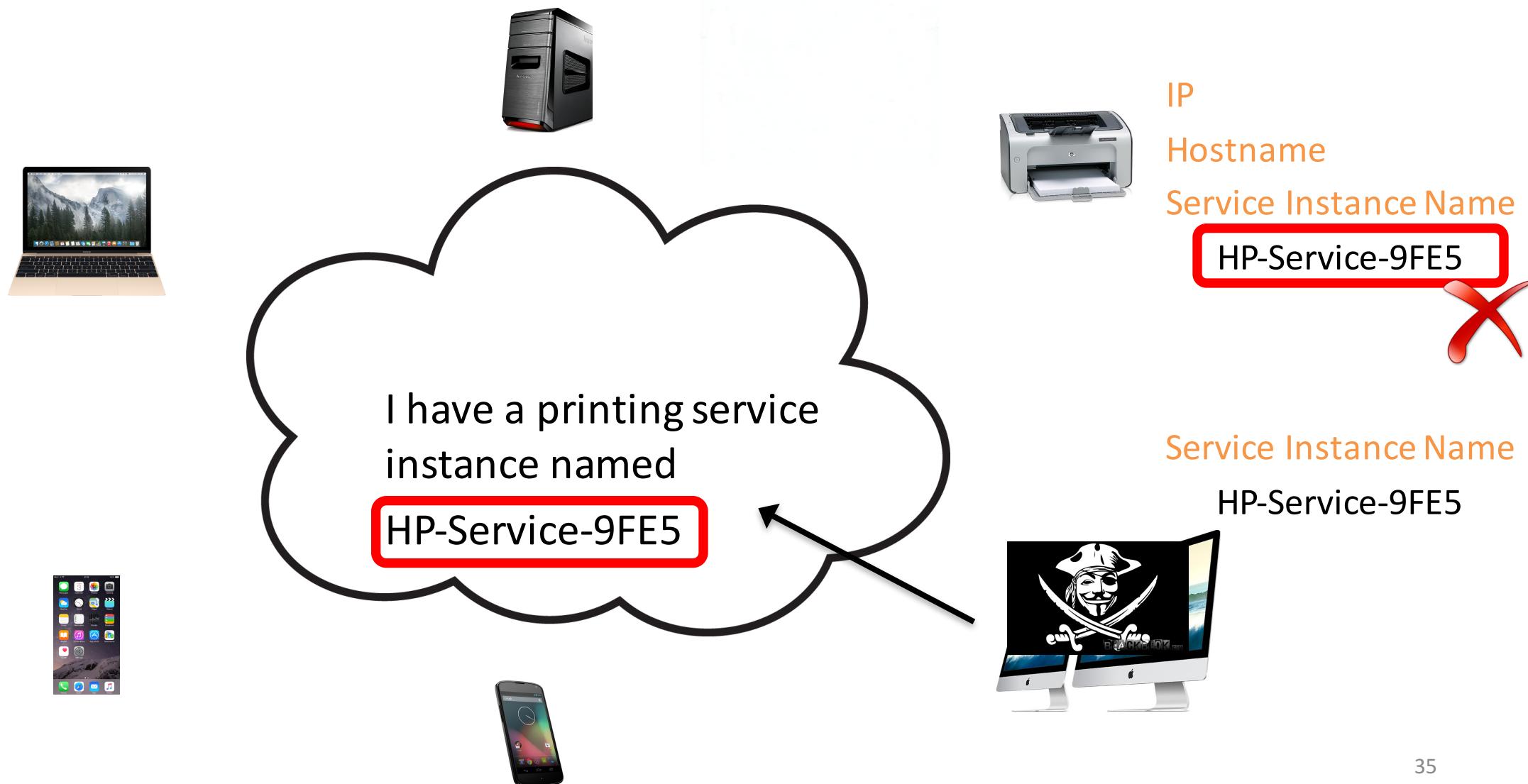
# A device infected by malware



# 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!

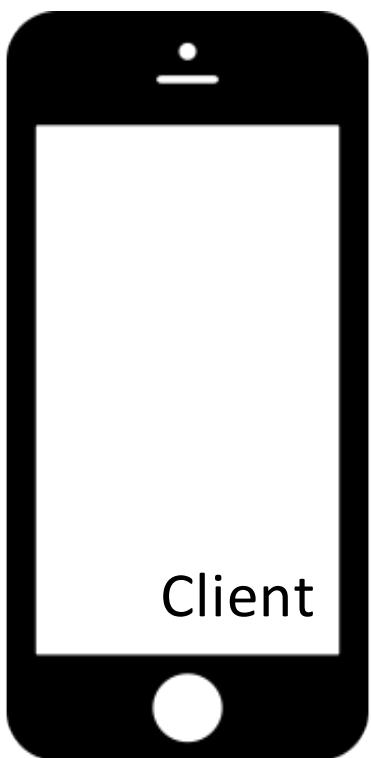
# Attack Bonjour

- 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

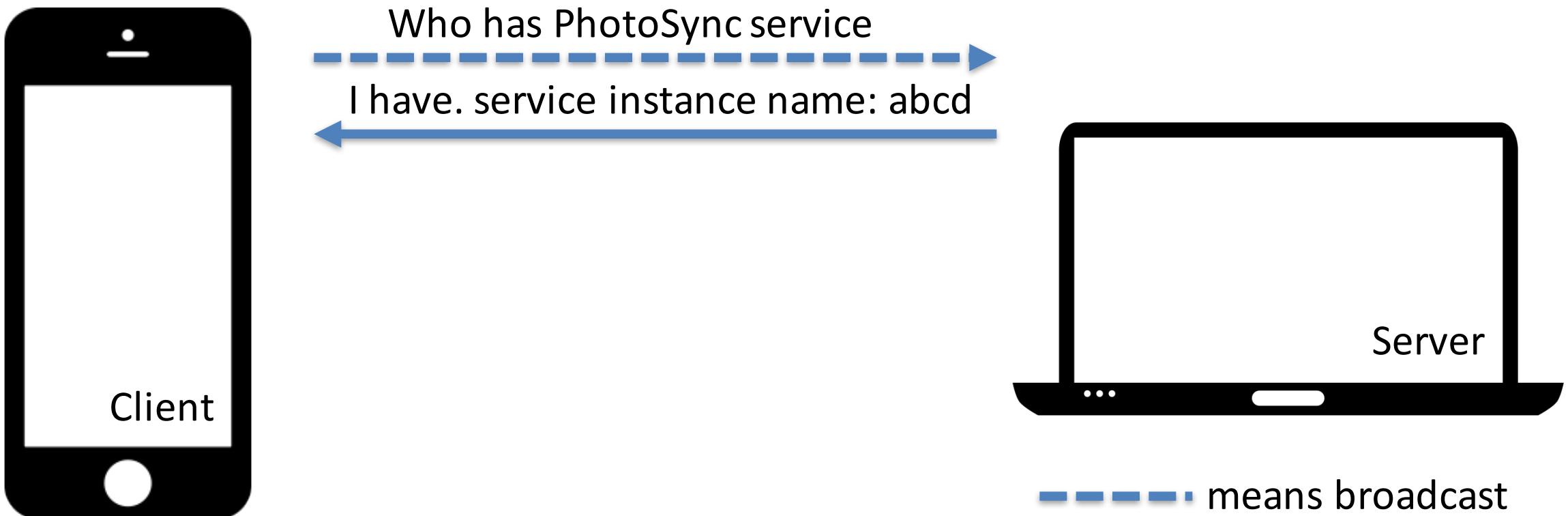
-----→



----- means broadcast

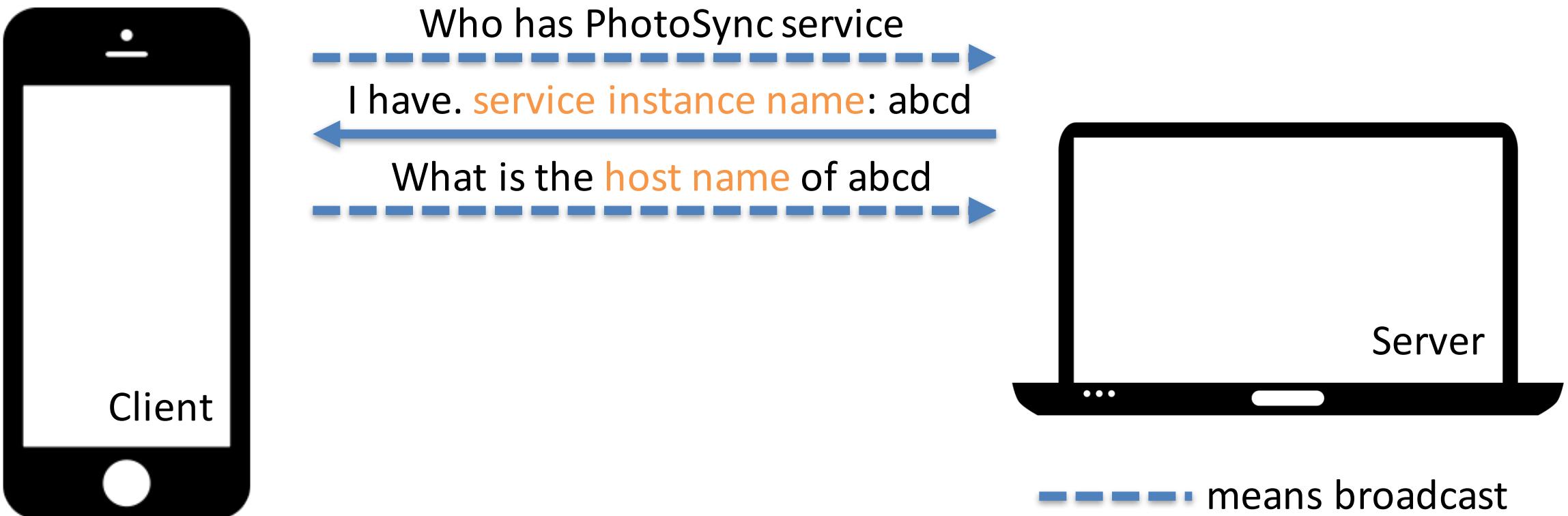
# Normally

- Discovery: Server responds with service instance name



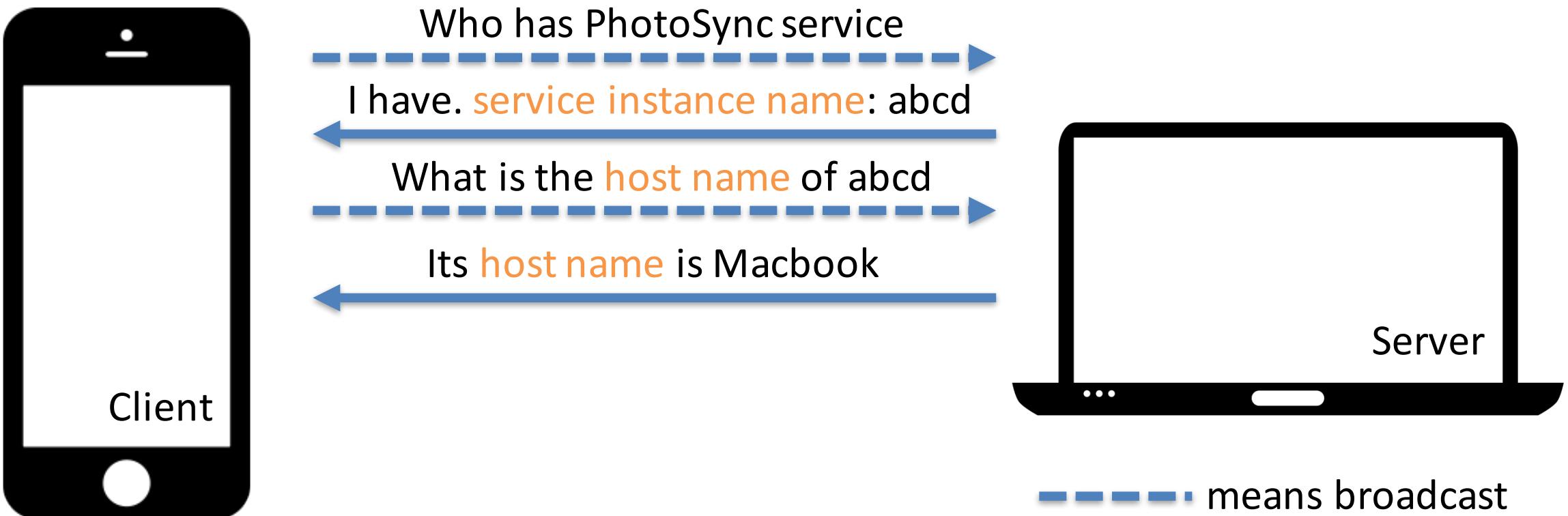
# Normally

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



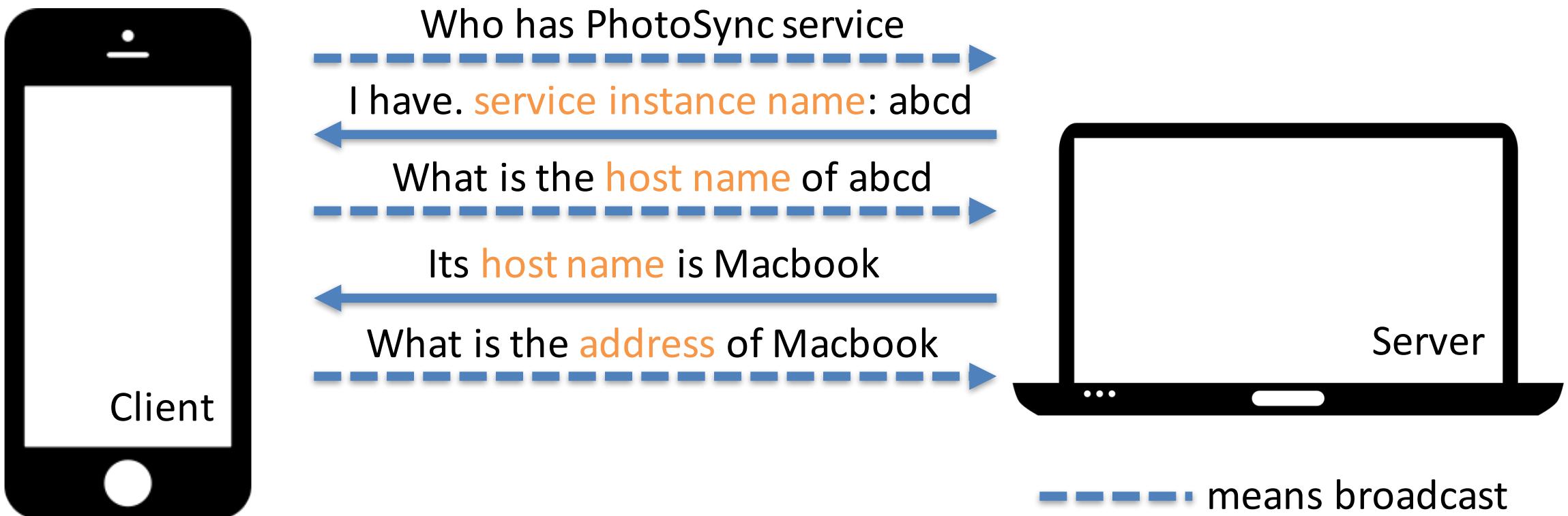
# Normally

- Resolution 1: Server responds with the host name



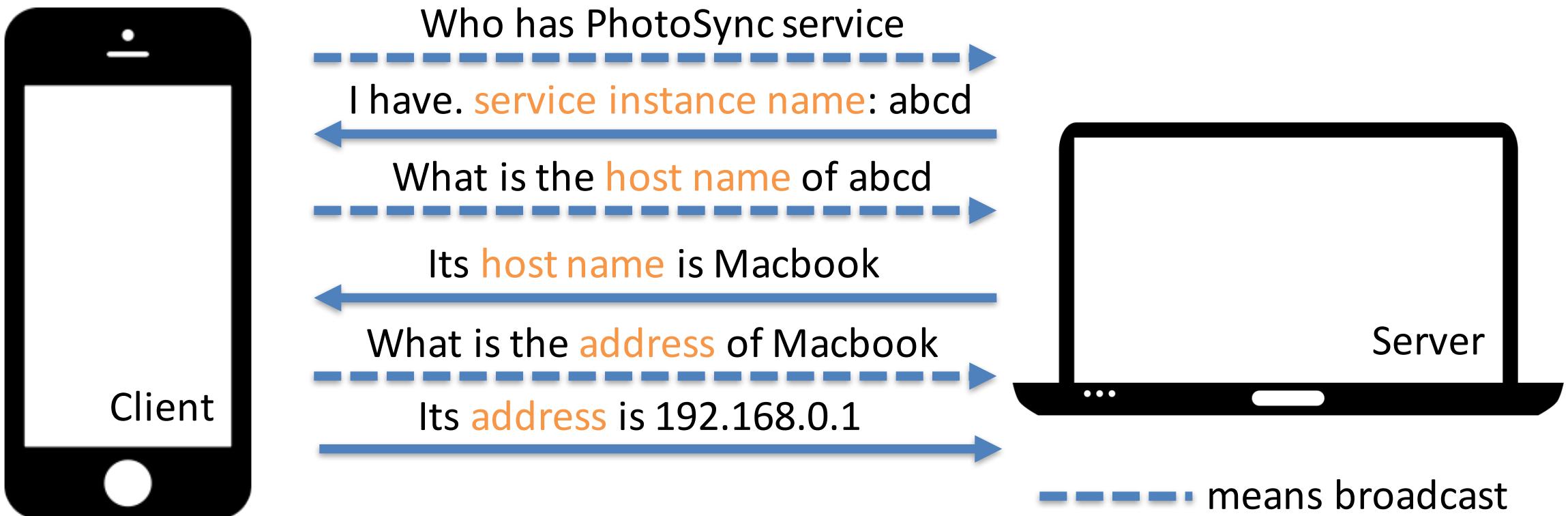
# Normally

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



# Normally

- Resolution 2: Server responds with its address

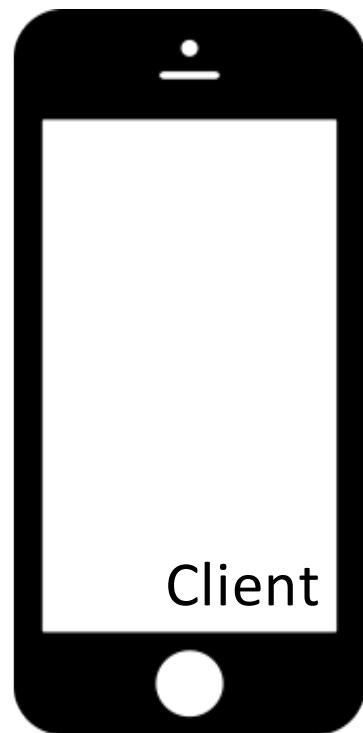


# What Can Go Wrong?

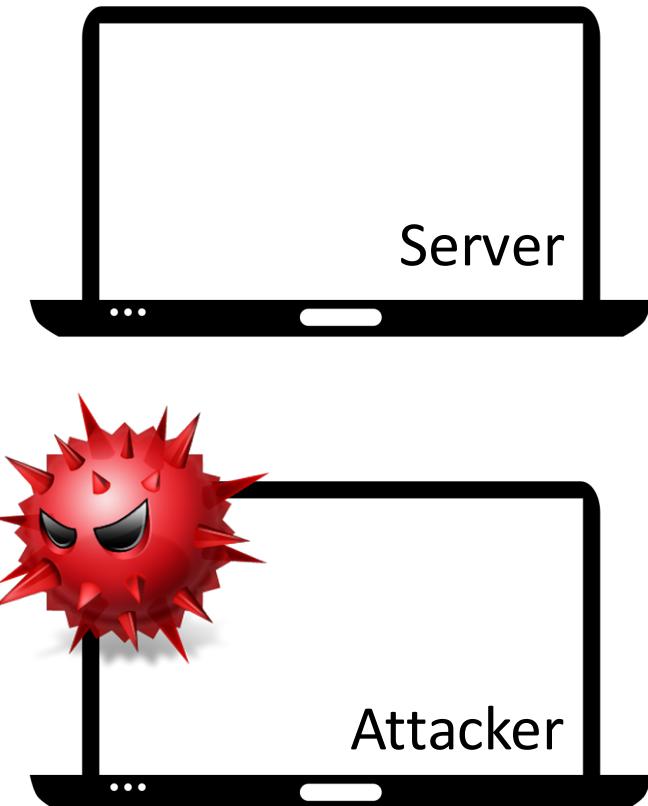
- Another malware-infected device spoofs the client
  - Successful Man-in-the-Middle
- During Resolution
  - Service instance name to host name
  - Host name to address

# What Can Go Wrong?

- Attack 1: service instance name to host name

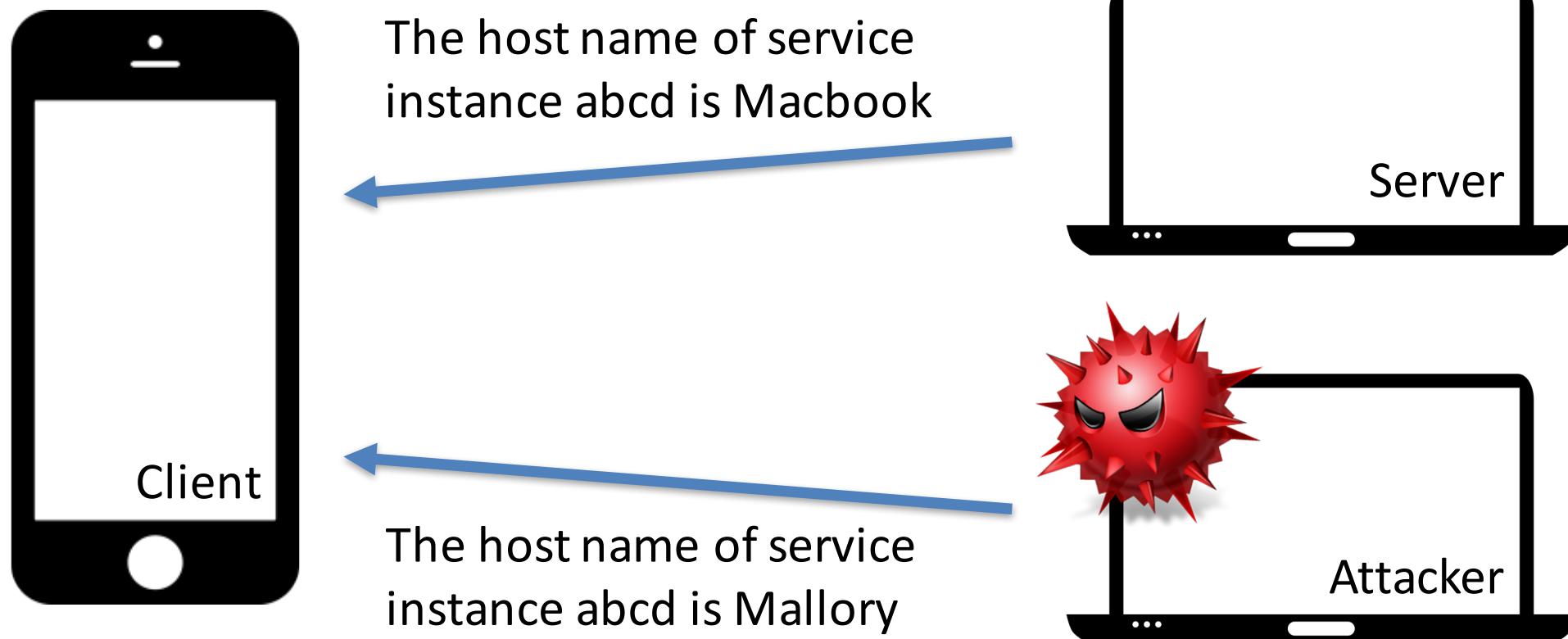


What is the **host name** of  
service instance abcd



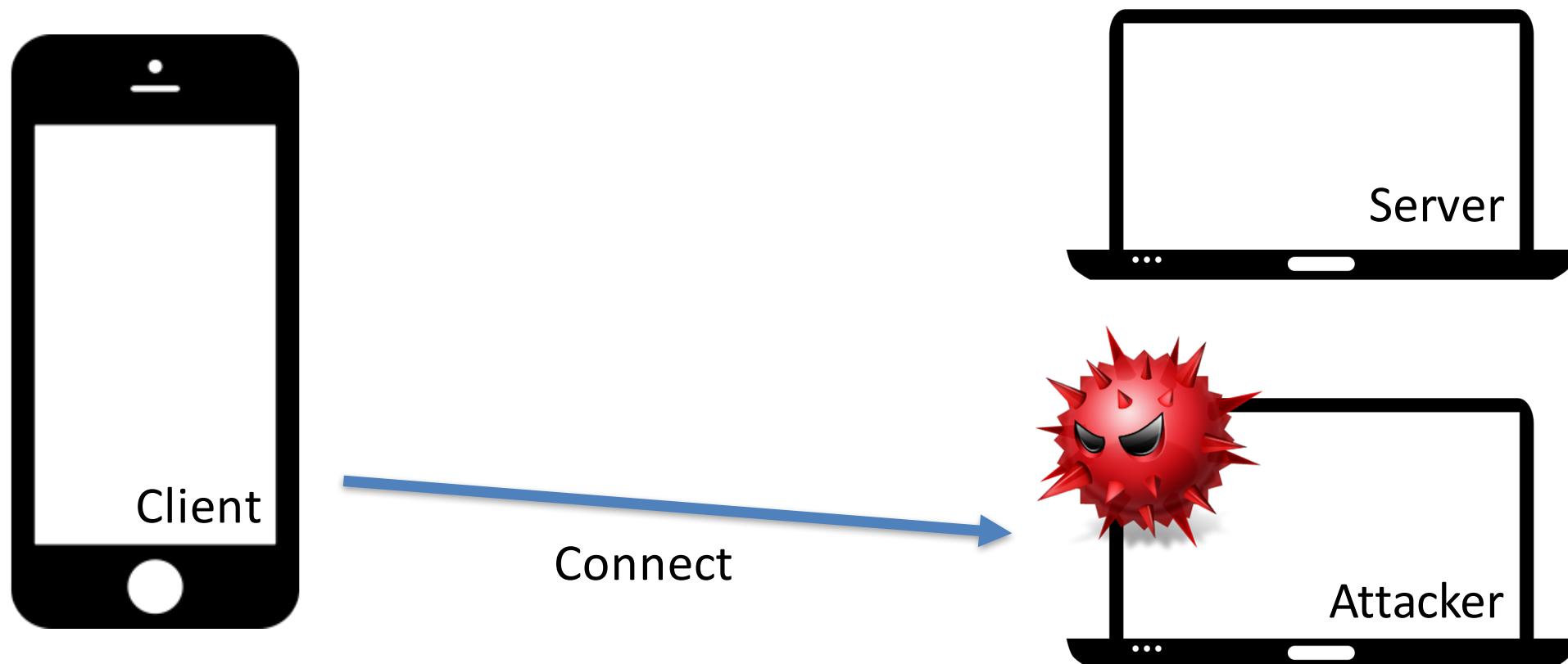
# What Can Go Wrong?

- Attack 1: service instance name to host name



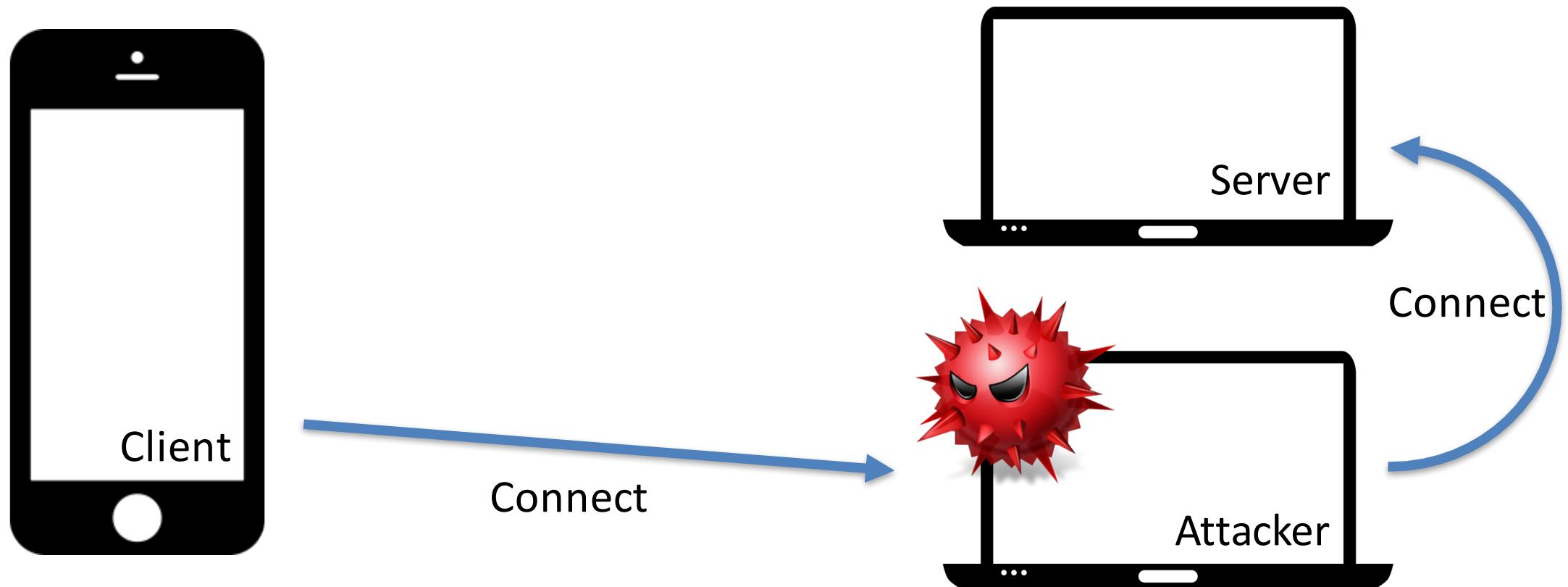
# What Can Go Wrong?

- Attack 1: service instance name to host name



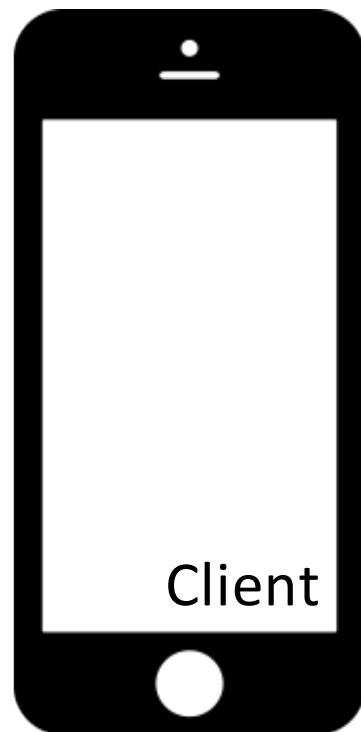
# What Can Go Wrong?

- Attack 1: service instance name to host name

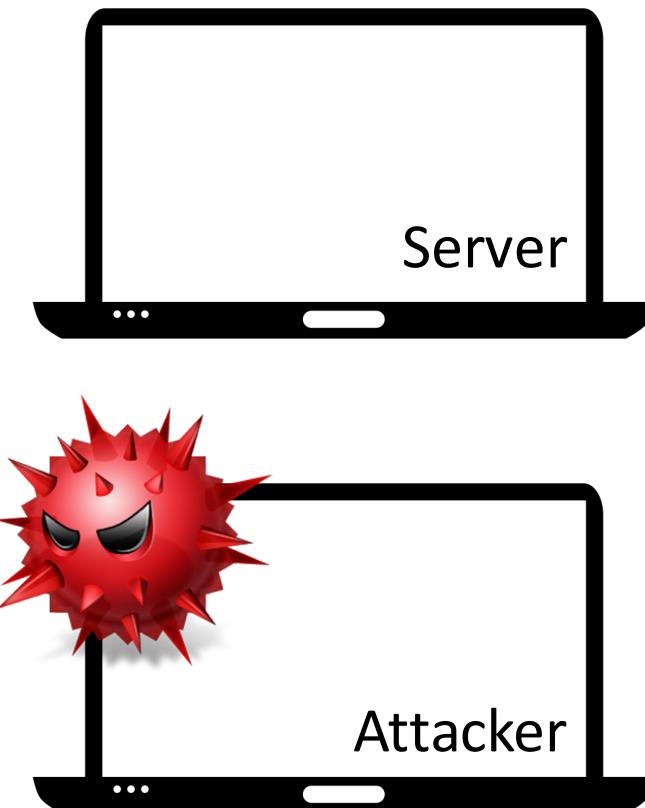


# What Can Go Wrong?

- Attack 2: service instance name to host name

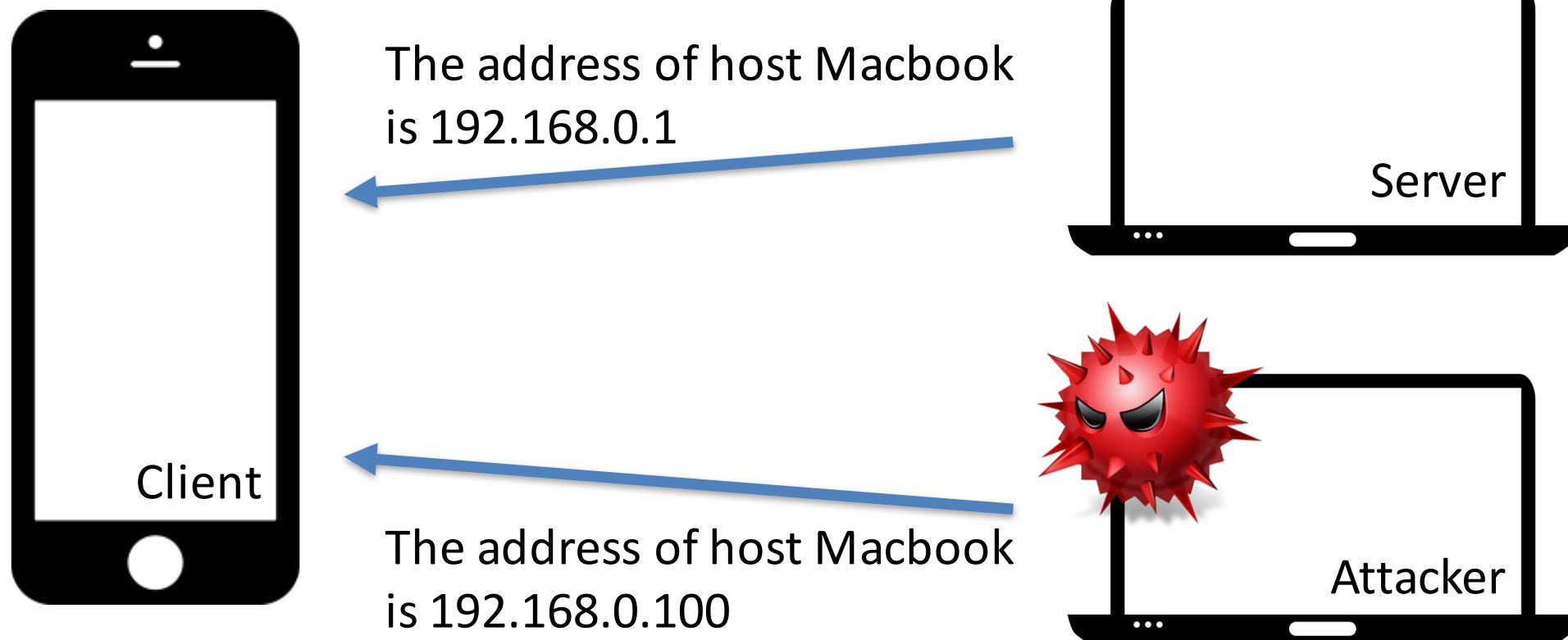


What is the **address** of  
host Macbook



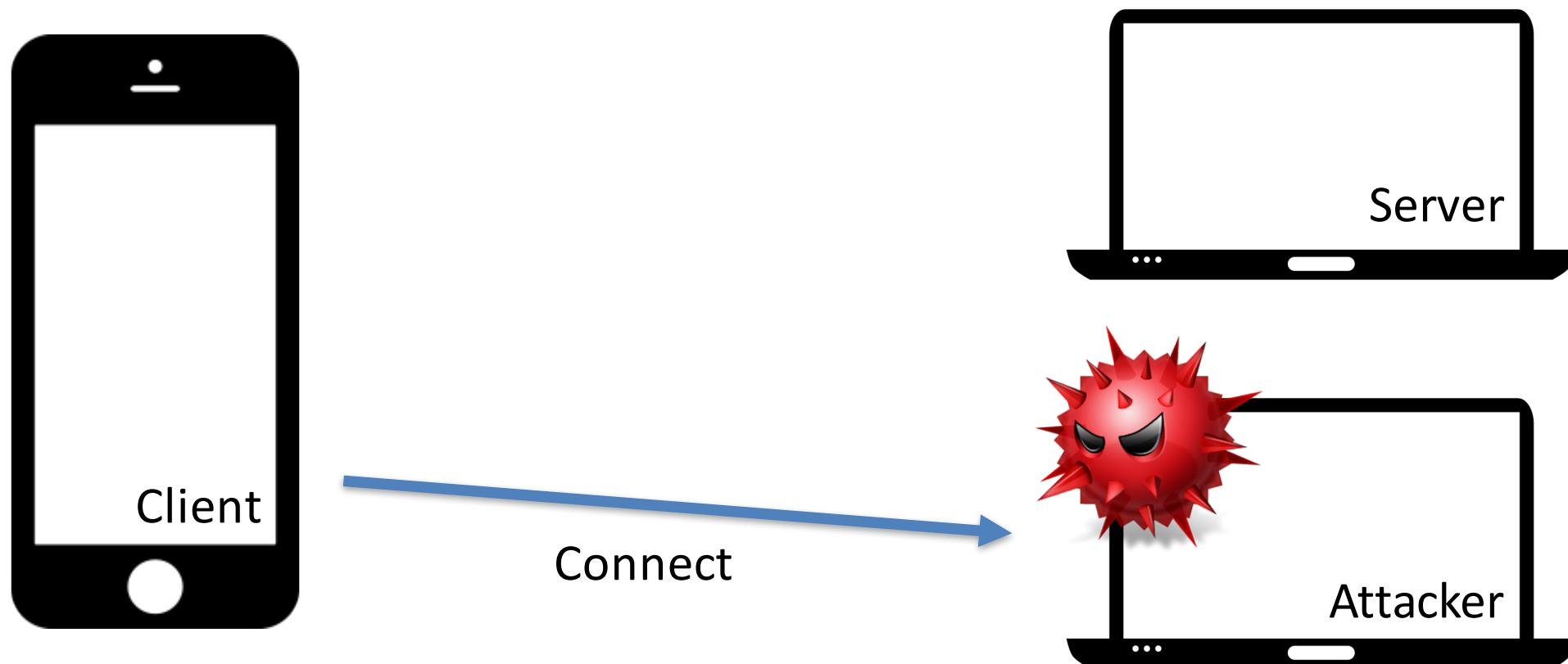
# What Can Go Wrong?

- Attack 2: service instance name to host name



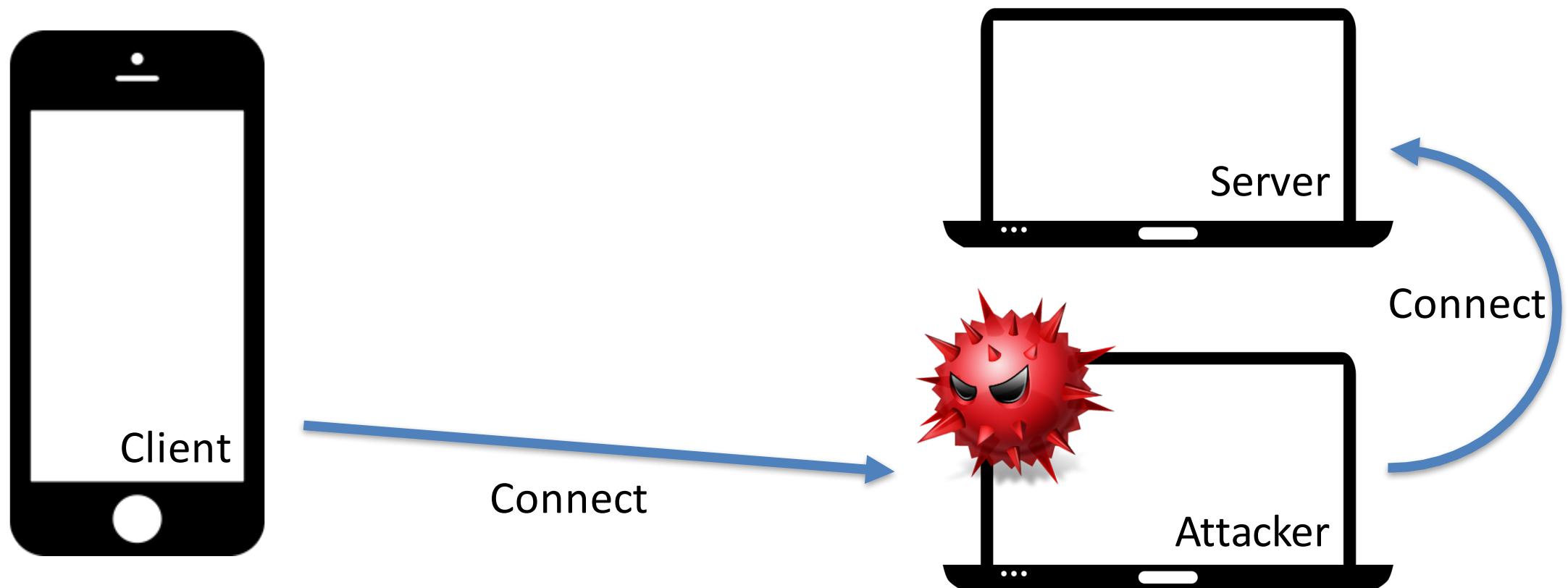
# What Can Go Wrong?

- 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=WUWusqgqFr0&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

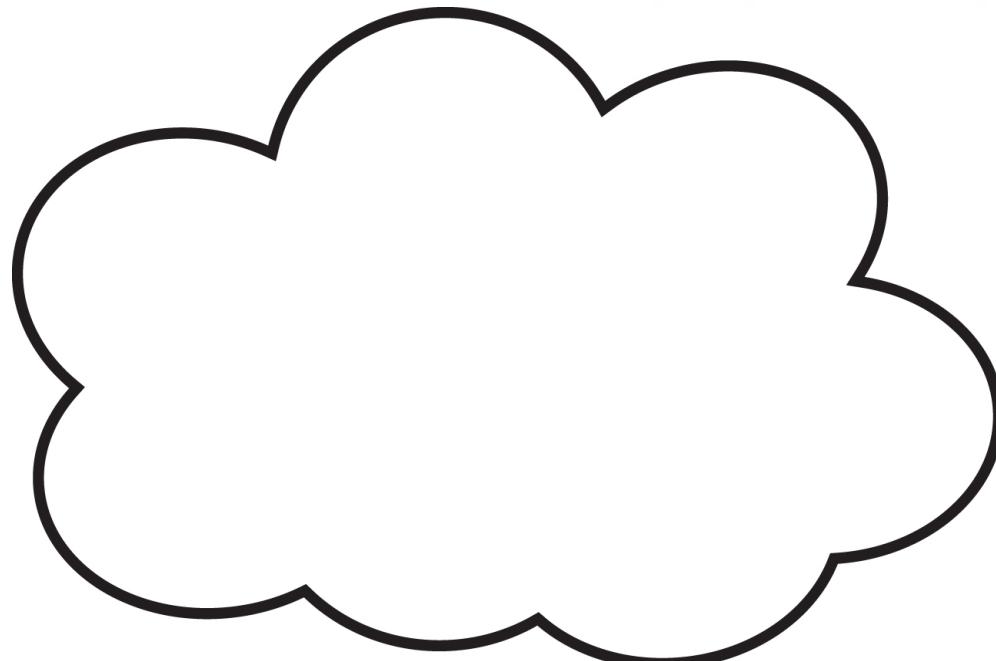


Jeff's Macbook:

Q1: Anyone has an  
airdrop service?

Alice's iPhone:

I have a service named  
abcd.airdrop.service

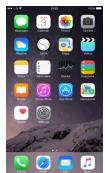
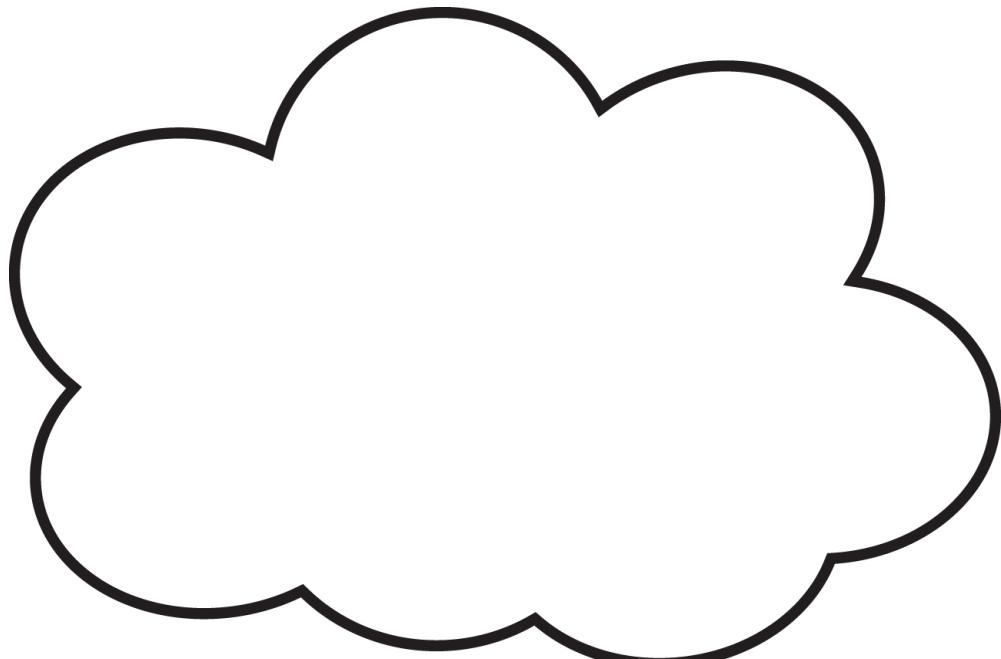


# Attack Airdrop



Jeff's Macbook:

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



# Attack Airdrop

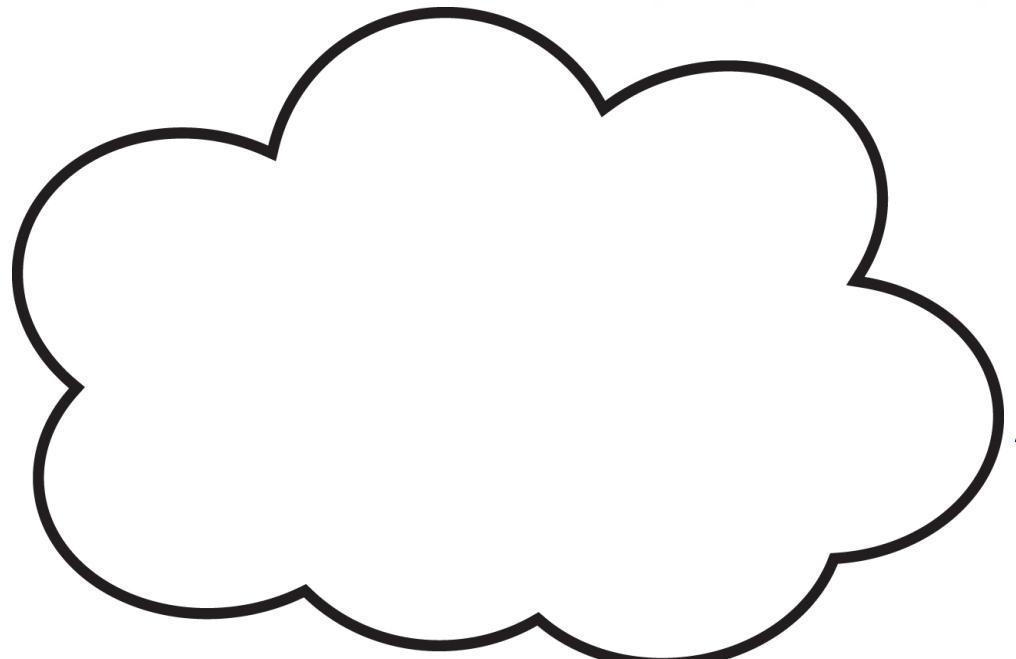


Jeff's Macbook:

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

Alice's iPhone:

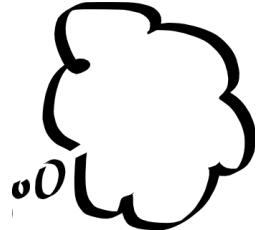
A2: It's **on host**  
`Alices.iphone.local`



Bob's iMac:

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



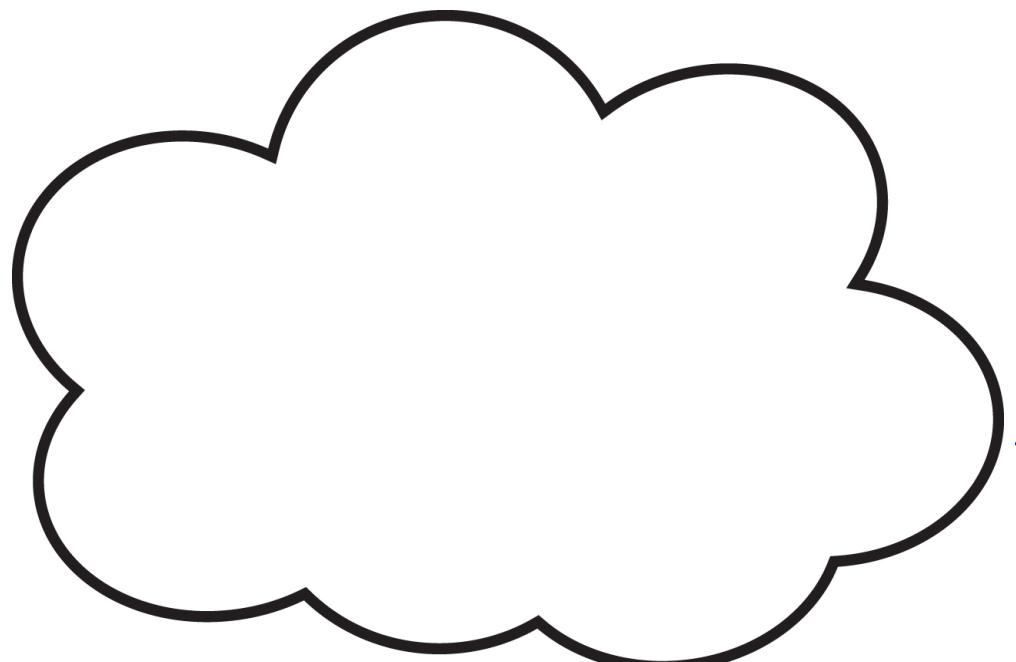


Alice's iPhone has service named abcd.airdrop.tcp,  
which is on host Bobs.imac.local



Jeff's Macbook:

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

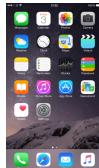


Bob's iMac:  
A2: It's **on host** Bobs.imac.local



Alice's iPhone:

A2: It's **on host**  
Alices.iphone.local



# Does TLS help?



Jeff's Macbook:  
Connect  
<https://Bobs.imac.local>

Alice's iPhone:  
A2: It's on host  
[Alices.iphone.local](https://Alices.iphone.local)



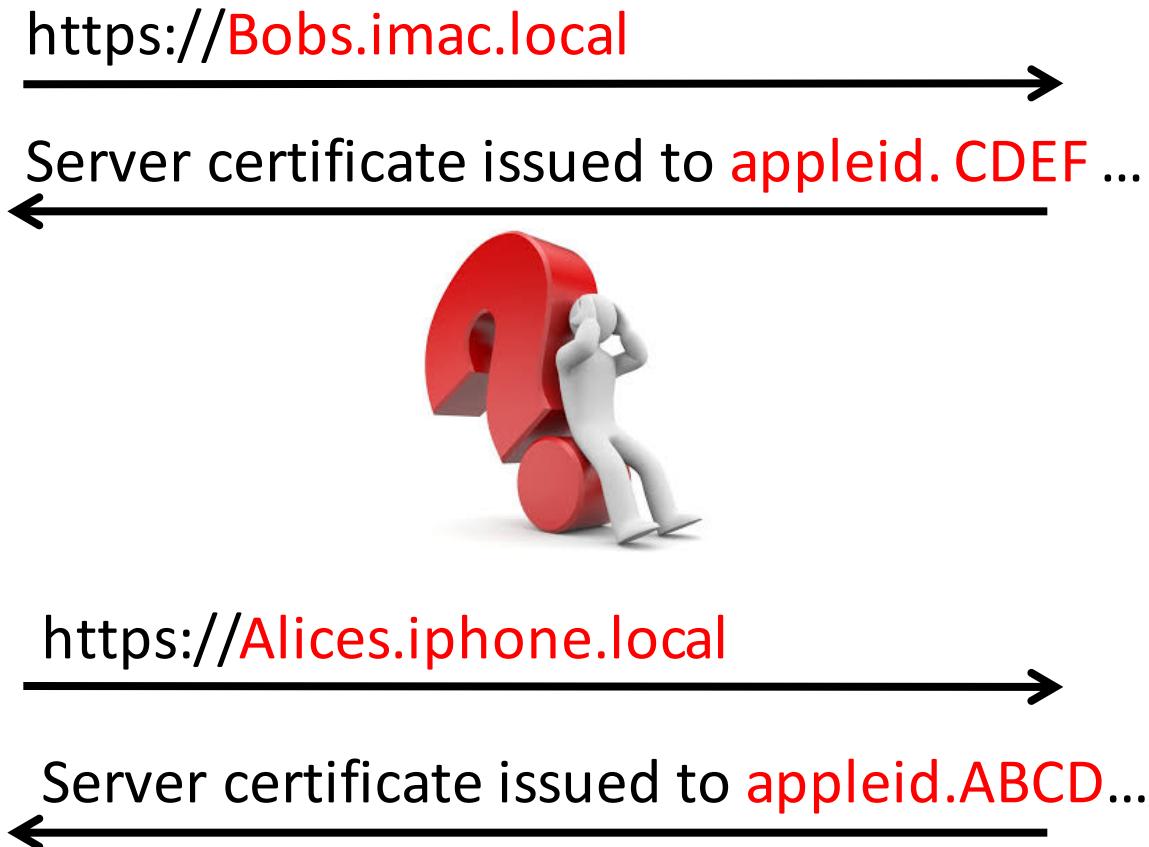
Bob's iMac:  
A2: It's on host [Bobs.imac.local](https://Bobs.imac.local)



# TLS in Airdrop



Jeff's Macbook



Bob's iMac



Alice's iPhone

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



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

# Domain should match the certificate



Jeff's Macbook

https://Bobs.imac.local

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



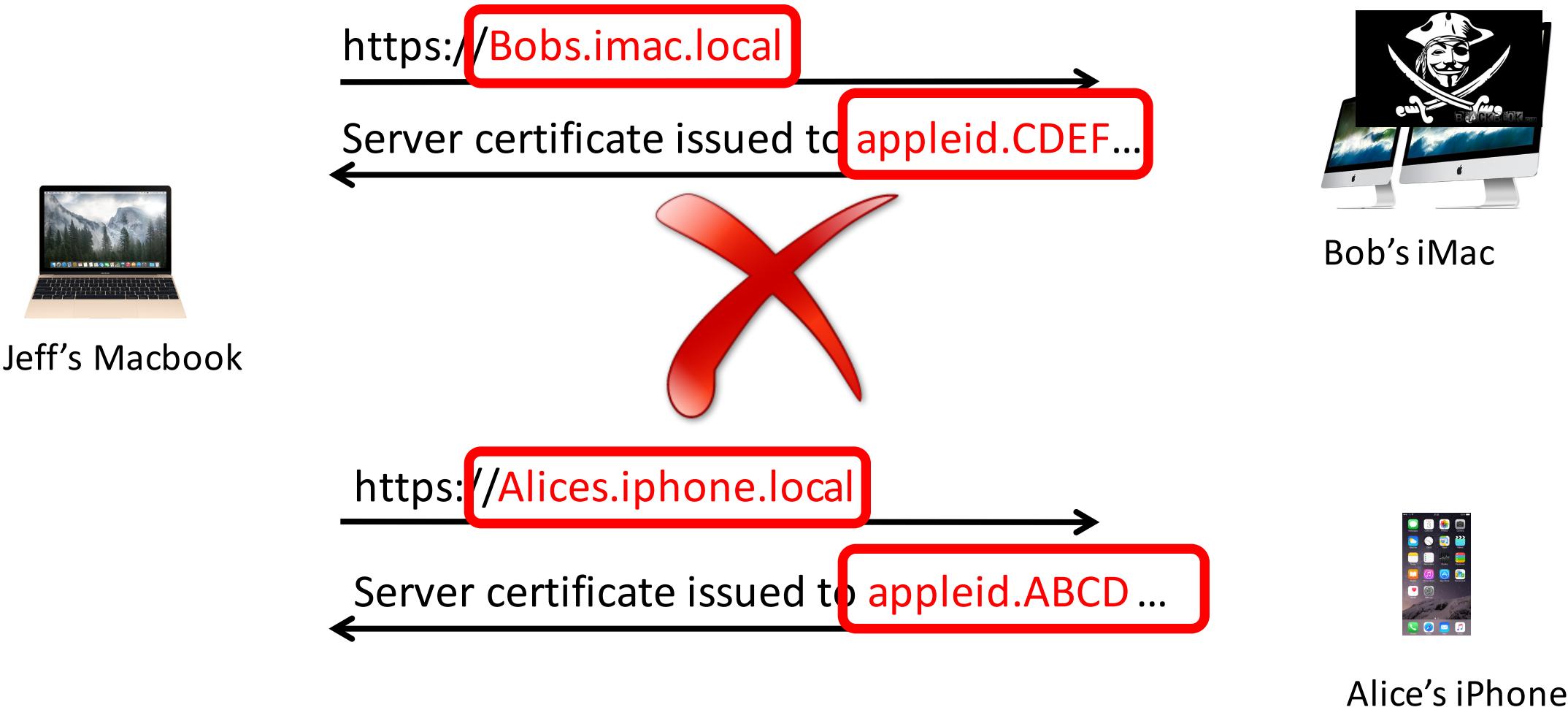
Bob's iMac

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

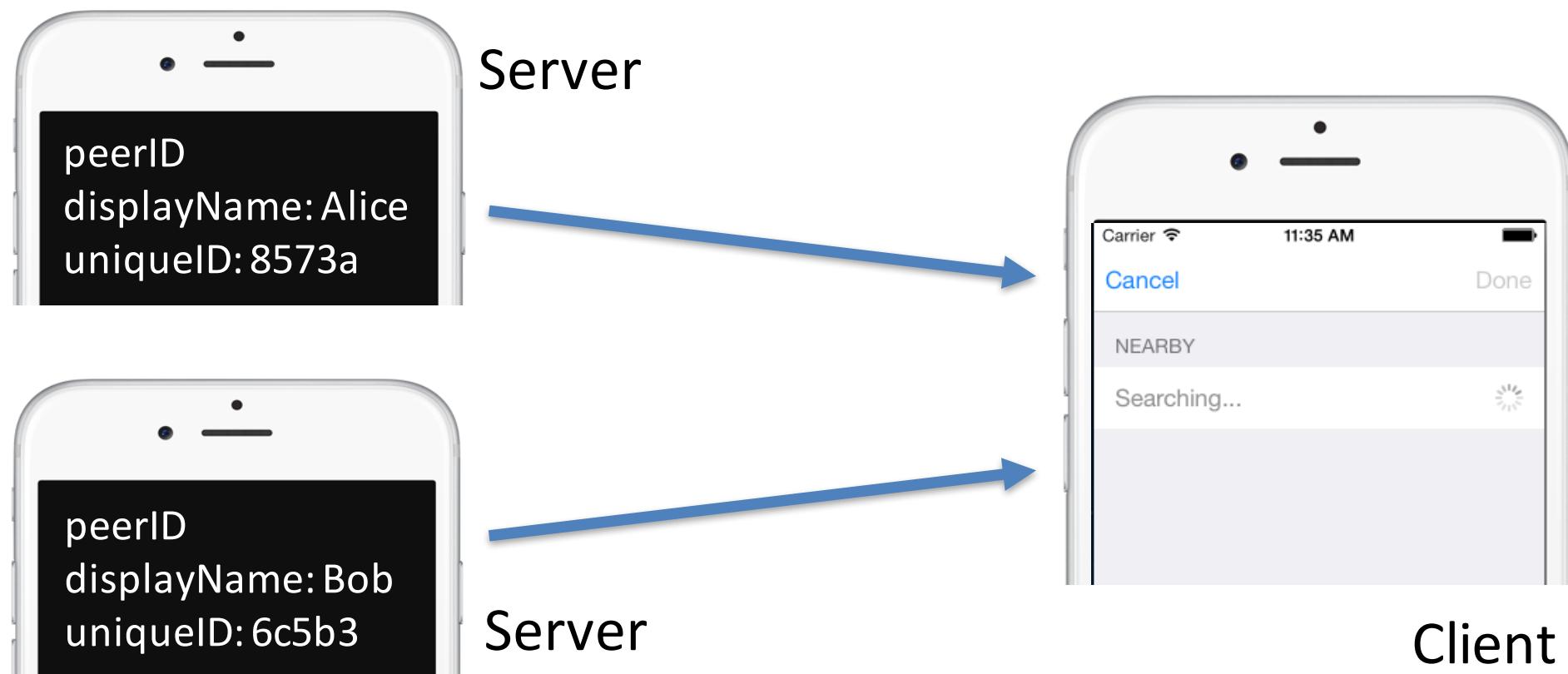
# Apple's Vulnerable framework

- 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)



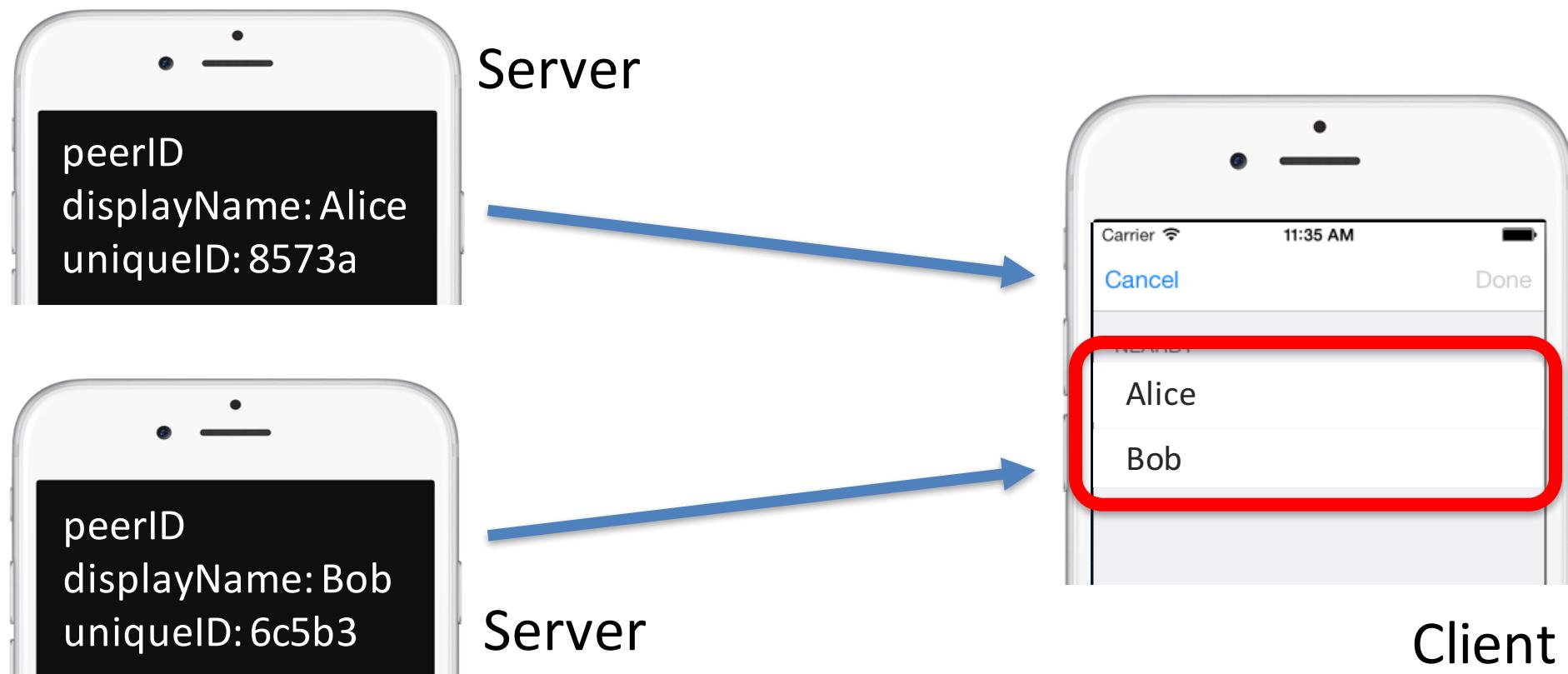
# Normally

- Automatic Service Discovery Without Configuration
  - Servers advertise peerIDs



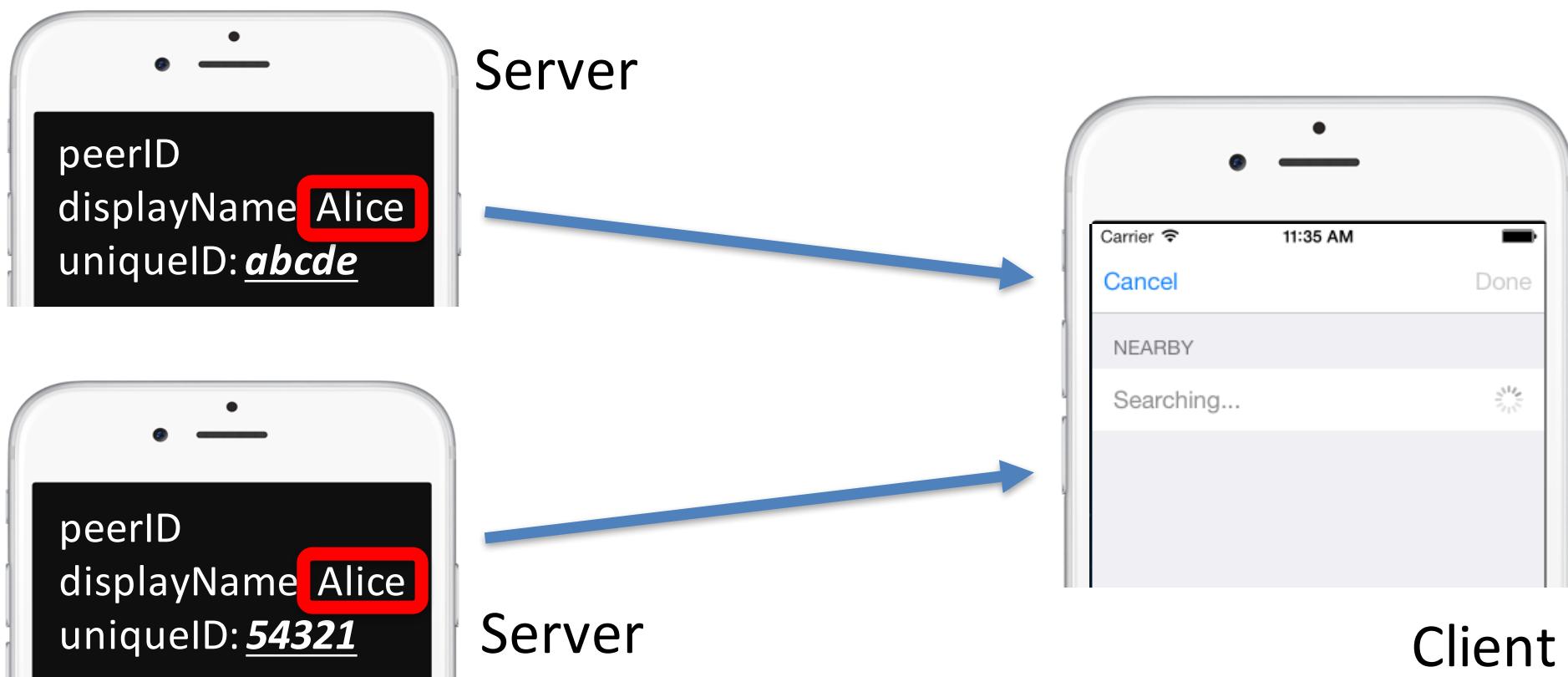
# Normally

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



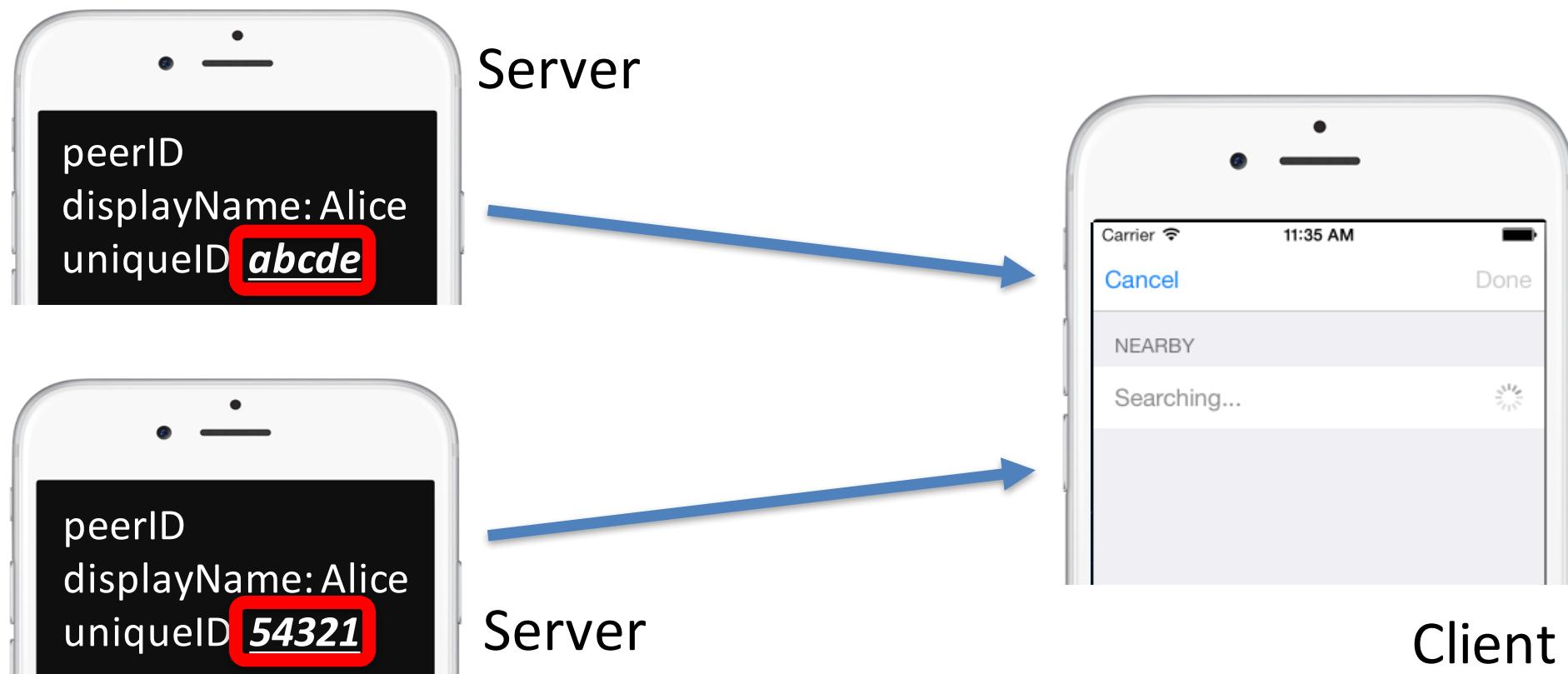
# Normally

- Even if servers have the same displayName



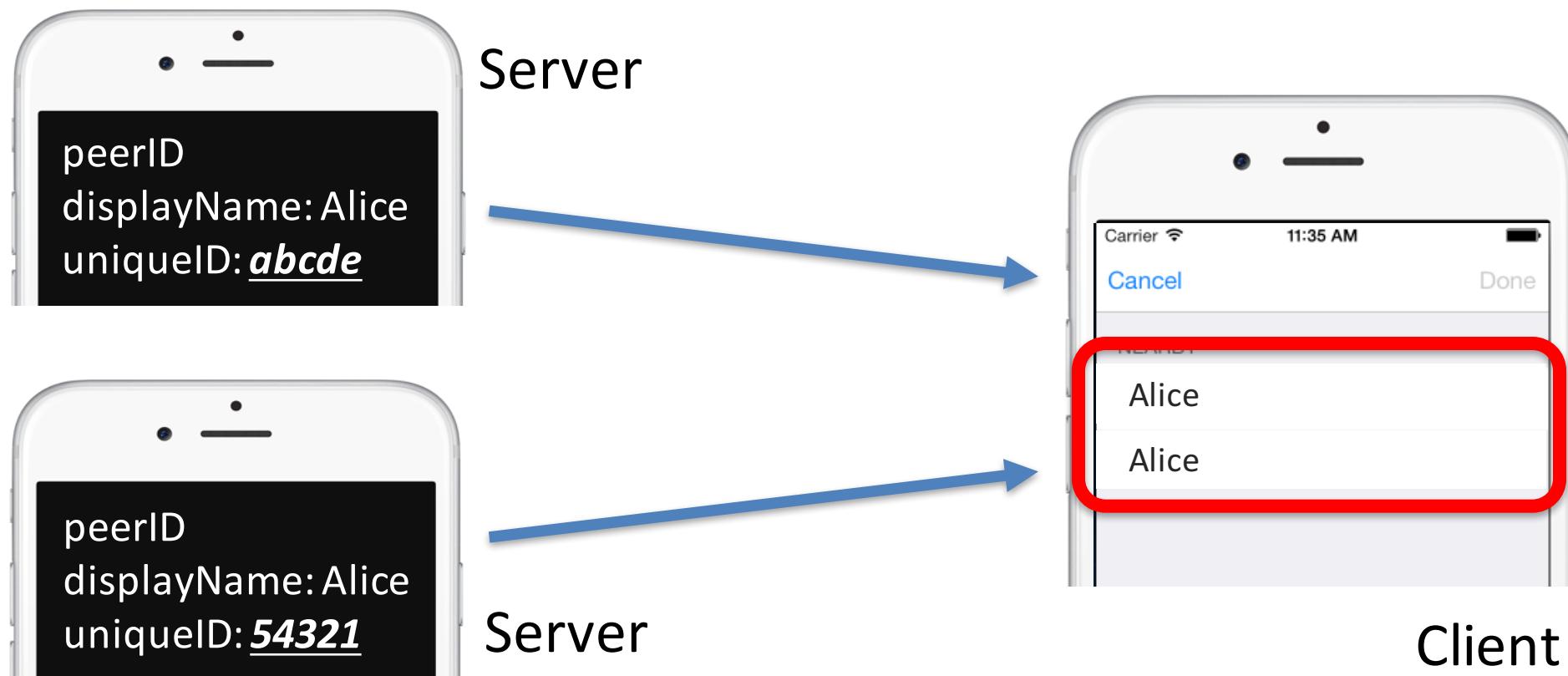
# Normally

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



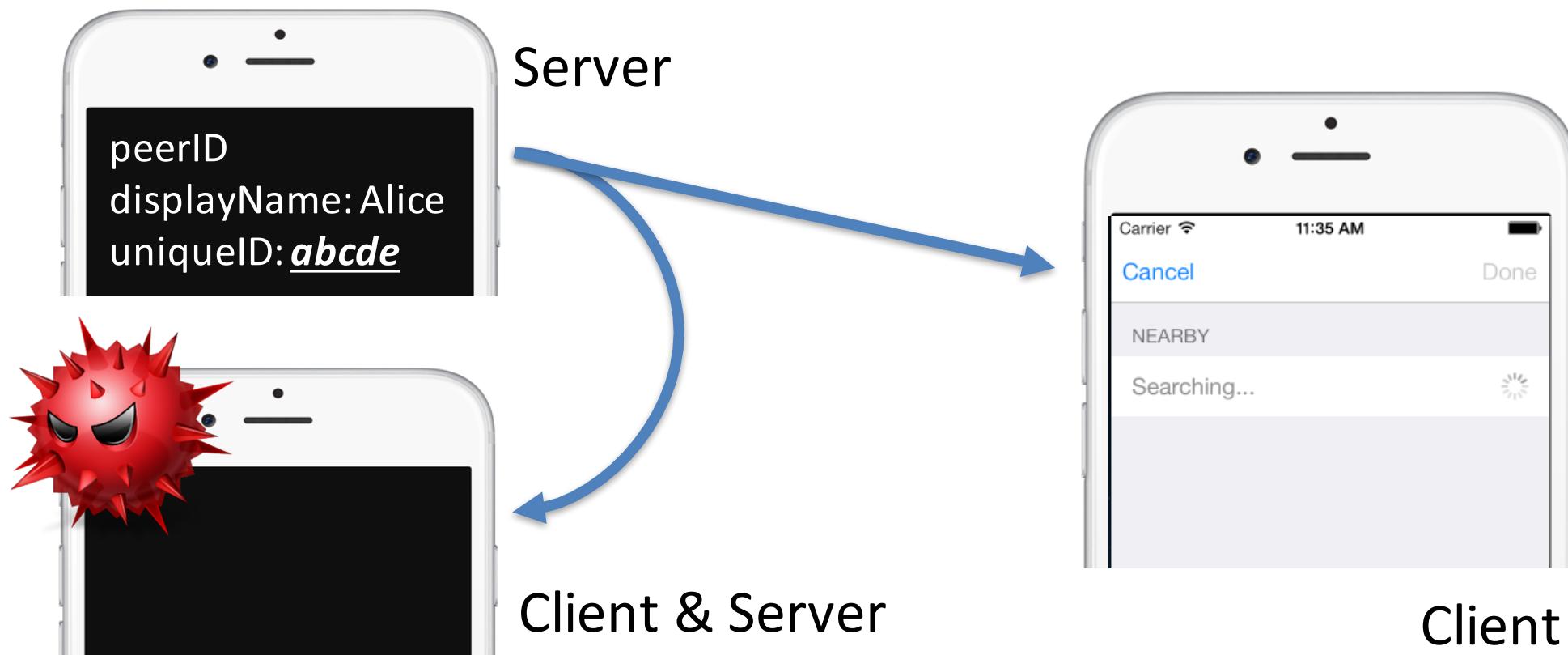
# Normally

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



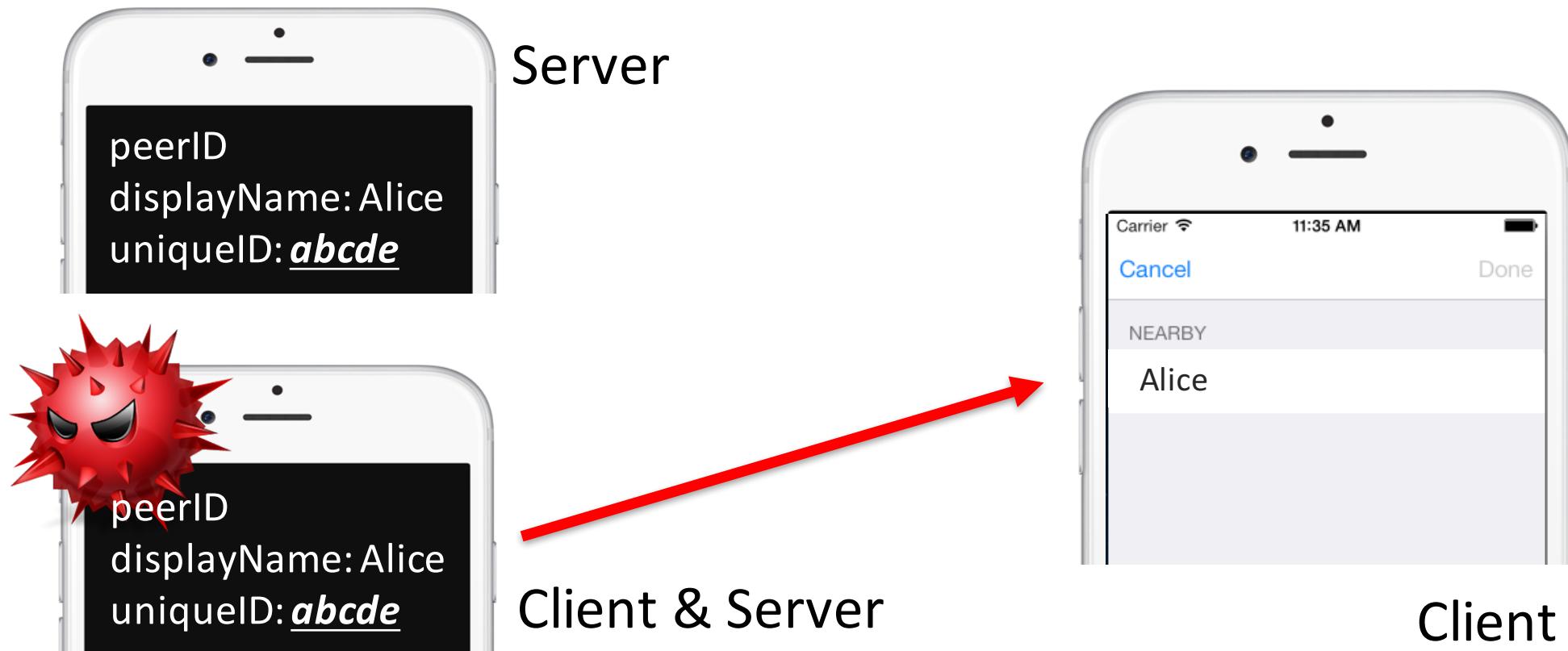
# What Can Go Wrong?

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



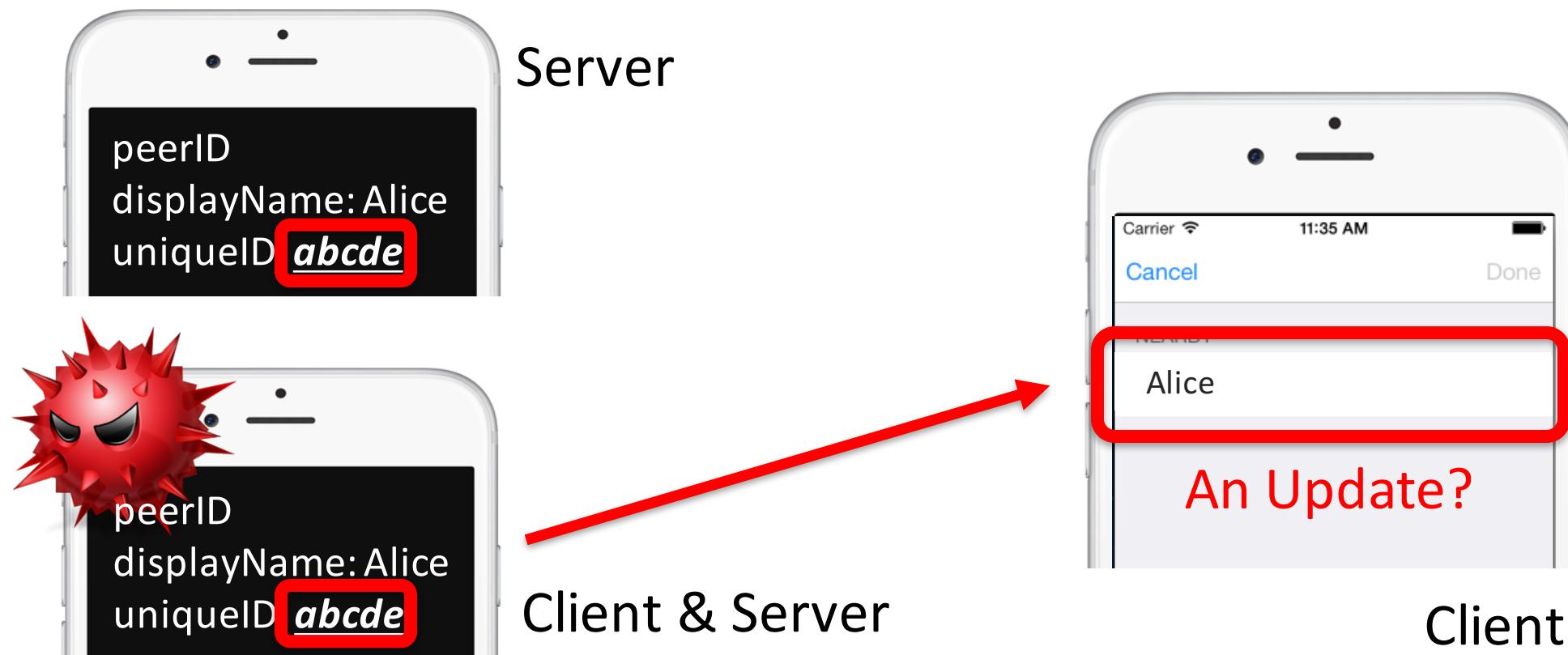
# What Can Go Wrong?

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



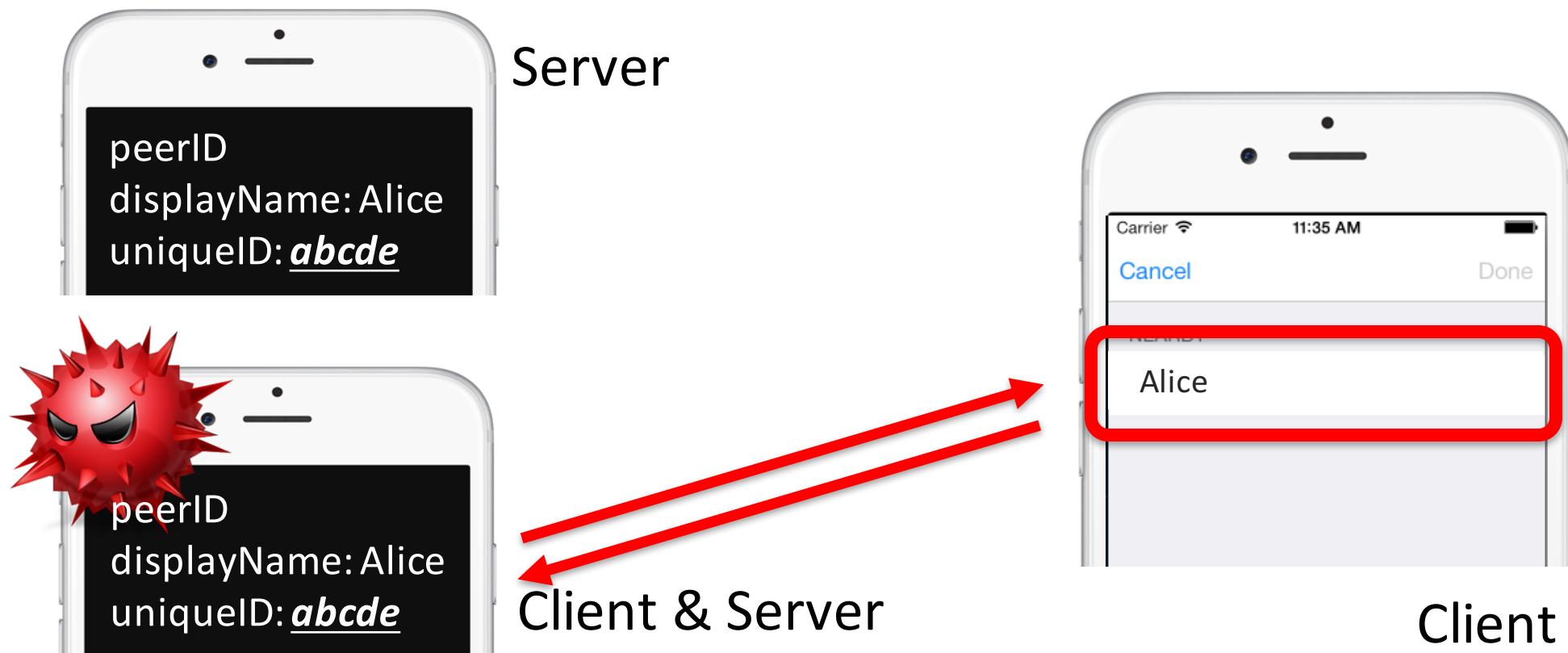
# What Can Go Wrong?

- 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?

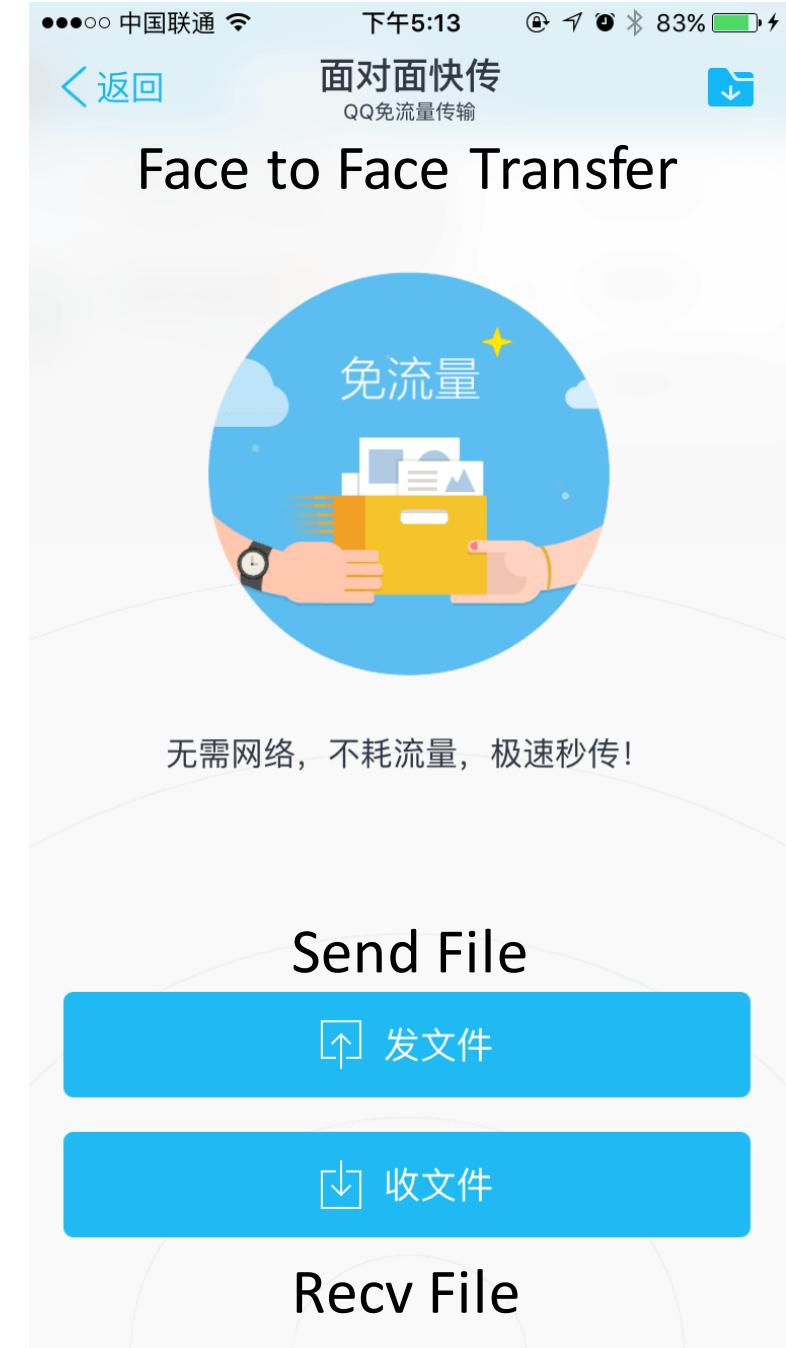
No!

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



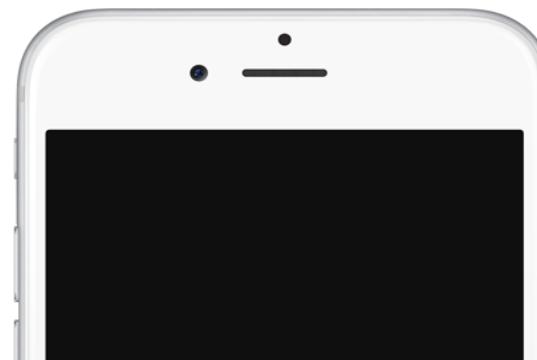
# Normally

- Receiver advertises its QQ ID

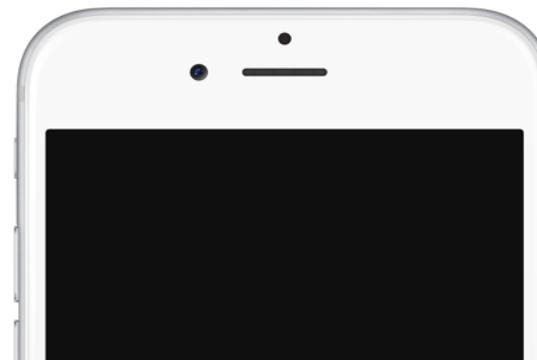


Sender

My QQ ID is 1234



Receiver



Receiver

My QQ ID is 4321

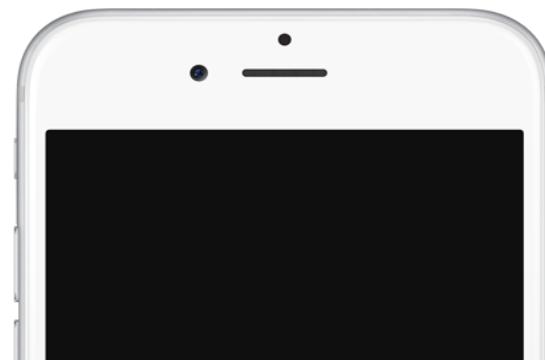
# Normally

- Sender browses for receivers and found their QQ IDs

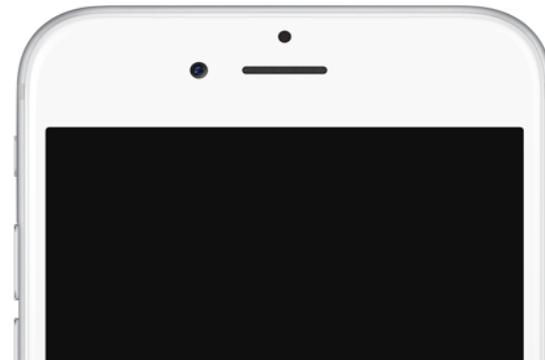


Sender

My QQ ID is 1234



Receiver

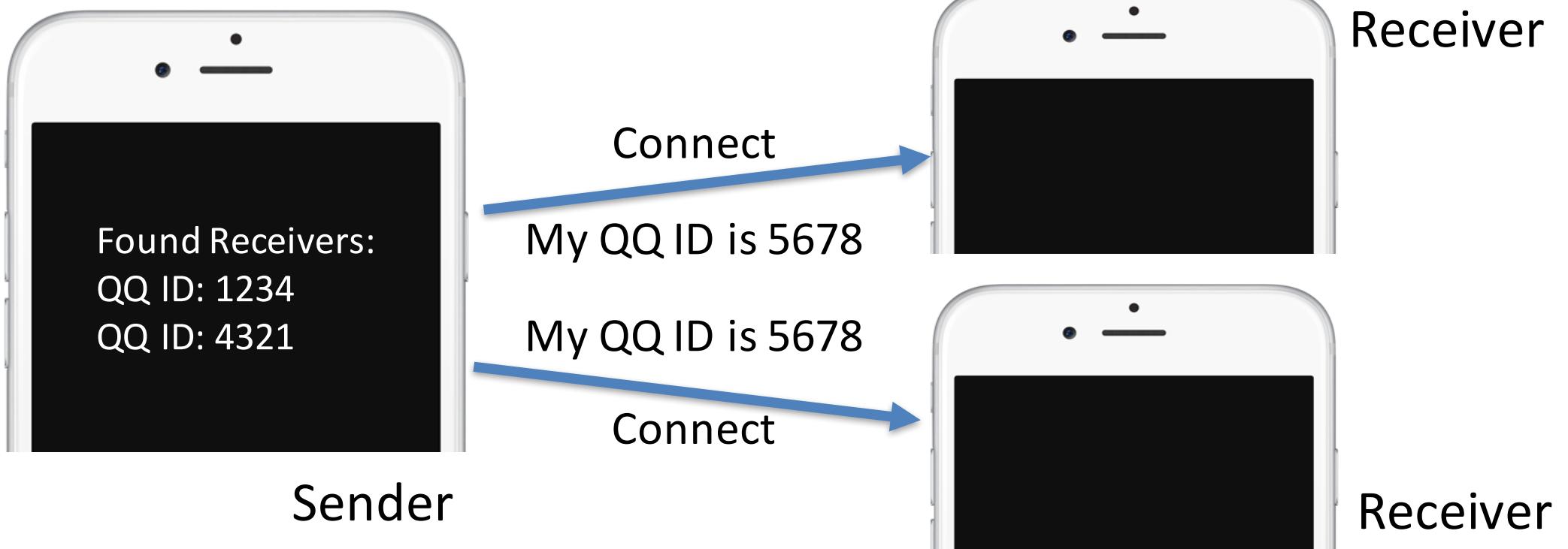


Receiver

My QQ ID is 4321

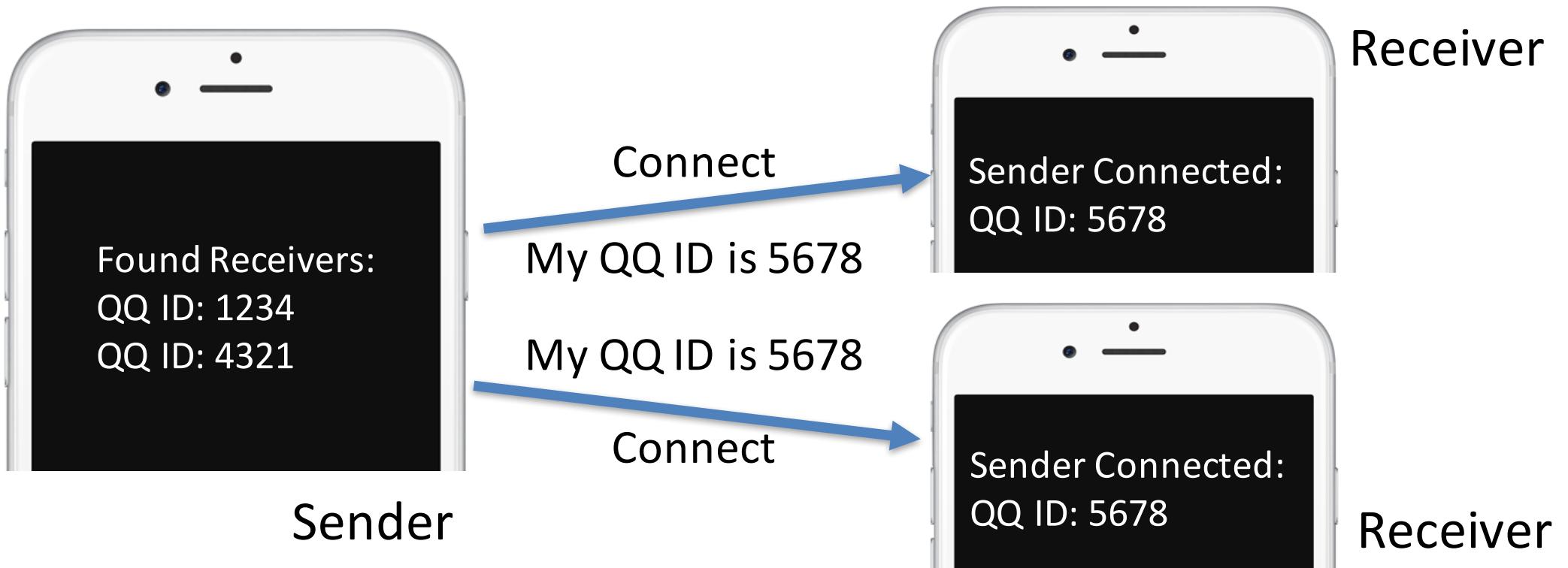
# Normally

- 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

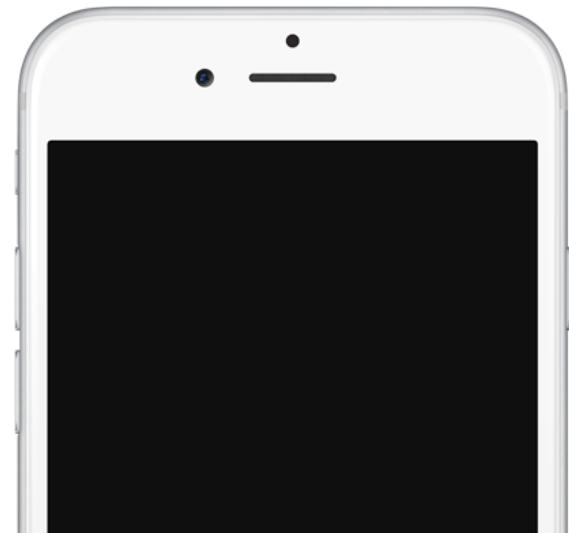


Sender



Attacker

My QQ ID  
is 1234



Receiver

# What Can Go Wrong?

- Attacker found victim receiver's QQ ID

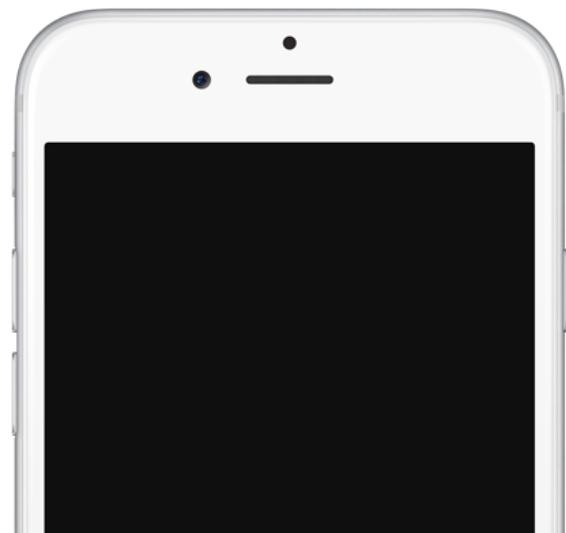


Sender



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

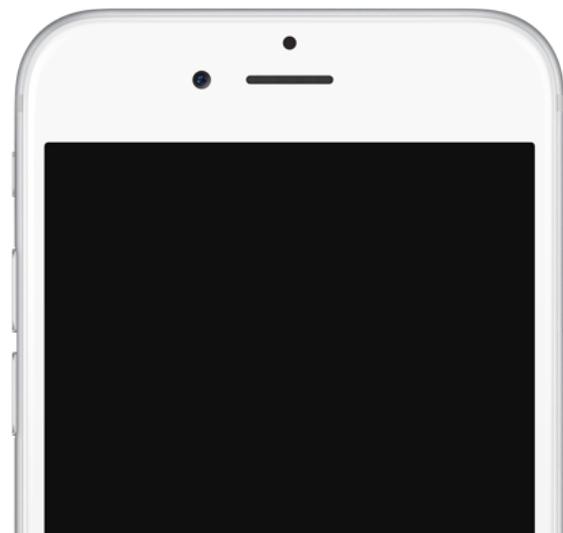


Sender



Attacker

Connect  
QQ ID:5678



Receiver

# Demo

- [https://www.youtube.com/watch?v=B71FID3\\_vrc](https://www.youtube.com/watch?v=B71FID3_vrc)

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

Case 5: Bluetooth

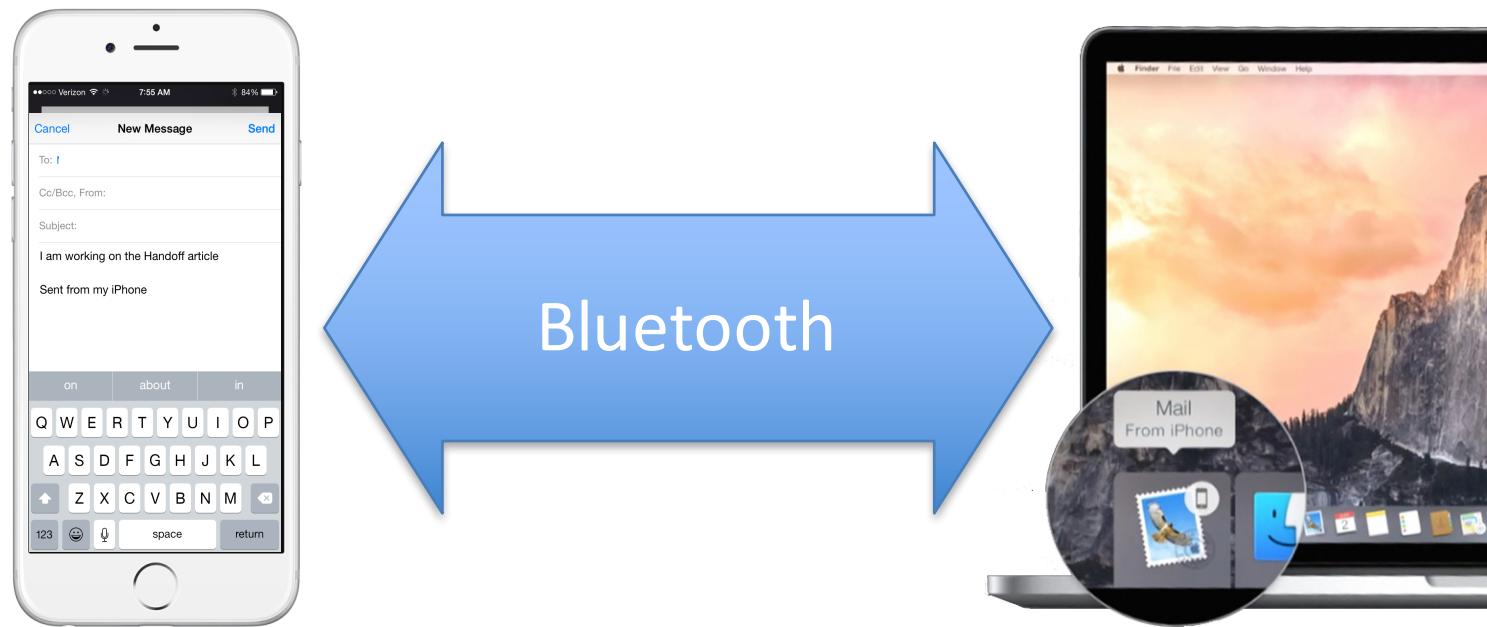
# All your iOS notifications belong to me

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



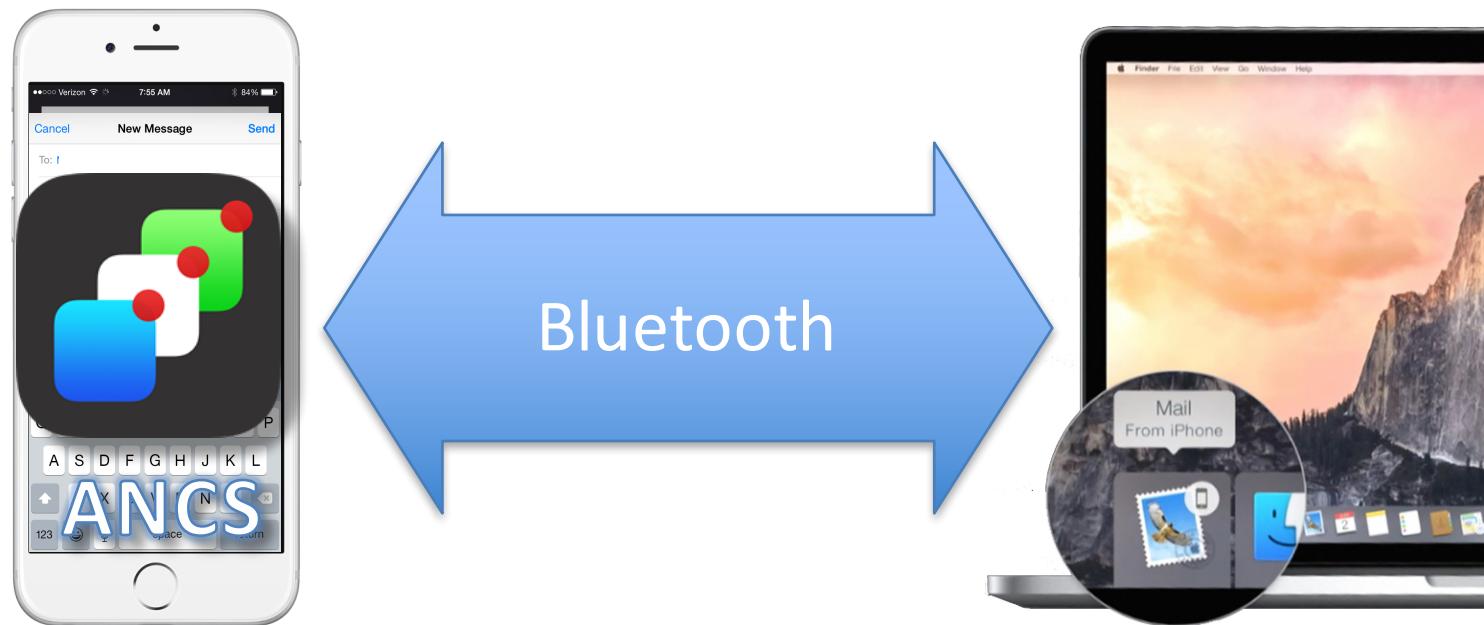
# Normally

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



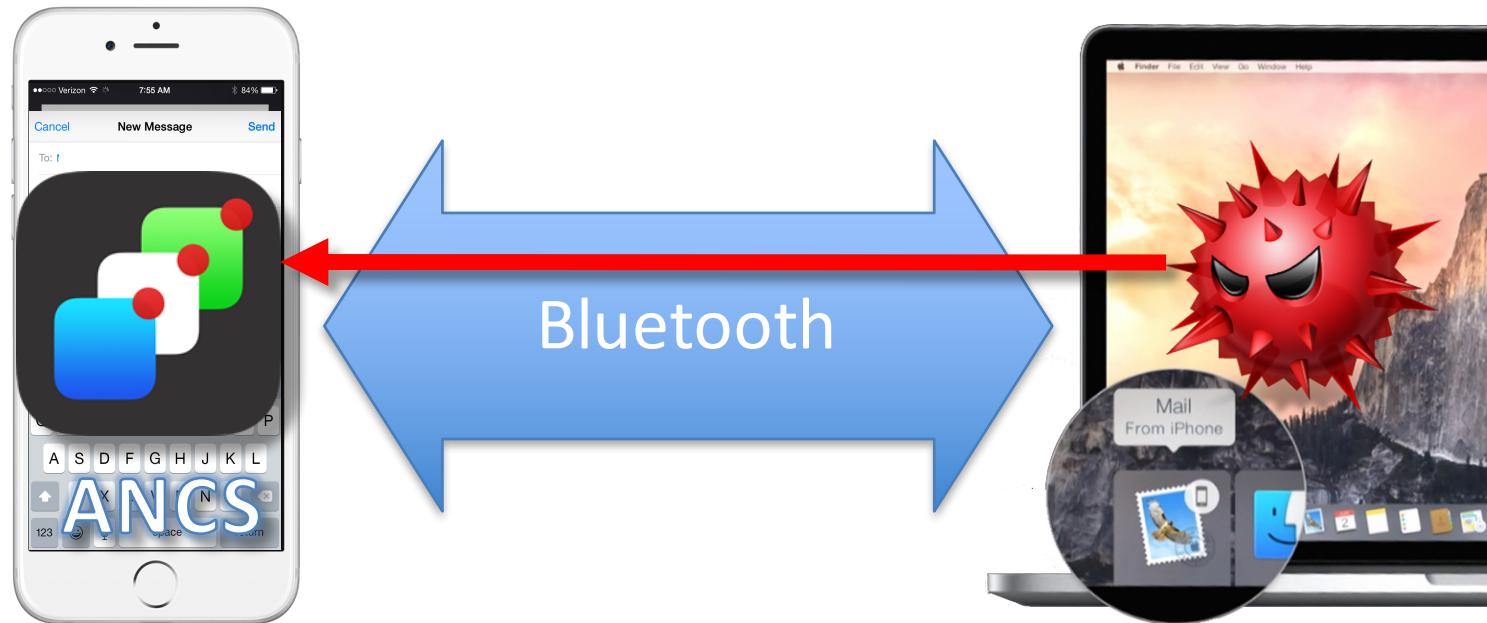
# What Can Go Wrong?

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



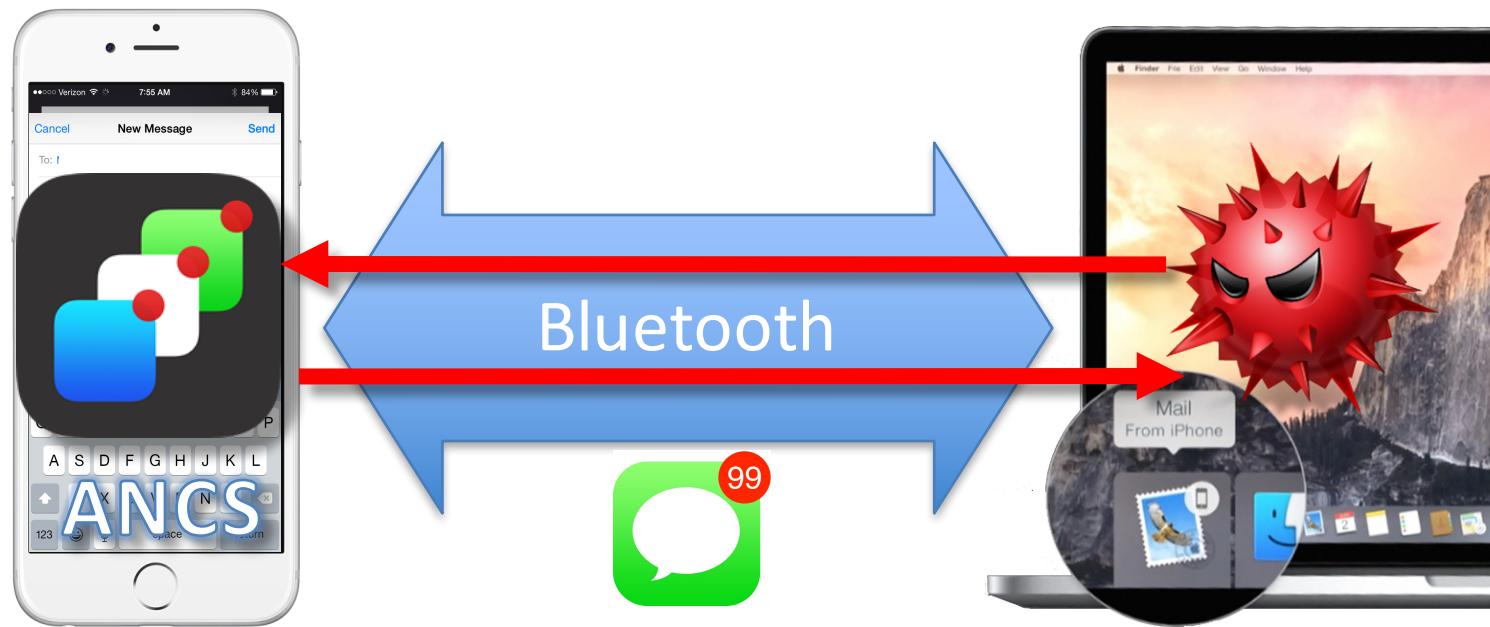
# What Can Go Wrong?

- Bluetooth ZeroConf: No app-level authentication
- Apple Notification Center Service (ANCS)
- Through Bluetooth channel created by Handoff



# What Can Go Wrong?

- Bluetooth ZeroConf: No app-level authentication
- Apple Notification Center Service (ANCS)
- Through Bluetooth channel created by Handoff



# 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

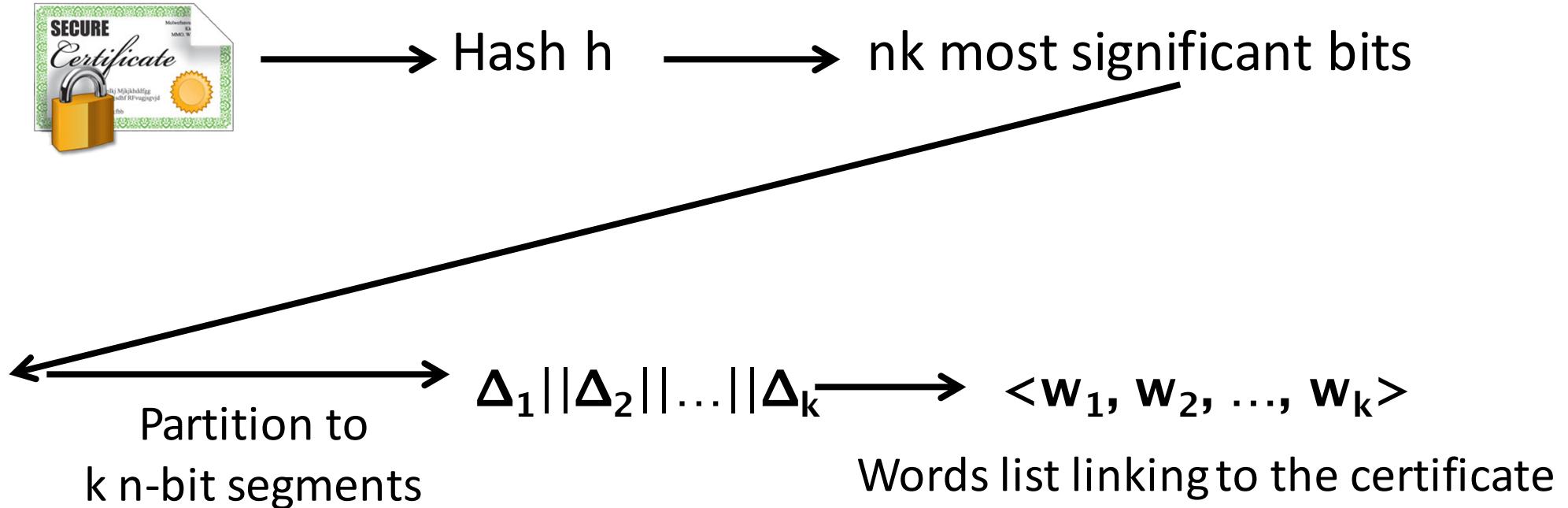
1. ZeroConf Concept
2. ZeroConf How
3. ZeroConf Breaking
4. Impact
5. Protecting ZeroConf

# 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