DISCOVERING AND EXPLOITING NOVEL SECURITY VULNERABILITIES IN APPLE ZEROCONF

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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/

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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

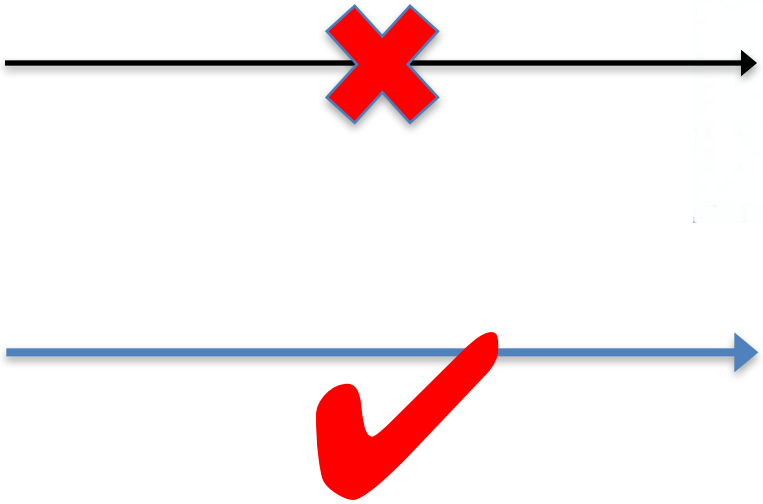
Bonjour

- 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

Is anybody using IP
fe80::abcd:1234....?

A printer configures itself

IP

fe80::abcd:1234

No?

Great, I'll take it.

A printer configures itself

IP

fe80::abcd:1234

Anybody using hostname

HP9FE5.host.local?

A printer configures itself

IP

fe80::abcd:1234

Hostname

HP9FE5.host.local

No?

Wonderful, I'll take it.

A printer configures itself

IP

fe80::abcd:1234

Hostname

HP9FE5.host.local

Service Instance Name

HP-Service-9FE5

Anybody having a printing service named HP-Service-9FE5?

A printer finishes configuring itself

IP

fe80::abcd:1234

Hostname

HP9FE5.host.local

Service Instance Name

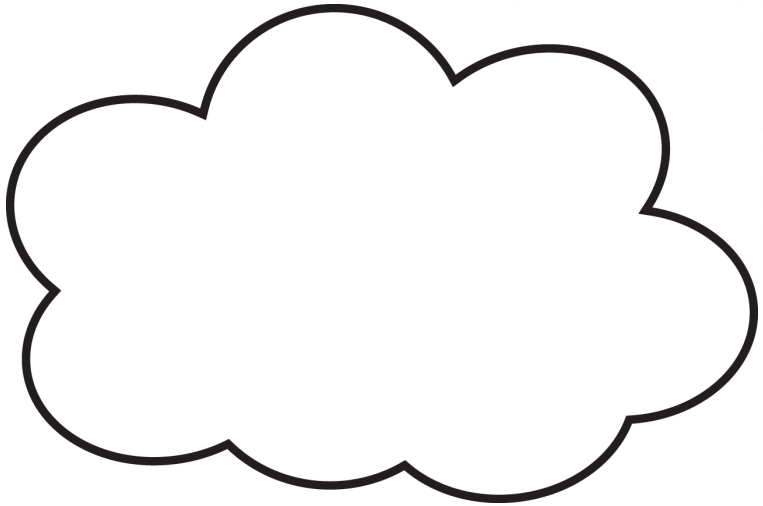
HP-Service-9FE5

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

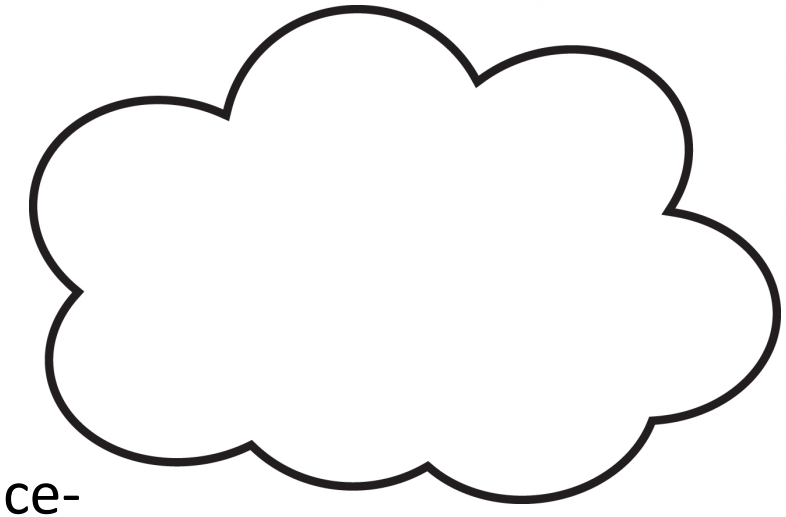
Automatically find the printer: Discovery



Q1:
Anyone has a printer service?

A1:
I have HP-Service-9FE5

Automatically find the printer: Resolution



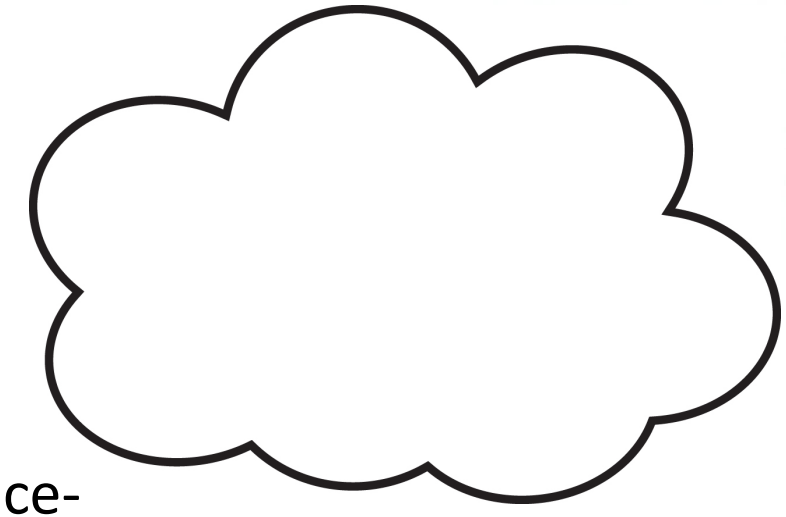
Q1:
Anyone has a printer service?

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?

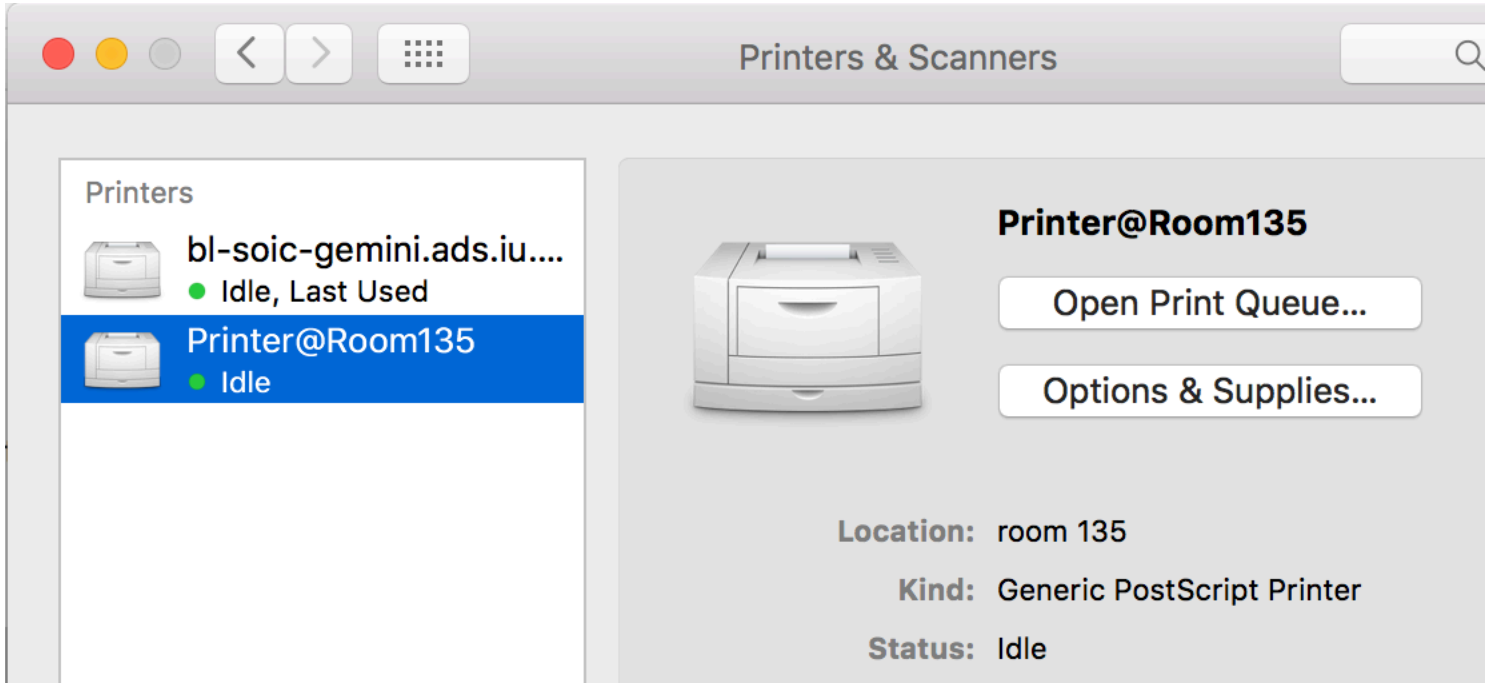
Q3:
What is the address of NPI9fe5.host.local?

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

IP

fe80::abcd:1234

Hostname

HP9FE5.host.local

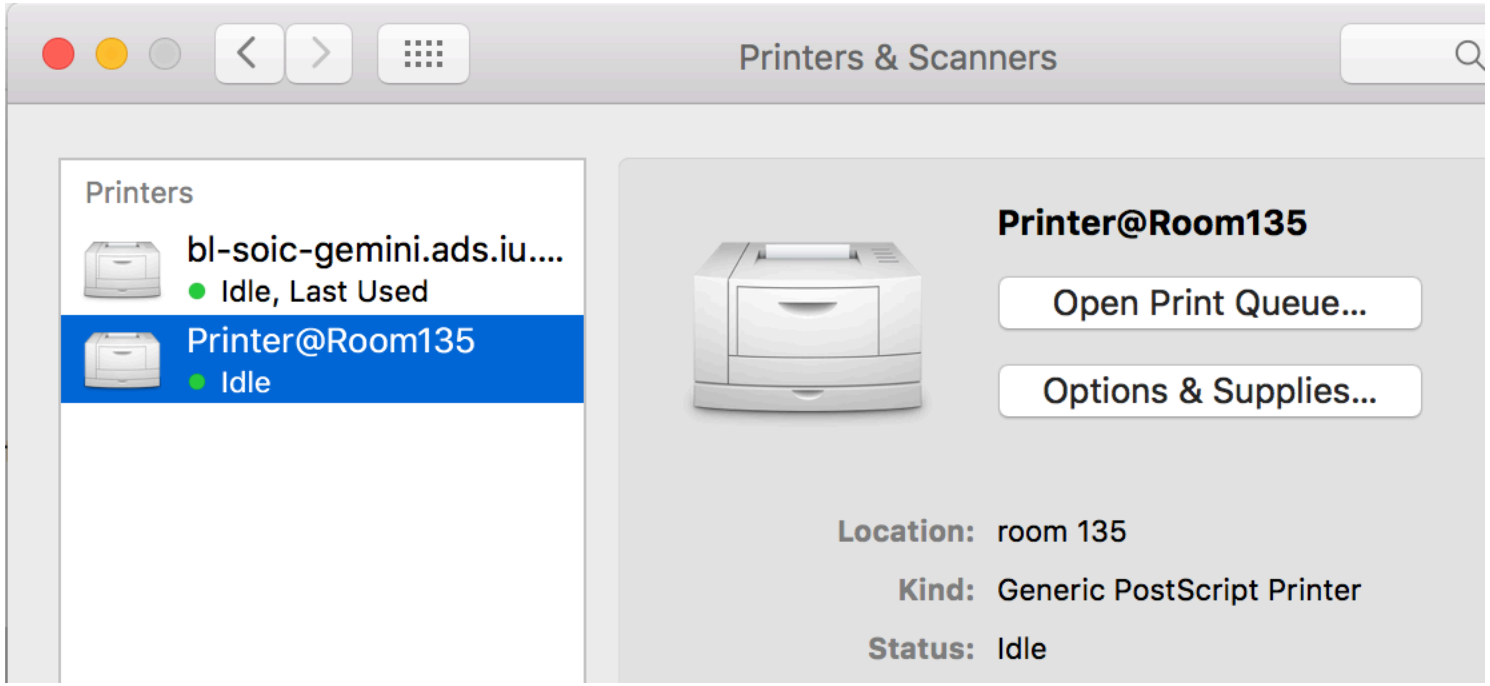
Service Instance Name

HP-Service-9FE5

Apple:

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

Service instance name HP-Service-9FE5 is saved



~~IP~~
~~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

IP

Hostname

Service Instance Name

HP-Service-9FE5

A device infected by malware

IP

Hostname

Service Instance Name

HP-Service-9FE5

I have a printing service instance named

HP-Service-9FE5

Service Instance Name

HP-Service-9FE5

A device infected by malware

IP

Hostname

Service Instance Name

HP-Service-9FE5

I have a printing service instance named

HP-Service-9FE5

Service Instance Name

HP-Service-9FE5

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

New Service Name

HP-Service-9FE5 (2)

Service Instance 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.

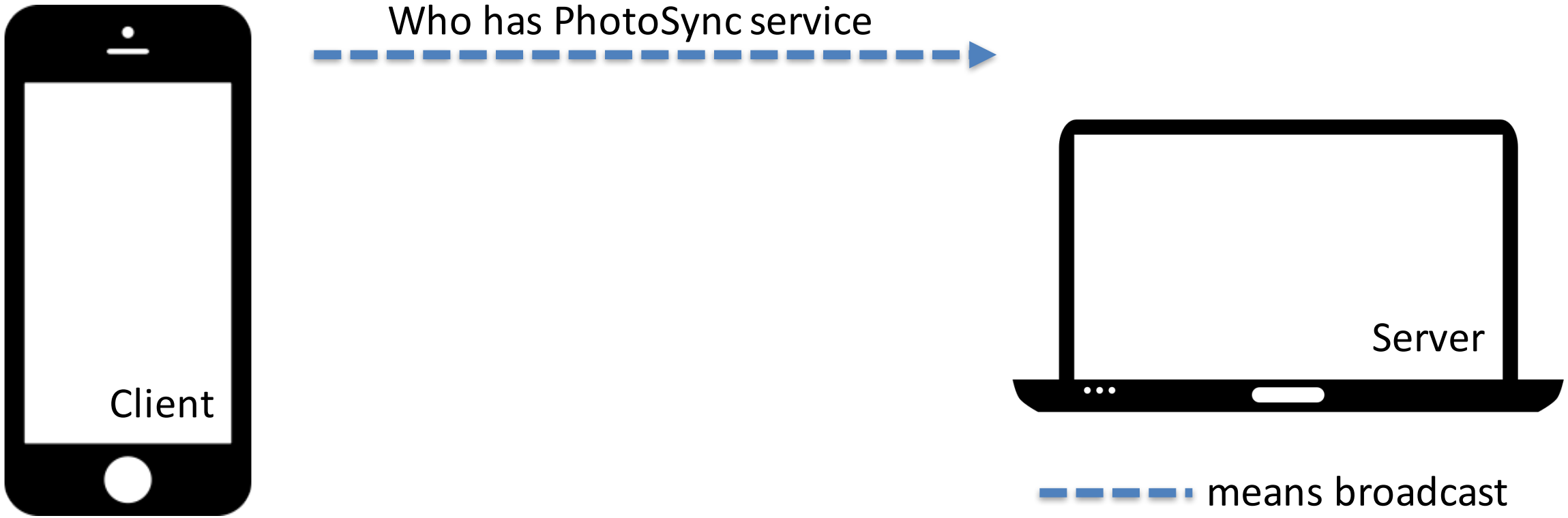
If not saving service instance names,
is it secure enough?

Attack Bonjour

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

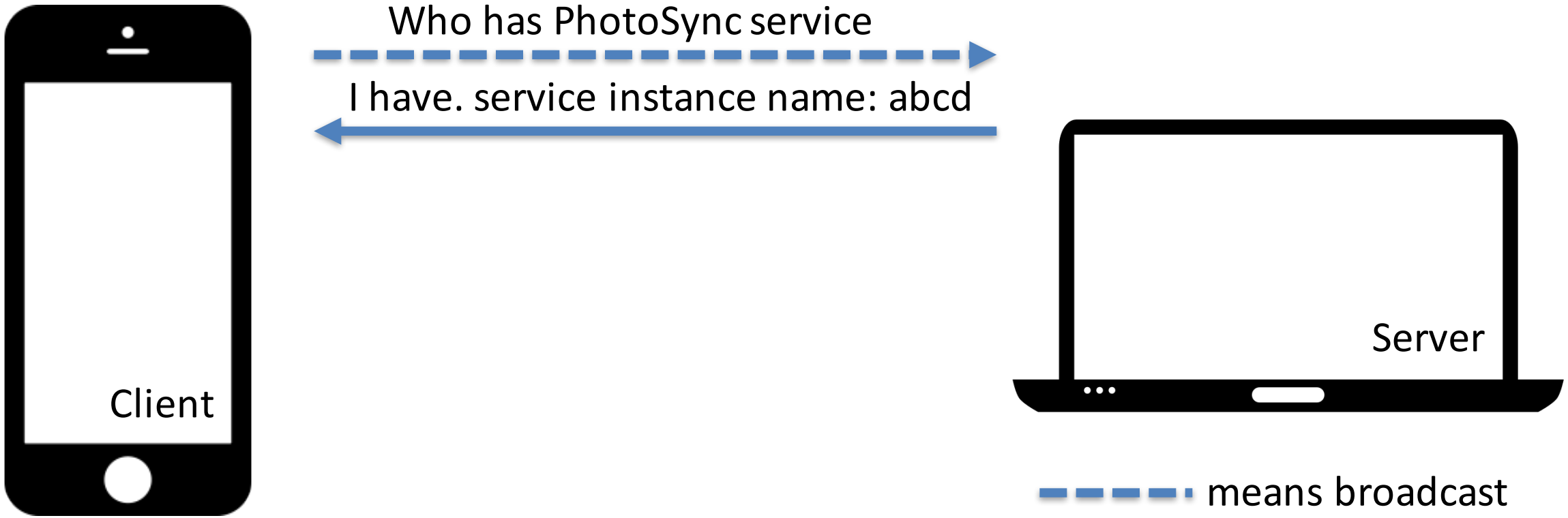
Normally

- Discovery: Client browses for server



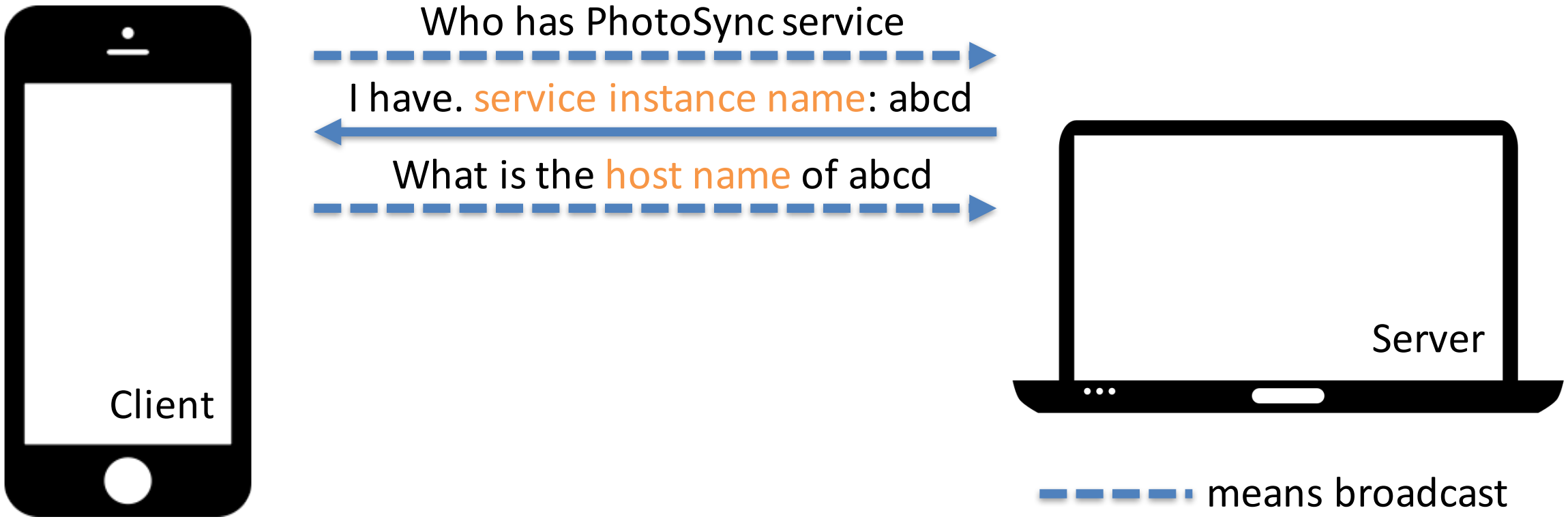
Normally

- Discovery: Server responds with service instance name



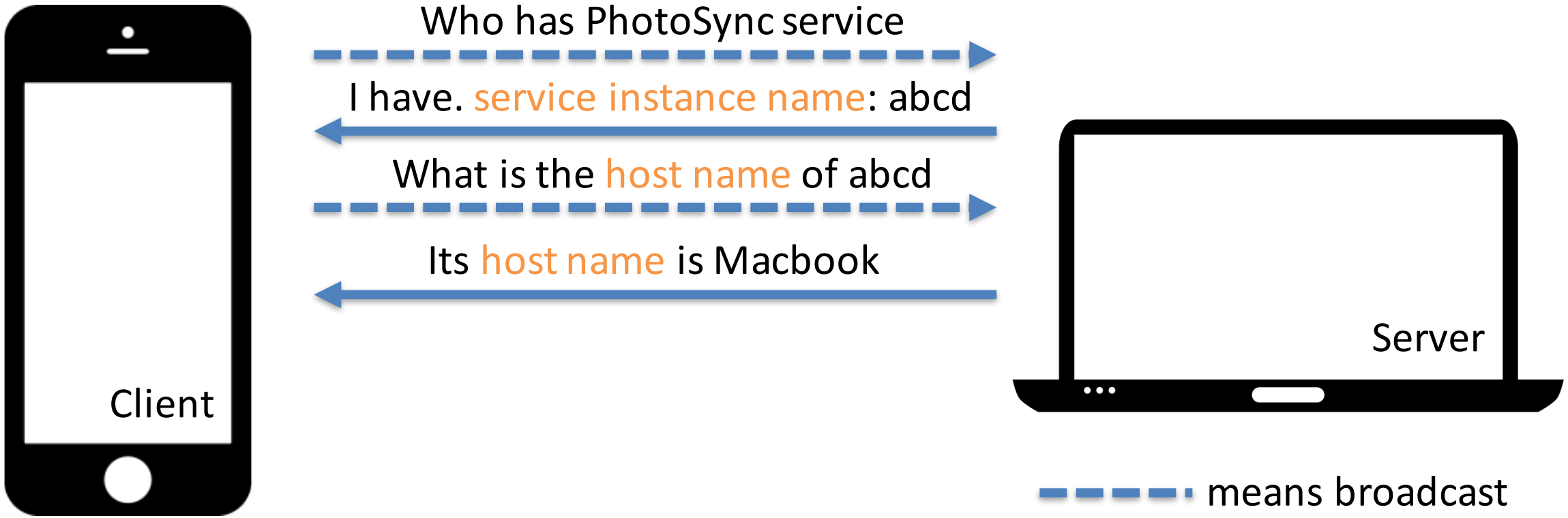
Normally

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



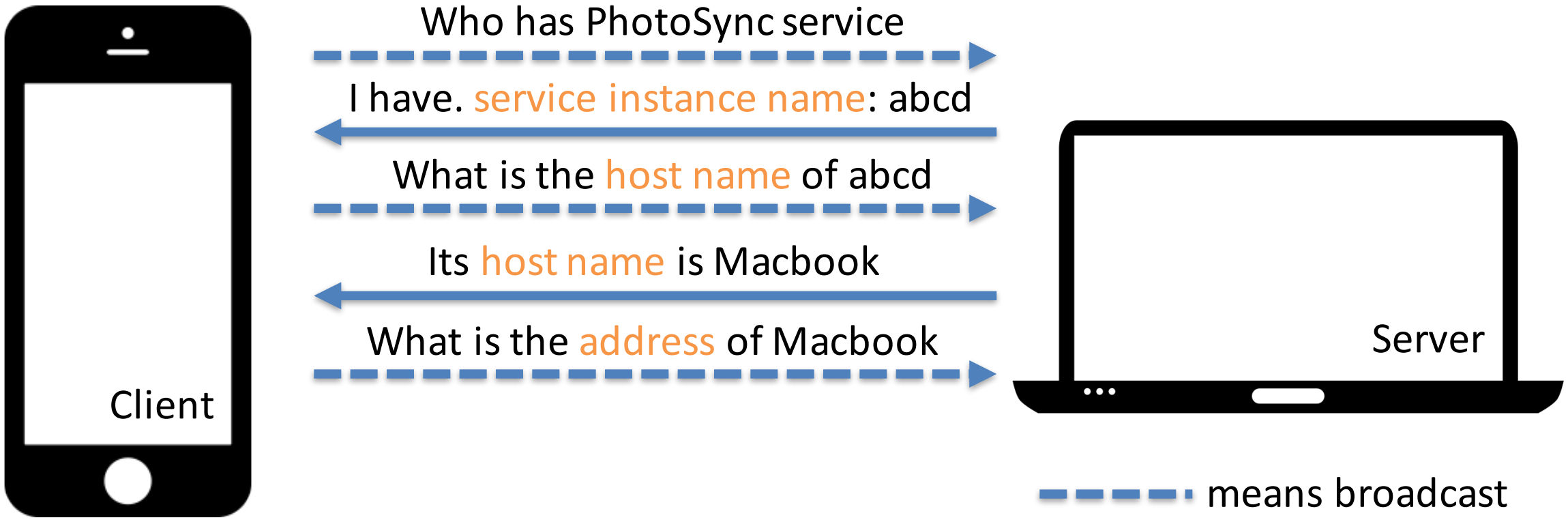
Normally

- Resolution 1: Server responds with the host name



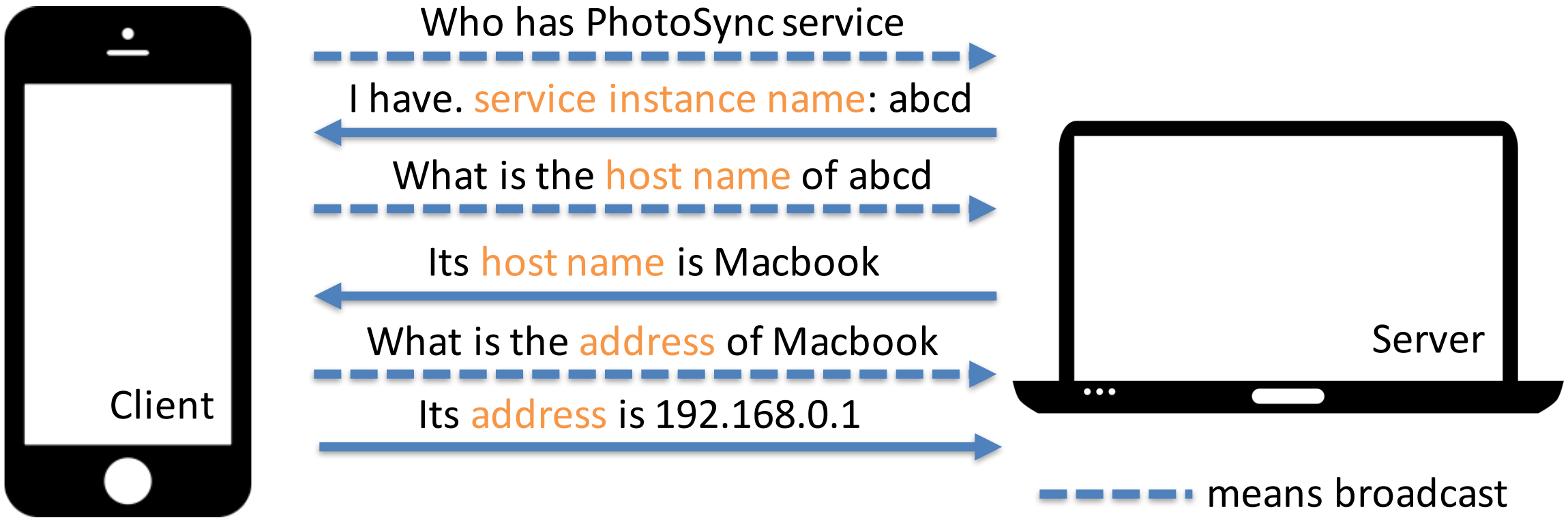
Normally

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



Normally

- Resolution 2: Server responds with its address

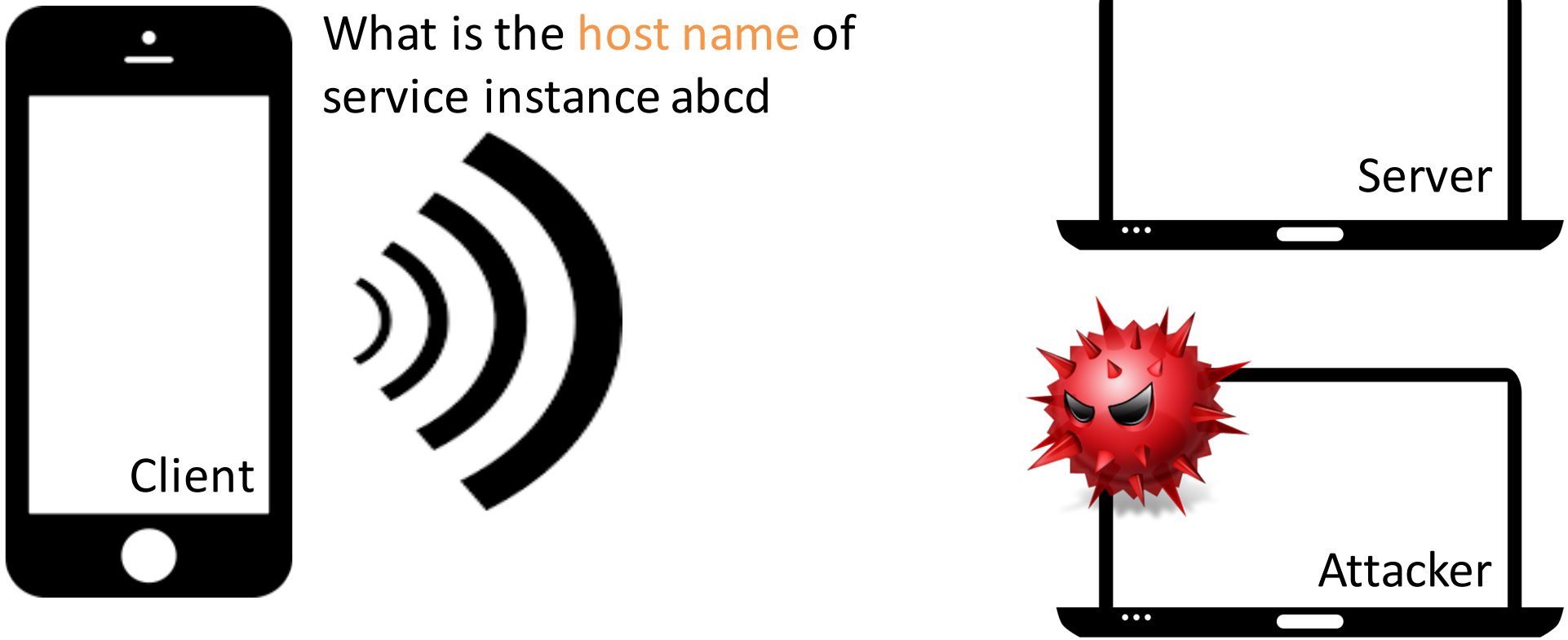


What Can Go Wrong?

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

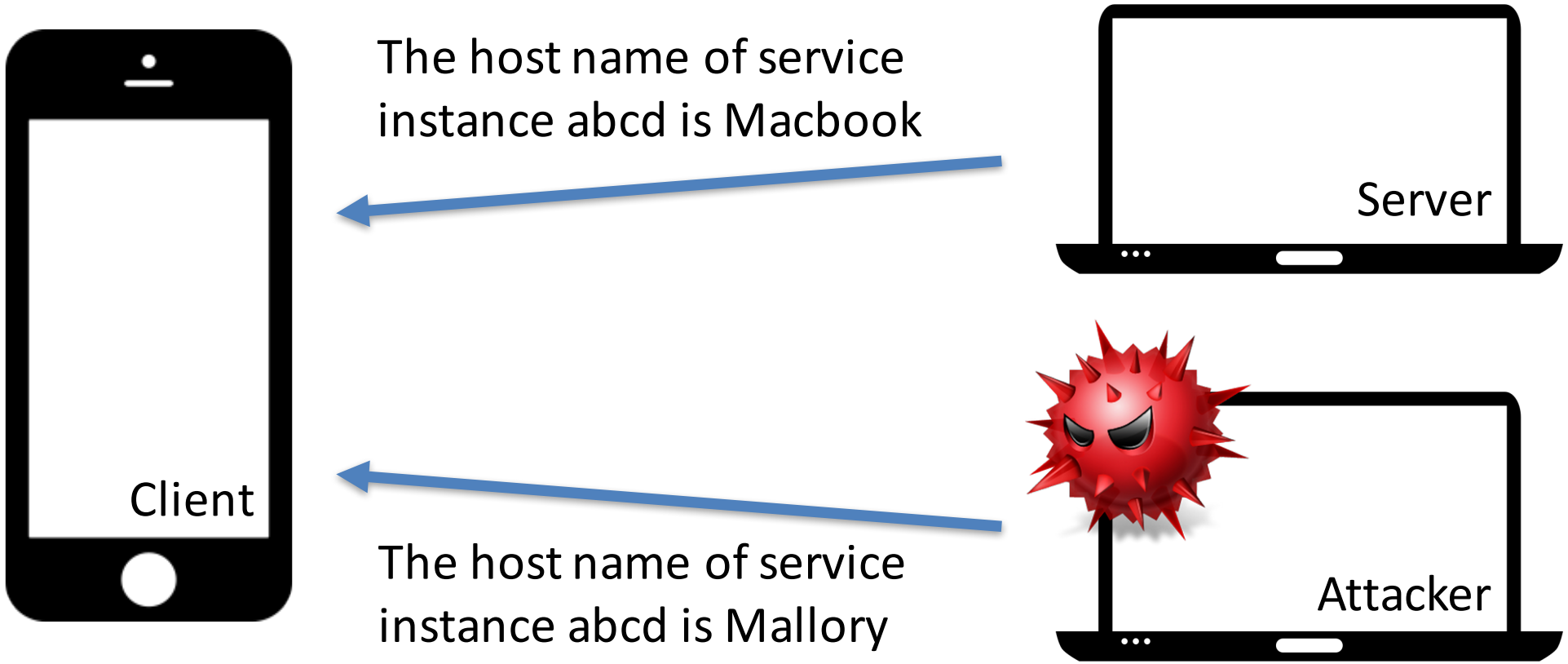
What Can Go Wrong?

- Attack 1: service instance name to host name



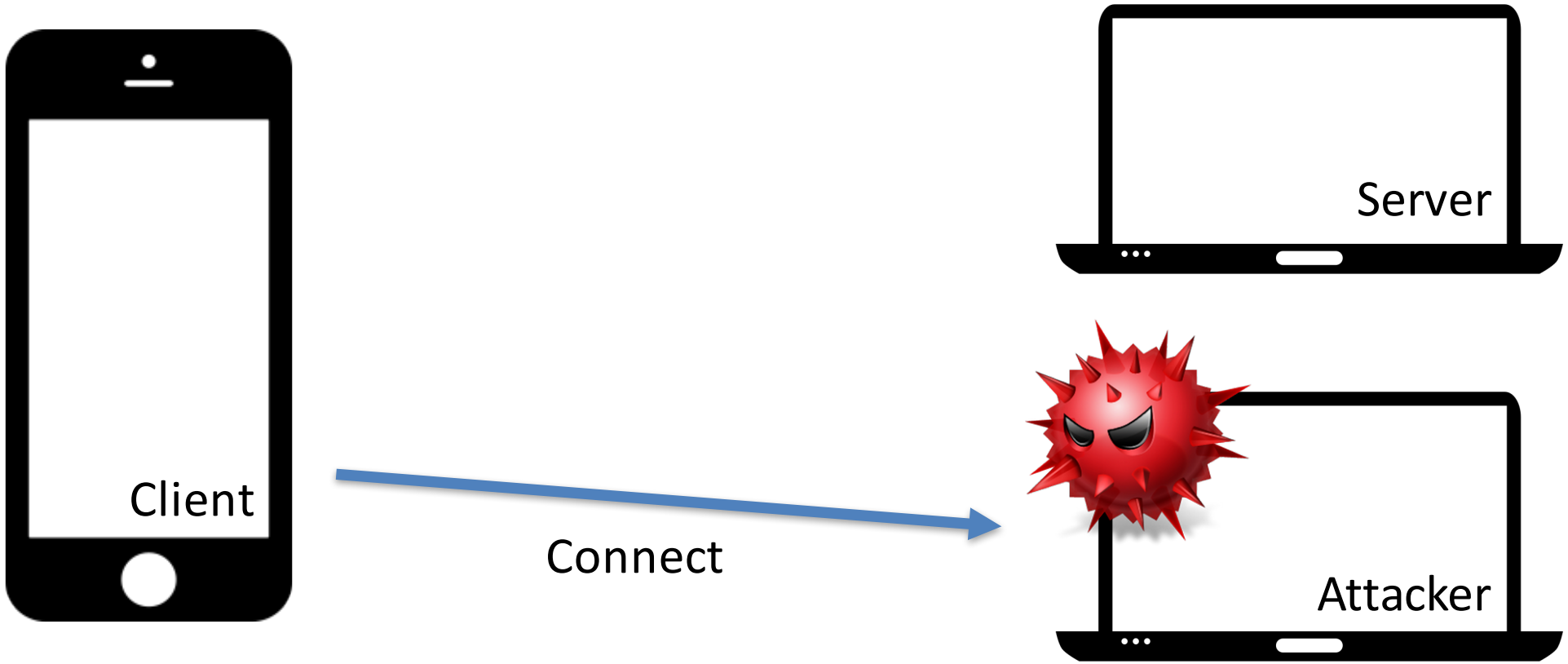
What Can Go Wrong?

- Attack 1: service instance name to host name



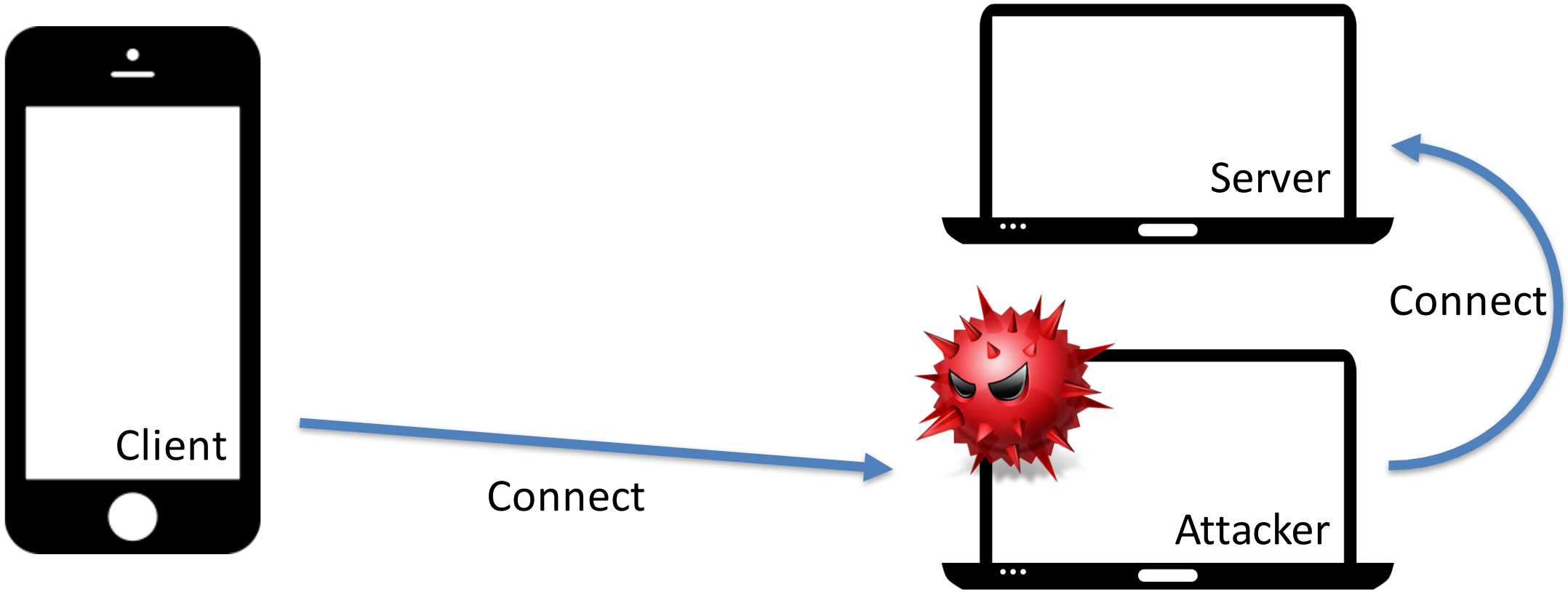
What Can Go Wrong?

- Attack 1: service instance name to host name



What Can Go Wrong?

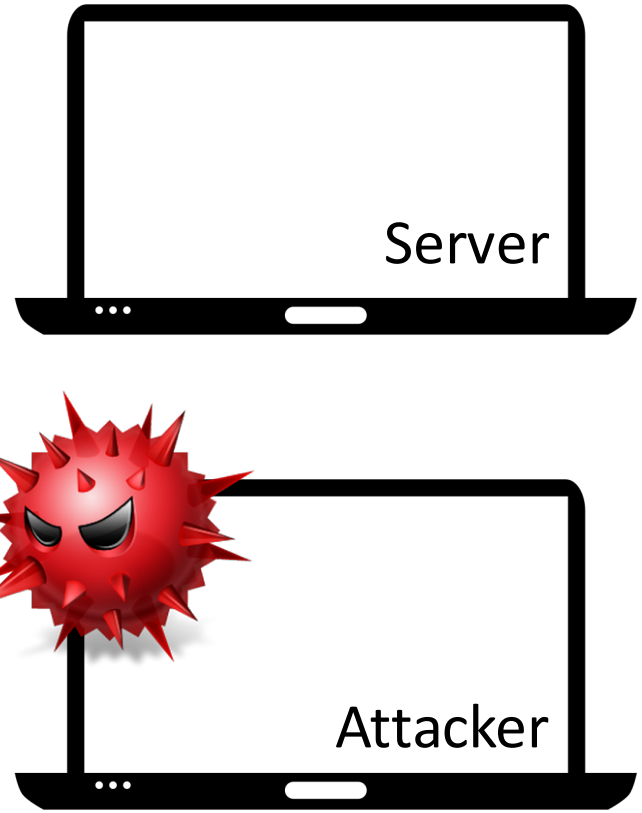
- Attack 1: service instance name to host name



What Can Go Wrong?

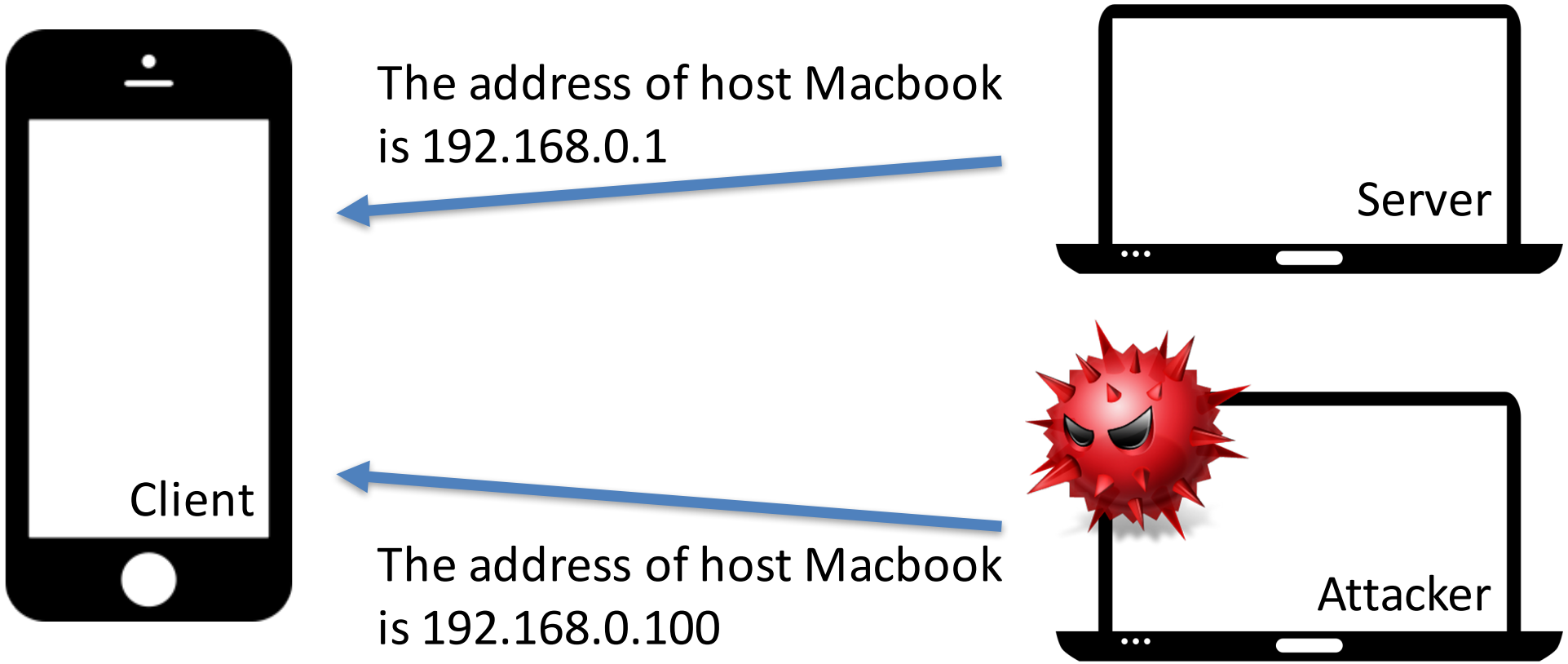
- Attack 2: service instance name to host name

What is the address of host Macbook



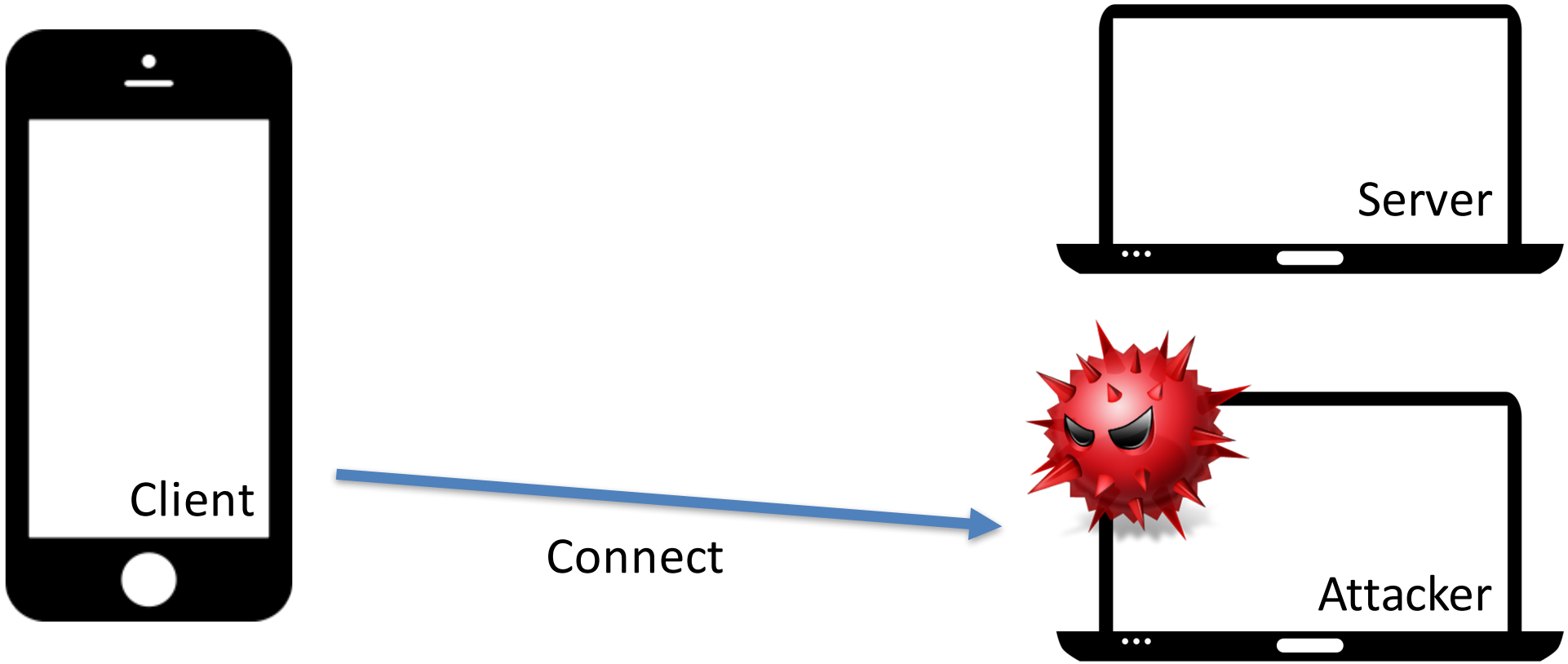
What Can Go Wrong?

- Attack 2: service instance name to host name



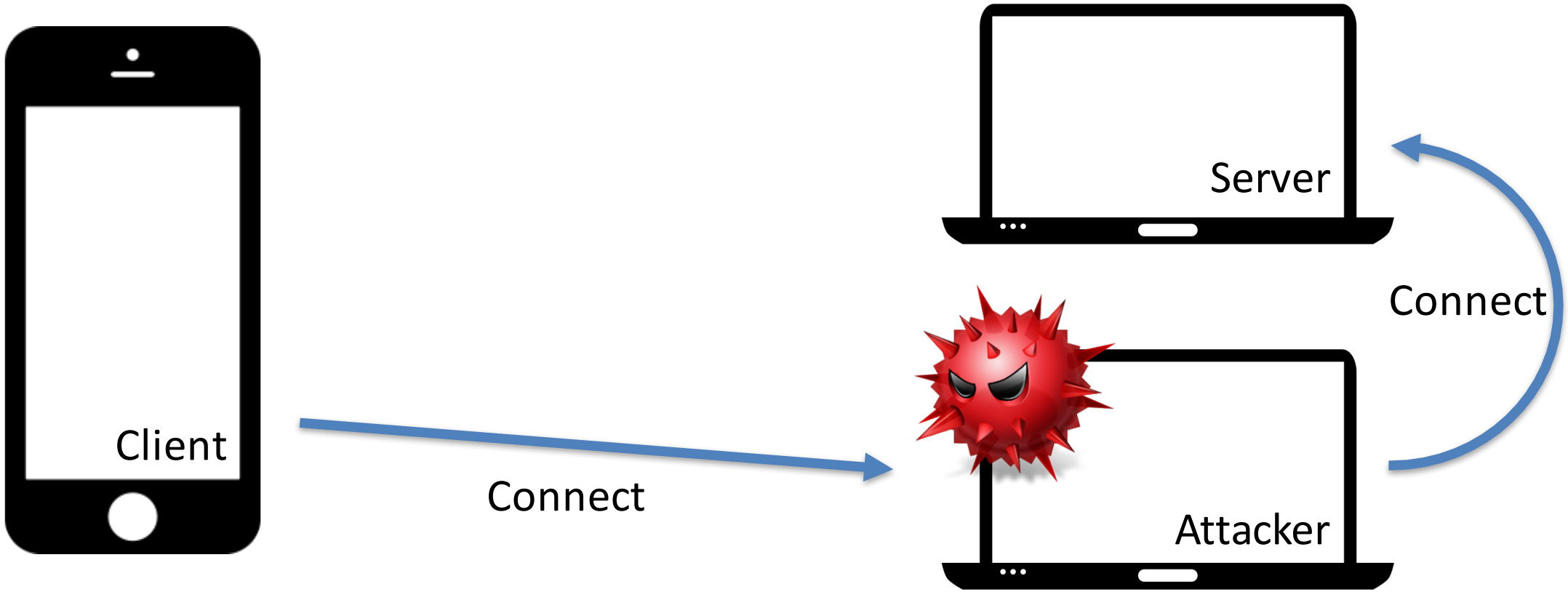
What Can Go Wrong?

- Attack 2: service instance name to host name



What Can Go Wrong?

- Attack 2: service instance name to host name



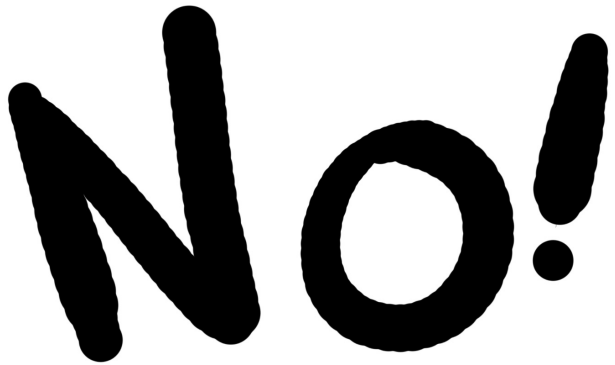
Demo

- 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?



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

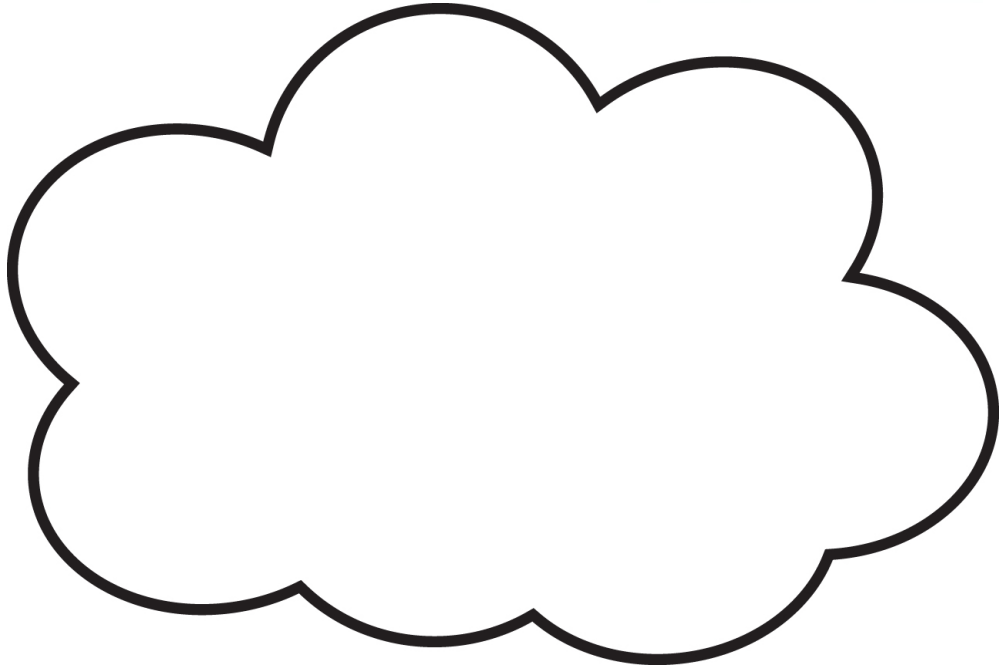
Case 2: Airdrop

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?

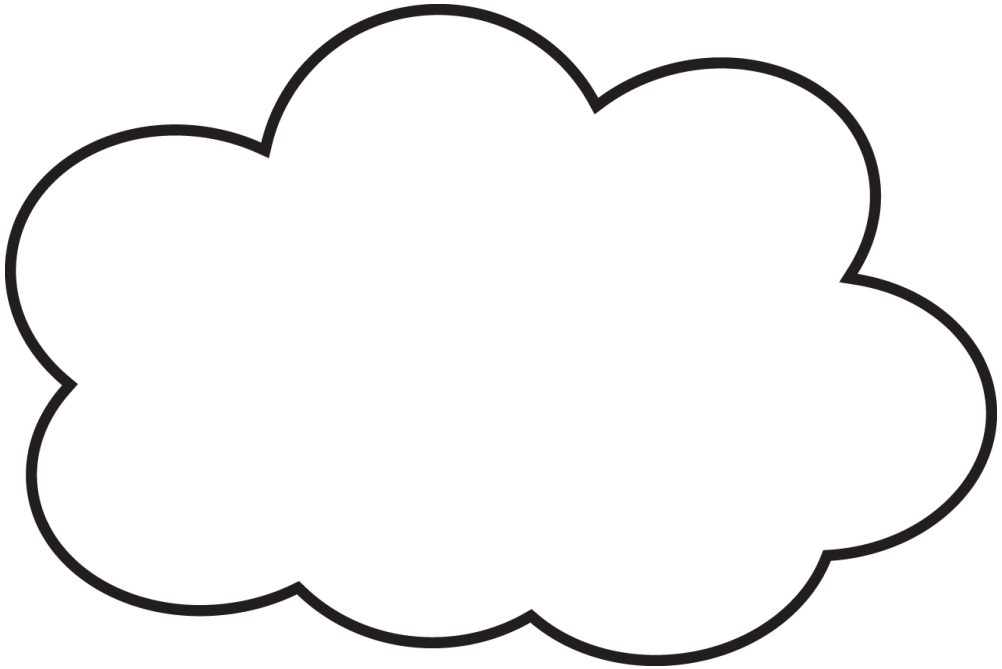


Alice's iPhone:
I have a service named abcd.airdrop.service

Attack Airdrop

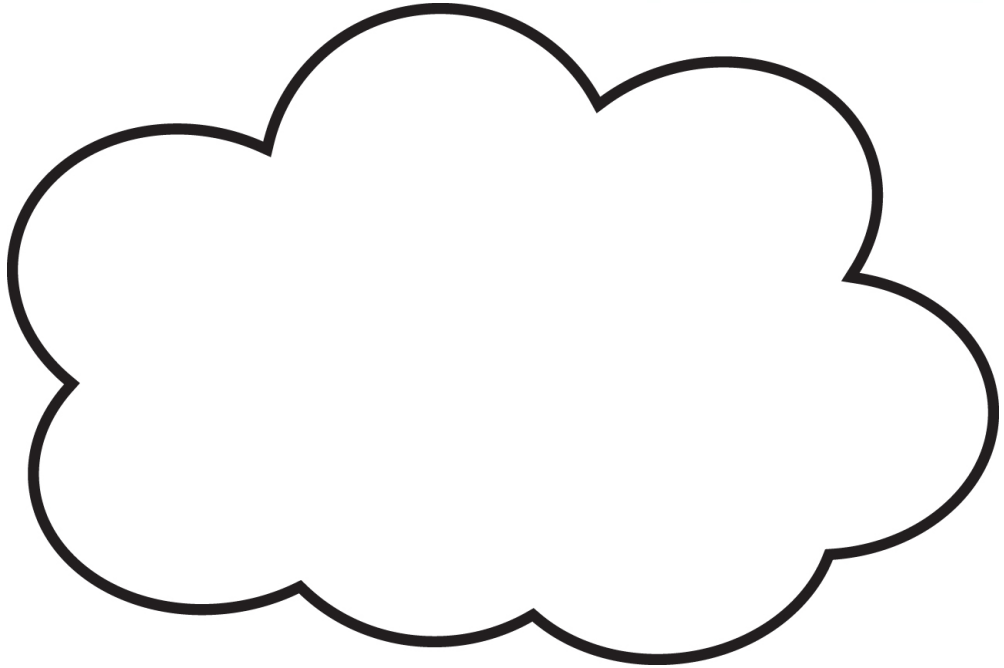
Jeff's Macbook:

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



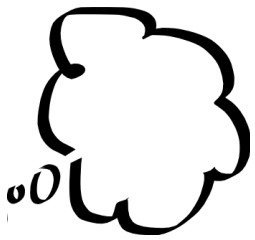
Attack Airdrop

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



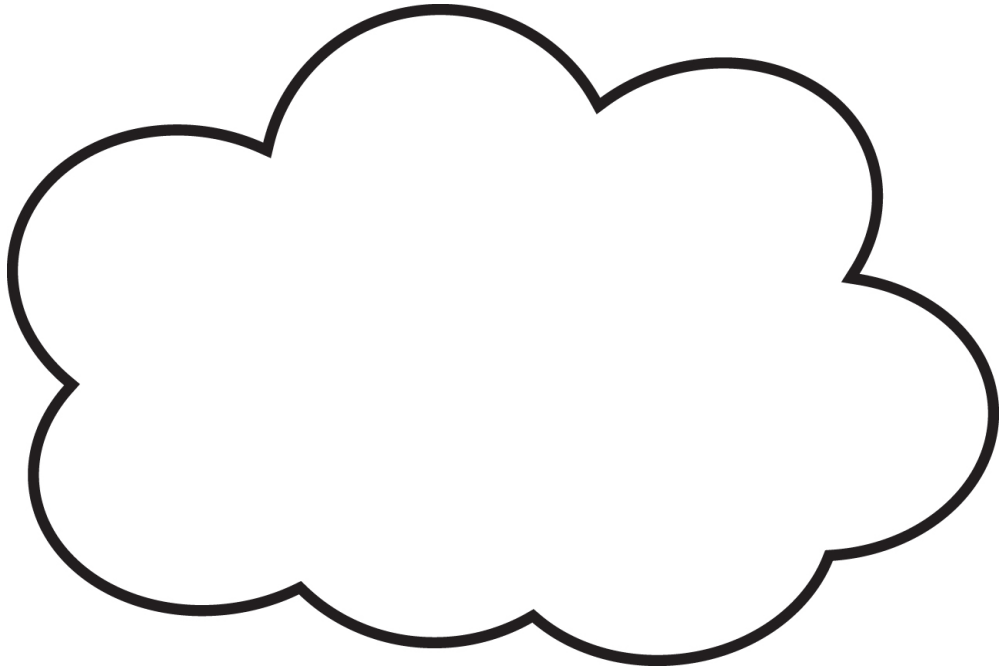
Bob's iMac:
A2: It's on host Bobs.imac.local

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

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

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

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

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

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

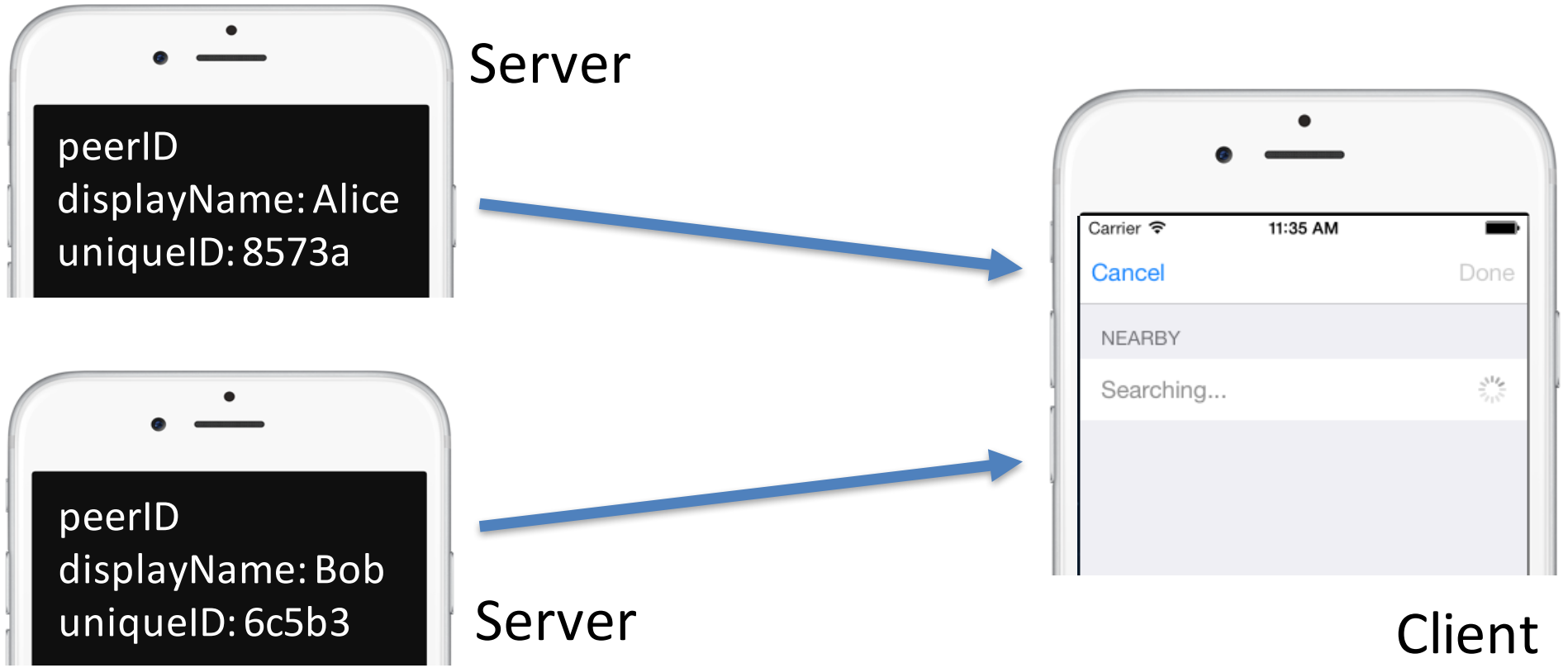
Apple’s Vulnerable framework

- 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)



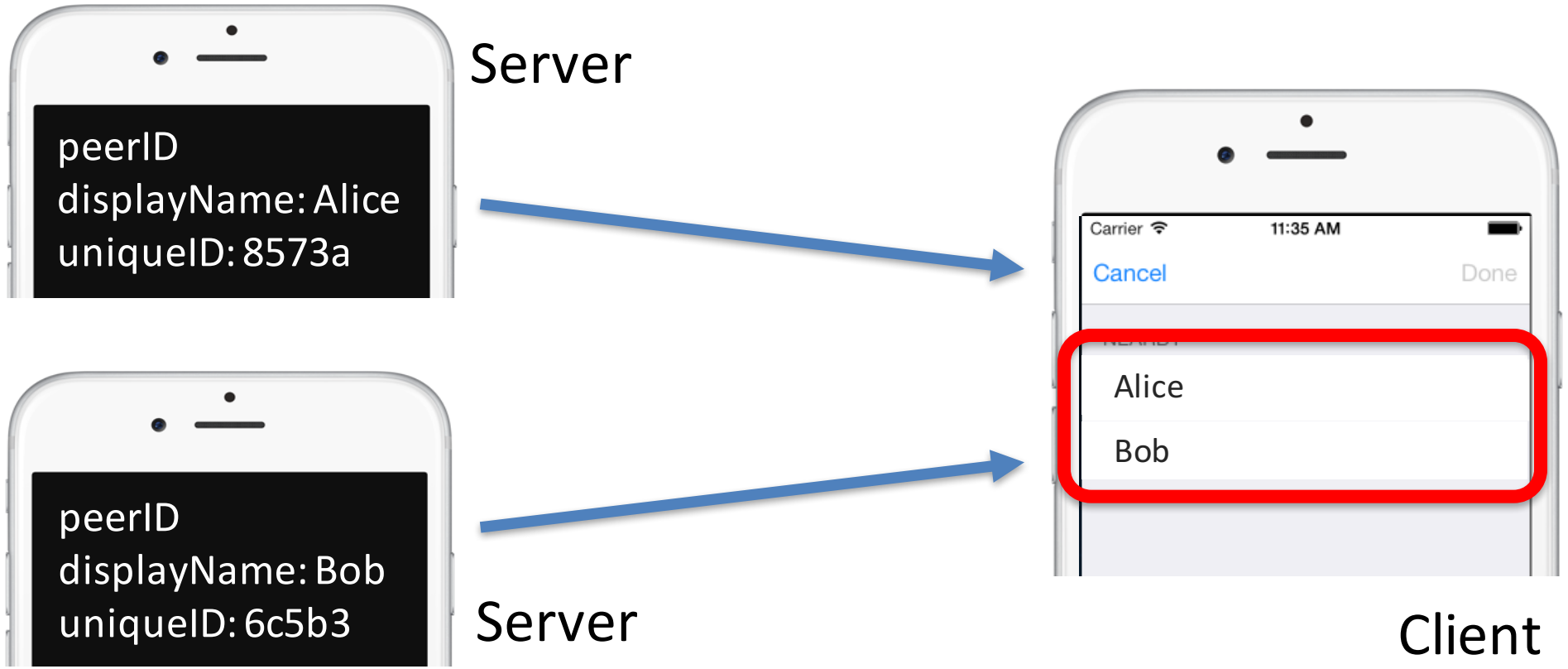
Normally

- Automatic Service Discovery Without Configuration
  - Servers advertise peerIDs



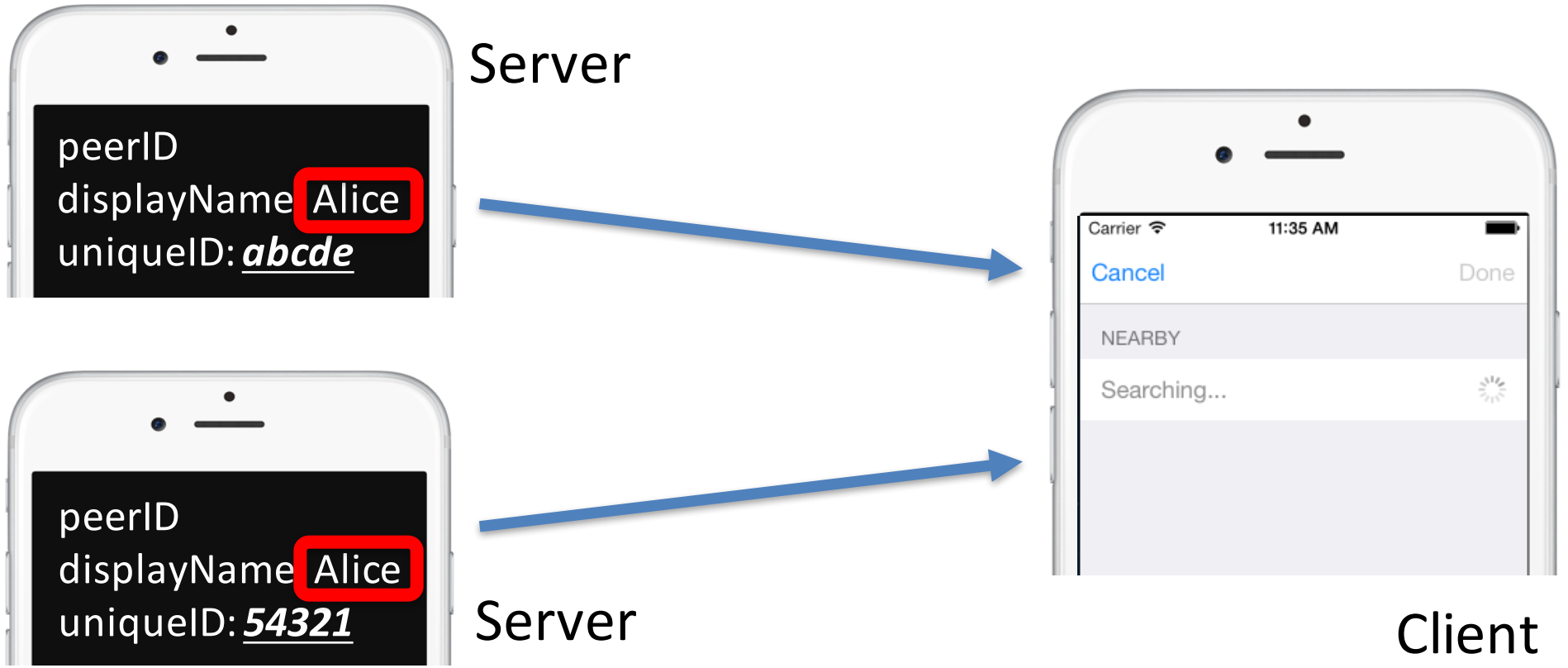
Normally

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



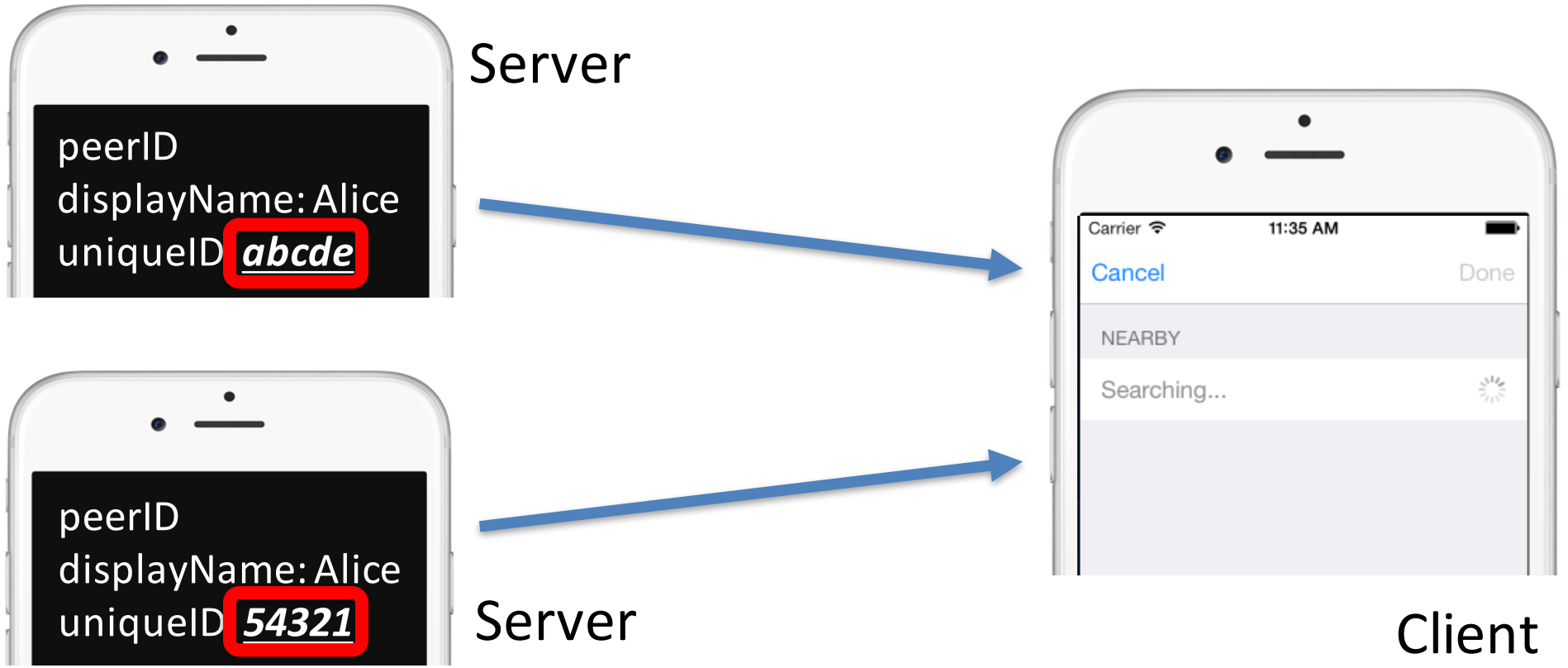
Normally

- Even if servers have the same displayName



Normally

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



Normally

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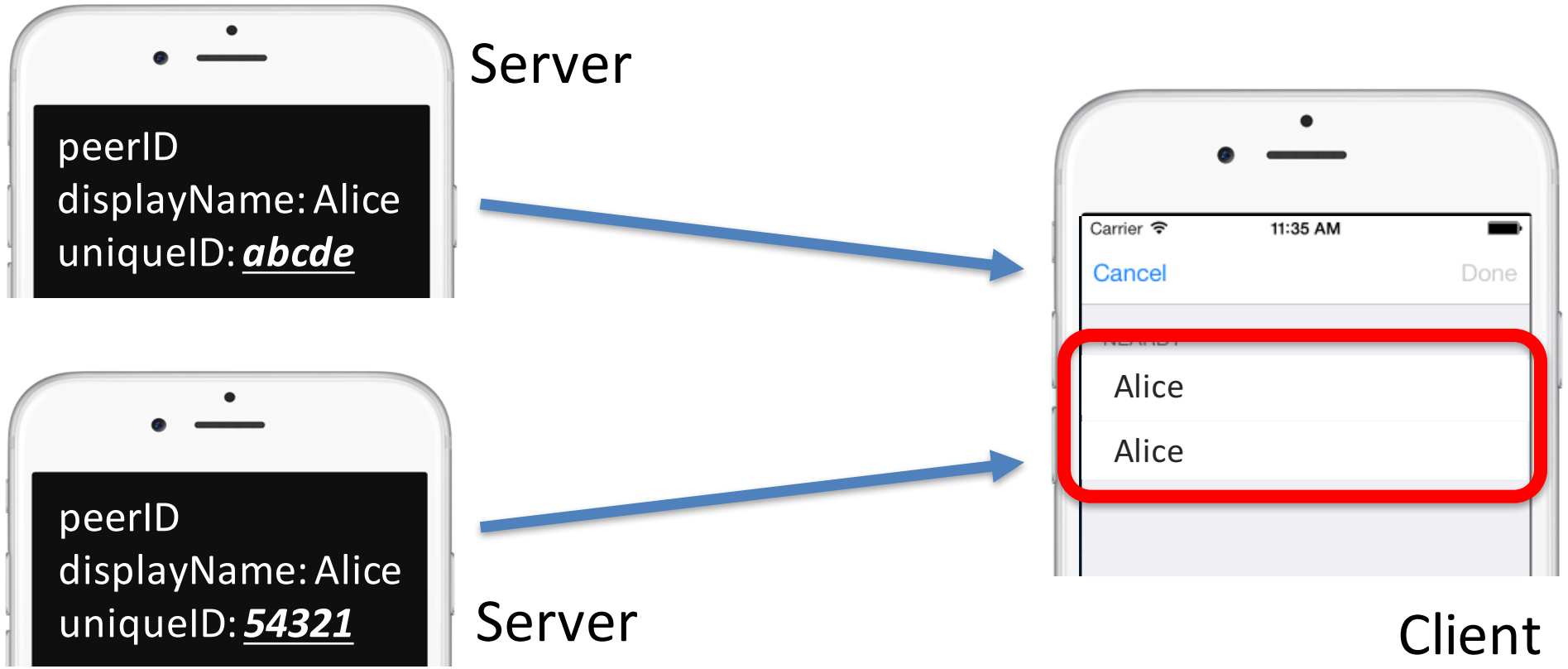
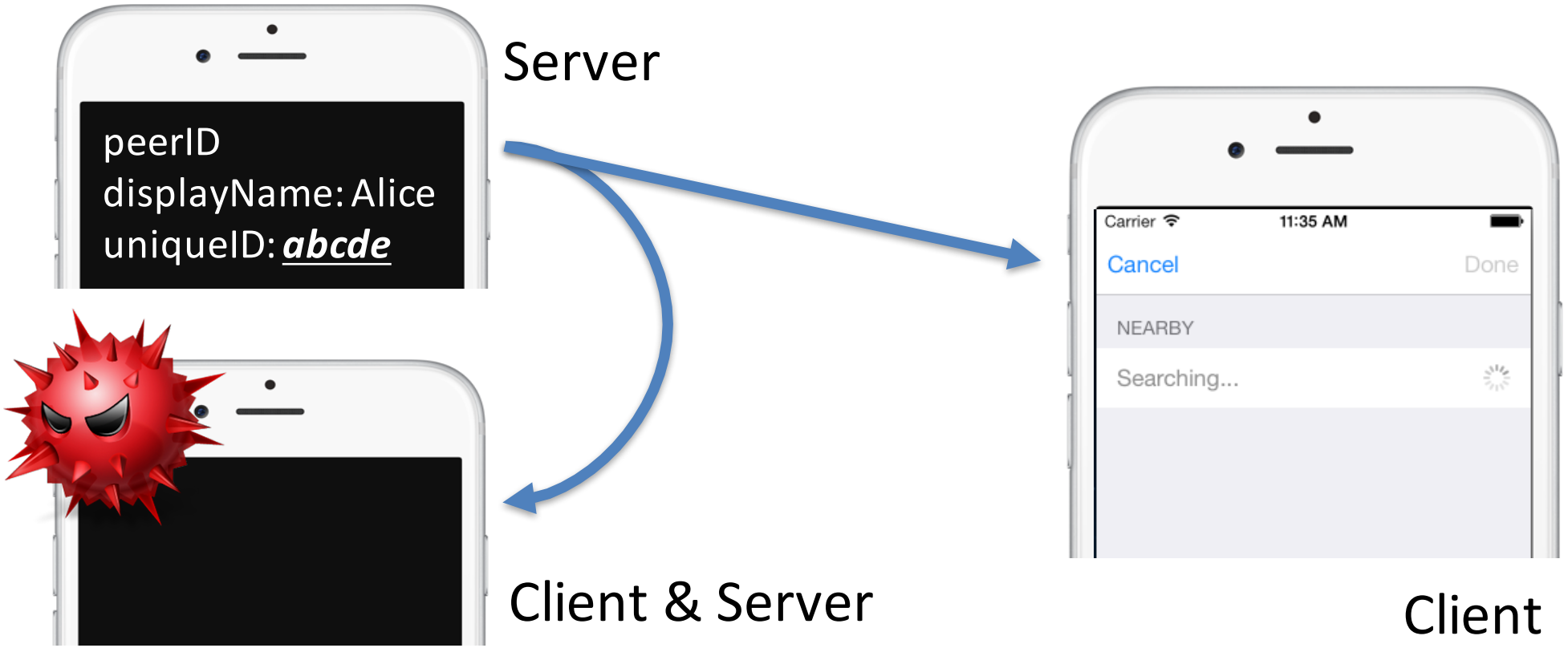


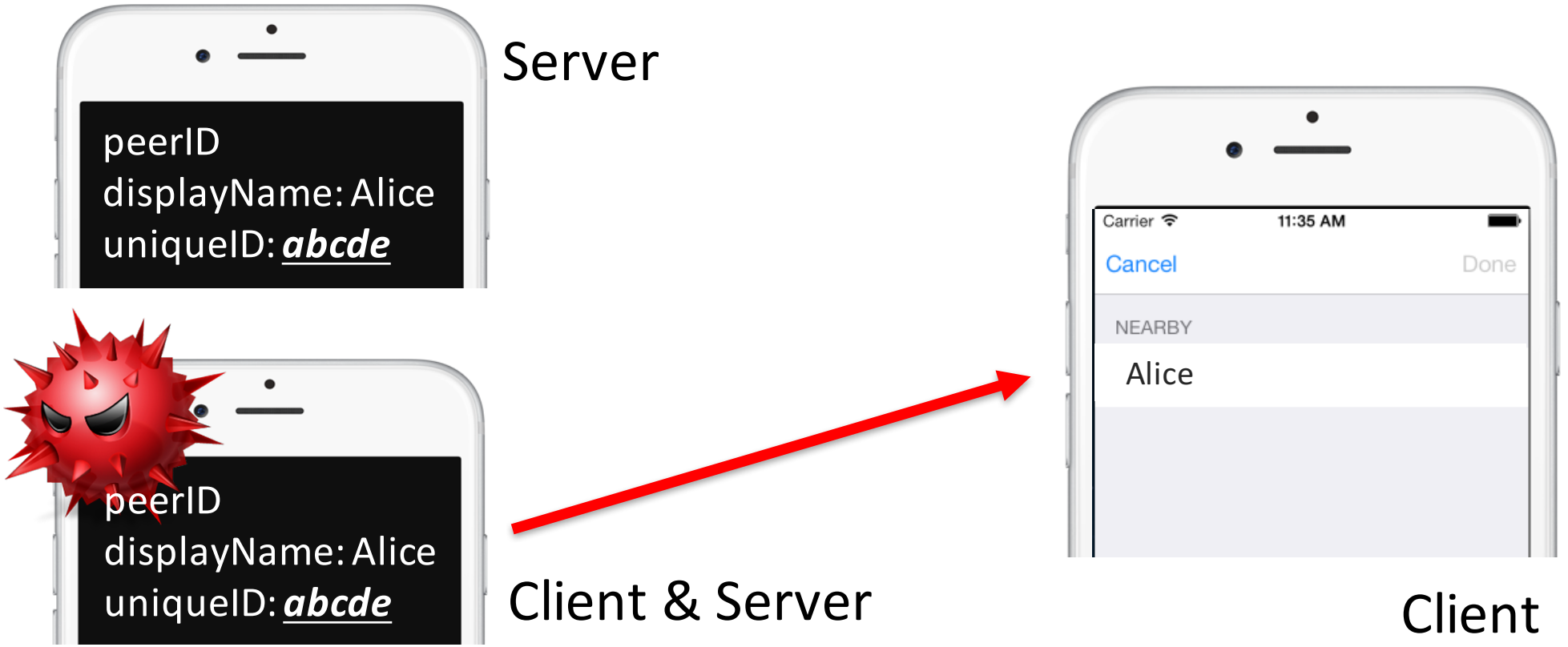
What Can Go Wrong?

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



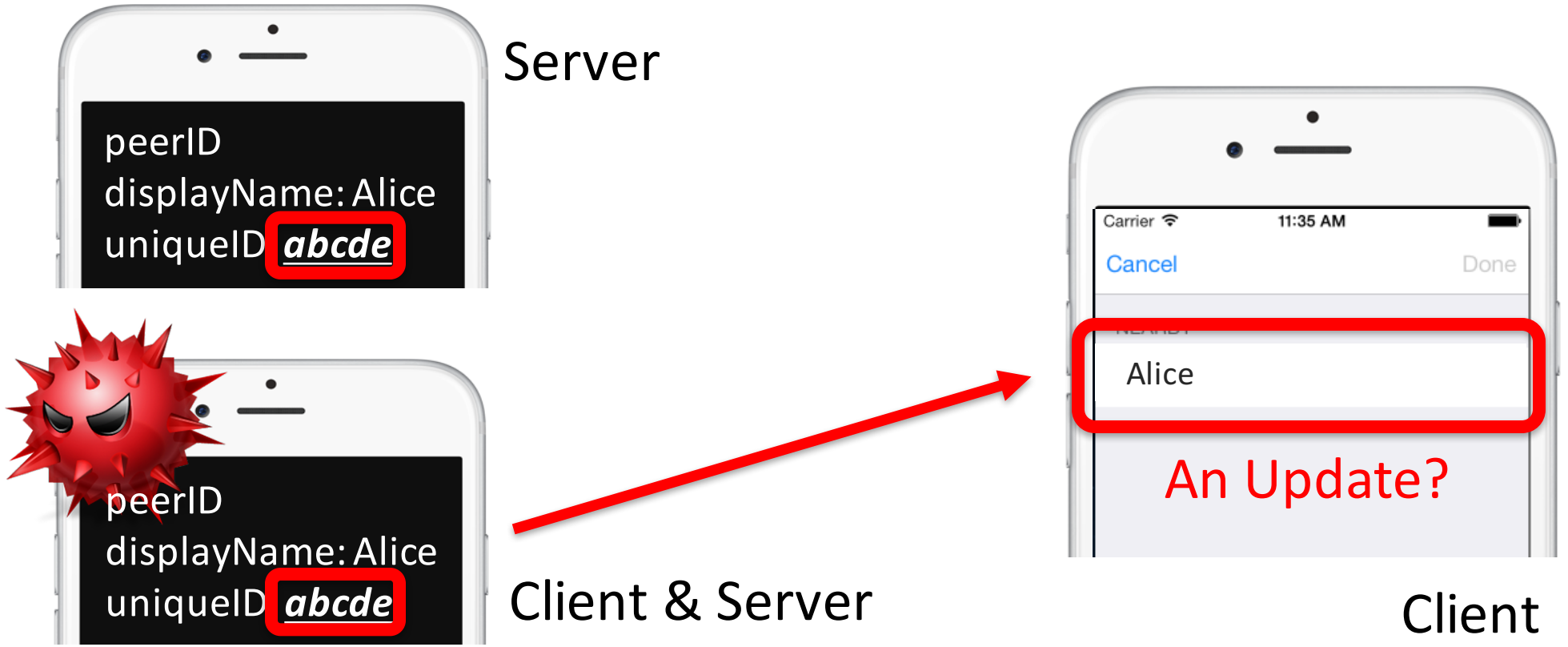
What Can Go Wrong?

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



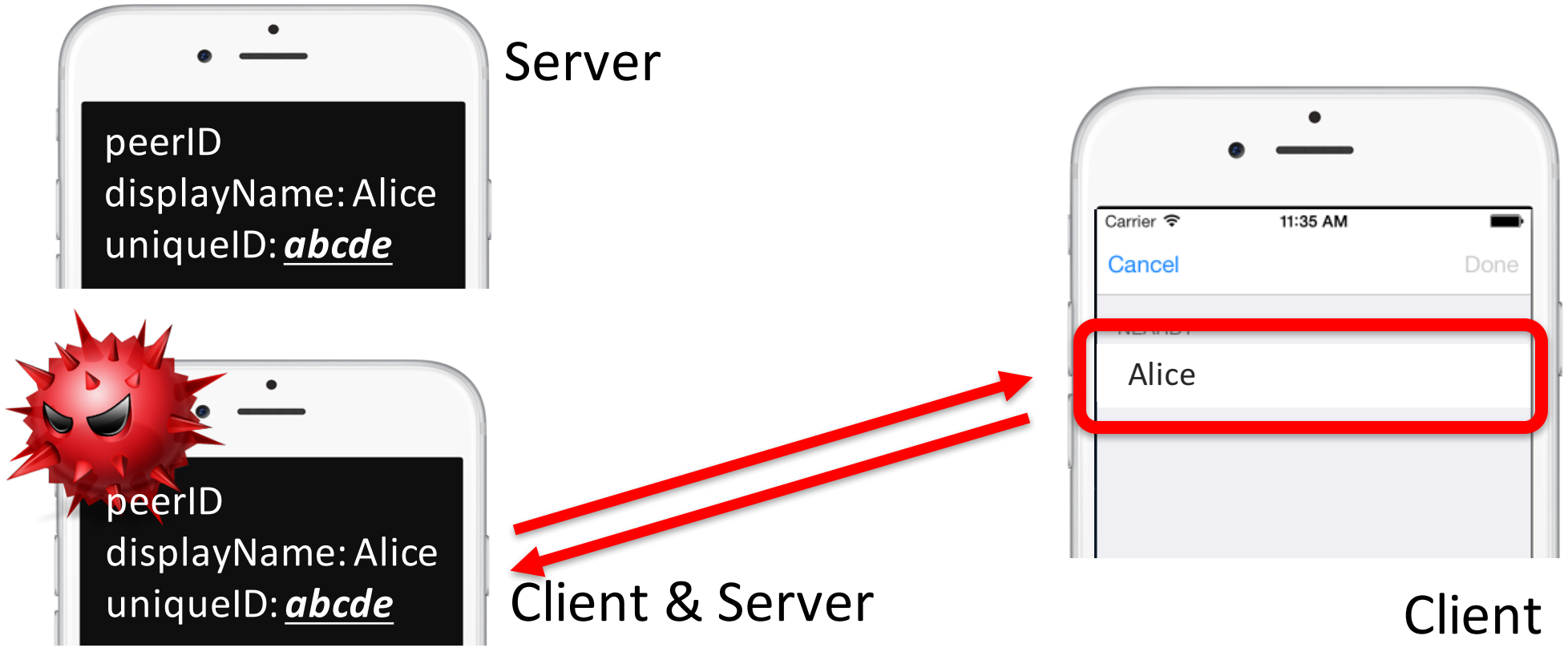
What Can Go Wrong?

- 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)**

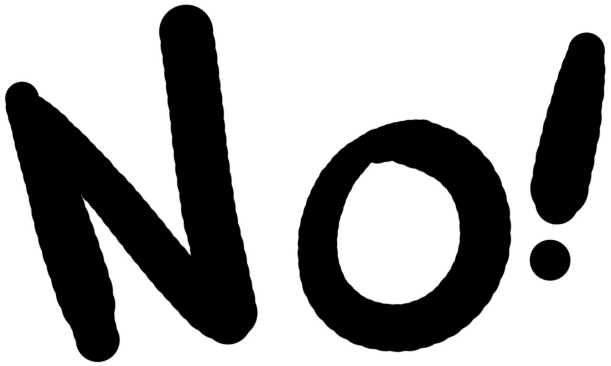


Technical Details

- 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?



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

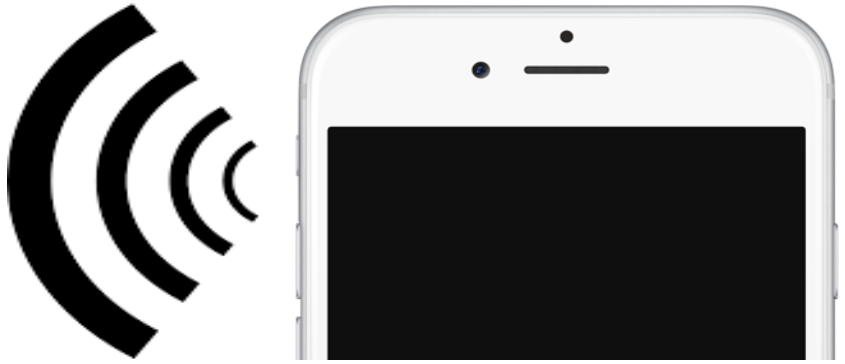
- Receiver advertises its QQ ID

Normally

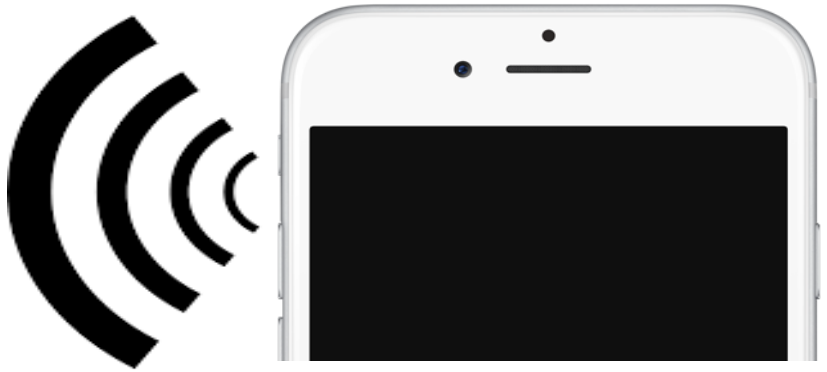
- Sender browses for receivers and found their QQ IDs

Sender

My QQ ID is 1234



Receiver

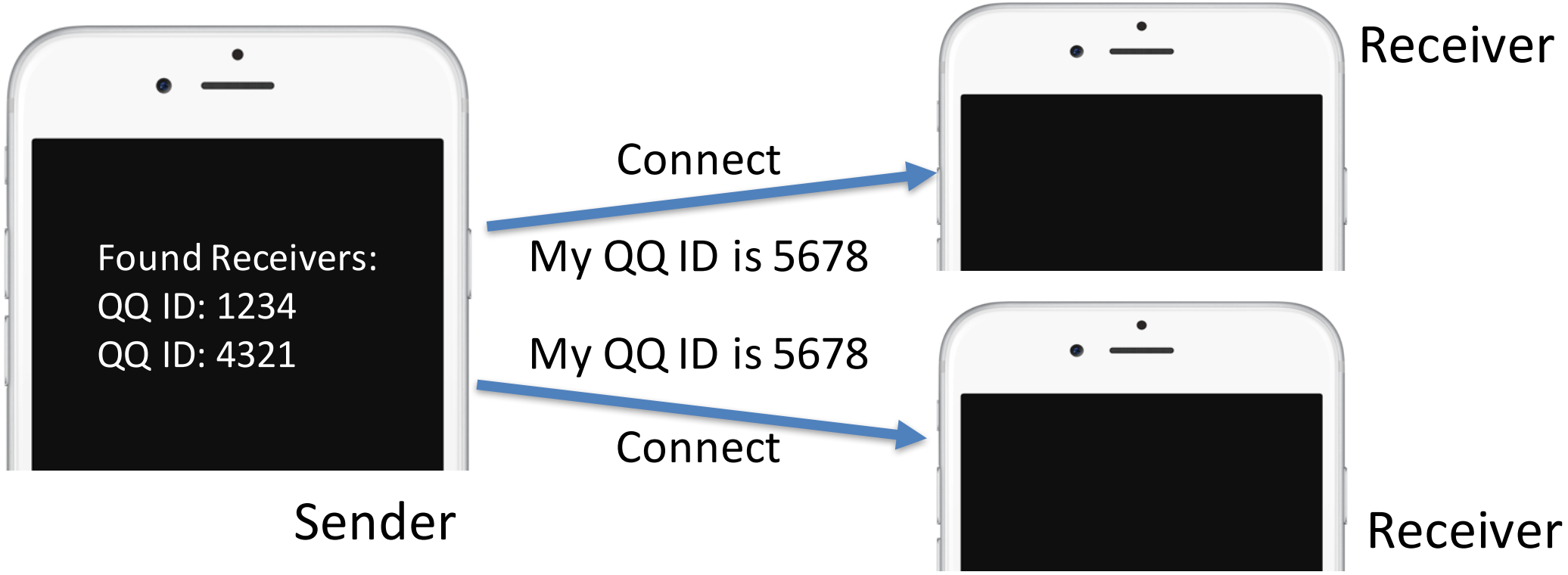


Receiver

My QQ ID is 4321

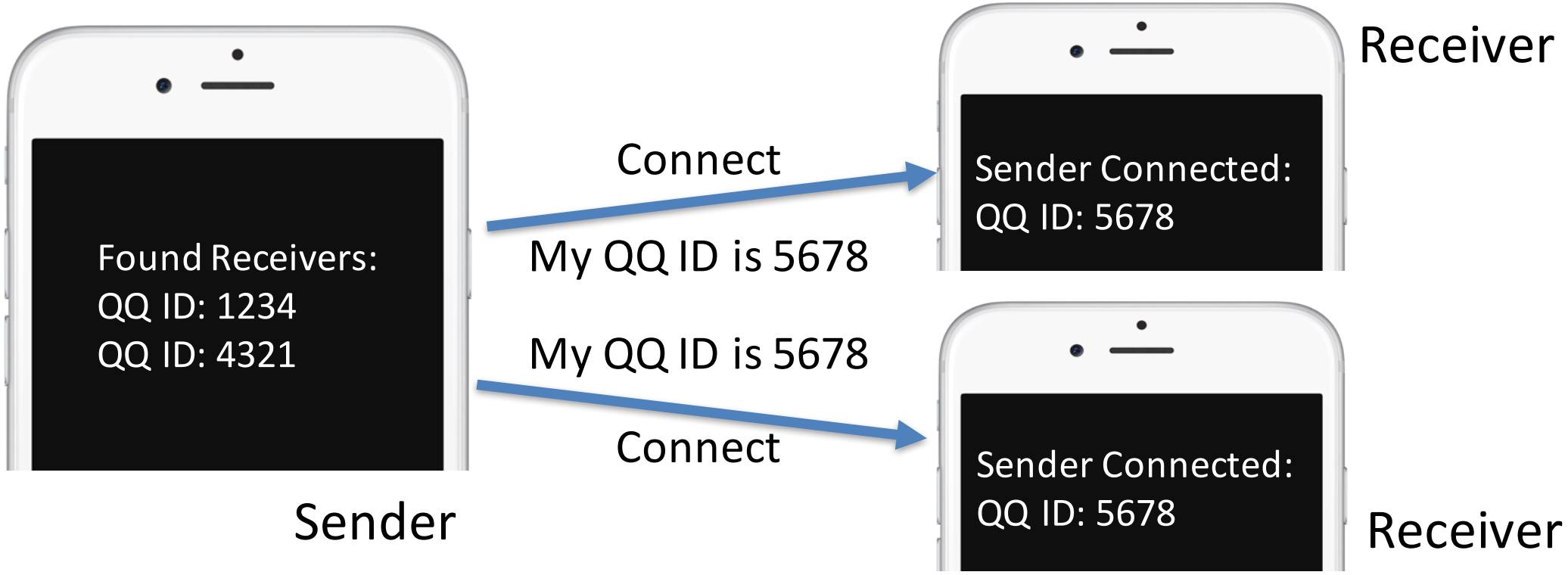
Normally

- Sender connects to receiver and gives its QQ ID



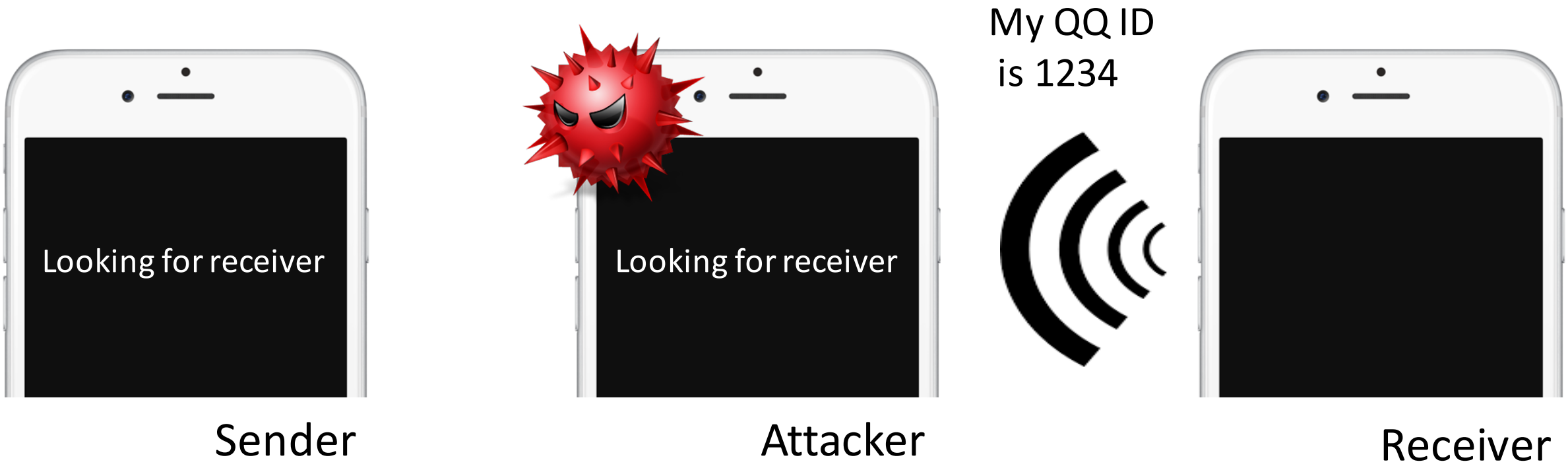
Normally

- Sender connects to receiver and gives its QQ ID



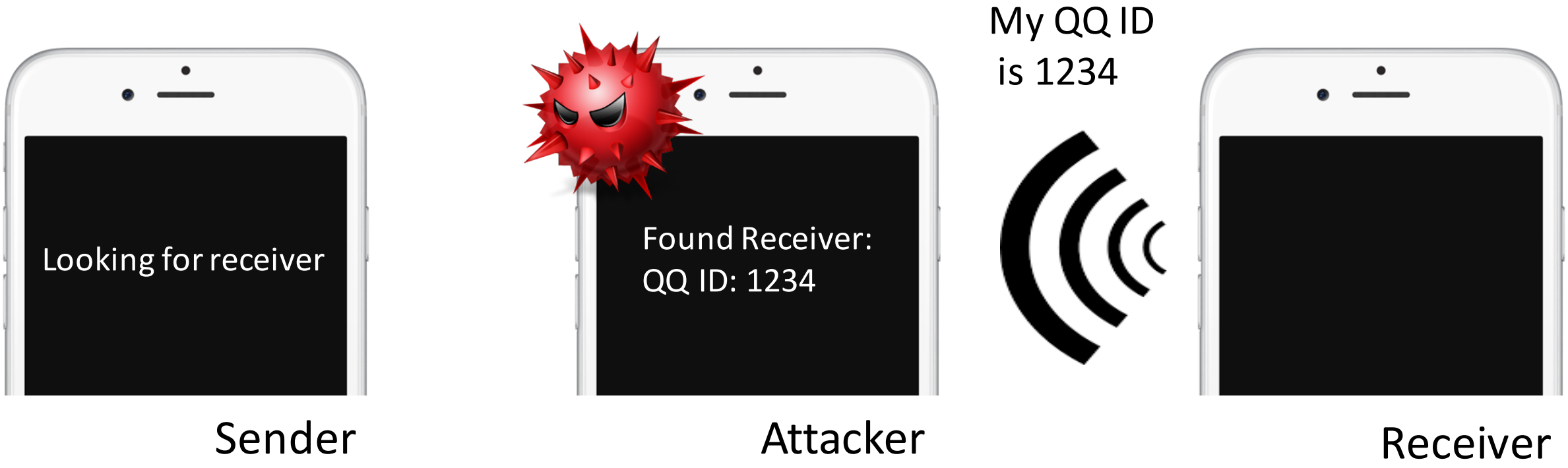
What Can Go Wrong?

- Receiver advertises its QQ ID



What Can Go Wrong?

- Attacker found victim receiver's QQ ID



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=B71FlD3_vrc

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

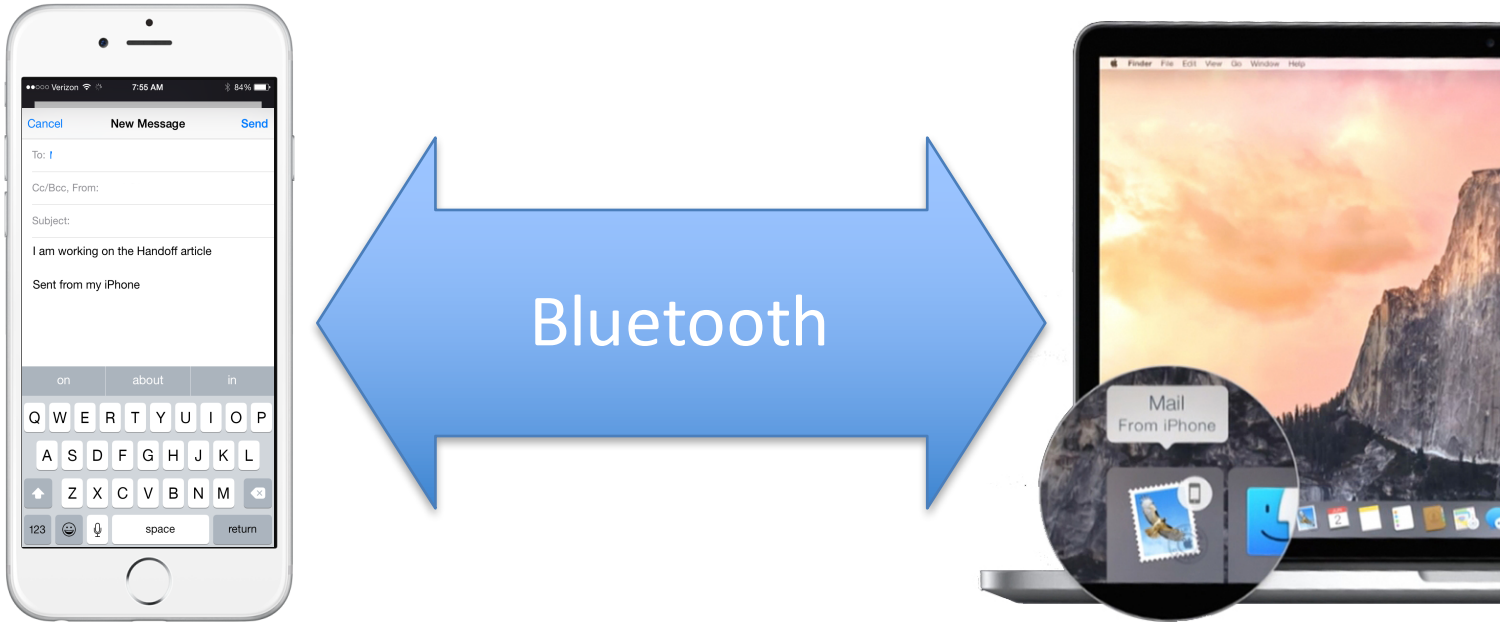
Case 5: Bluetooth

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

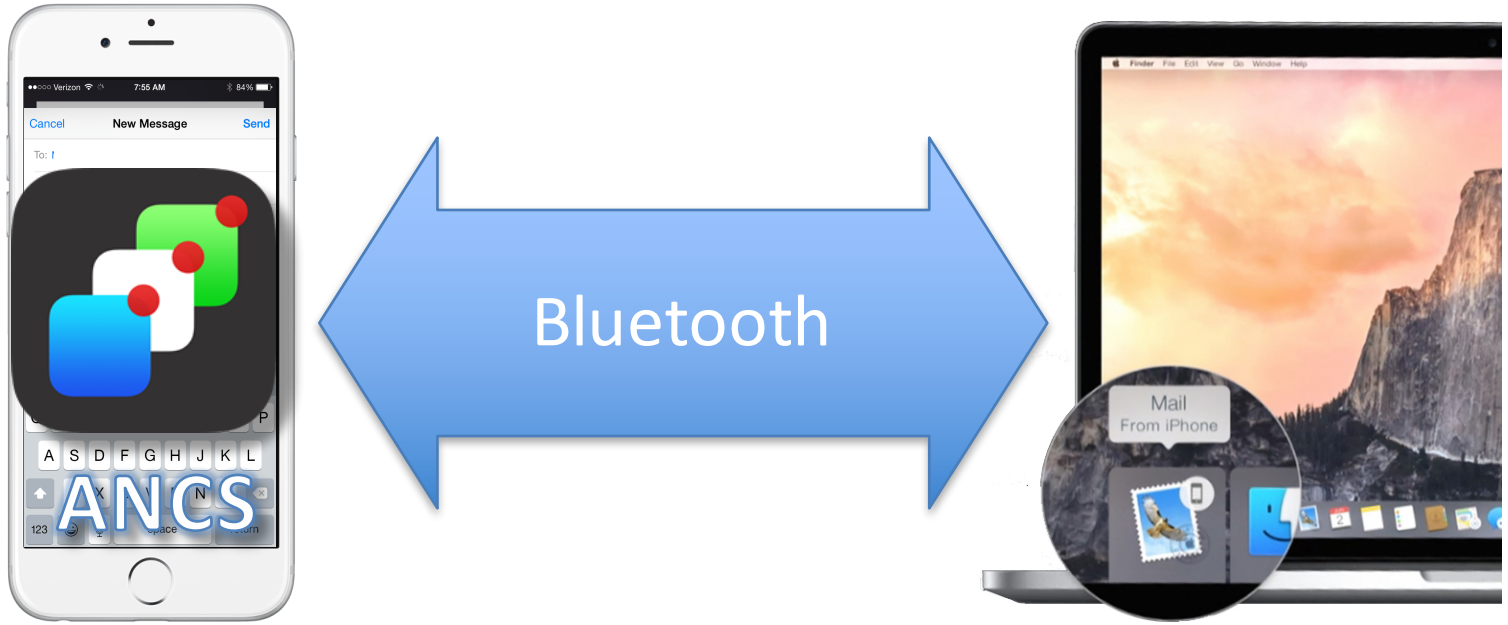
Normally

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



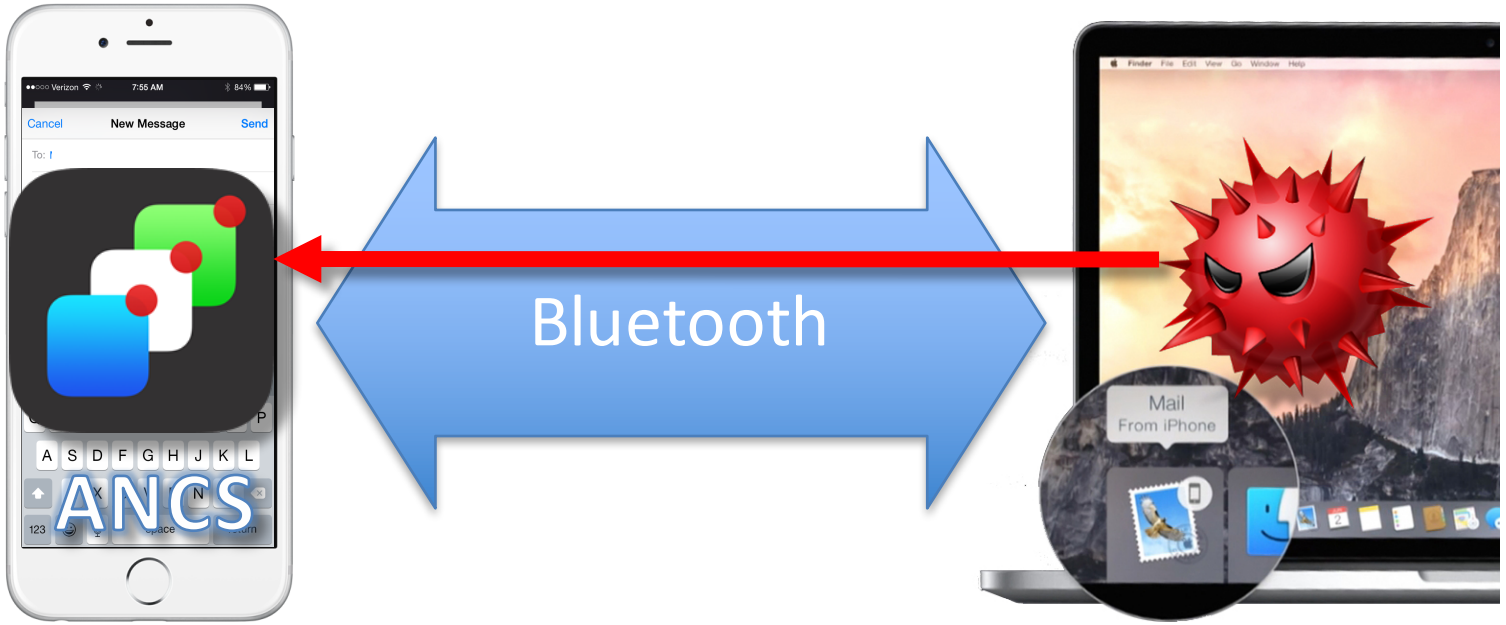
What Can Go Wrong?

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



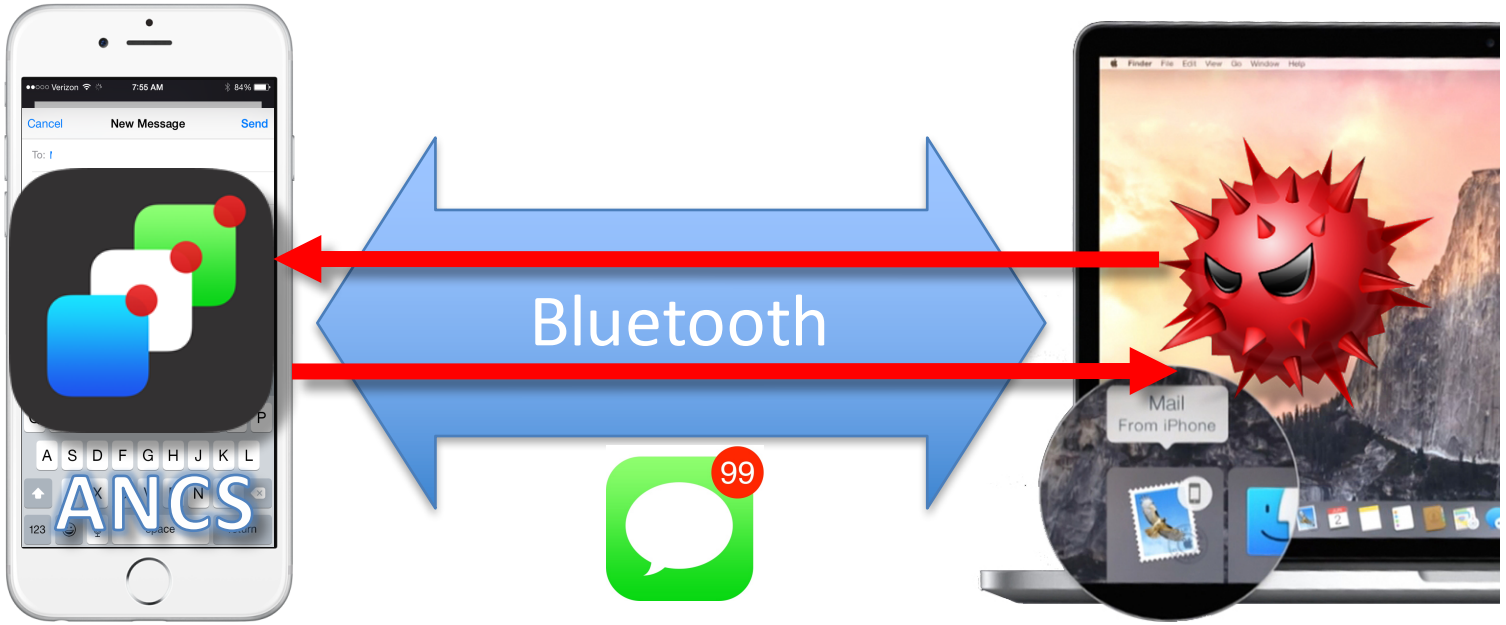
What Can Go Wrong?

- 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

Hash h → nk most significant bits

Partition to k n-bit segments → $\Delta_1||\Delta_2||\ldots||\Delta_k$ → $<w_1, w_2, \ldots, w_k>$

Words list linking to the 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