PriSrv: Privacy-Enhanced and Highly Usable Service Discovery in Wireless Communications (NDSS 2024)

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Service Discovery

- **Service discovery protocols (SDPs)** are essential components of networking systems
  - They enable devices and services to **dynamically discover** and communicate with each other in a network environment
  - They facilitate the **automatic detection and advertisement** of available services, making it easier for devices to locate and interact with desired resources
  - Well known SDPs includes

    Wi-Fi, AirDrop, BLE, DNS-SD, mDNS, SSDP, UPnP, etc.

Attacks on SDPs

SDPs	Man-in-the Middle (MitM) Attacks	Spoofing Attacks	Denial-of-service (DoS) Attacks	User Identification Attacks	Tracking Attacks
DNS-SD [18]	√				
mDNS [19]	√				
SSDP [20]	√				
UPnP [21]			√		
Wi-Fi [1]	√	√		√	√
BLE [3]	√	√		√	√
AirDrop [2]	√	√		√	
PrivateDrop [16]				√	
CBN [9]	√	√			
WTSB [5]				√	√

[16] A. Heinrich, M. Hollick, T. Schneider, M. Stute, C. Weinert. PrivateDrop: practical privacy-preserving authentication for Apple airDrop. In USENIX Security, 2021.

[9] A. Cassola, E. O. Blass, G. Noubir. Authenticating privately over public Wi-Fi hotspots. In CCS, 2015.

[5] D. J. Wu, A. Taly, A. Shankar, D. Boneh. Privacy, discovery, and authentication for the internet of things. In ESORICS, 2016.

SDPs: Requirements

Privacy Enhancement Requirements

1. Private Service Broadcast
2. Mutual Authentication
3. Bilateral Anonymity
4. Bilateral Flexible Policy Control
5. Selective Attribute Disclosure
6. Multi-Show Unlinkability

High Usability Requirements

1. No Pre-registered Pairing
2. No Third-party Dependency during Service Discovery
3. No In-advance Identity Issuance

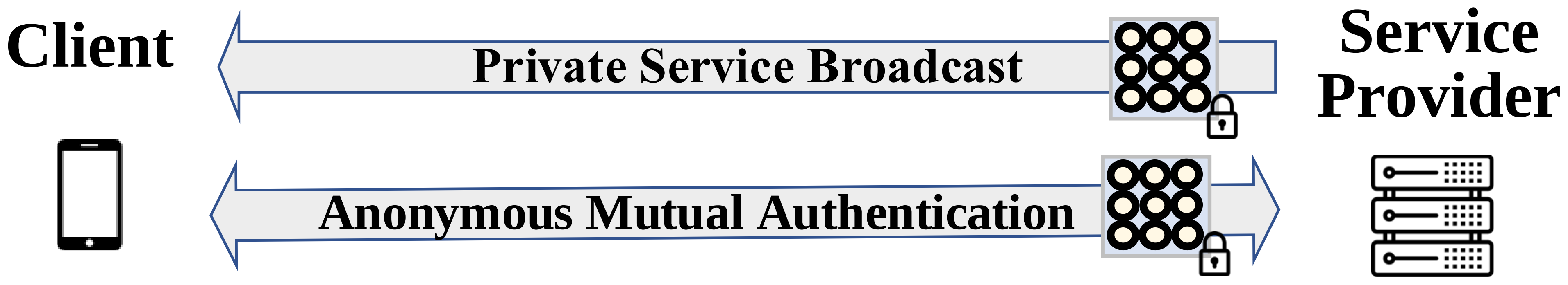
PriSrv: Contributions

- **PriSrv: the first service discovery protocol, to meet both privacy enhancement and high usability requirements**
  - **Core Components of PriSrv**
    - Anonymous Credential-based Matchmaking Encryption (ACME)
    - Fast Anonymous Credential (FAC)
  - **Interoperability with Existing Protocols**
    - Extensible Authentication Protocol (EAP), mDNS, BLE, AirDrop
  - **Deployment on Multiple Platforms in Real Networks**
    - Multiple hardware platforms: desktop, laptop, mobile phone and Raspberry Pi
    - **"immediate response"**: delay stays well bellow 1 second

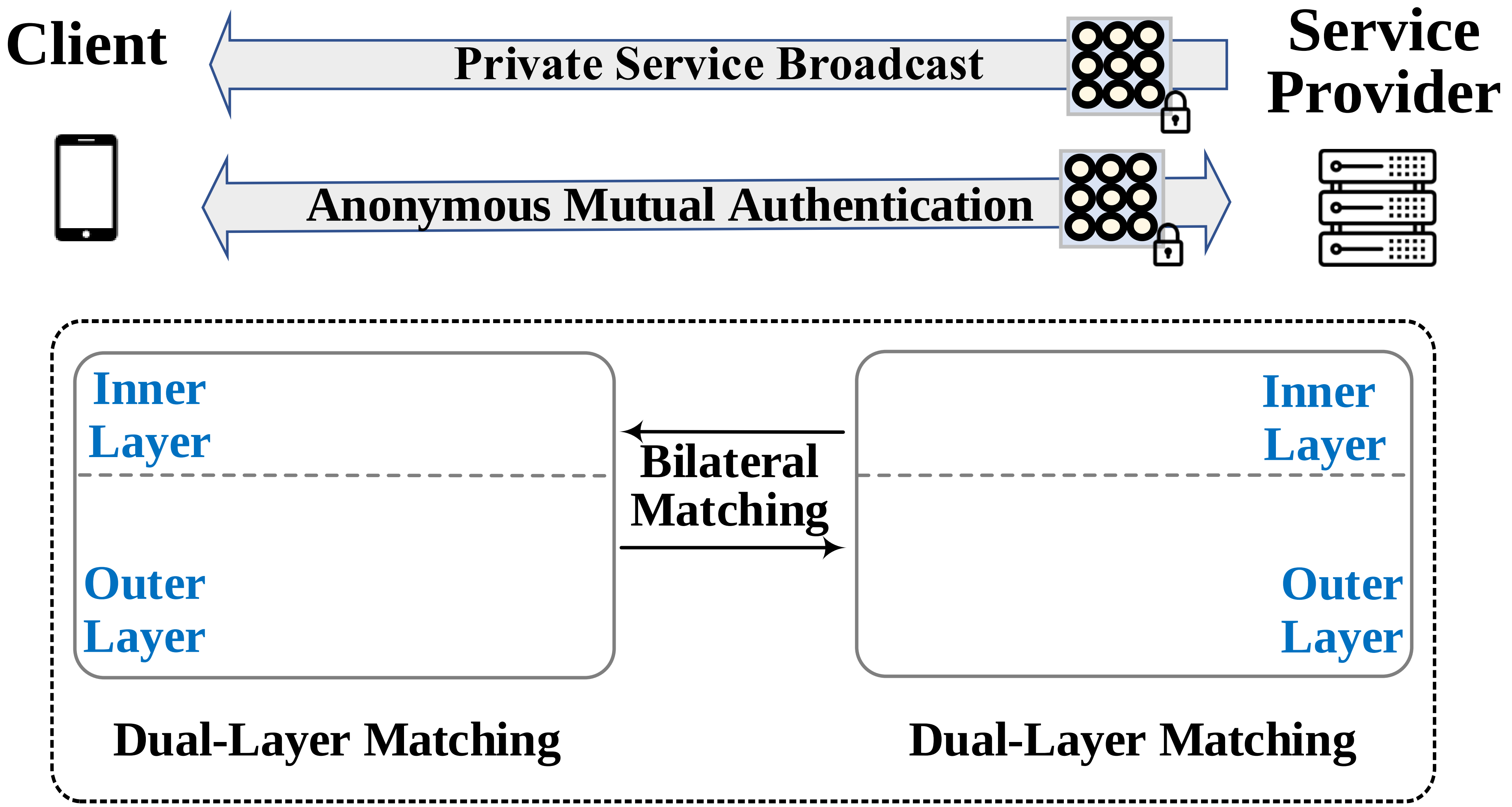
Comparison of SDPs

SD Protocols	Privacy Enhancement						High Usability		
	Private Broadcast	Mutual Authn.	Bilateral Anon.	Bilateral Flex. Pol. Ctrl.	Sel. Attr. Disclosure	Multi-Show Unlinkability	No Pre-reg. Pairing	No 3rd-party Dependence	No In-advance ID Issuance
DNS-SD [18]	×	×	×	×	×	×	√	×	×
mDNS [19]	×	×	×	×	×	×	√	√	×
SSDP [20]	×	×	×	×	×	×	√	√	√
UPnP [21]	×	×	×	×	×	×	√	√	√
Wi-Fi [1]	×	√	×	×	×	×	√	√	×
BLE [3]	×	√	×	×	×	×	√	√	√
AirDrop [2]	×	√	×	×	×	×	√	√	×
PrivateDrop [16]	×	√	√	×	×	×	√	√	×
CBN [9]	×	×	×	×	×	×	×	√	×
WTSB [5]	√	√	√	×	×	×	√	√	×
PriSrv	√	√	√	√	√	√	√	√	×

Overview of PriSrv



Overview of PriSrv



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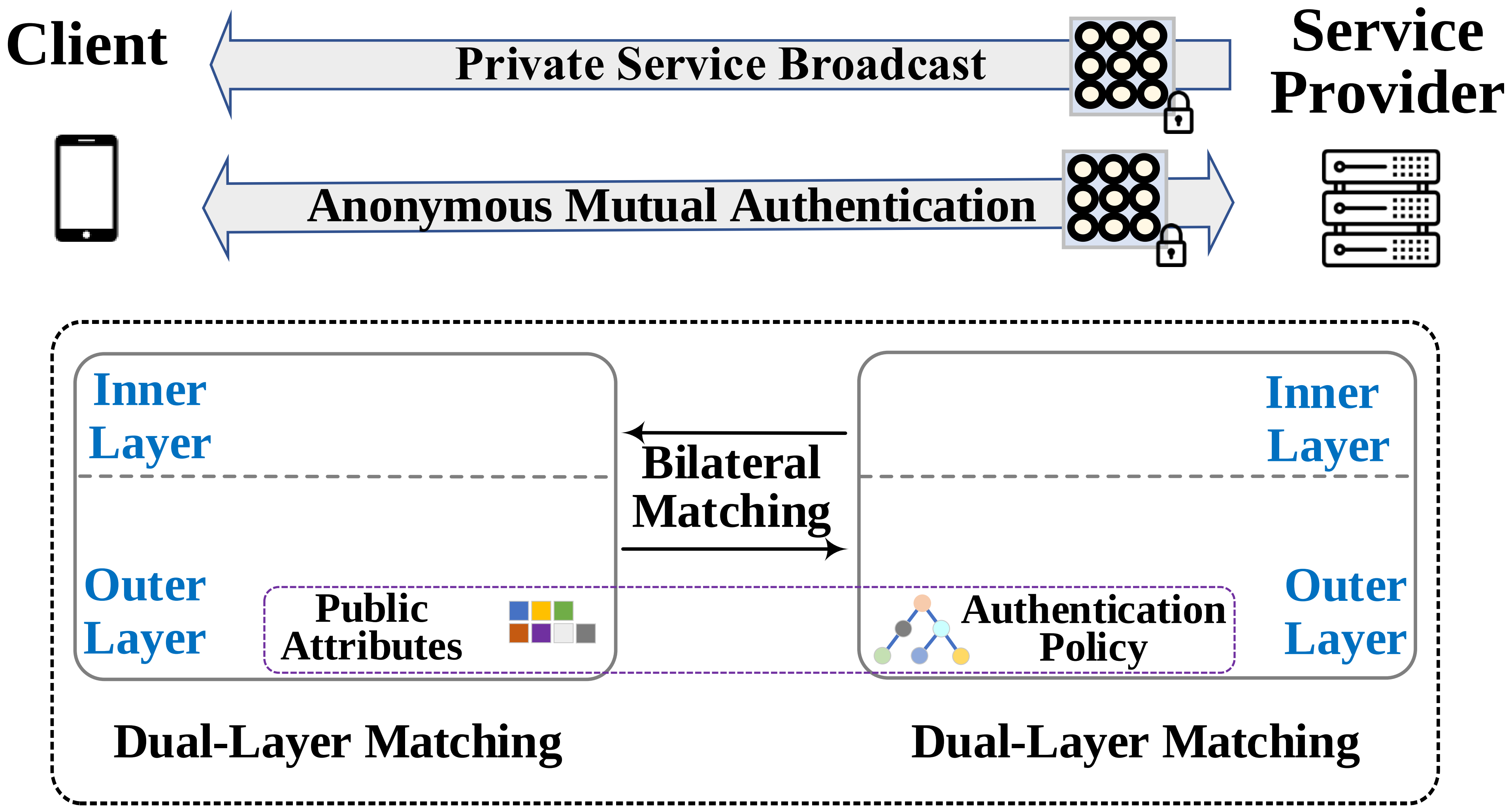

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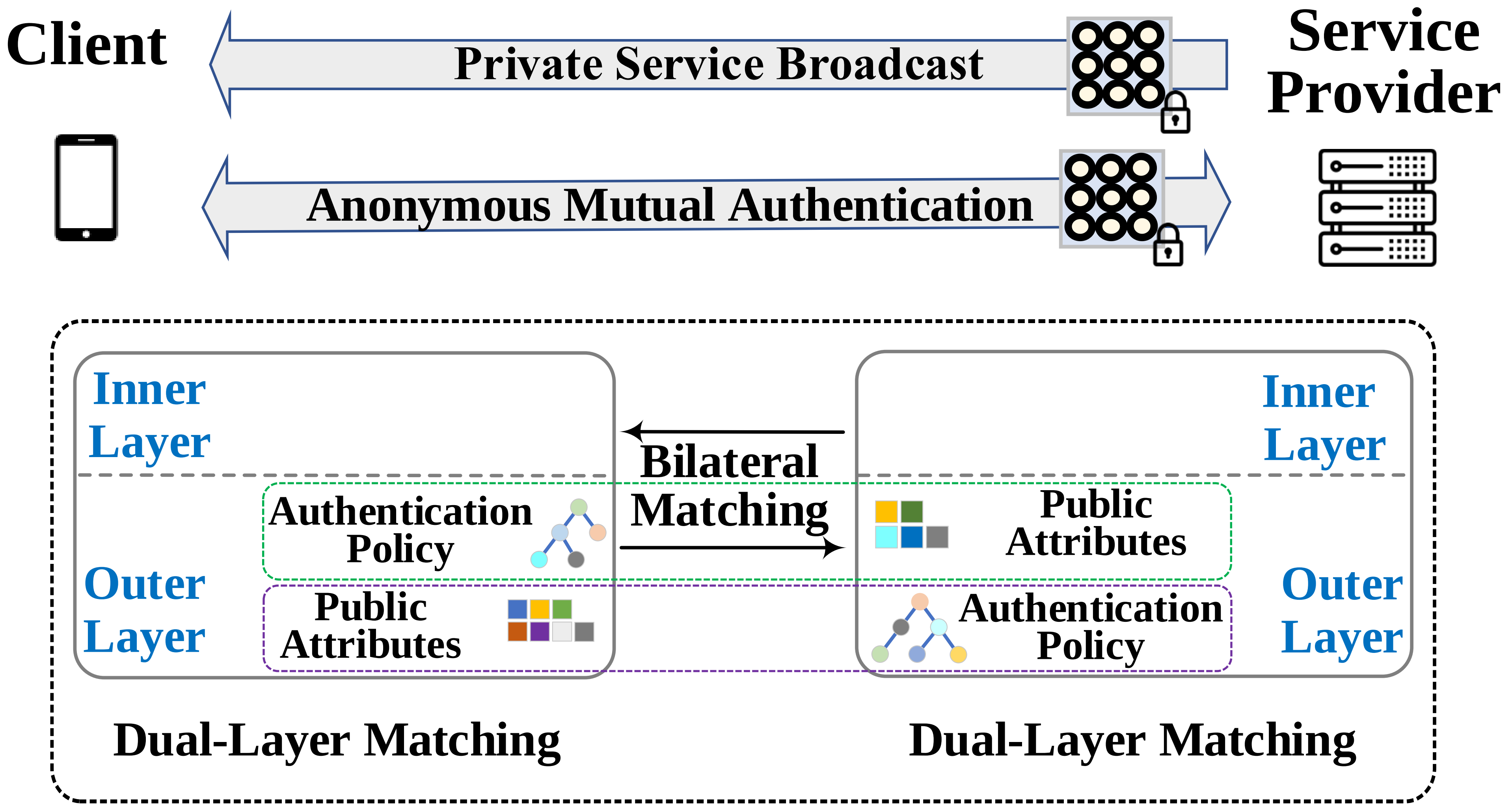

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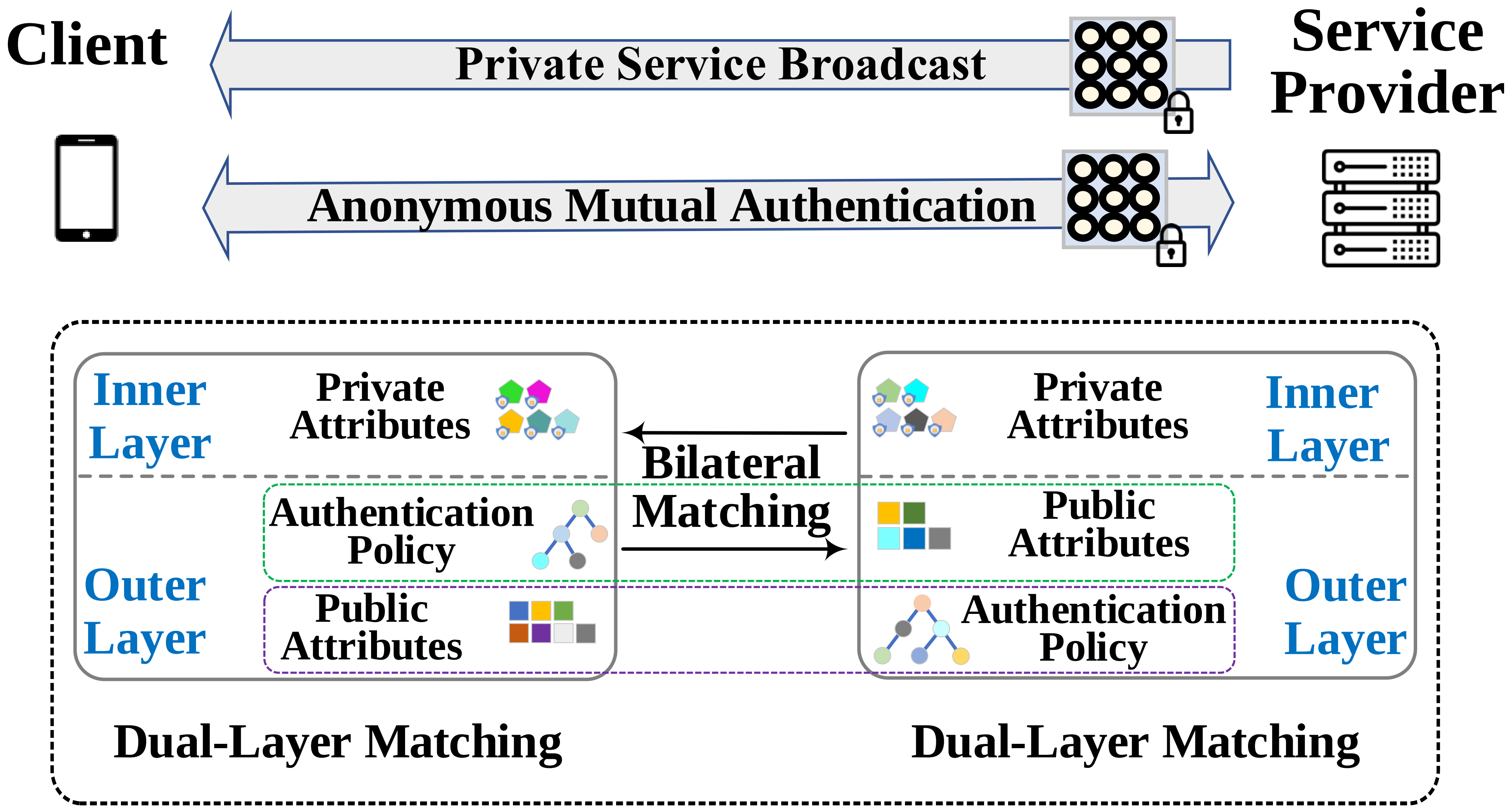

Example

Smart Office: screen mirroring service

Smart TV: Service Provider

Client Device

Example

Smart Office: screen mirroring service

Smart TV: Service Provider

Public Attributes: (device type, vendor, model, OS, domain name)
Private Attributes: (device name, location, IP address, security domain)
Service Policy: Device Type = "Smart phone ∨ Laptop"
∧ OS = "Android ∨ iOS ∨ Windows"
∧ Department = "A ∨ B"

Public Attributes: (device type, model, OS, department)
Private Attributes: (device name, classified device, IP address, security domain)
Connection Policy: Device Type = "TV" ∧ Vendor = "C ∨ D"
∧ Domain Name = "*.XYZ.COM"

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If the **public attributes** of the **service provider** satisfy the **policy** of **client**
and
the **public attributes** of the **client** satisfy the **policy** of **service provider**,

the screen mirroring service can be **discovered** and used by the client.

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The **private attributes** of smart TV and client device are used for **mutual authentication**.

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Connection Policy: Device Type = “TV” ∧ Vendor = “C ∨ D”
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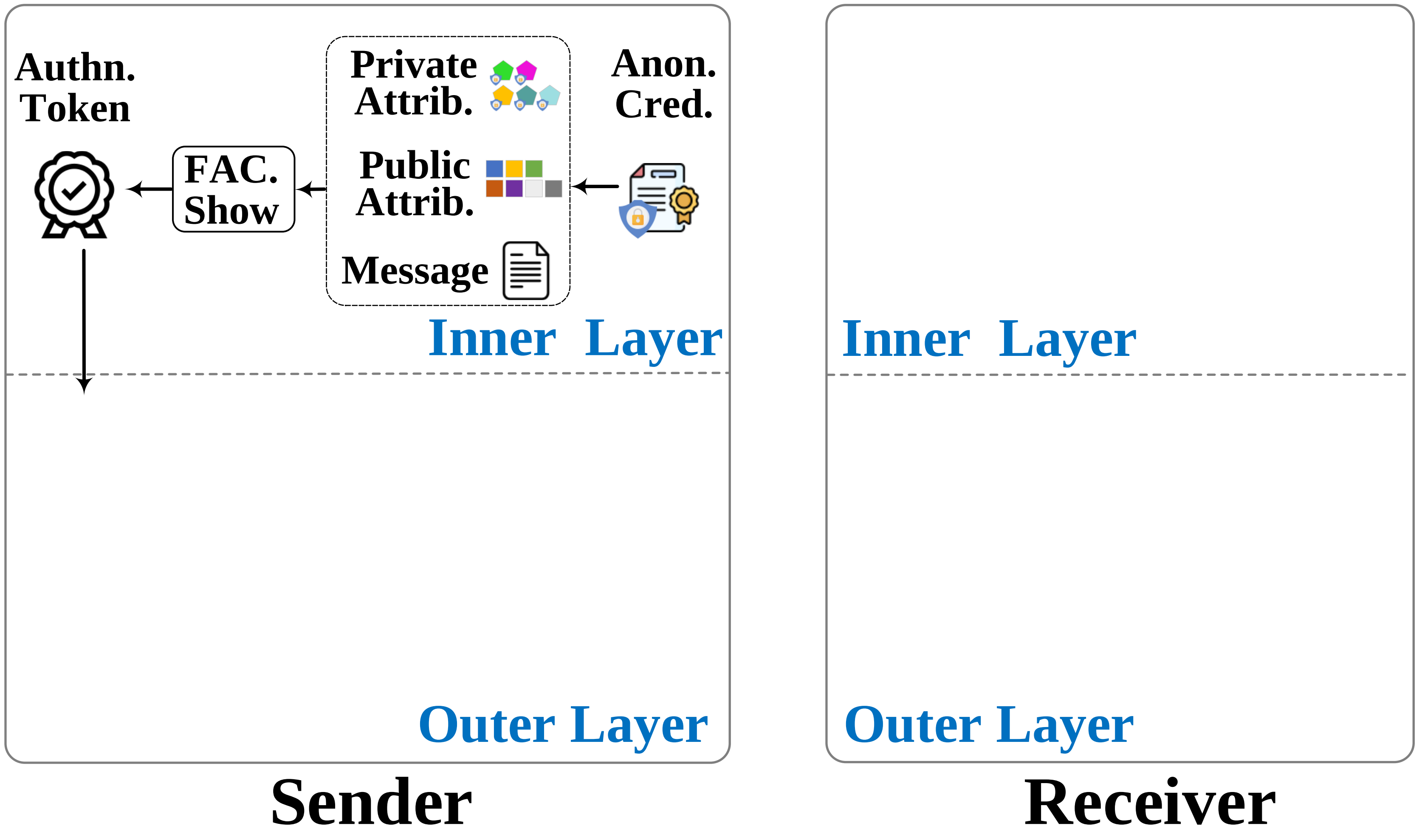
Client Device

ACME

- Anonymous Credential-based Matchmaking Encryption (ACME)
  - A new cryptographic primitive to support several core features in PriSrv
    - bilateral policy control, anonymous authentication, selective attribute disclosure
  - ACME is a variant of Matchmaking Encryption (ME)
    - The sender and receiver can use anonymous credentials to prove their attributes without revealing their identities
    - Provide stronger privacy guarantees and flexible policy enforcement
  - Fast Anonymous Credential (FAC): Building block of ACME
    - Enable fast anonymous authentication
    - Maintain a constant and small credential size

Architecture of ACME



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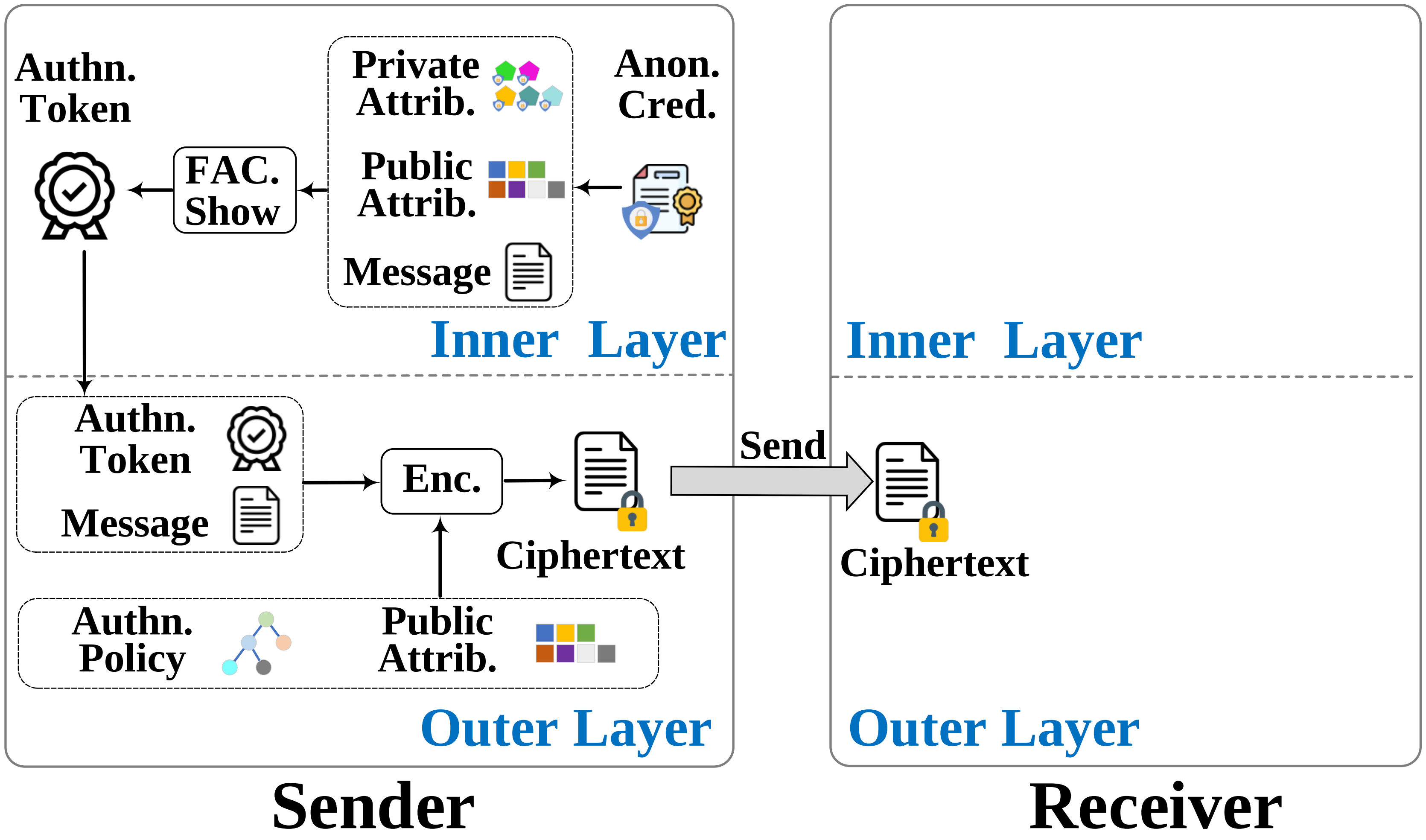

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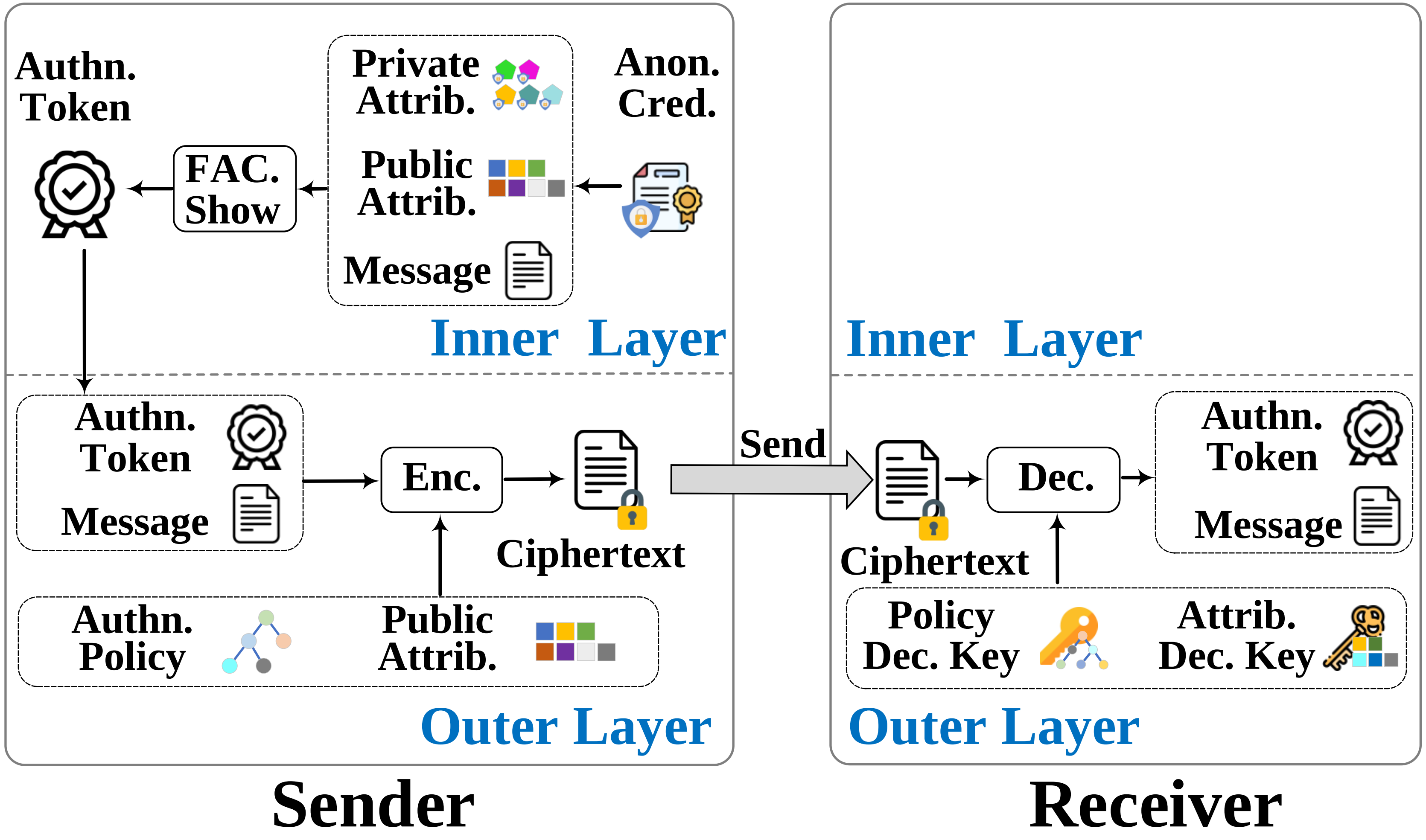

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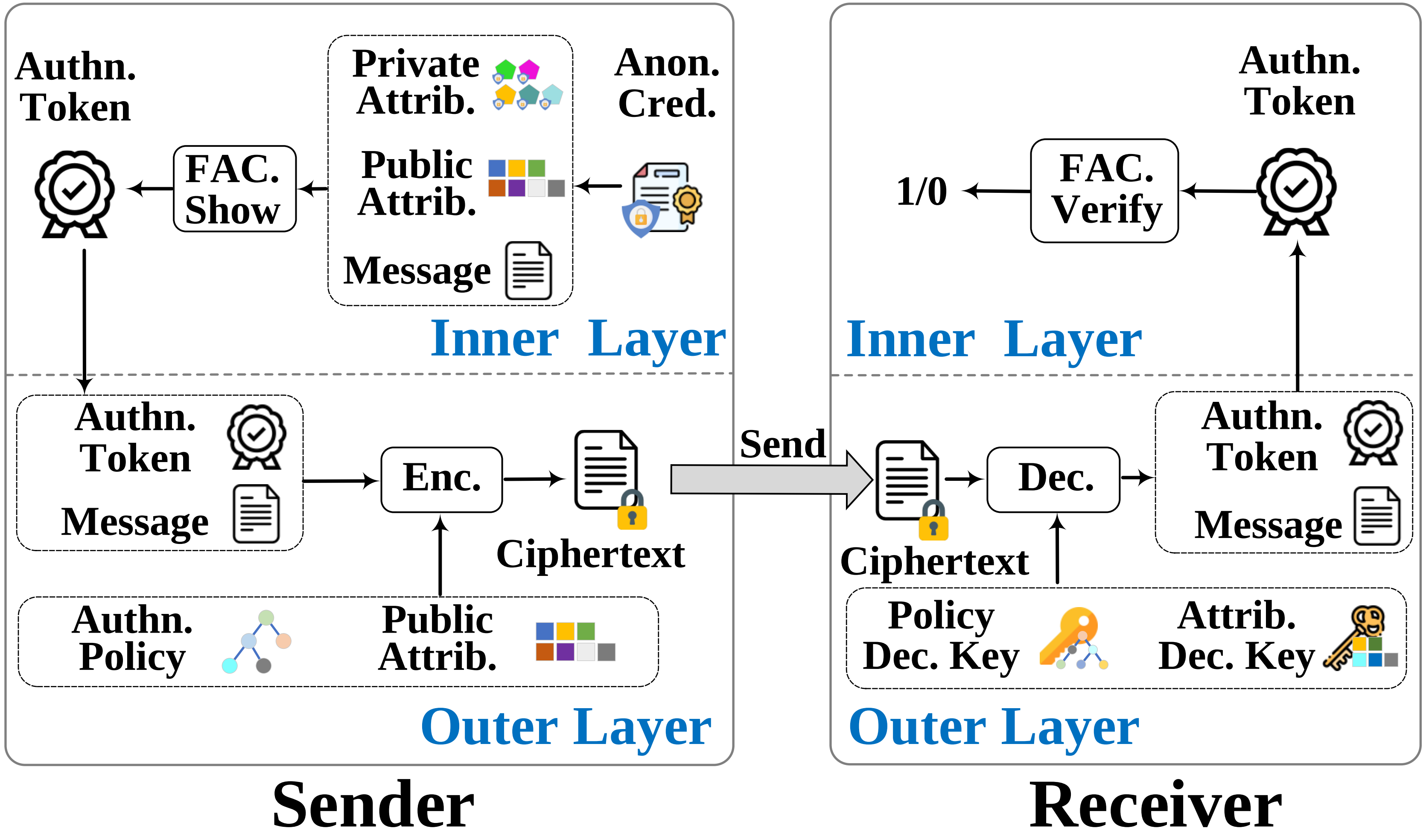

PriSrv Protocol

Service Broadcast Phase
Service Provider S's Broadcast: $bid, \mathsf{CT}_B \leftarrow \mathcal{ACME}.\mathsf{Enc}(\mathsf{cred}_s, \vec{x}_s, f_s, MSG_B)$
where $MSG_B = \{bid \| Z \| Service_{Type} \| Service_{Par} \| K_c\}$, $z \xleftarrow{\$} \mathbb{Z}_p^*$, $Z \leftarrow h^z \in G_2$, $K_c \leftarrow \mathcal{MAC}.\mathsf{KeyGen}(1^\lambda)$

Anonymous Mutual Authentication Phase	
Client (C)	**Service Provider** (S)
$(\mathsf{cred}_c, \mathsf{DK}_{\vec{x}_c}, \mathsf{DK}_{f_c})$	$(\mathsf{cred}_s, \mathsf{DK}_{\vec{x}_s}, \mathsf{DK}_{f_s})$

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$MSG_B \leftarrow \mathcal{ACME}.\mathsf{Dec}(\mathsf{DK}_{\vec{x}_c}, \mathsf{DK}_{f_c}, \mathsf{CT}_B)$		
$x_1, x_2 \xleftarrow{\$} \mathbb{Z}_p^*$, $X_1 \leftarrow g^{x_1} \in G_1$, $X_2 \leftarrow h^{x_2} \in G_2$		
$\sigma_c \leftarrow \mathcal{MAC}.\mathsf{MAC}(K_c, M_c)$		
where $M_c = (\text{“}C \rightarrow S\text{”}, bid, sid, X_1, X_2, Z)$		
$K_s \leftarrow \mathcal{MAC}.\mathsf{KeyGen}(1^\lambda)$	$\xrightarrow{bid, sid, \sigma_c, \mathsf{CT}_c}$	
$\mathsf{CT}_c \leftarrow \mathcal{ACME}.\mathsf{Enc}(\mathsf{cred}_c, \vec{x}_c, f_c, MSG_c)$		
where $MSG_c = (K_s, M_c)$		

PriSrv Protocol

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Client:

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Client → Service Provider: $bid, sid, \sigma_c, \mathsf{CT}_c$

Service Provider:

$MSG_c \leftarrow \mathcal{ACME}.\mathsf{Dec}(\mathsf{DK}_{\vec{x}_s}, \mathsf{DK}_{f_s}, \mathsf{CT}_c)$

$b_c \leftarrow \mathcal{MAC}.\mathsf{Verify}(K_c, M_c, \sigma_c)$

If $b_c = 0$, abort; otherwise,

$y \xleftarrow{\$} \mathbb{Z}_p^*$, $Y \leftarrow g^y \in G_1$

$\sigma_s \leftarrow \mathcal{MAC}.\mathsf{MAC}(K_s, M_s)$

where $M_s = (\text{“}S \rightarrow C\text{”}, bid, sid, X_1, X_2, Y, Z)$

$SSK_{c,s} \leftarrow H(X_1^y, X_2^z)$

Service Provider → Client: M_s, σ_s

PriSrv Protocol

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If $b_s = 0$, abort; otherwise,	$\xleftarrow{M_s, \sigma_s}$	where $M_s = (\text{“}S \rightarrow C\text{”}, bid, sid, X_1, X_2, Y, Z)$
$SSK_{c,s} \leftarrow H(Y^{x_1}, Z^{x_2})$		$SSK_{c,s} \leftarrow H(X_1^y, X_2^z)$

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$SSK_{c,s} \leftarrow H(Y^{x_1}, Z^{x_2})$		$SSK_{c,s} \leftarrow H(X_1^y, X_2^z)$

Interoperability

- Privacy Enhanced EAP
  - Extends RFC 3748 on Extensible Authentication Protocol (EAP) to support private service discovery

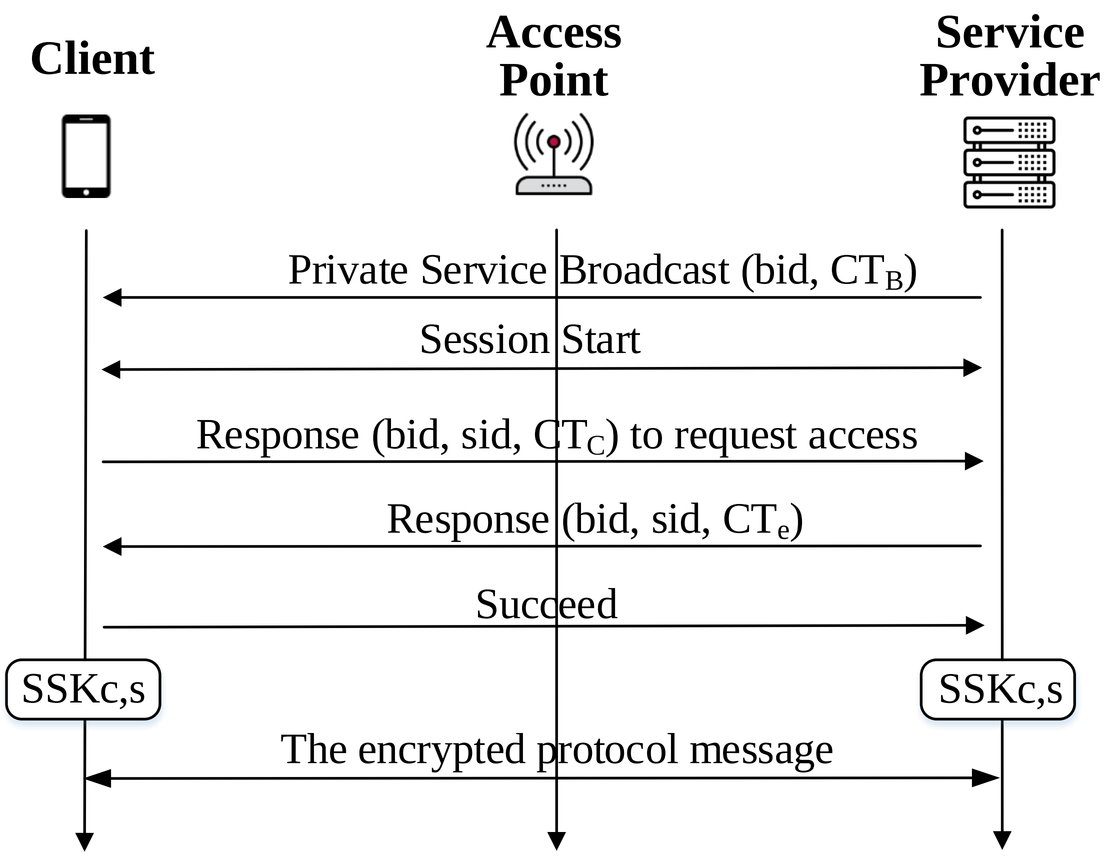

Fig. 4: Architecture of Privacy Enahnced EAP

Interoperability

- Privacy Enhanced EAP
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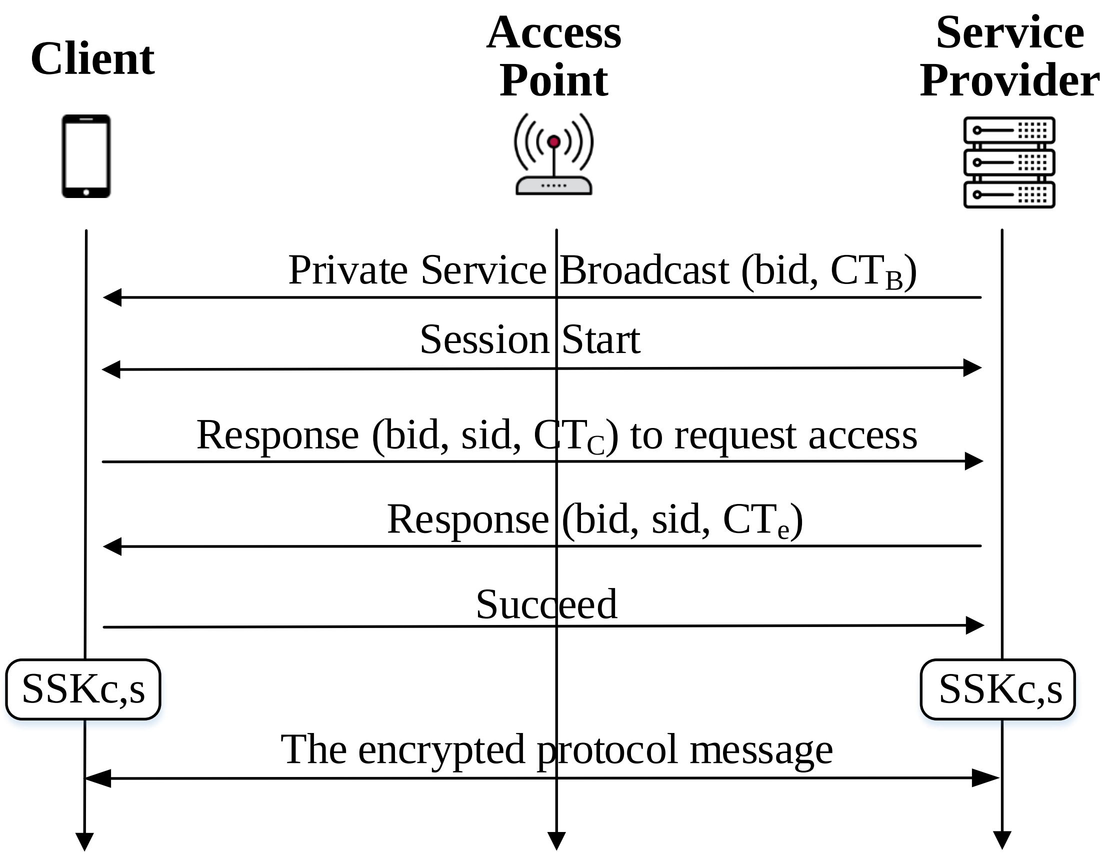
- Privacy Enhanced mDNS and BLE
  - PriSrv can be integrated in the Vanadium framework for developing privacy enhanced mDNS and BLE



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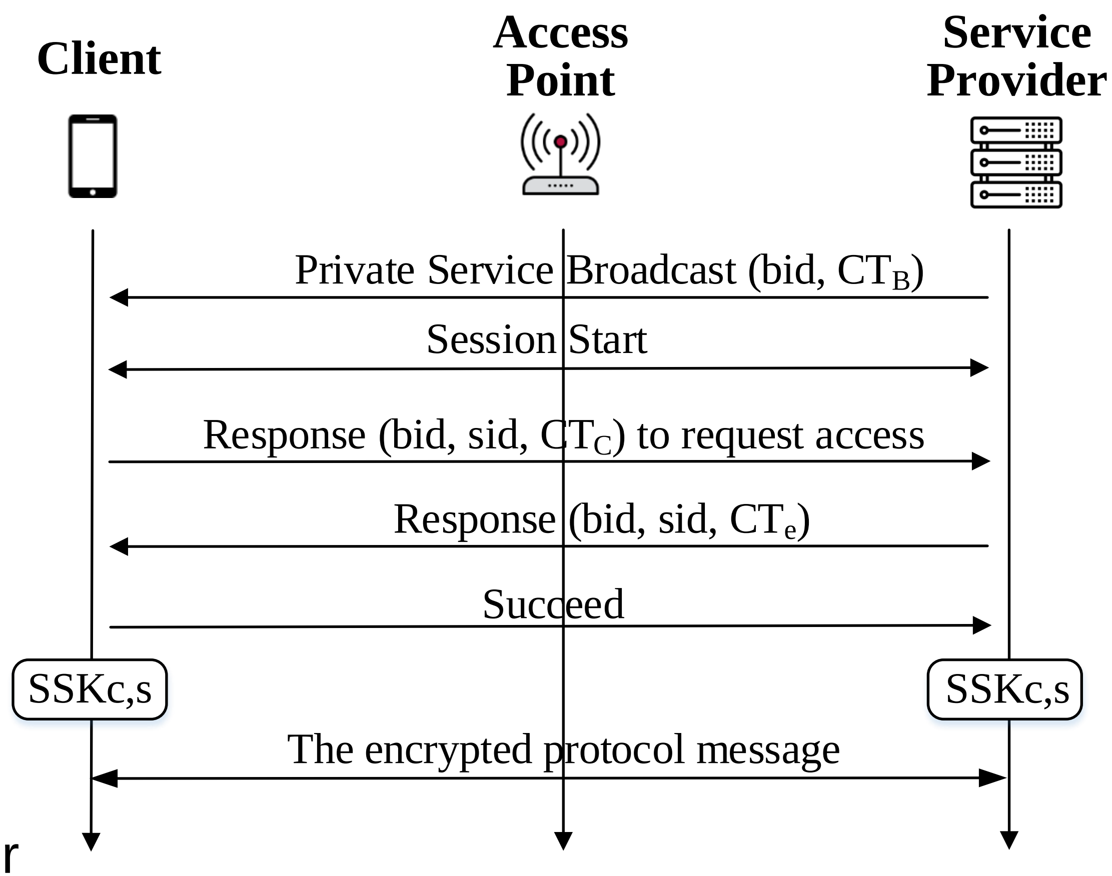
- Privacy Enhanced mDNS and BLE
  - PriSrv can be integrated in the Vanadium framework for developing privacy enhanced mDNS and BLE
- Privacy Enhanced Apple AirDrop
  - Avoid transmitting identifier of service provider during broadcast phase
  - Encrypt certificates of both parties using ACME



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Implementation and Performance

Device	Private Service Broadcast					
	MNT159 (80-bit Security)		MNT201 (90-bit Security)		BN256 (100-bit Security)	
	Comp.	Comm.	Comp.	Comm.	Comp.	Comm.
1	158.931	164.34	180.337	212.96	202.822	537.98
2	216.493	164.34	261.059	212.96	287.287	537.98
3	385.553	164.34	443.686	212.96	482.725	537.98
4	638.259	164.34	880.868	212.96	1188.392	537.98

Device	Anonymous Mutual Authentication					
	MNT159 (80-bit Security)		MNT201 (90-bit Security)		BN256 (100-bit Security)	
	Comp.	Comm.	Comp.	Comm.	Comp.	Comm.
1	429.282	164.45	517.512	213.09	673.039	538.83
2	576.161	164.45	686.054	213.09	854.177	538.83
3	727.572	164.45	892.712	213.09	972.163	538.83
4	1224.365	164.45	1832.187	213.09	2711.013	538.83

TABLE VII: Performance of PriSrv (ms/KB)

No.	Type	Hardware Platforms
1	Desktop	Intel® Core™ i9-7920X CPU @ 2.9GHz×12, 16GB
2	Laptop	Intel® Core™ i5-10210U CPU @ 1.6GHz×4, 8GB
3	Phone	ARM Cortex @2.84GHz+3×2.4GHz, 4GB
4	Raspberry Pi	ARM Cortex @1.5GHz×4, 2GB

TABLE III: Hardware Platforms for Experiments

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TABLE III: Hardware Platforms for Experiments

On Device 1-3
Private Service Broadcast Phase: Below 0.538 s
Mutual Authentication Phase: below 0.893 s

Stay well **below 1 s**, which humans perceive the delays as an **"immediate response"**

Implementation and Performance

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3	Phone	ARM Cortex @2.84GHz+3×2.4GHz, 4GB
4	Raspberry Pi	ARM Cortex @1.5GHz×4, 2GB

TABLE III: Hardware Platforms for Experiments

On Device 1-3

Private Service Broadcast Phase: below 0.538 s
Mutual Authentication Phase: below 0.893 s

Stay well **below 1 s**, which humans perceive the delays as an **"immediate response"**

On Device 4

Private Service Broadcast Phase: below 1.189 s
Mutual Authentication Phase: below 2.712 s

Delays are **longer but not too significant**

Limitations and Open Problems

- Large Message Size
  - This large size of the outer discovery broadcast poses a scalability challenge
    - particularly on slower networks like BLE, resulting in high transmission overhead and reception delays
  - Packet Loss
    - clients must wait for the broadcast ciphertext in the subsequent round to receive full packets, causing additional delays in reception

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- Unlinkability across Multiple layers
  - PriSrv protects its own payloads for achieving unlinkability **at its positioned layer**
  - As for achieving unlinkability at lower layers, the lower layer headers must be protected using specific anti-tracking mechanisms designed at lower layers

Q&A

Thank You!