A Path Layer for the Internet

Enabling Network Operations on Encrypted Traffic

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mami
measurement and architecture for a middleboxed Internet

measurement | architecture | experimentation

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Increasing Deployment of Encryption

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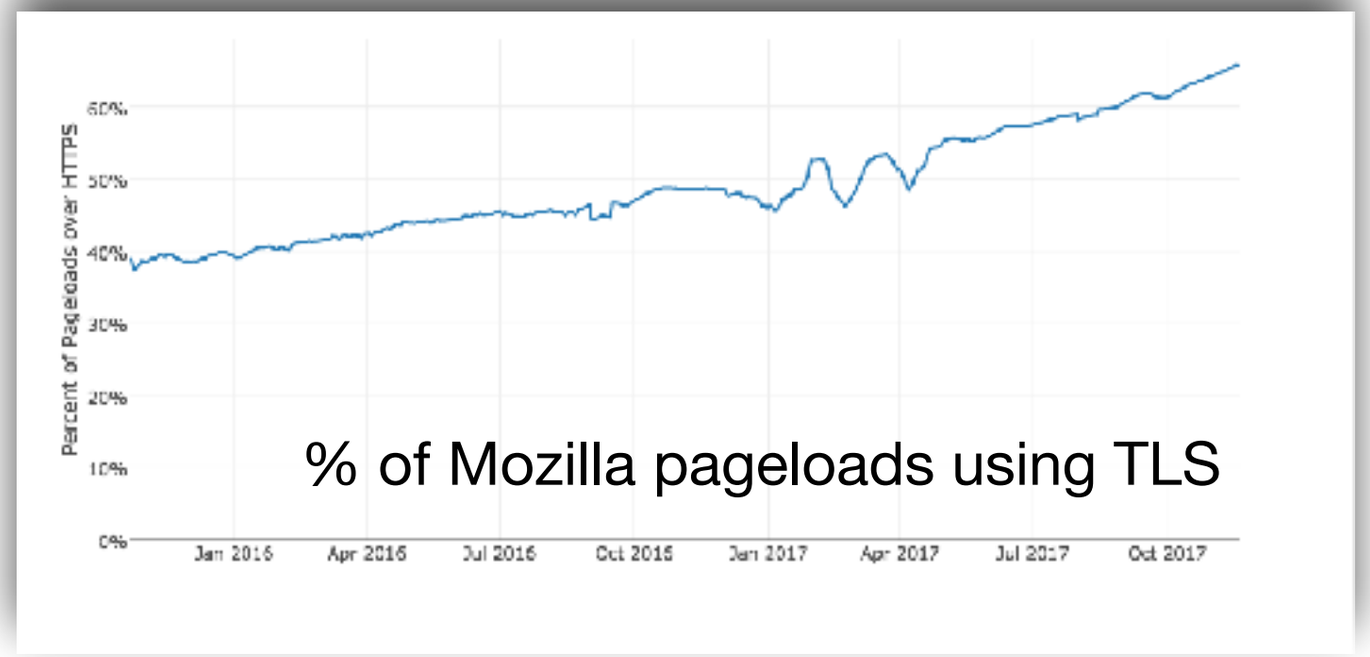

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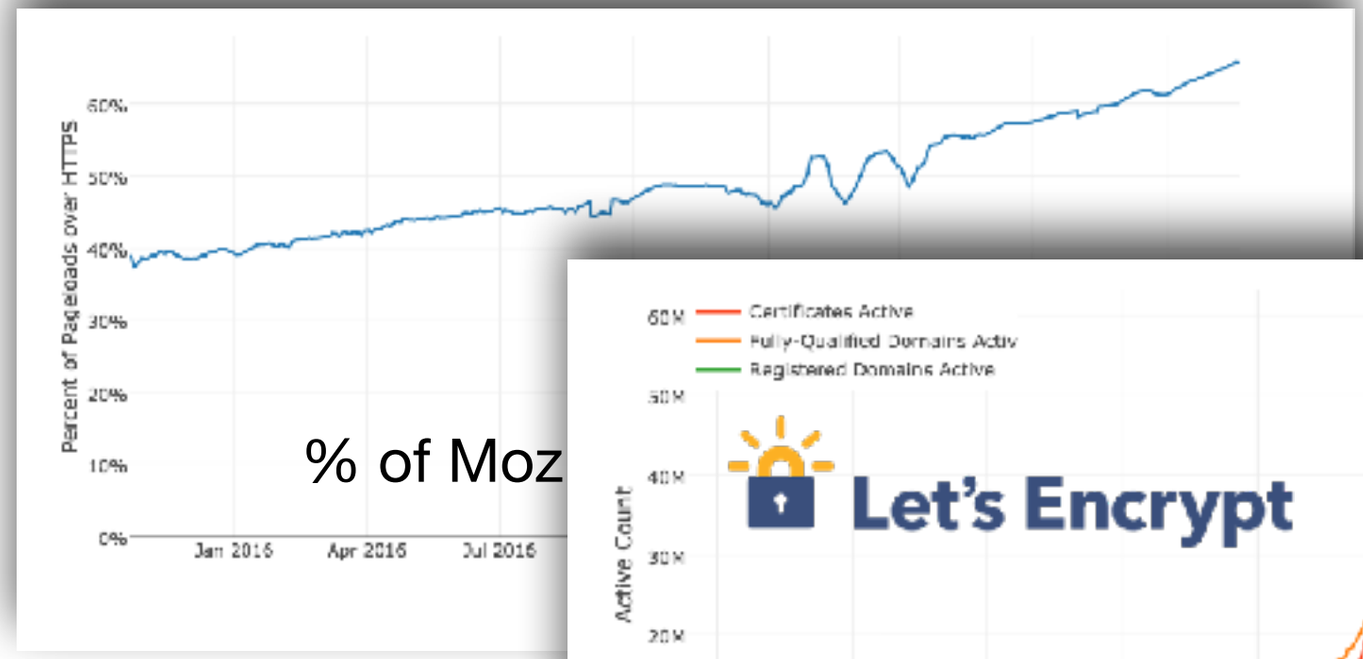

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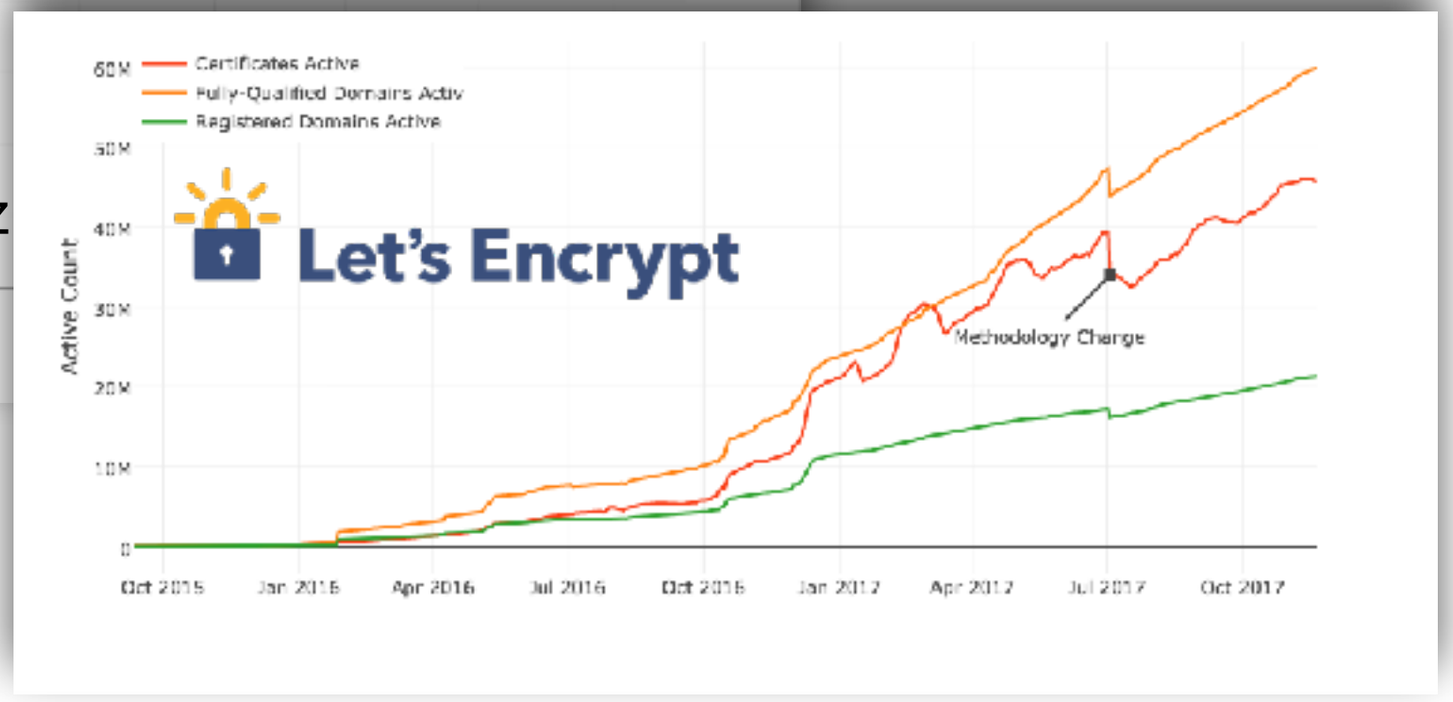

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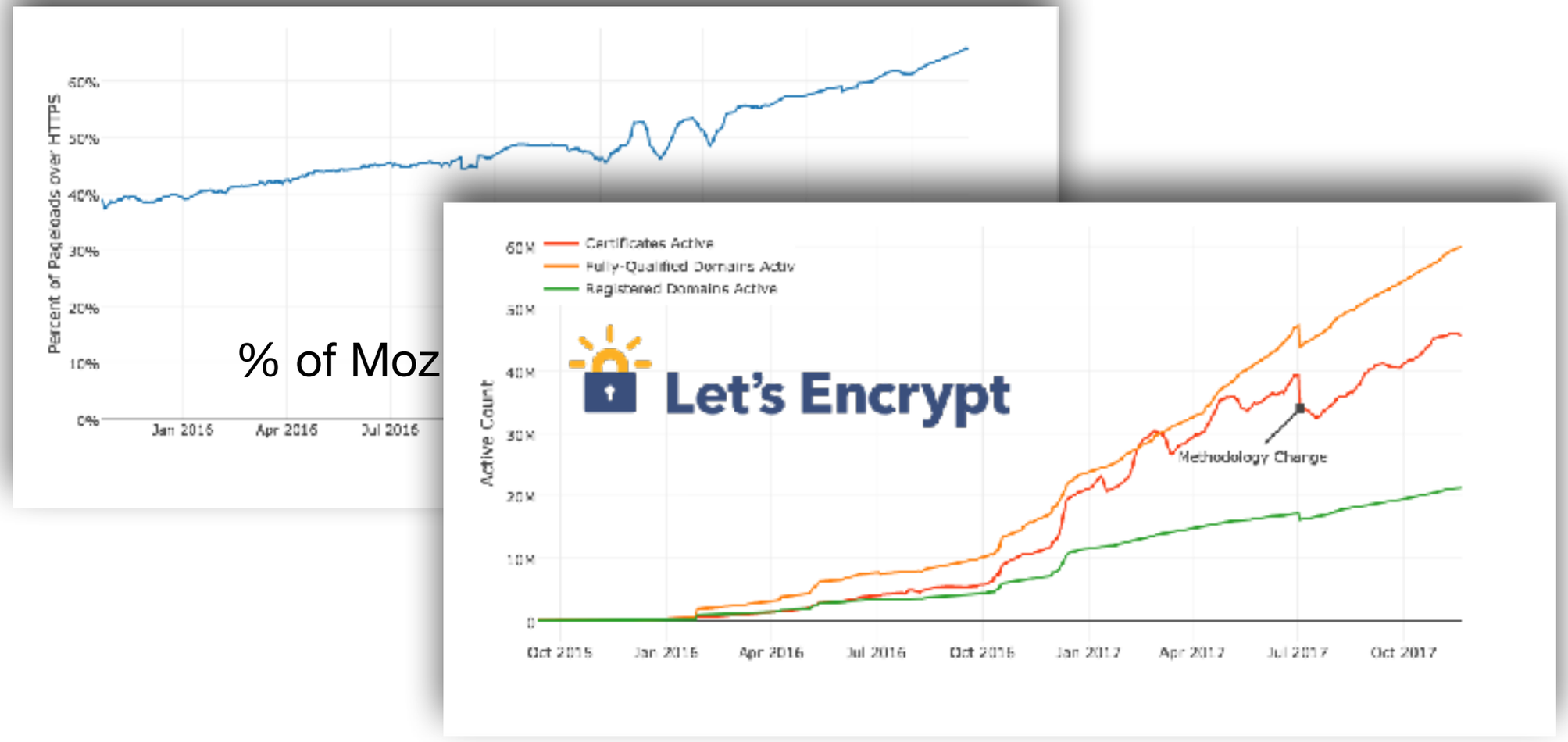
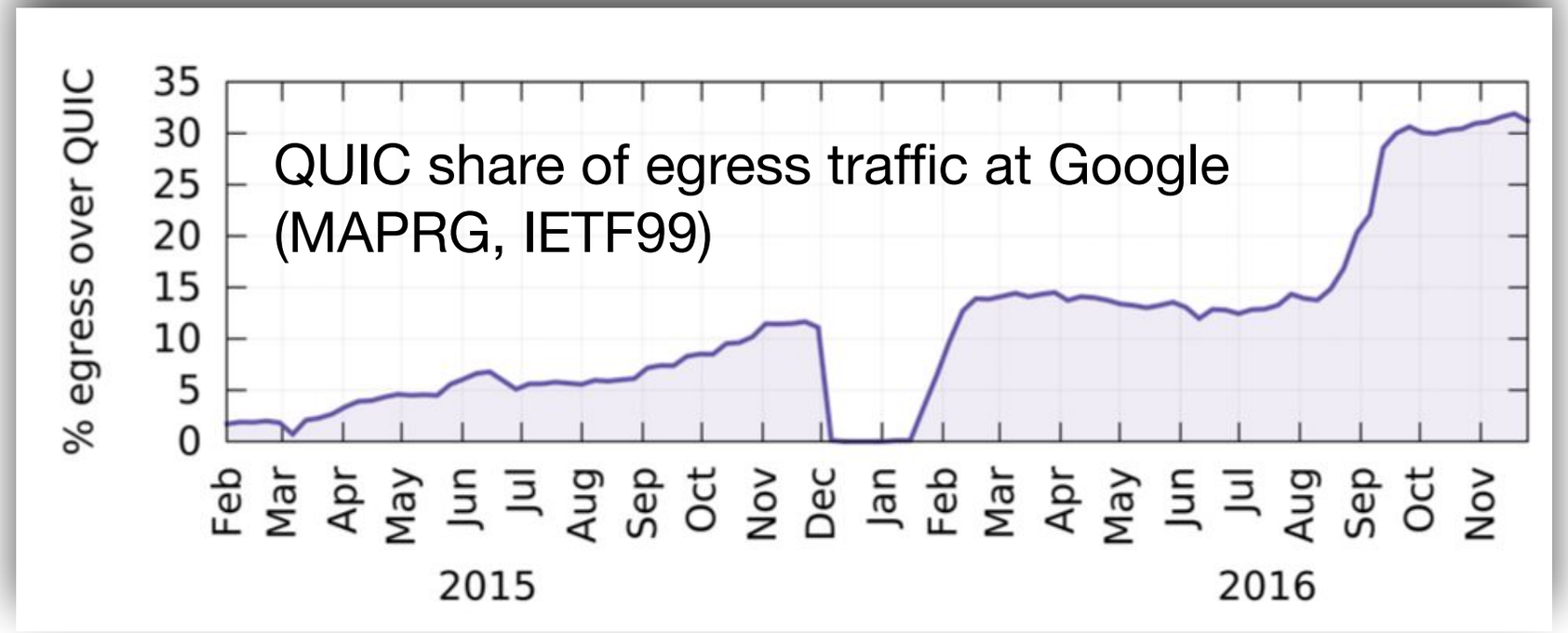


- → No management function that needs cleartext access to application headers/payload will work on the new Internet.

Protocol Stack Encryption



- QUIC: new, UDP-encapsulated transport, optimized for HTTP/2
- Developed/deployed by Google, 7% of Internet traffic end-2016.
- Under standardization in the IETF, expected deployments 2019.
- QUIC ***encrypts everything*** not needed to establish communication and forward packets.
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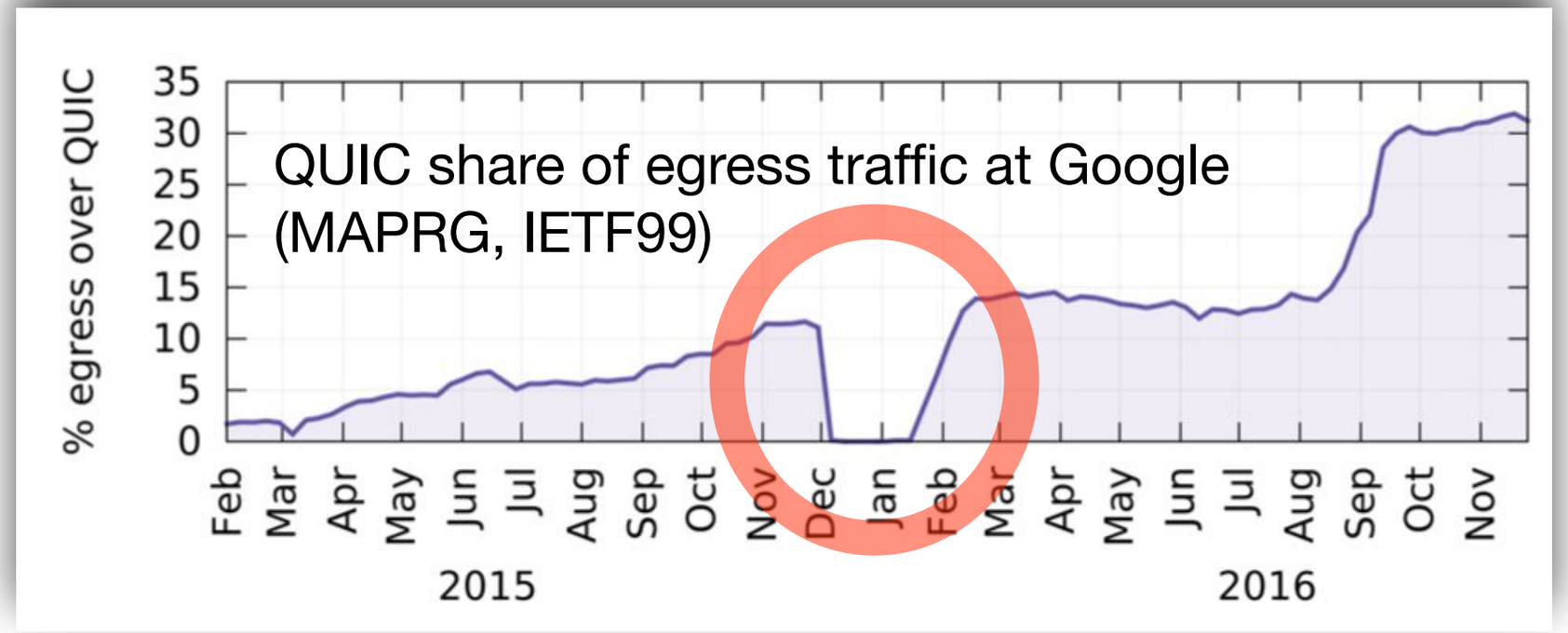

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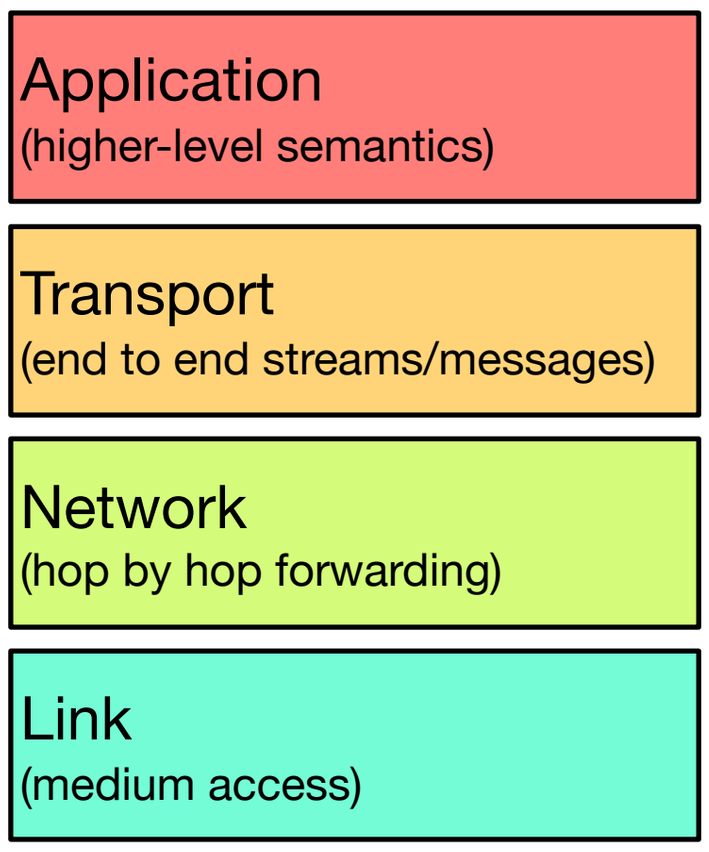
Explicit Cooperation

- The cleartext party is over, and DPI is dead.
  - Encryption for privacy, security, *and protocol evolvability*.

- A third way: replace use of cleartext by in-network functions with ***endpoint-controlled signaling***.
  - Explicit cooperation based on declarative, advisory signals requiring no trust between endpoints and path can reduce disruption driven by increased encryption.

Introducing the Path Layer

- The boundary between network (hop-by-hop, stateless) and transport (end-to-end, stateful) blurred by in-network state.
- Approach: add a layer to the stack to support these functions and use crypto to reinforce the boundary.



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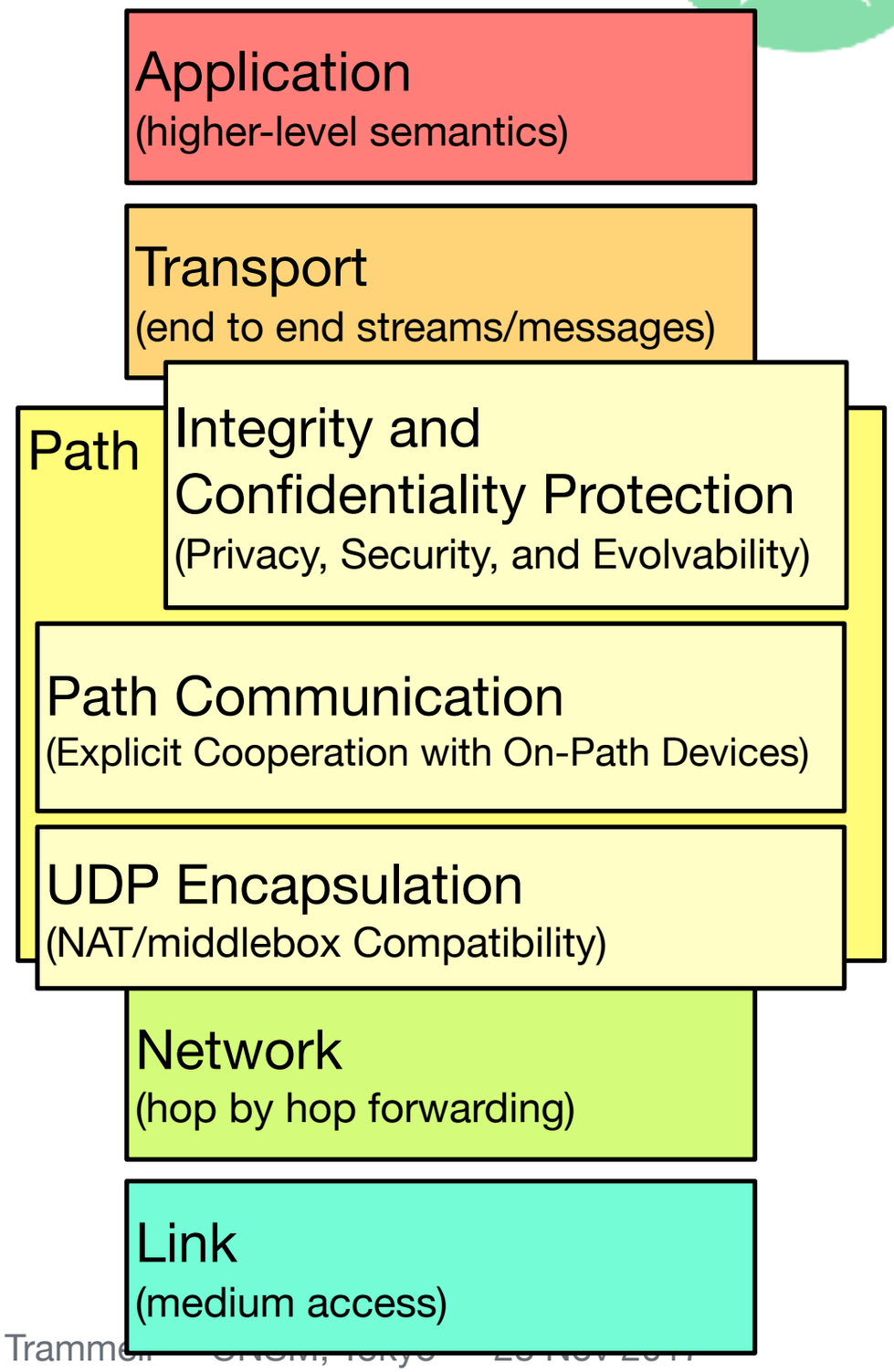

Path Layer Principles

- An endpoint should be able to **explicitly expose signals** to be used by on-path devices. Everything not intended for use by the path should be encrypted.
- An endpoint should be able to **request signals** from devices on the path.
- An on-path device **should not be able to forge, change, or remove** a signal sent by an endpoint.
- The **endpoint should control signaling** between endpoints and the path, or from one on-path device to another.
- It should be possible for an endpoint to request and receive signals from a **previously unknown on-path device**.
- The mechanism should present no significant surface for amplification attacks.

Applications of the Path Layer

- Transport-Independent On-Path State
- Latency Measurement
- Loss and Congestion Measurement
- Path Trace Accumulation
- Loss/Latency Tradeoff
- Path MTU Discovery

Today's talk

- Generic mechanism allows for future extensibility

Sender to Path Signaling

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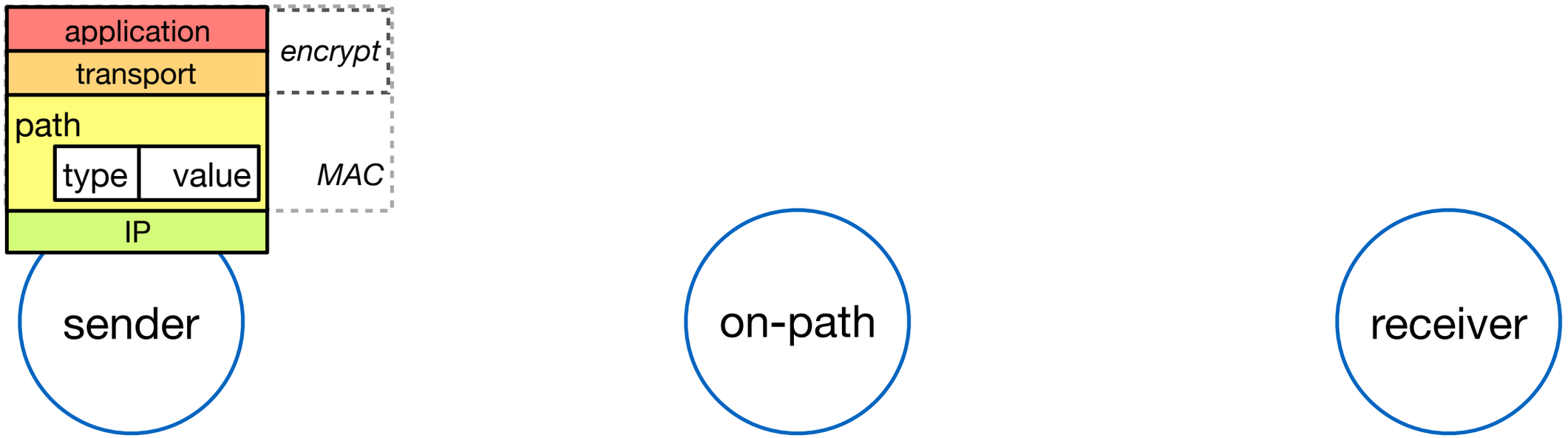

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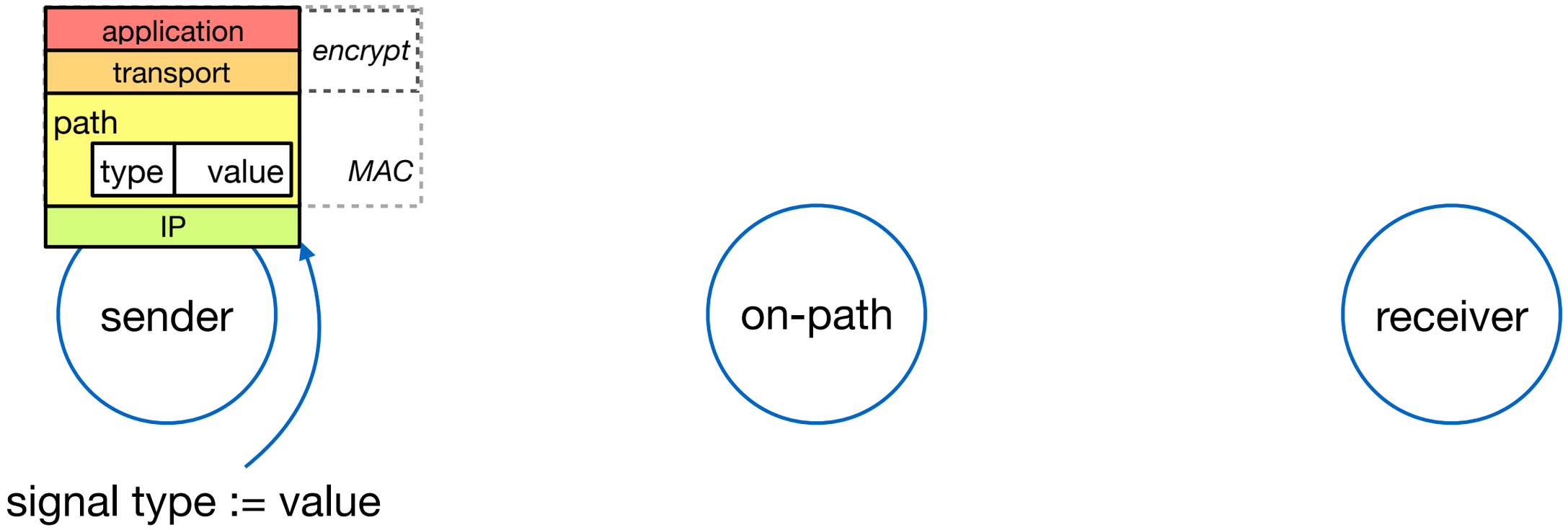

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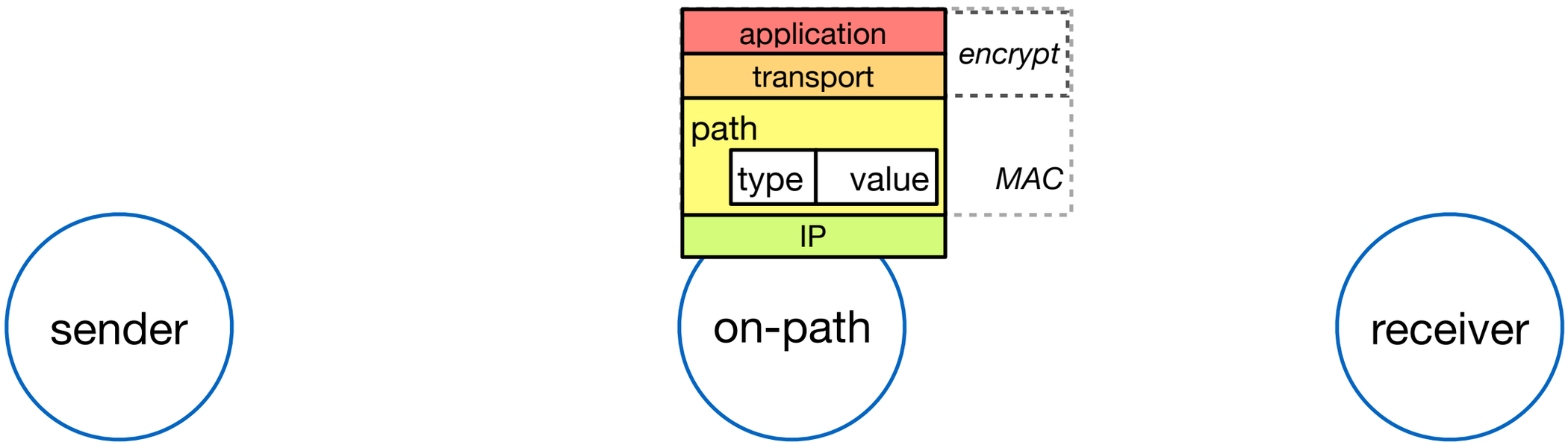

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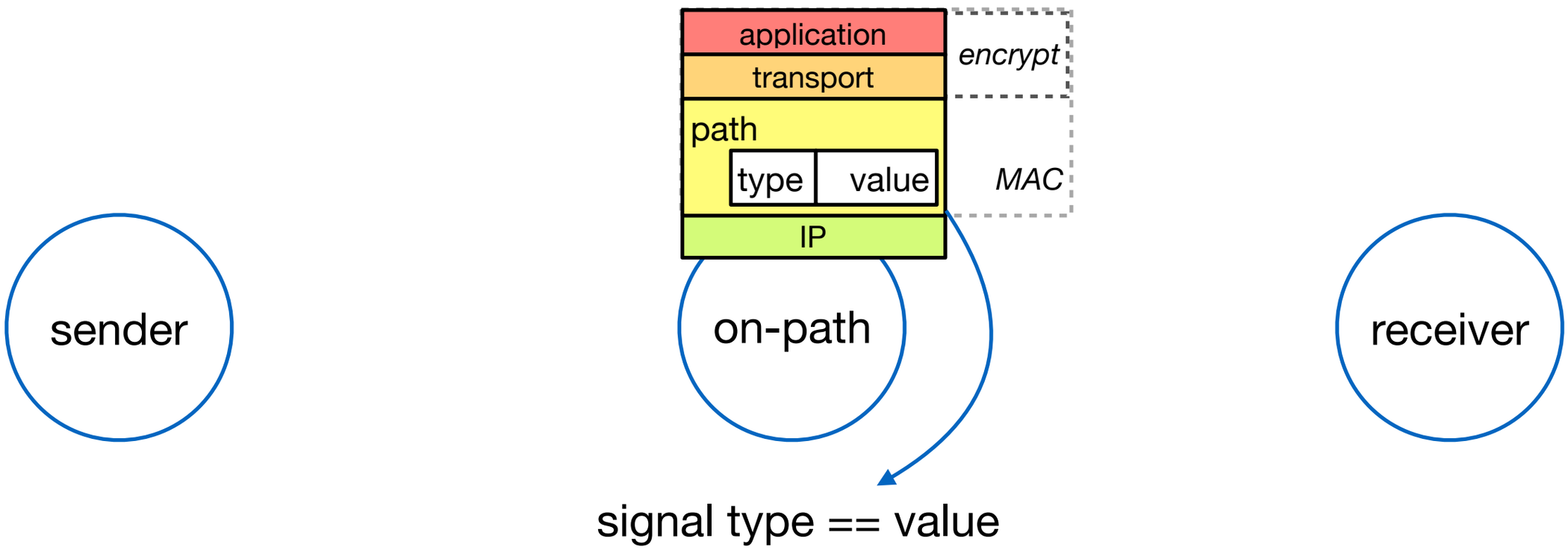

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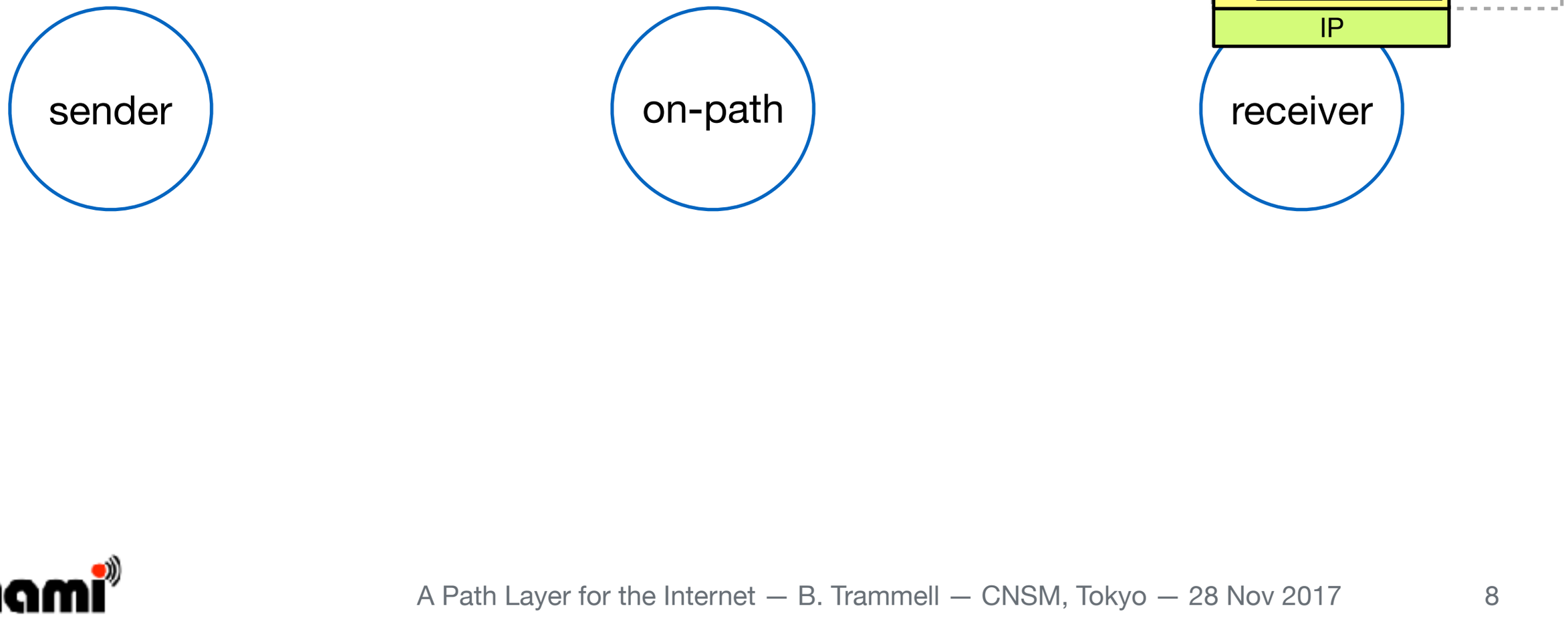

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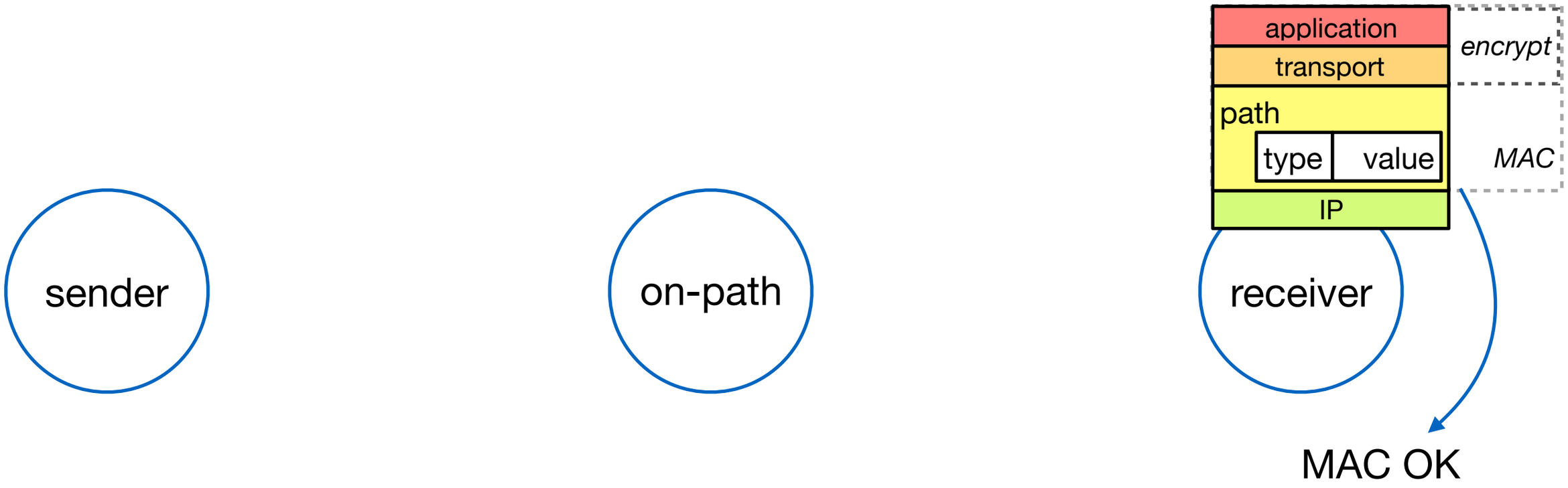

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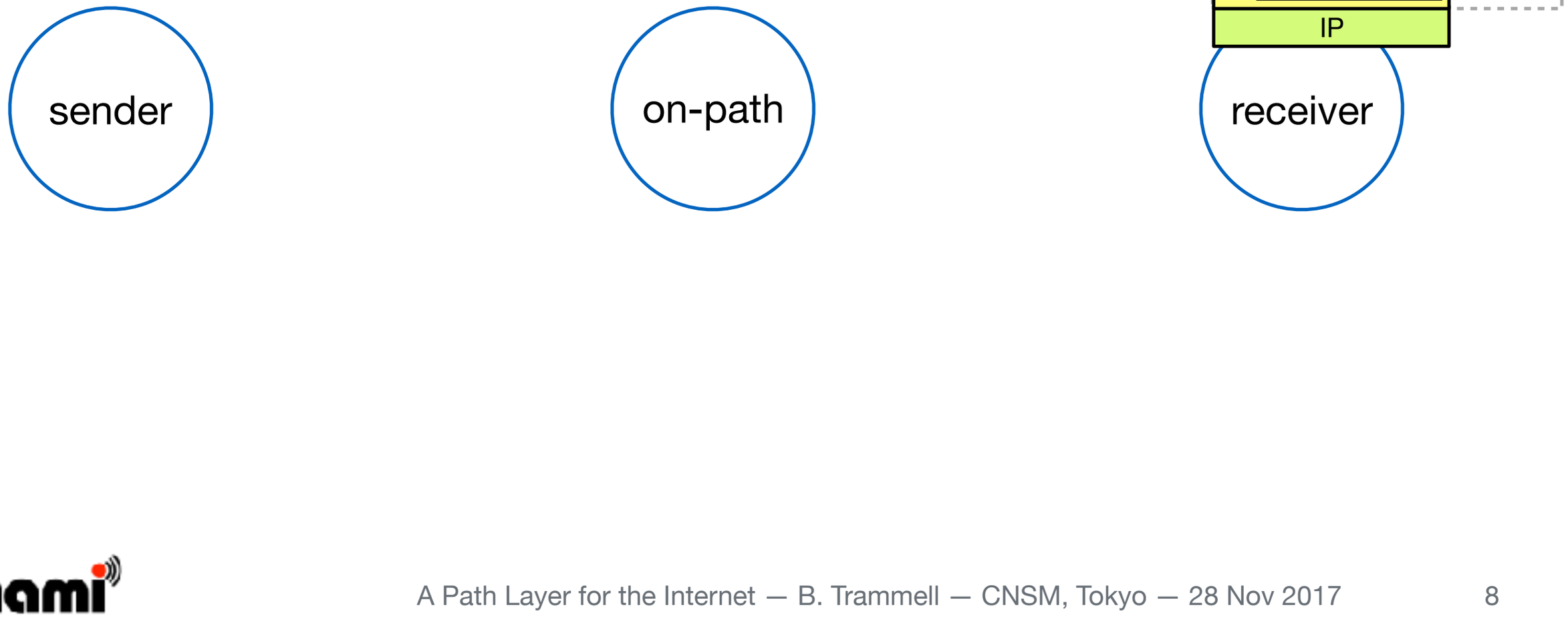

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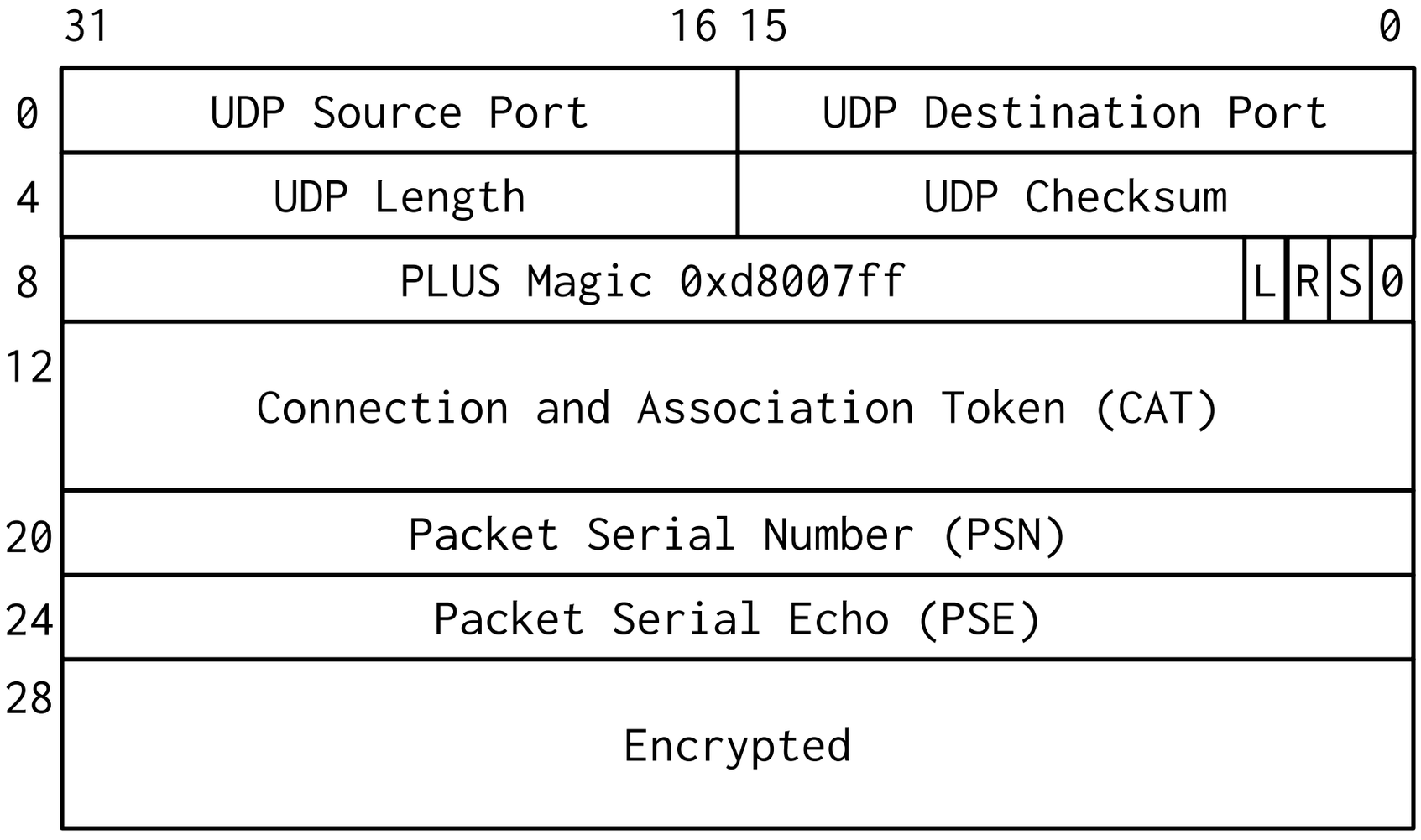
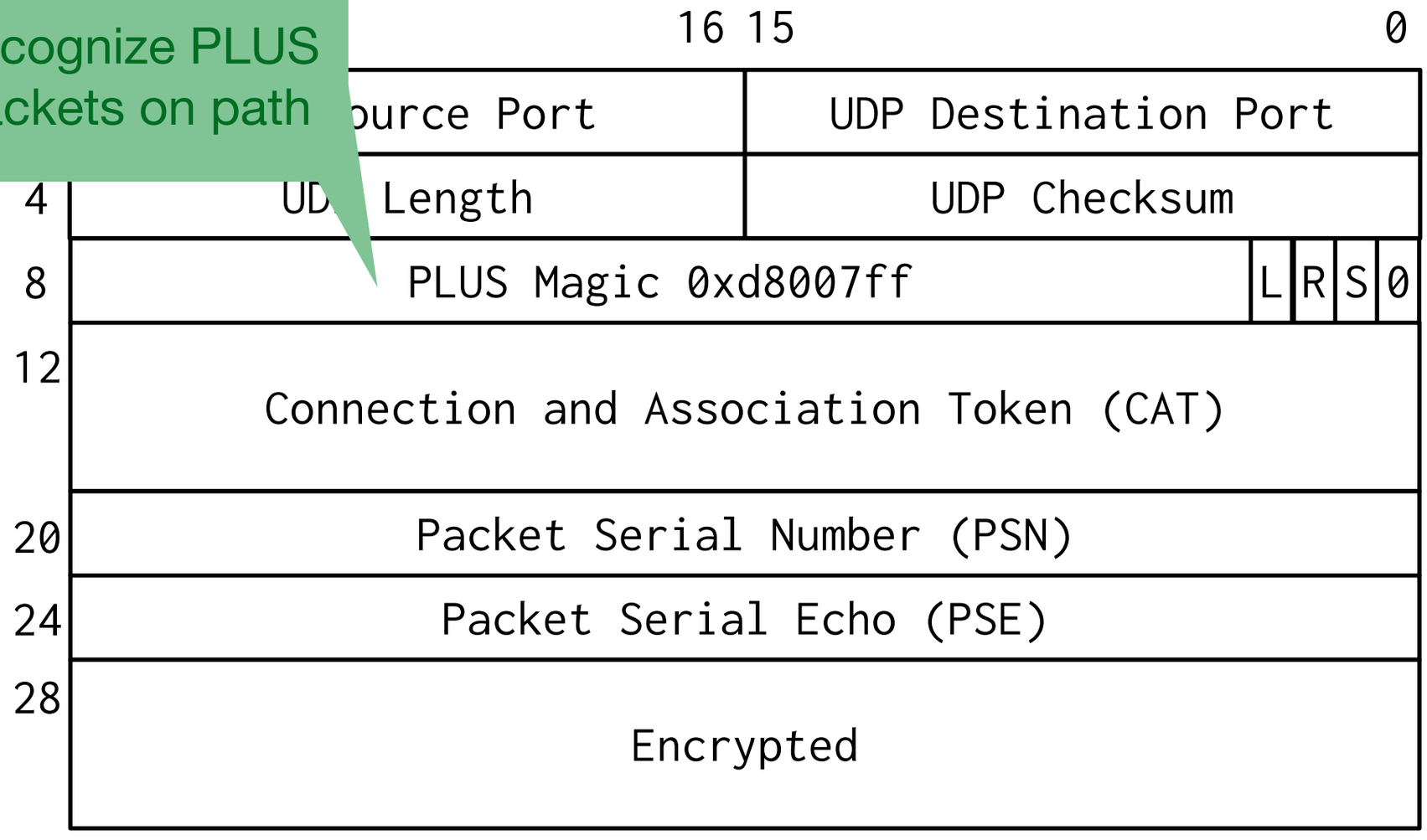


Basic PLUS Header

Recognize PLUS packets on path



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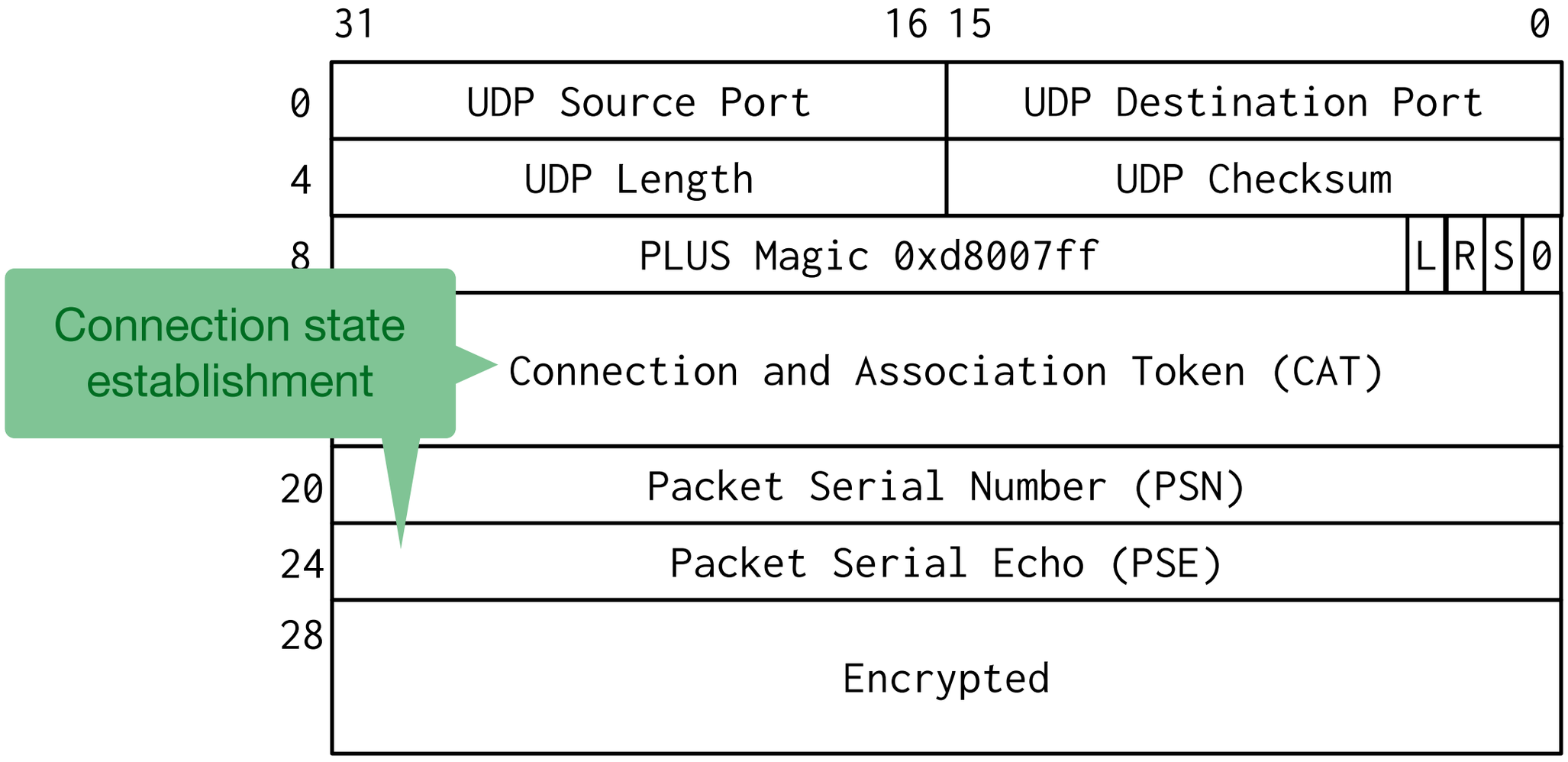

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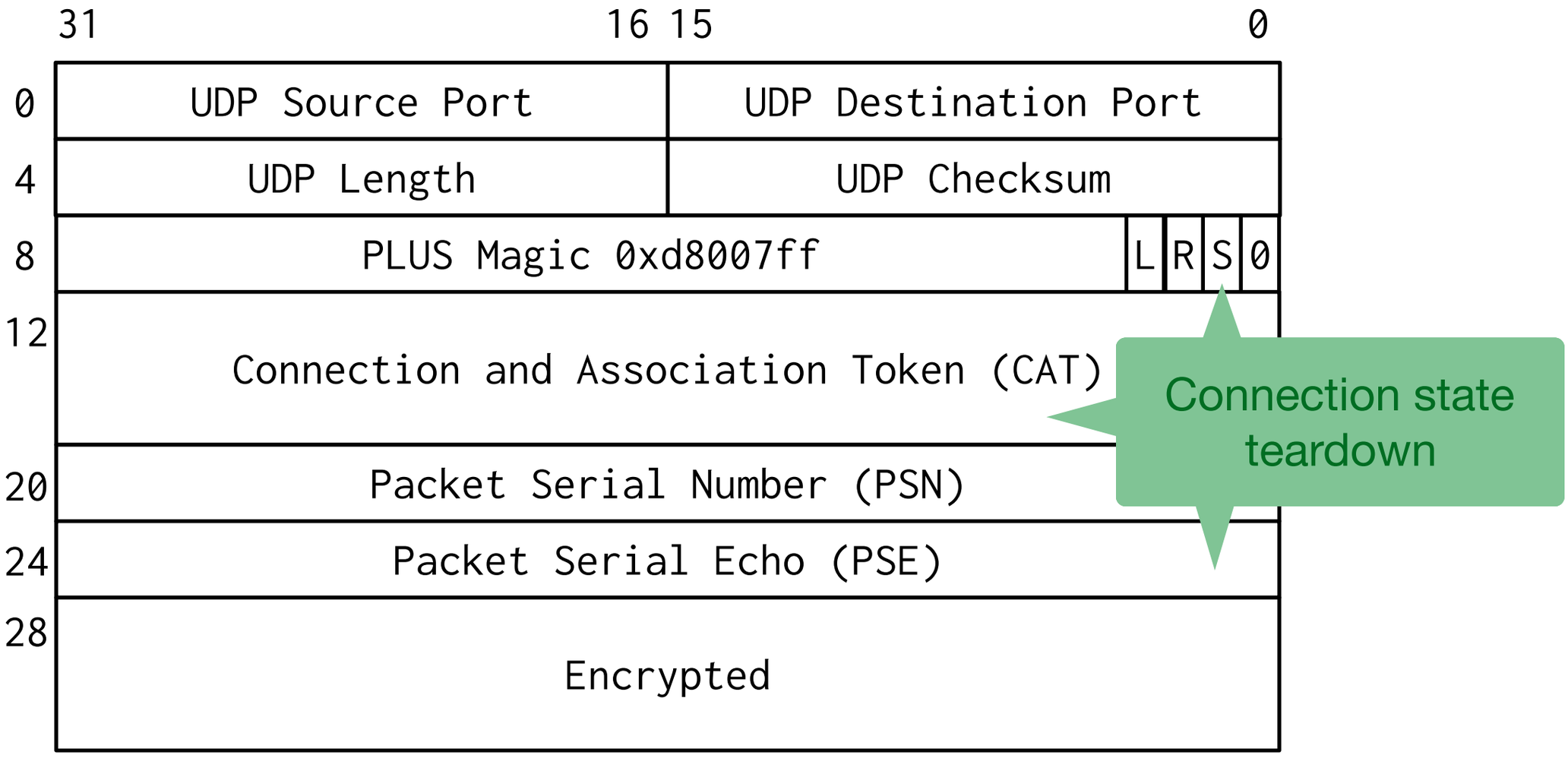

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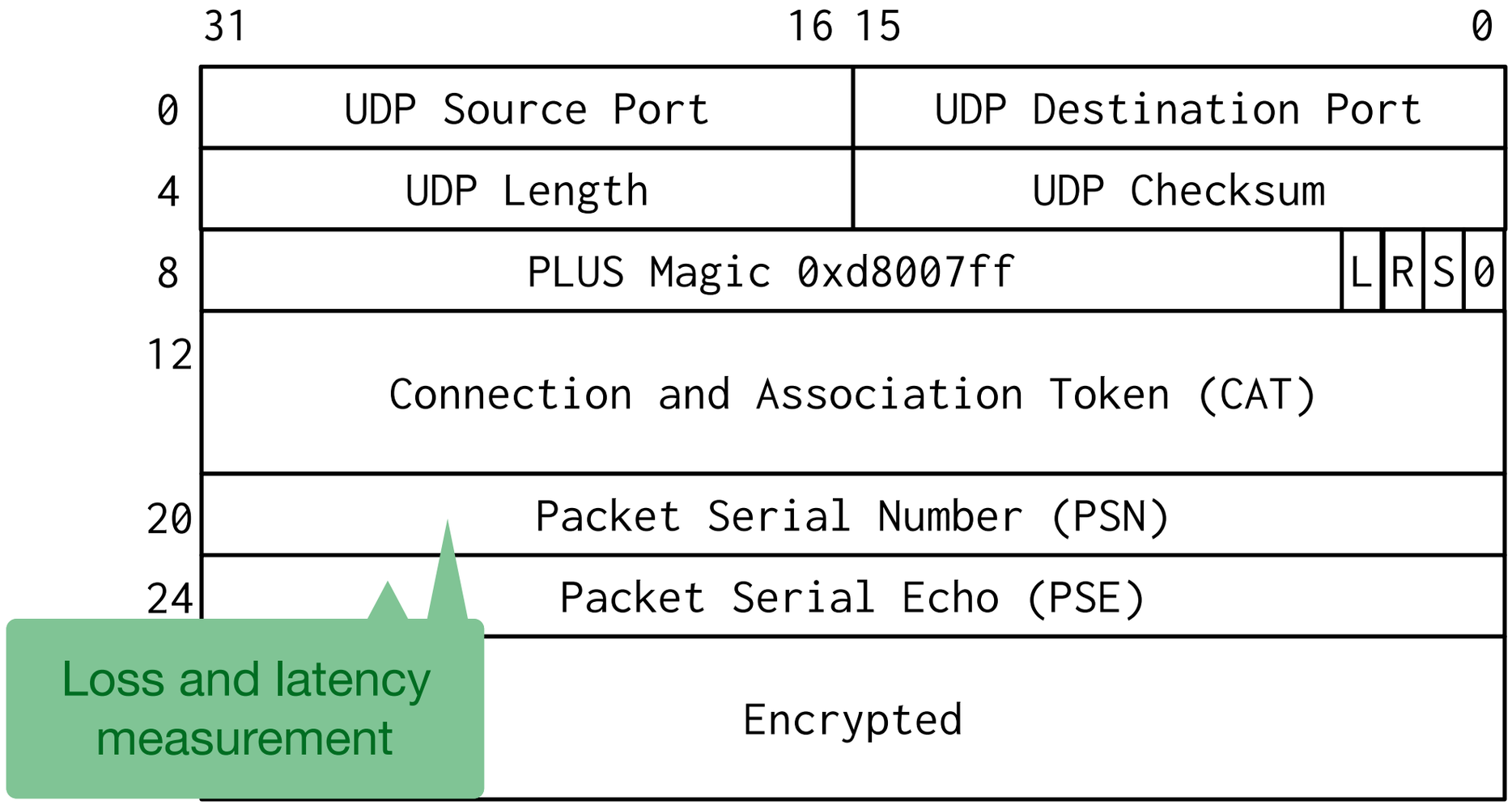

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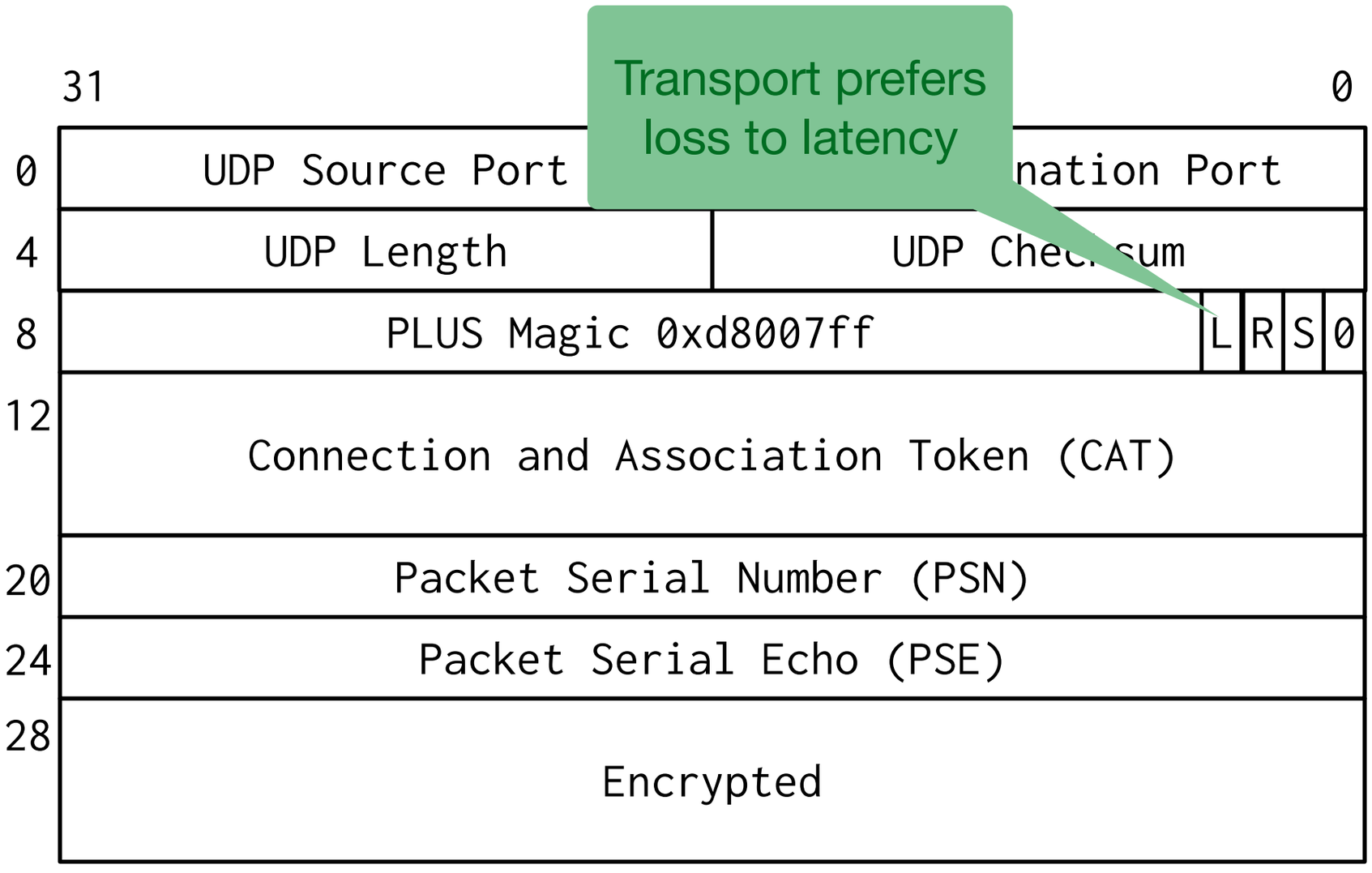

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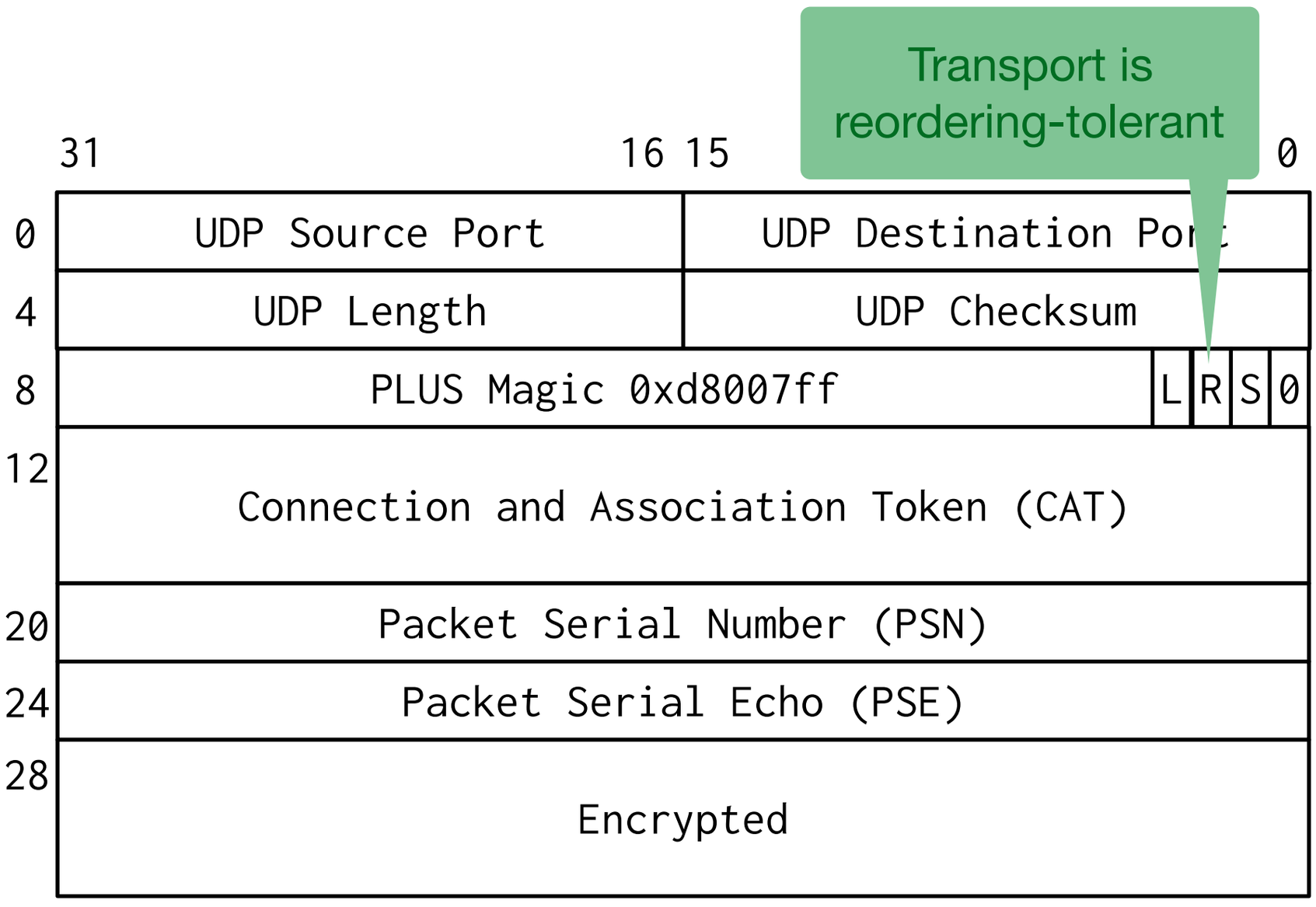

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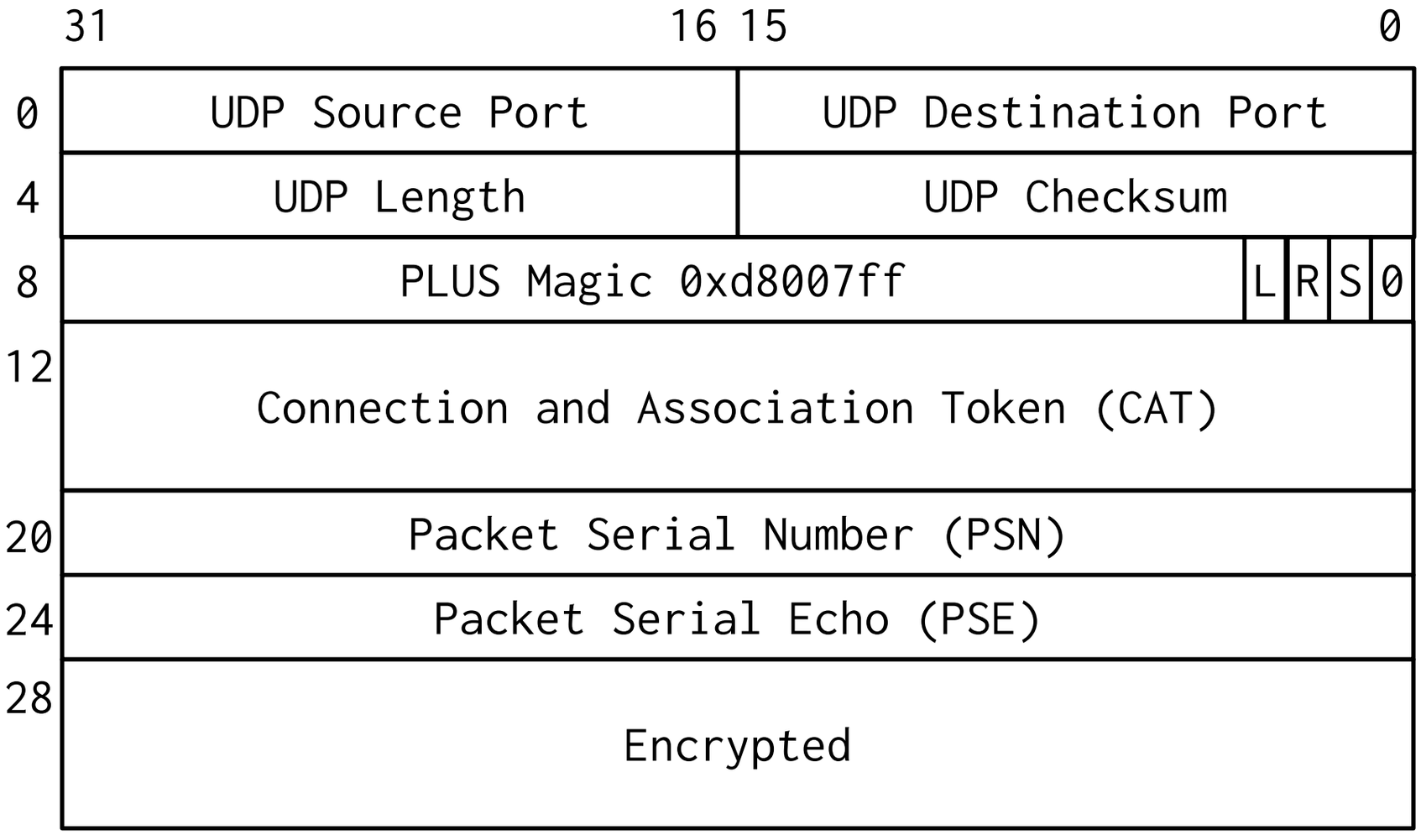
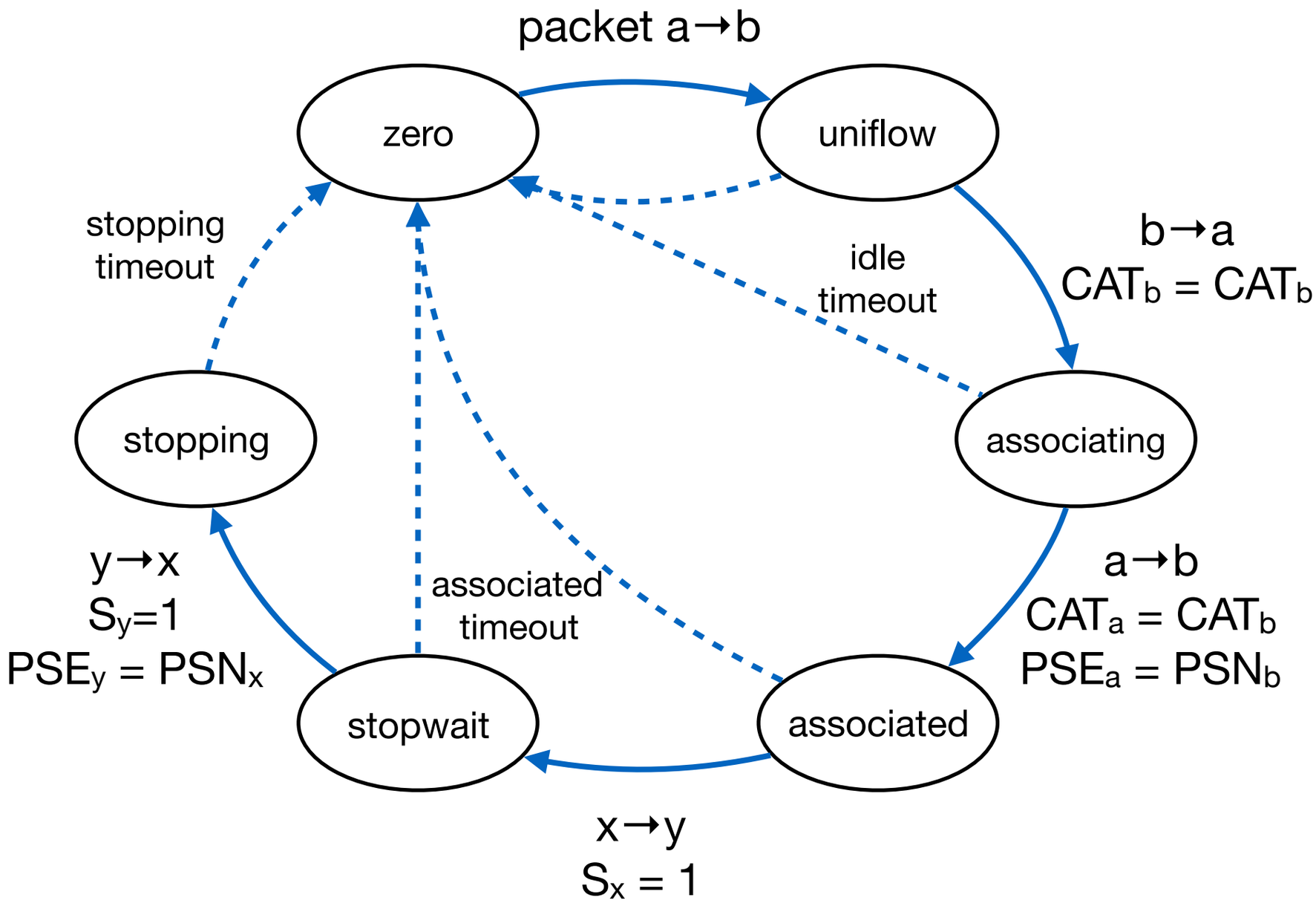


Transport-Independent On-Path State



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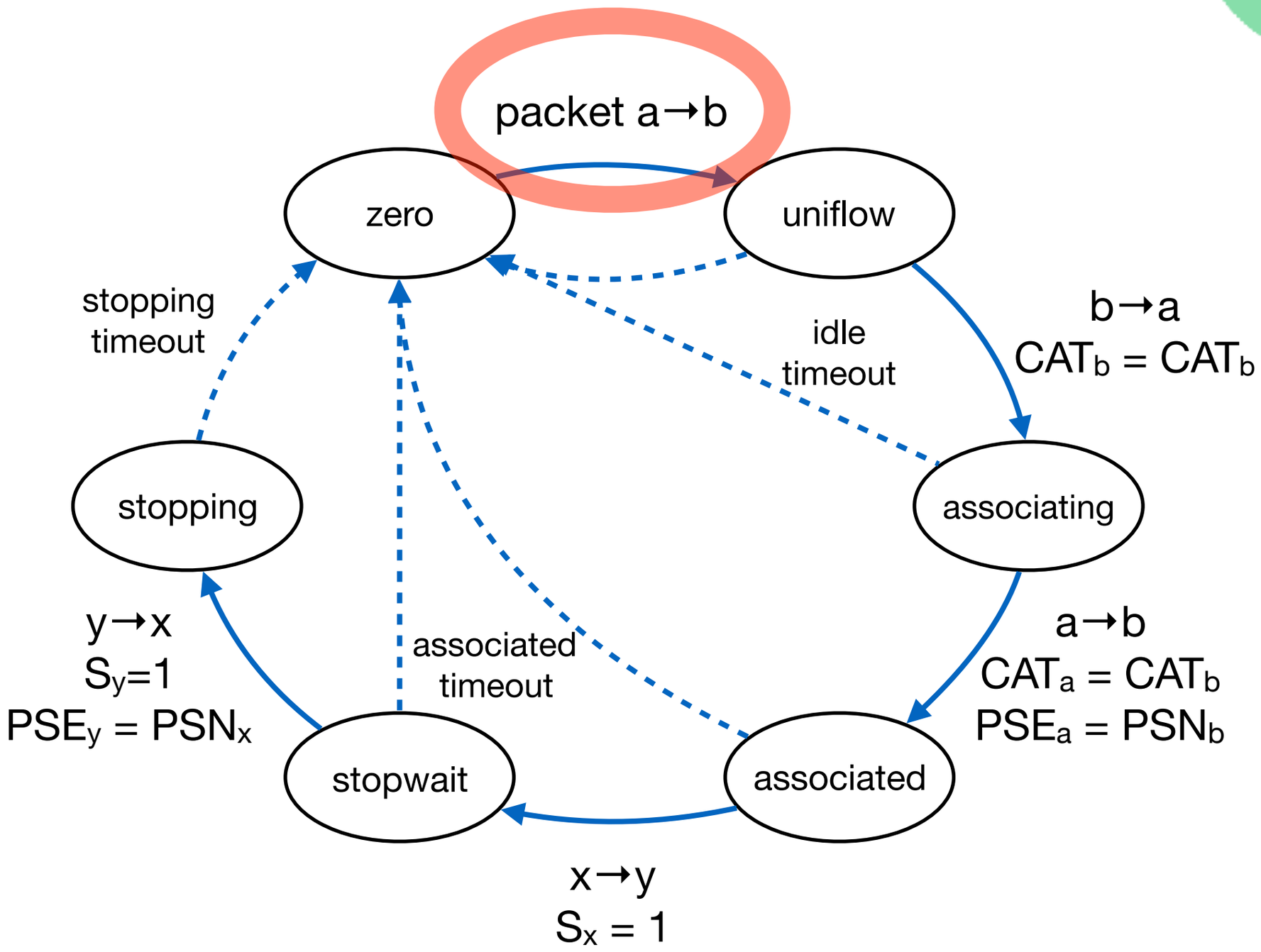

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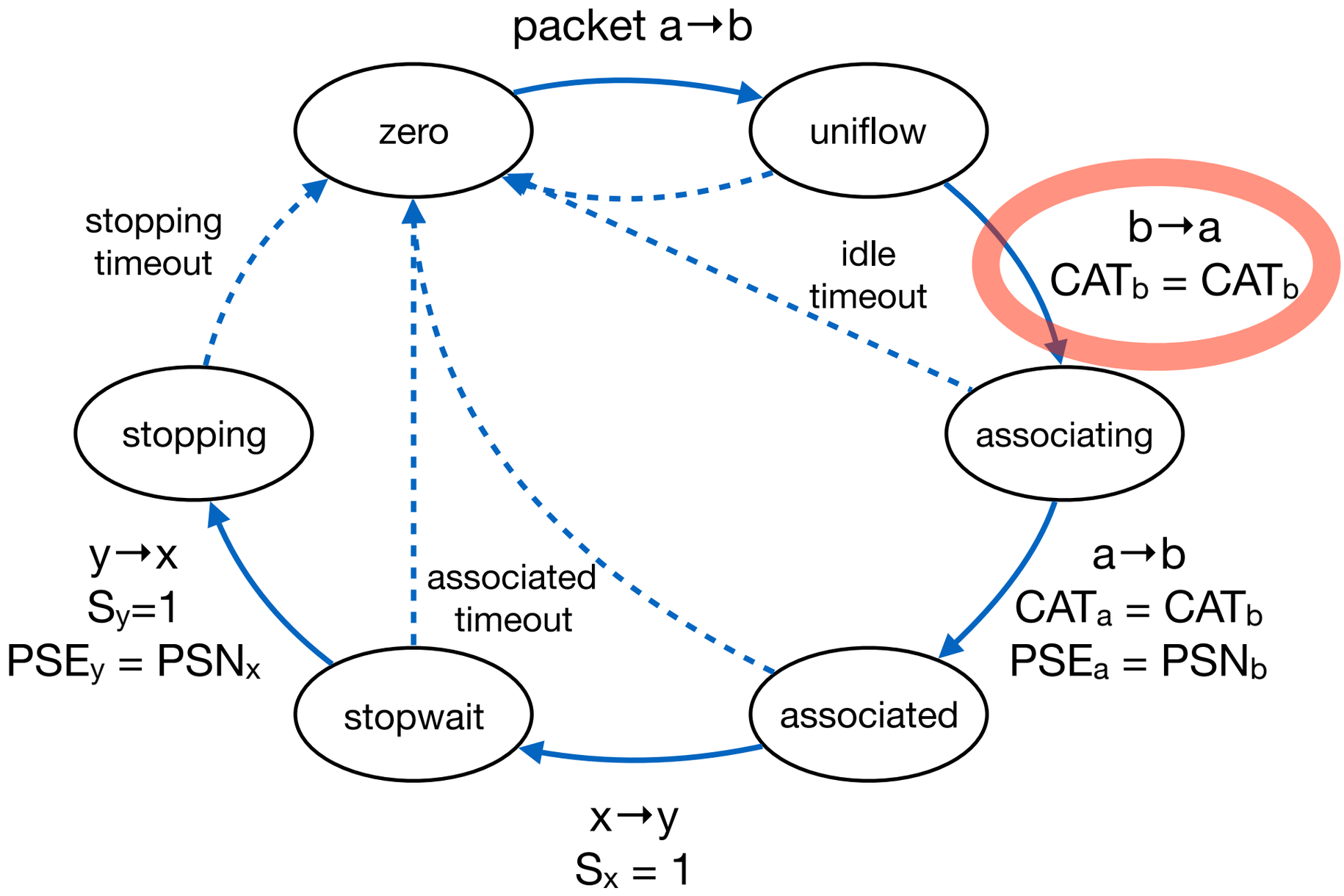

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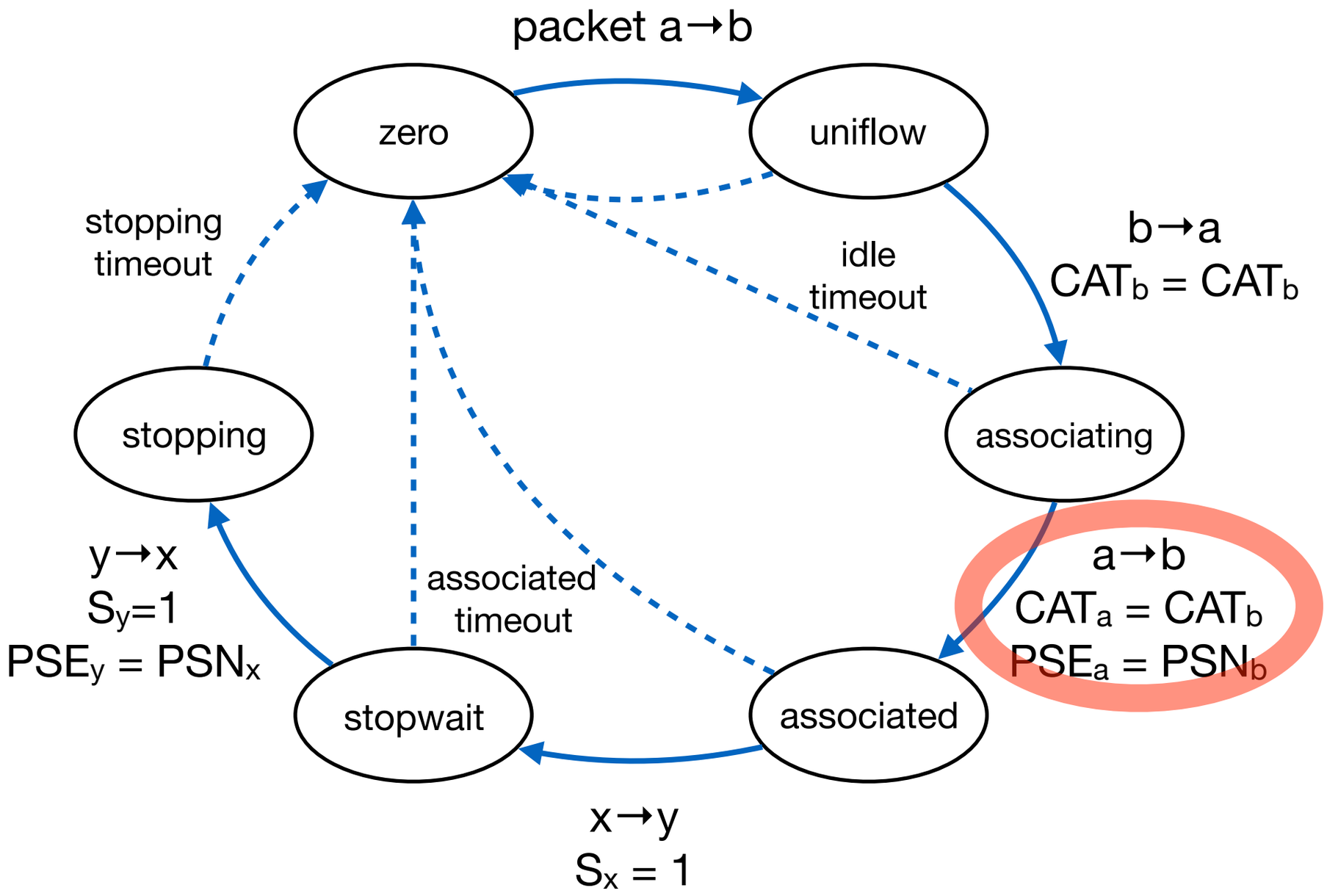

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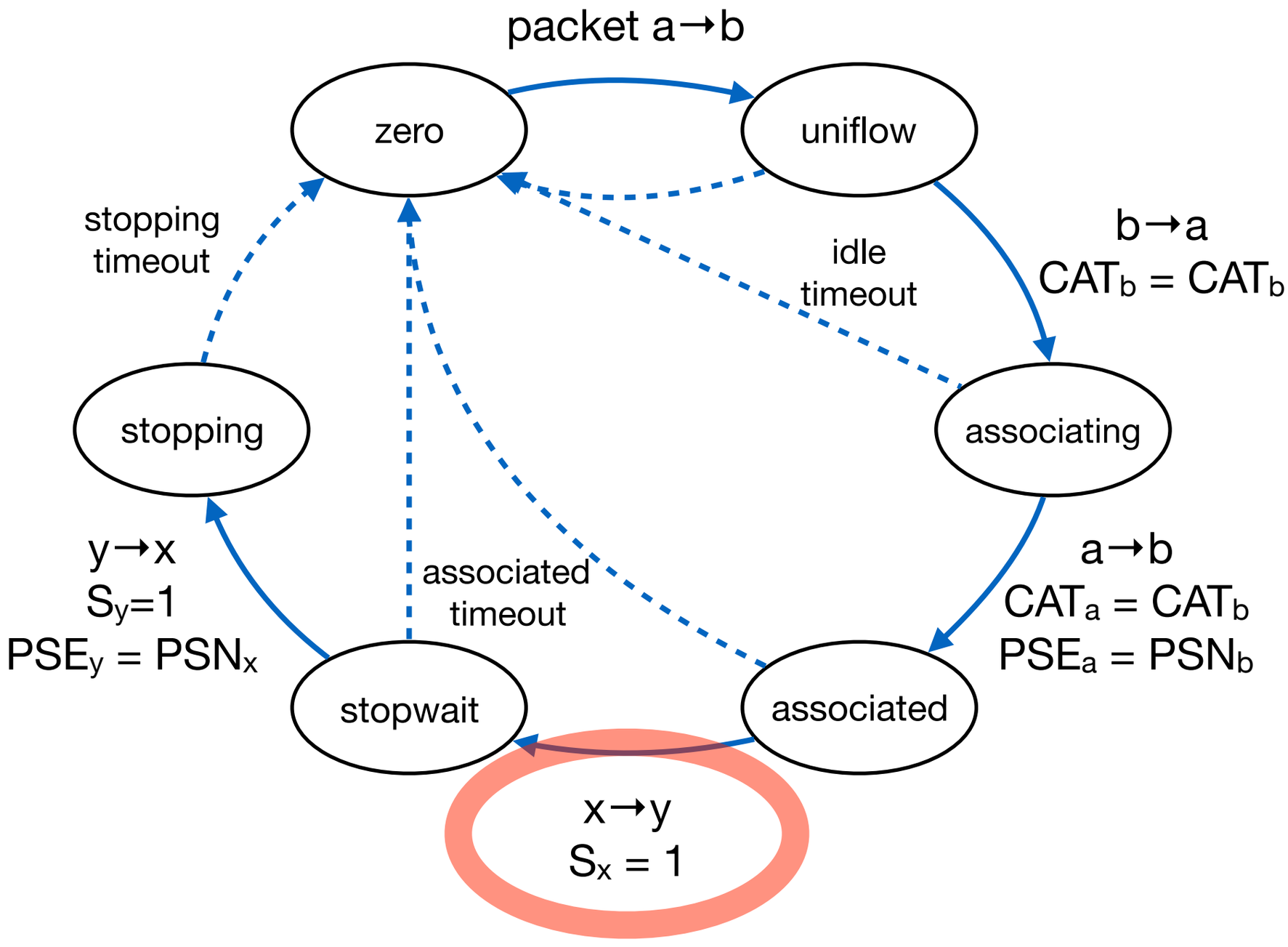

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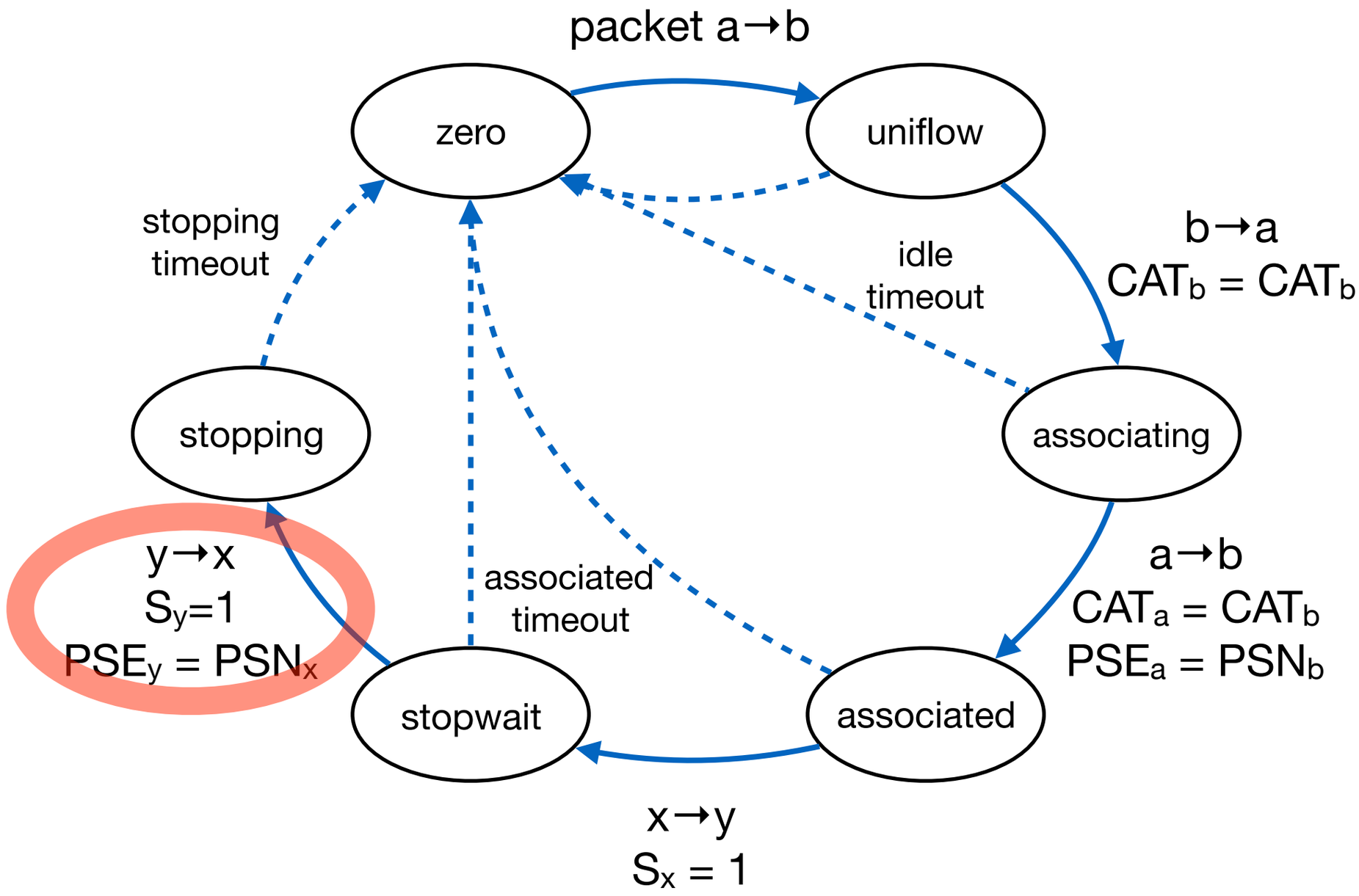

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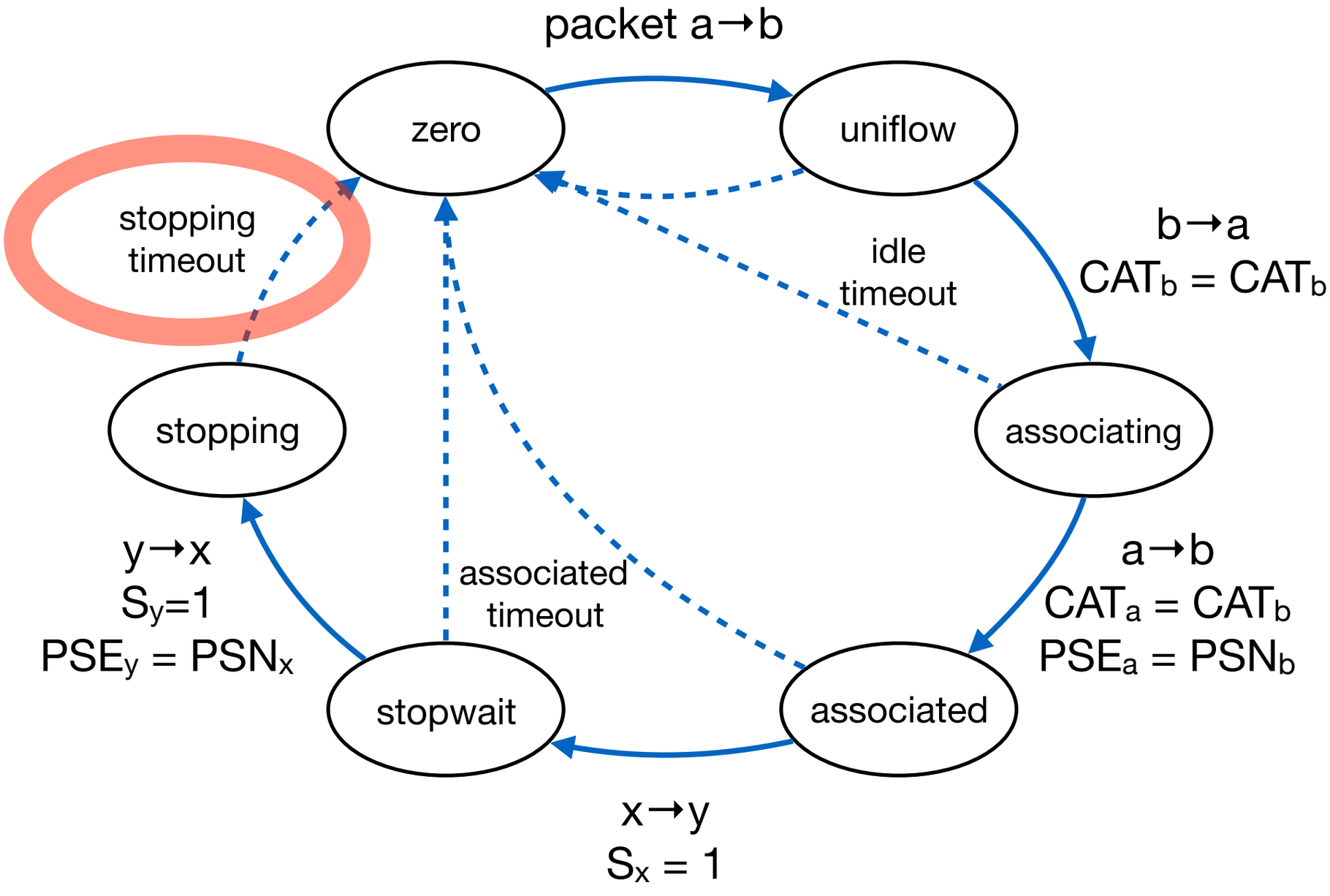

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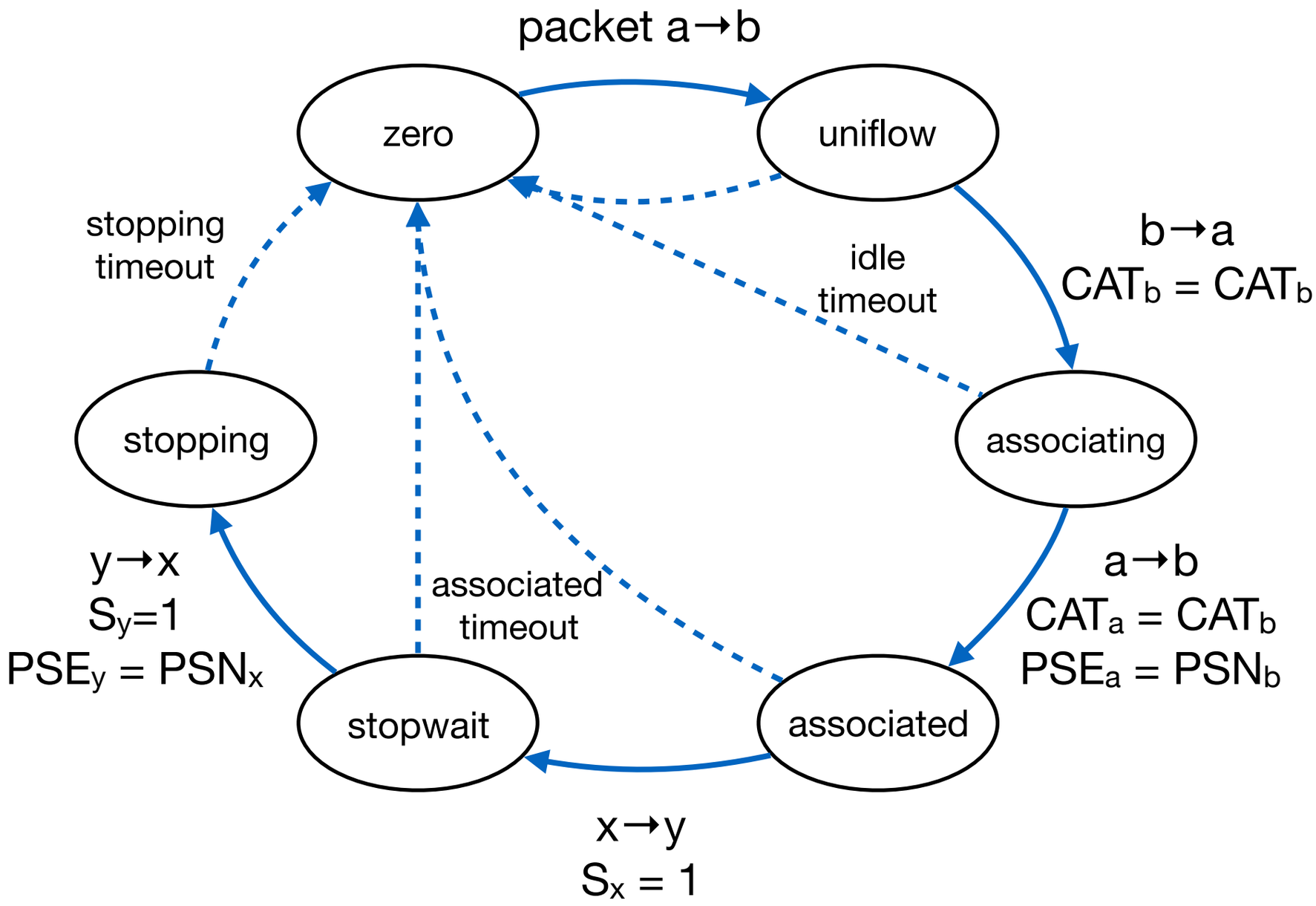

Latency Measurement

- PSN/PSE are explicit measurement signals replacing TCP SEQ/ACK + TSOPT

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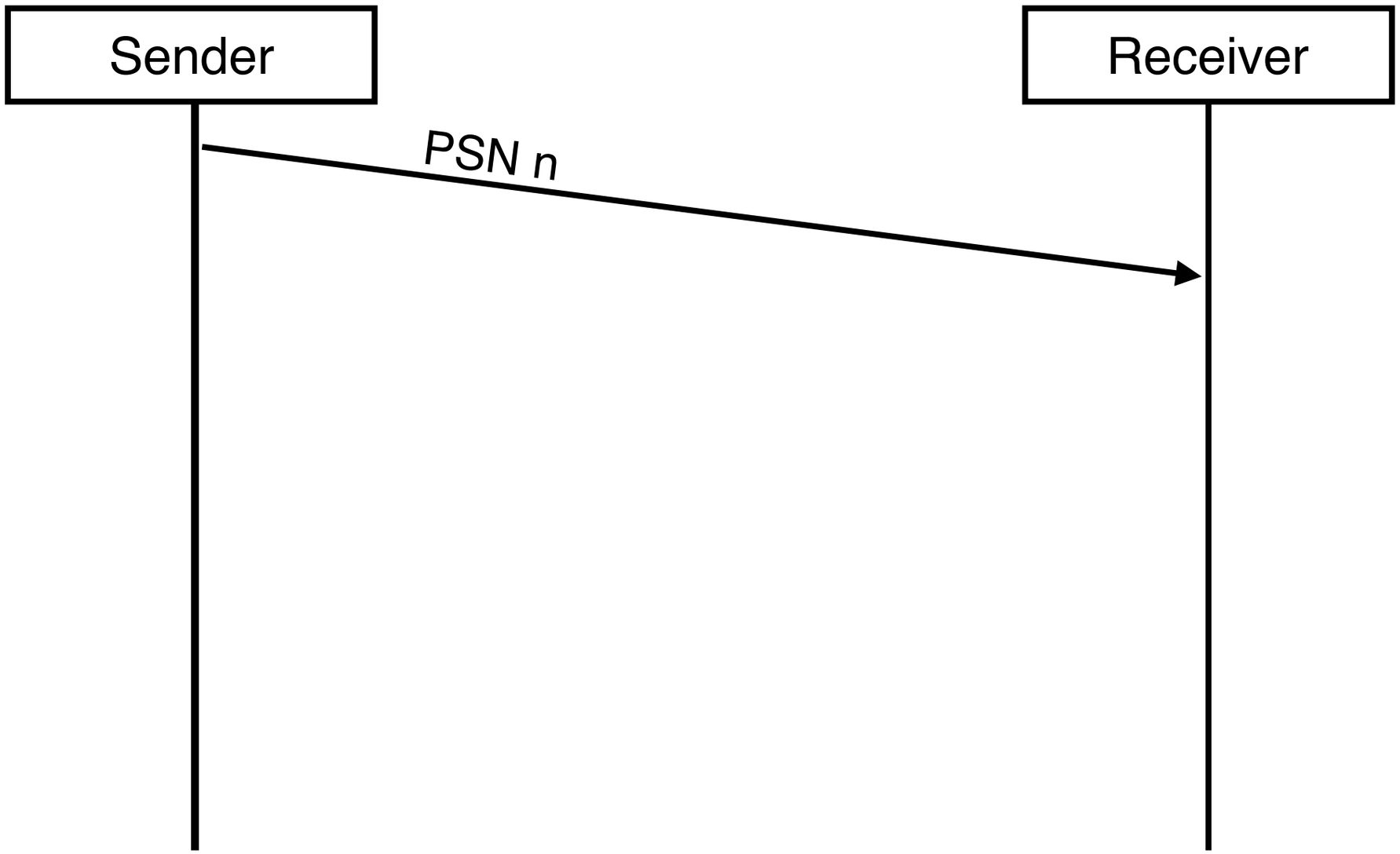

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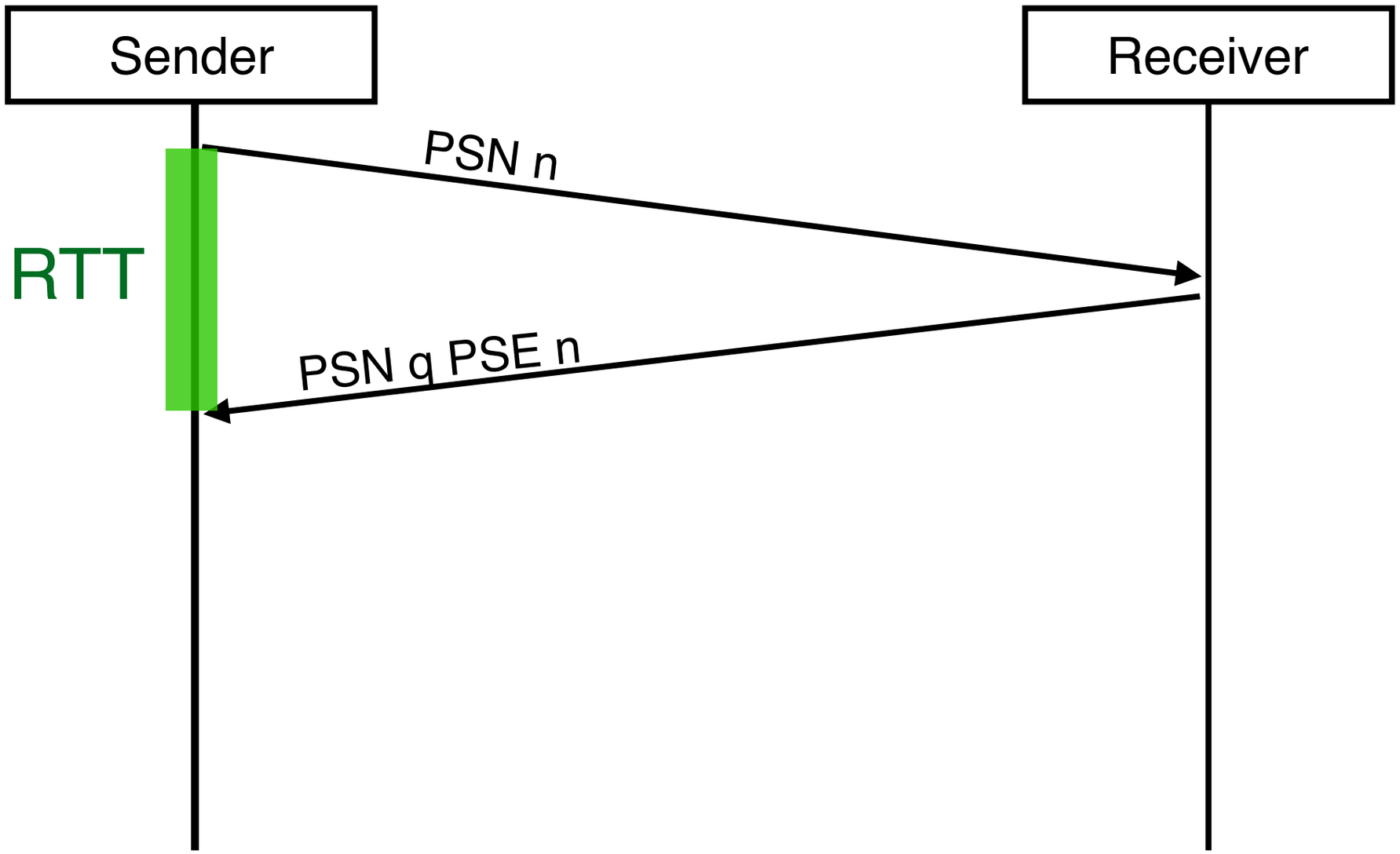

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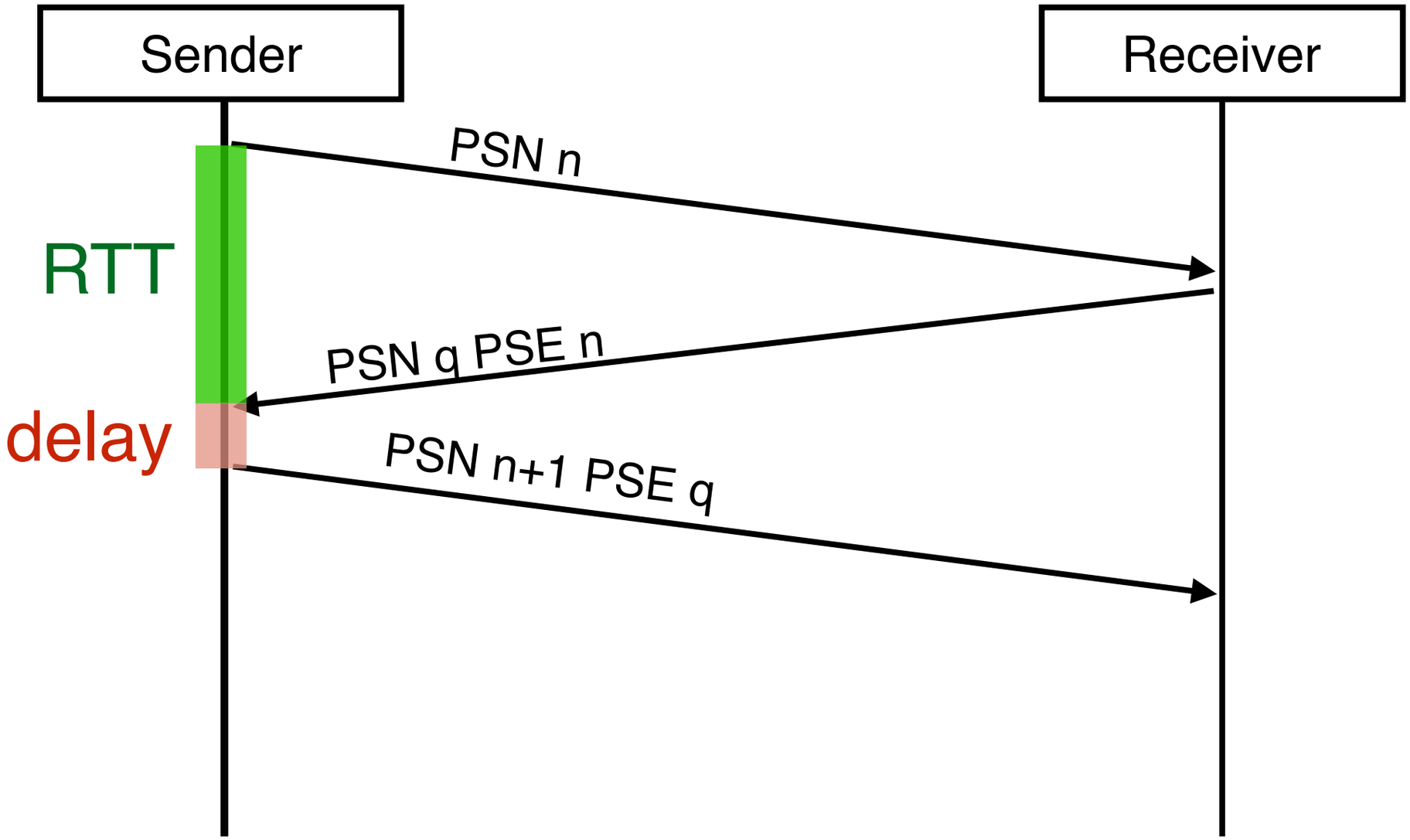

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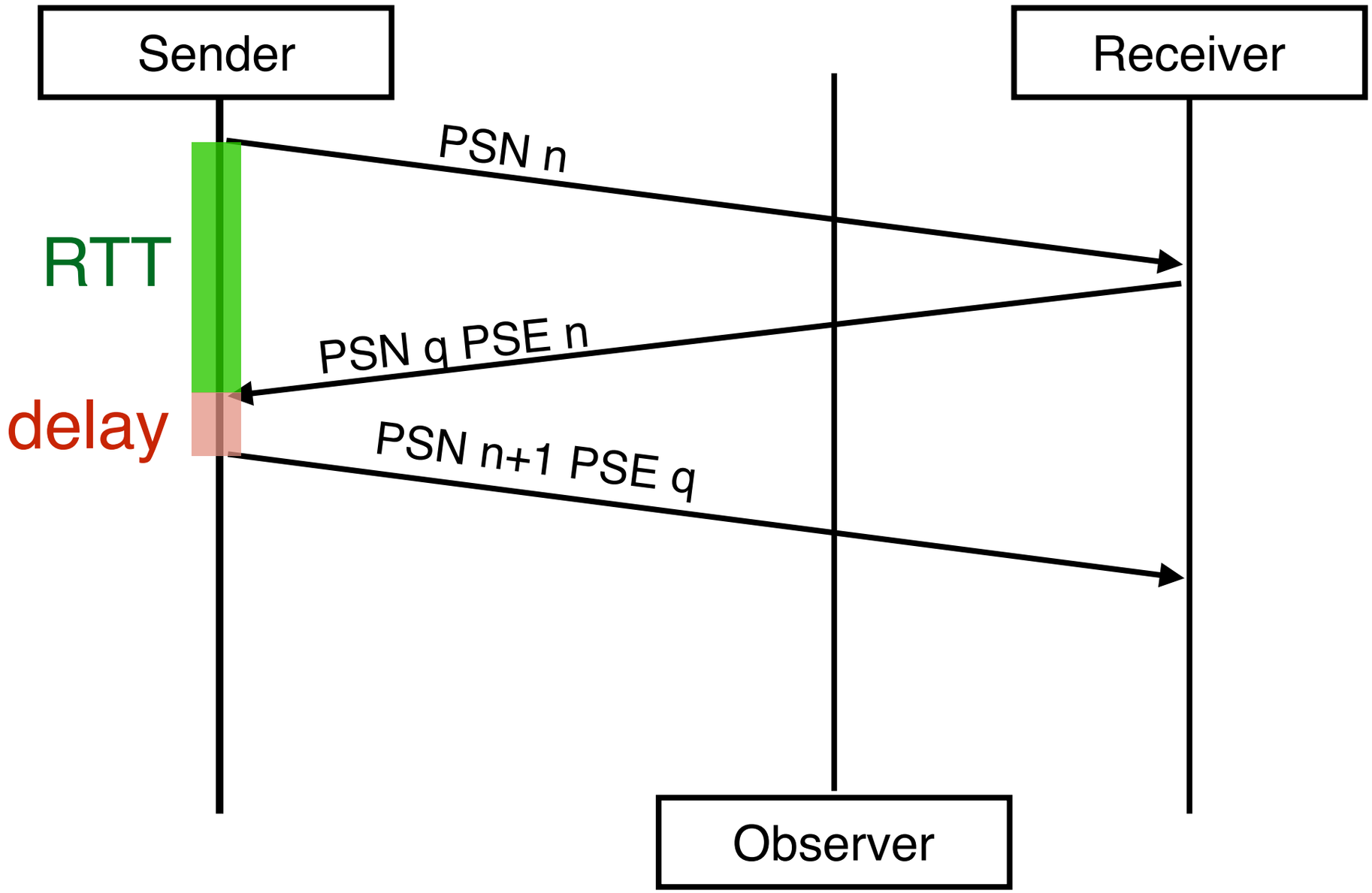

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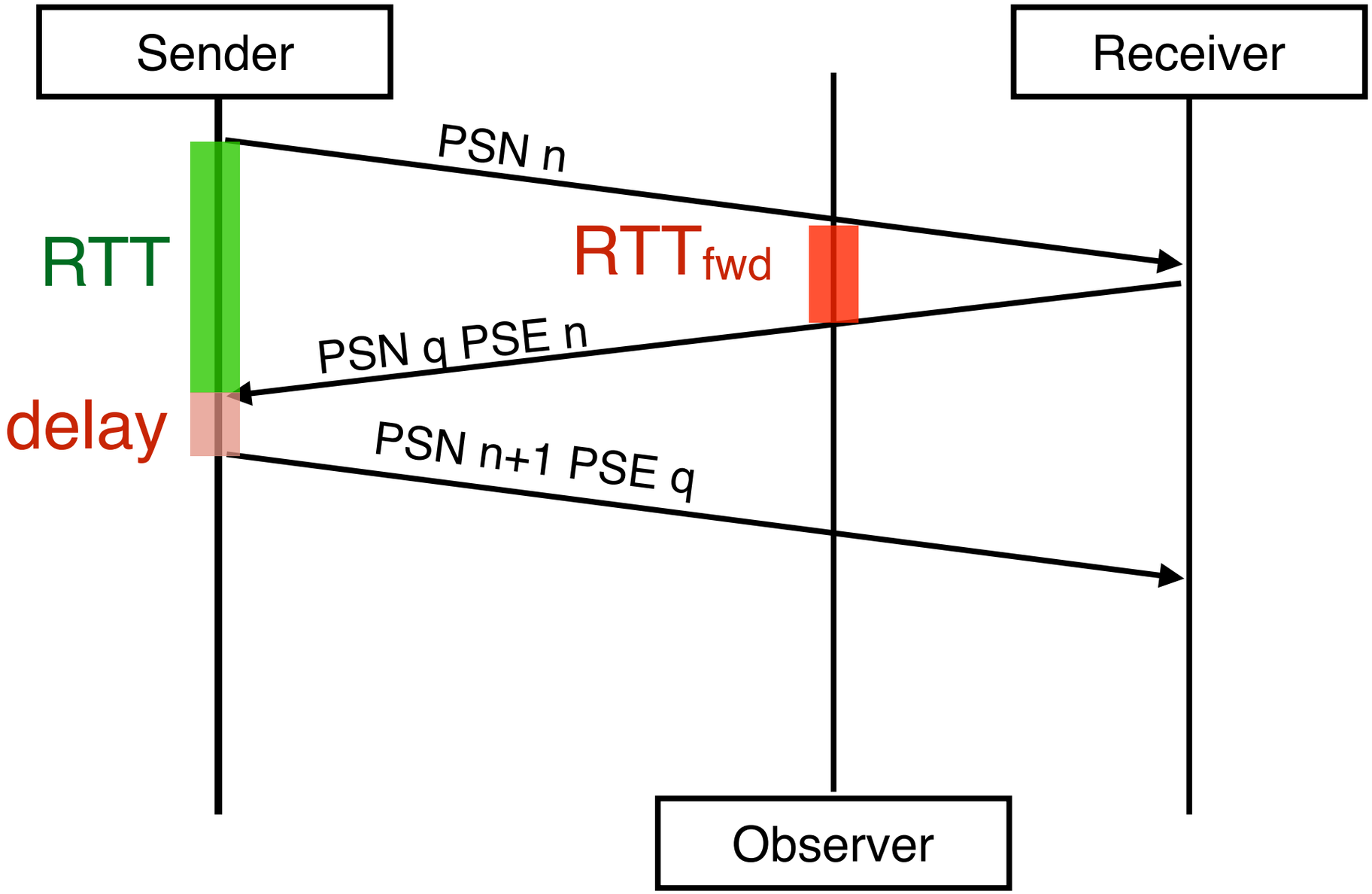

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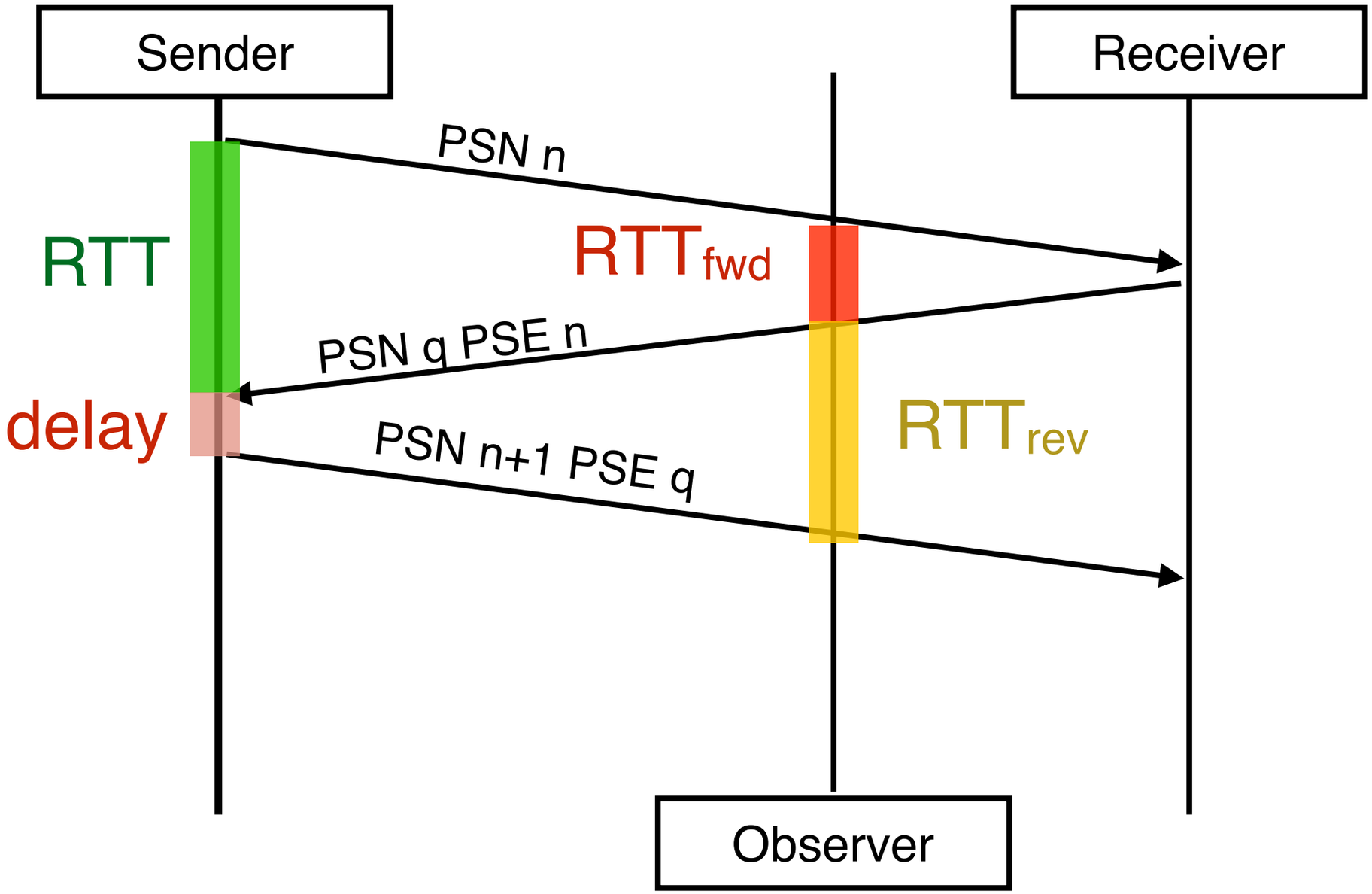

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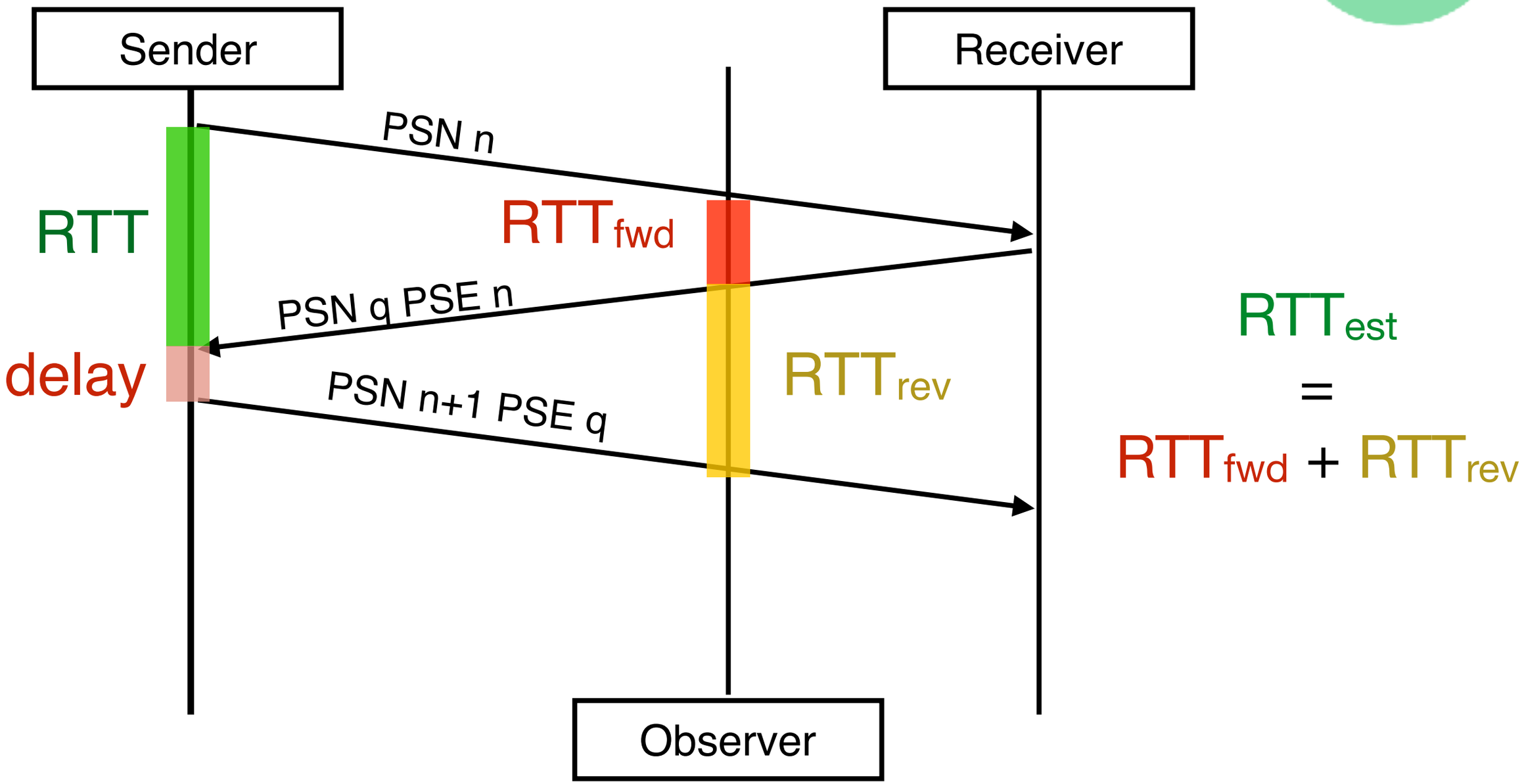

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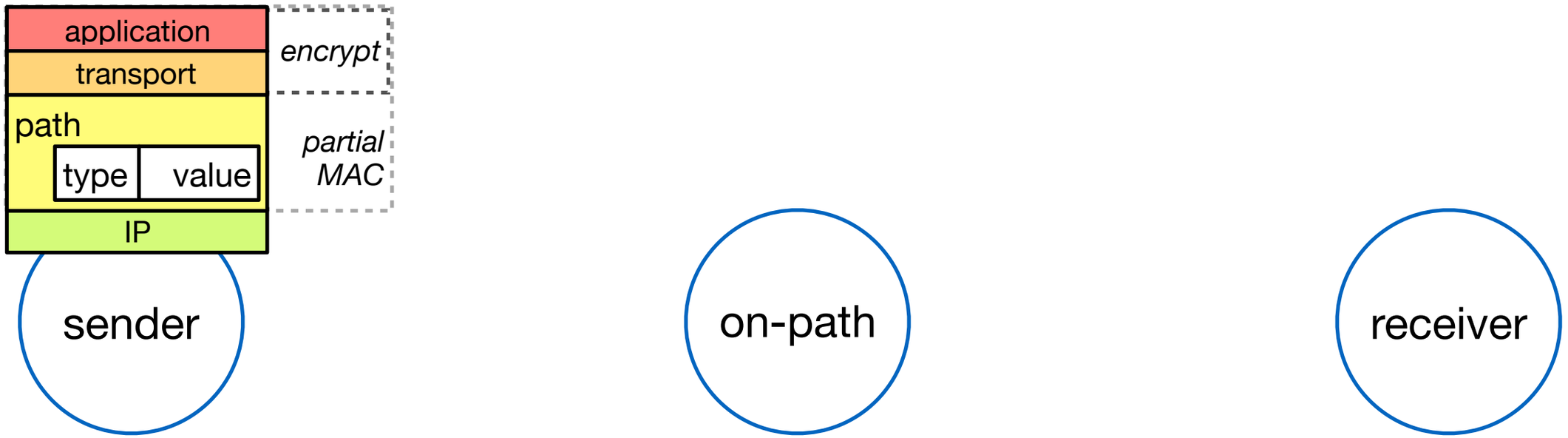

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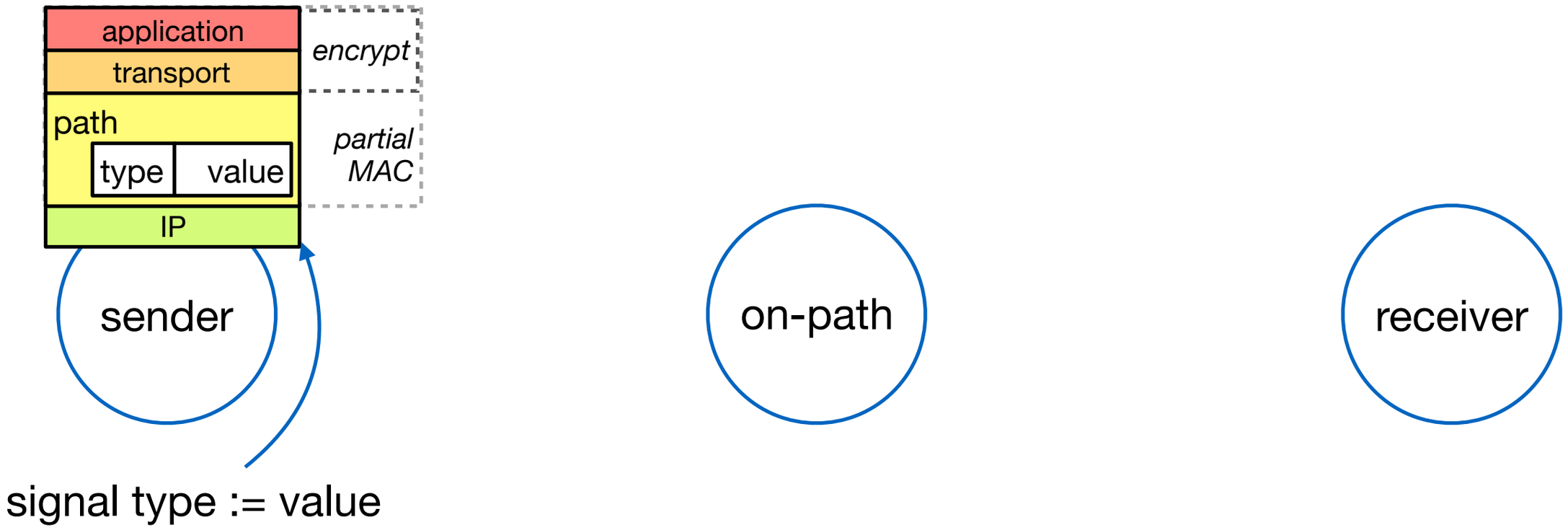

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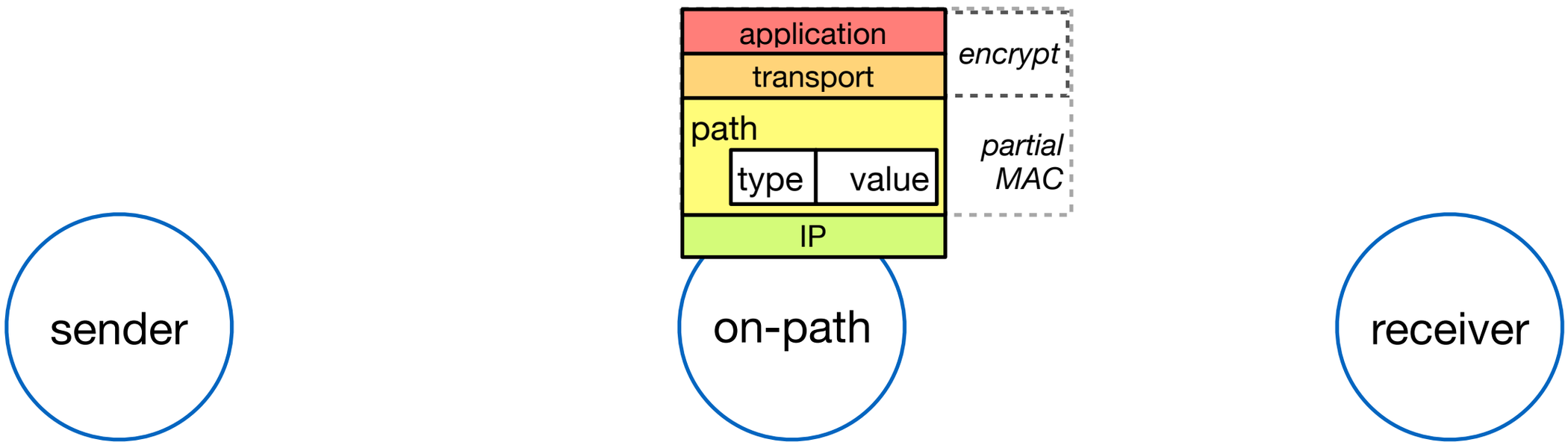

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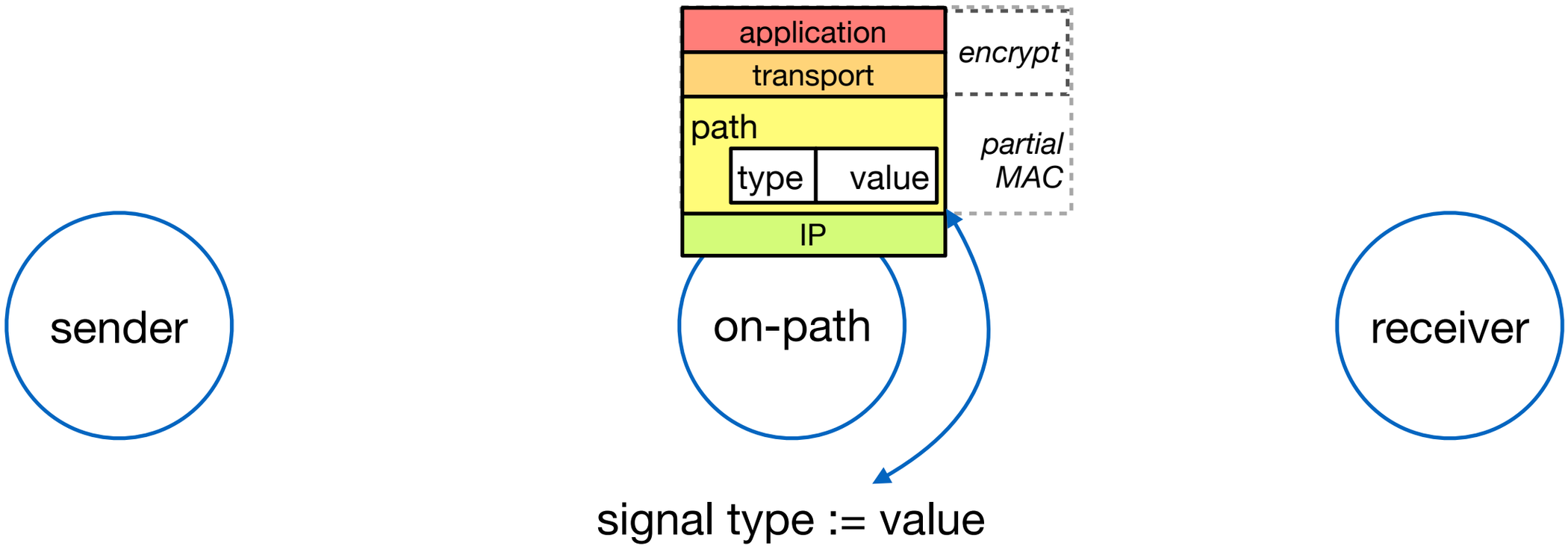

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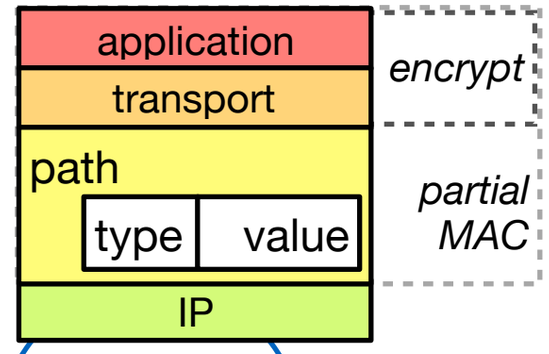

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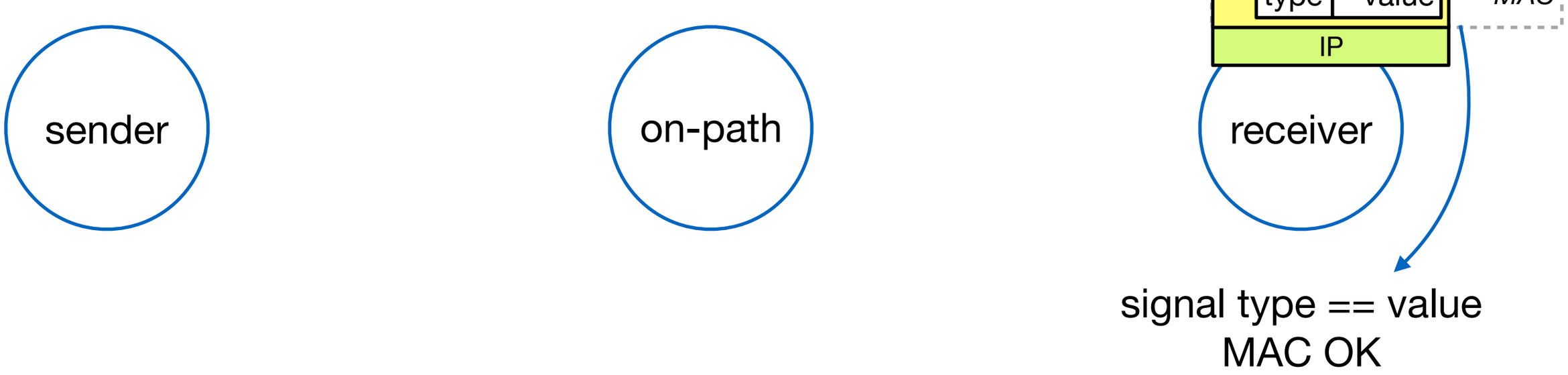

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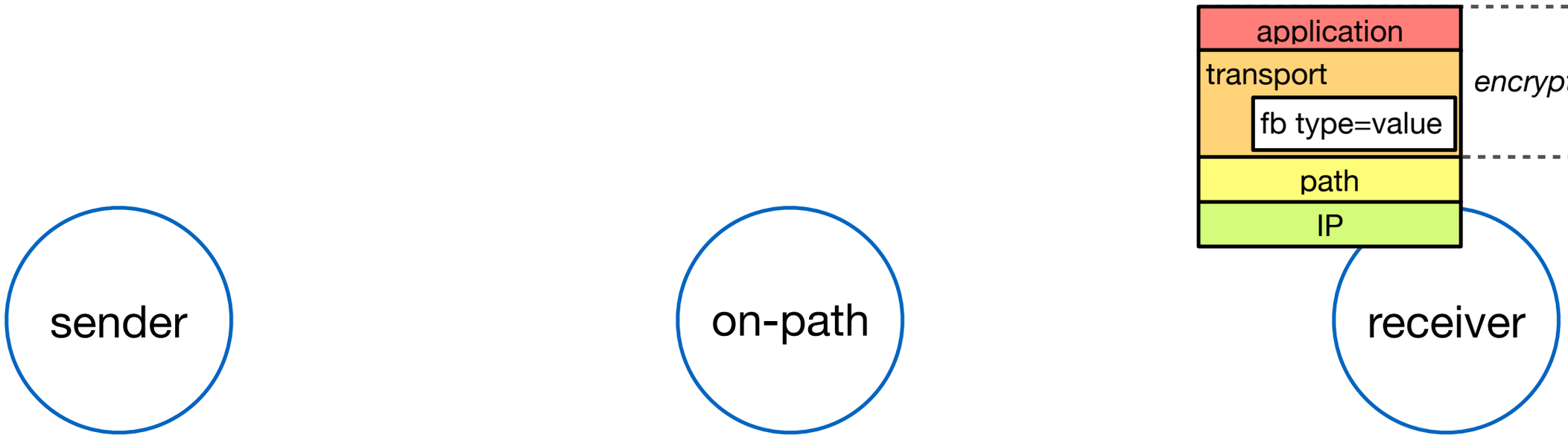

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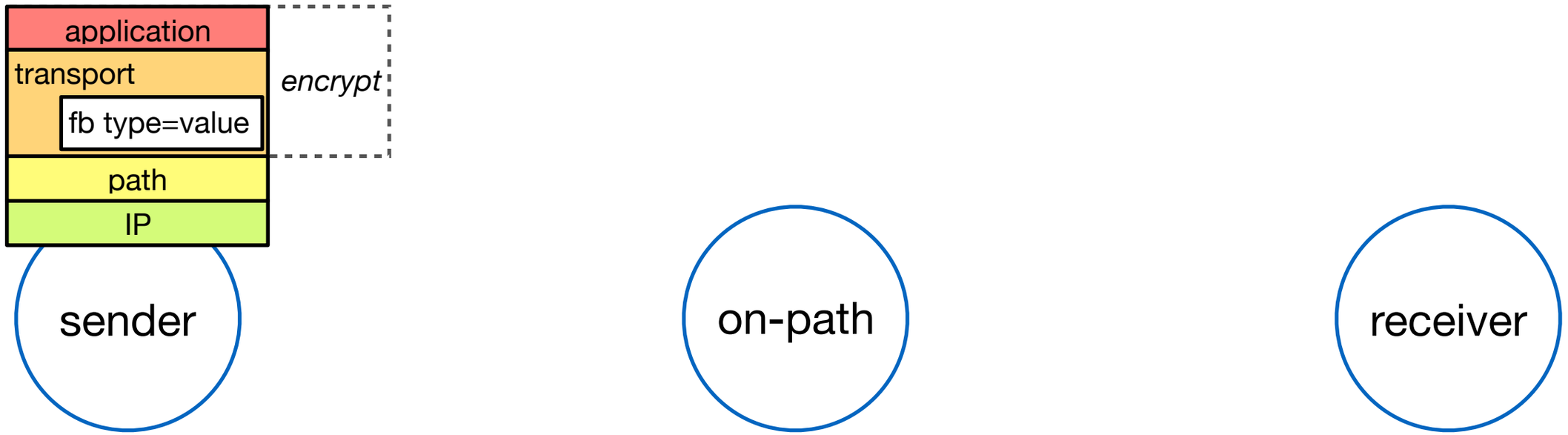

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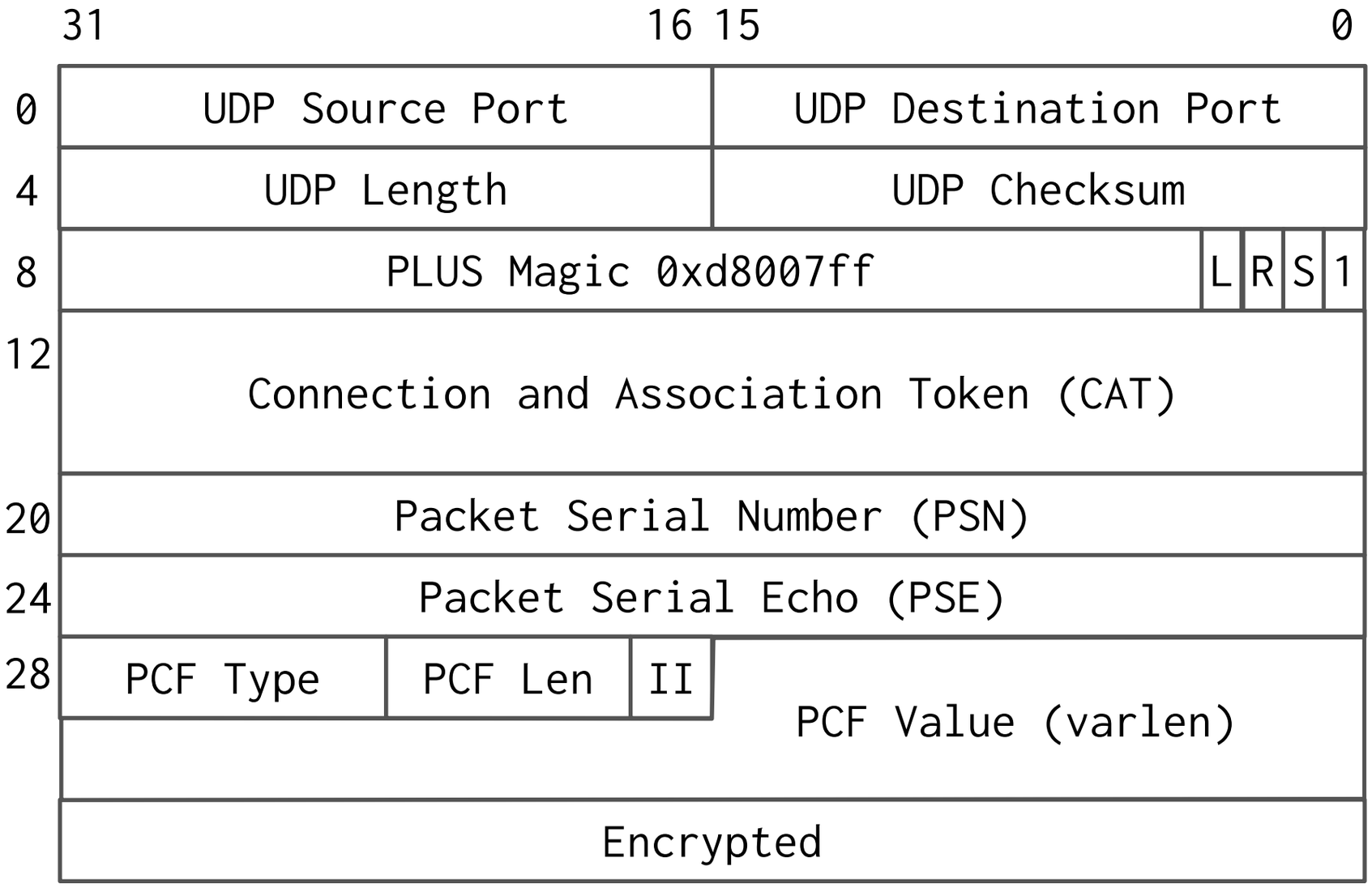

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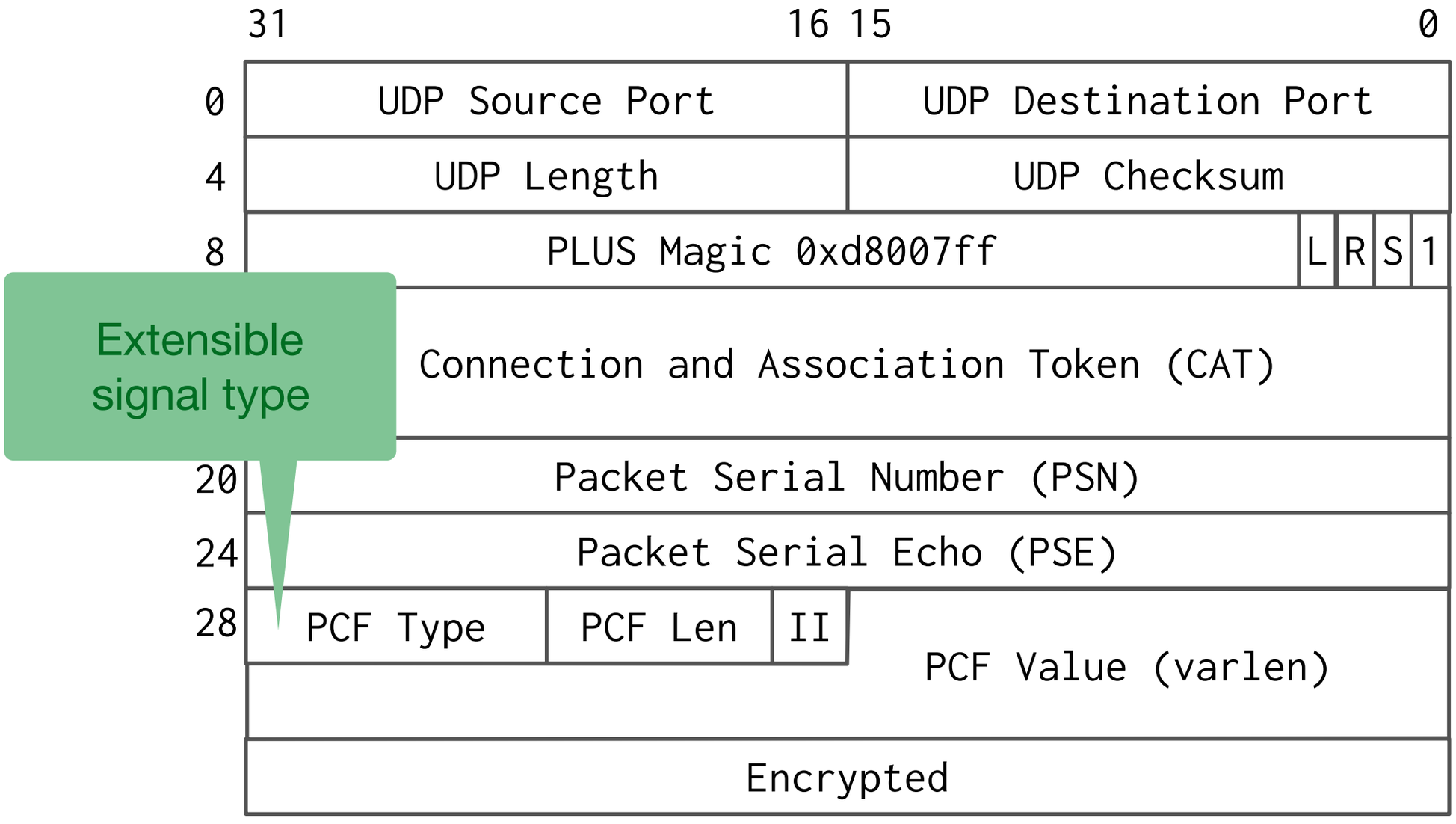

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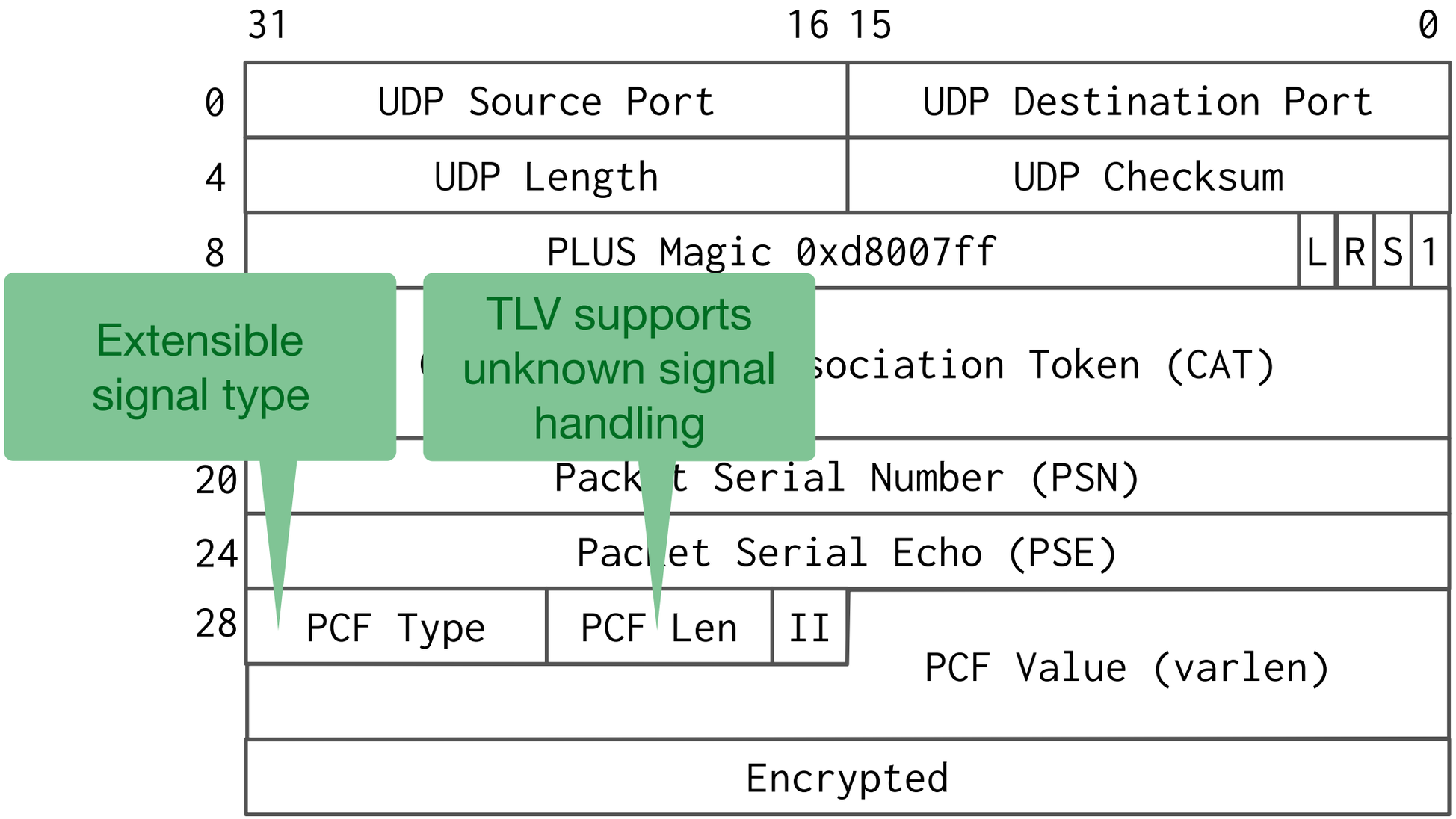

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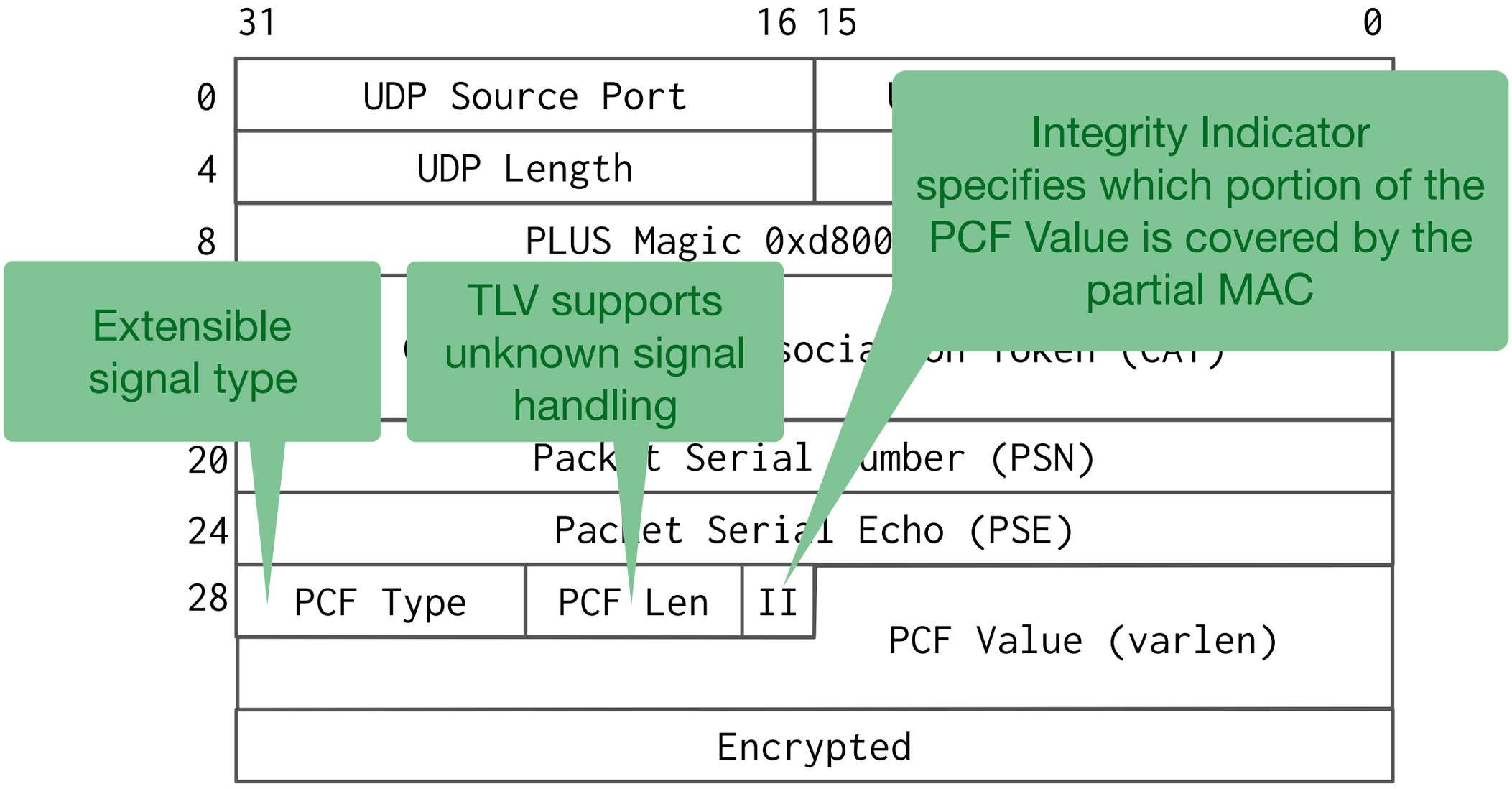

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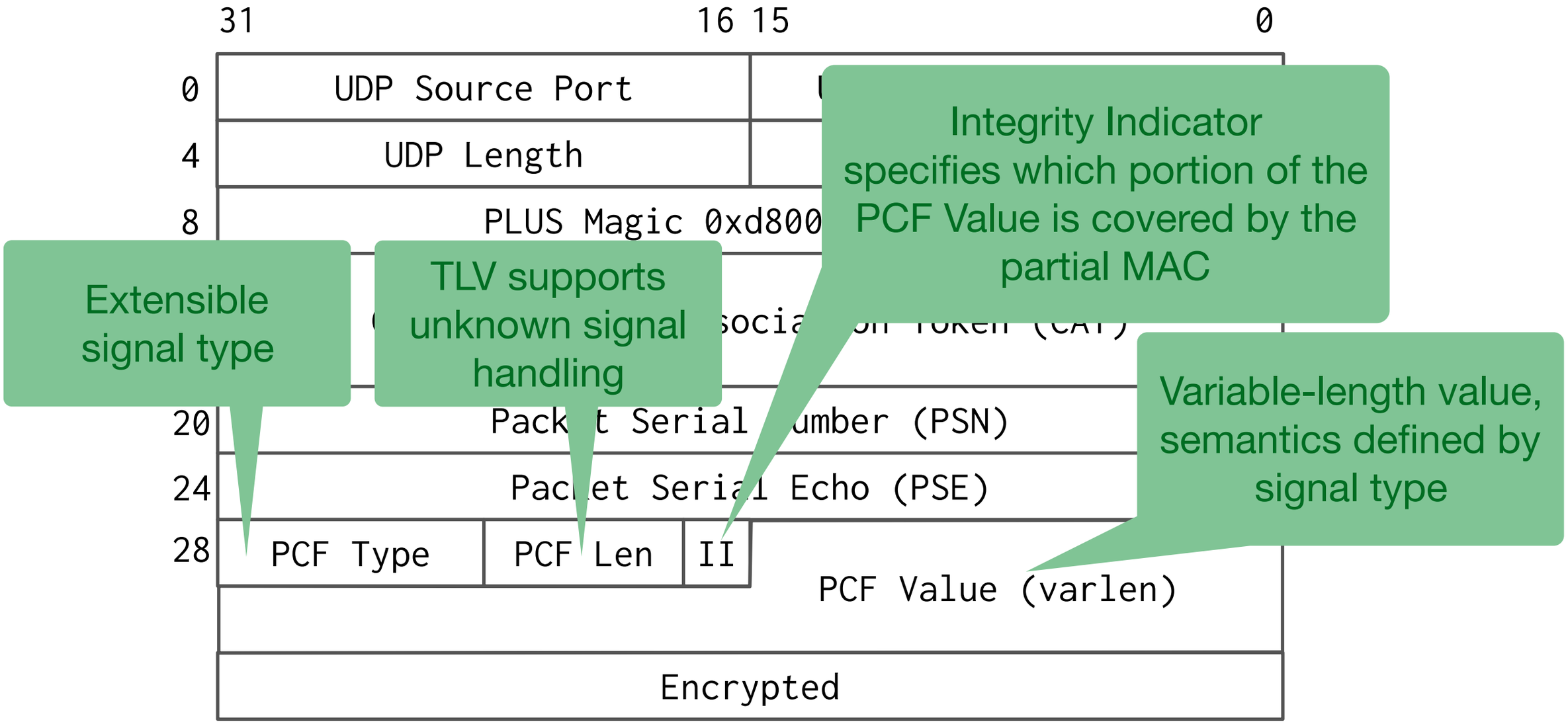


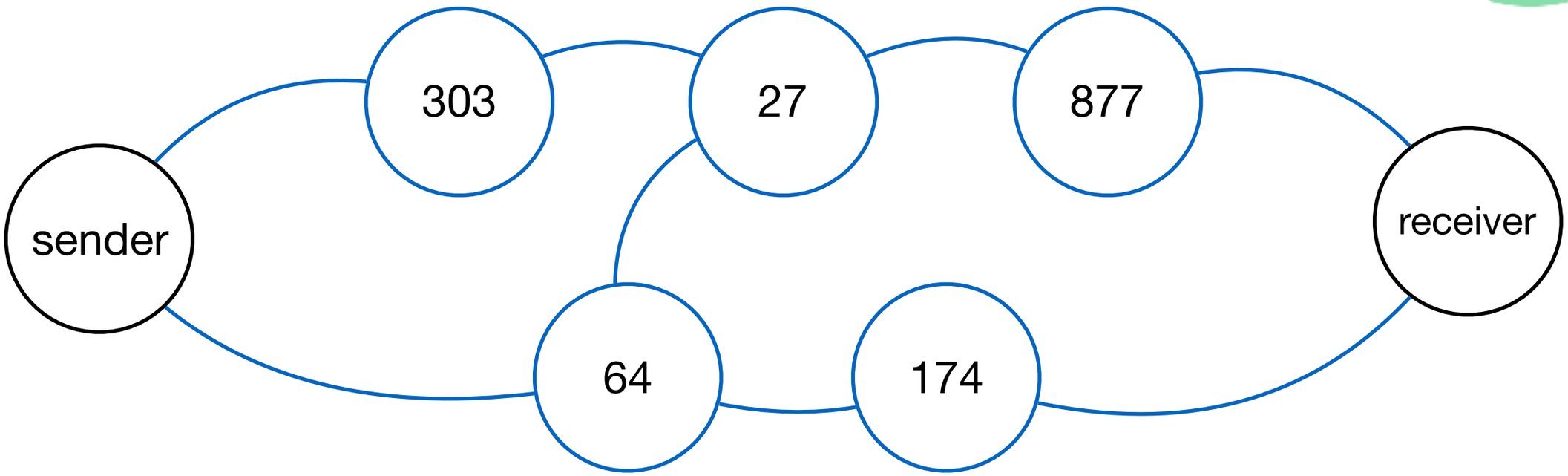
Loss and Congestion Measurement

- PSN is serial, so sequence gaps can be used to estimate one-point upstream loss and loss between two points.
- Full-path loss requires signaling using extended header:

PCF type: 1	len:[2,4,8,16]	II: 11(full)
Cumulative Loss Count (uint[8,16,32,64])		
Cumulative ECE Count (uint[8,16,32,64])		

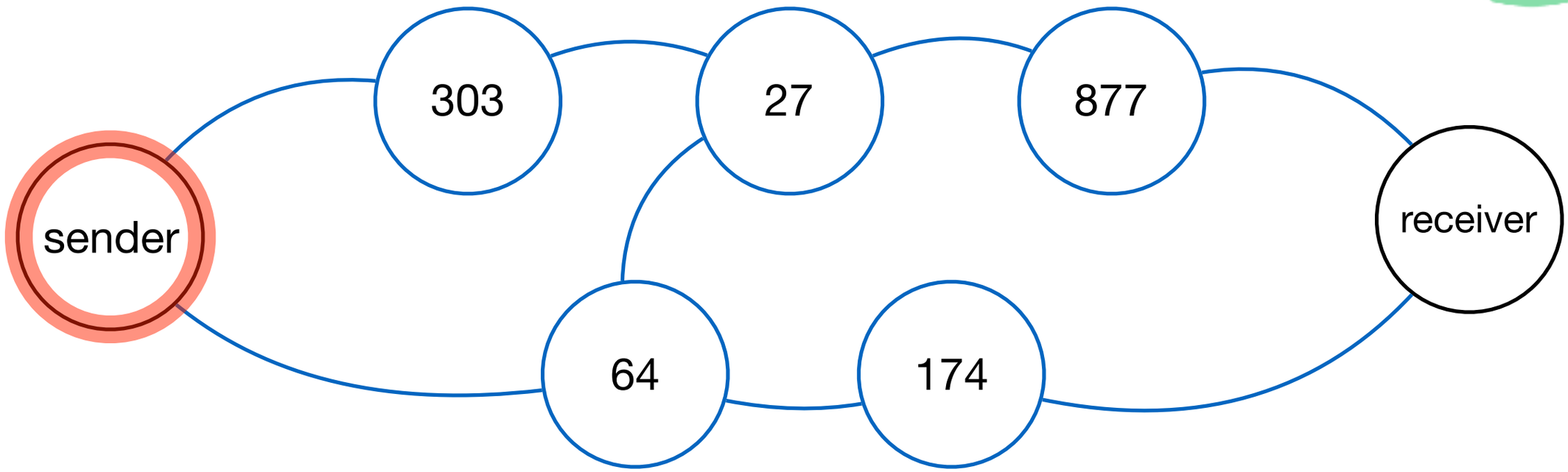
- Feed-forward of cumulative loss and ECE seen by sender allows accurate counting anywhere along the path.
- Sender-side sampling allows efficiency tradeoff.

Path Tracing



- Each PLUS-aware hop XORs random value per node to PCF type 4 value.
- Value at receiver indicates which path was taken without identifying path.

Path Tracing



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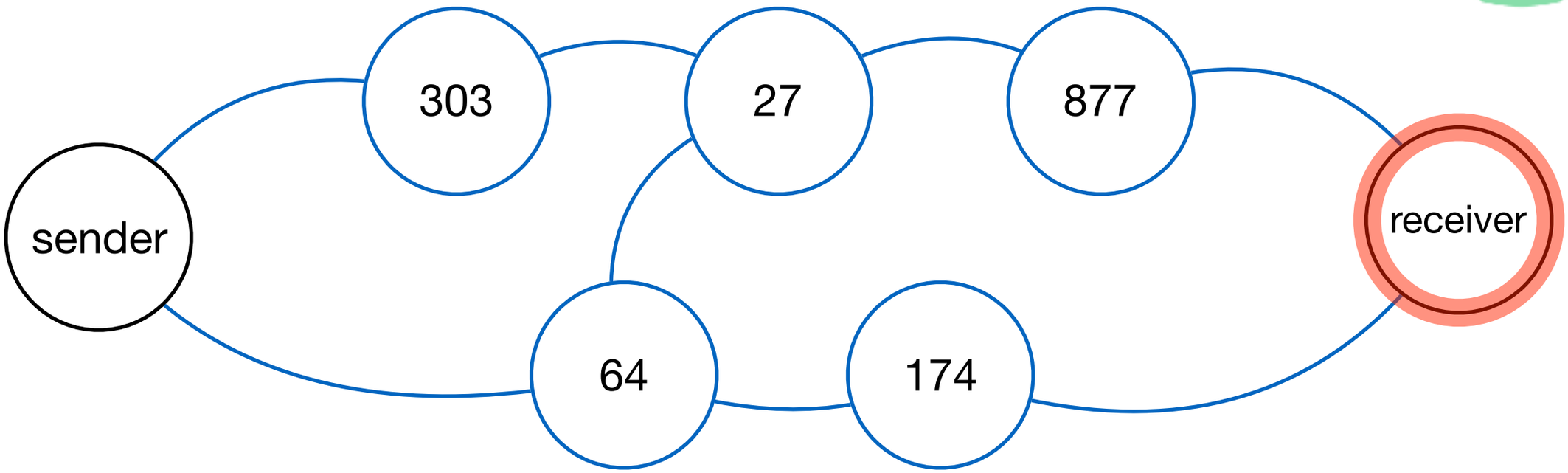
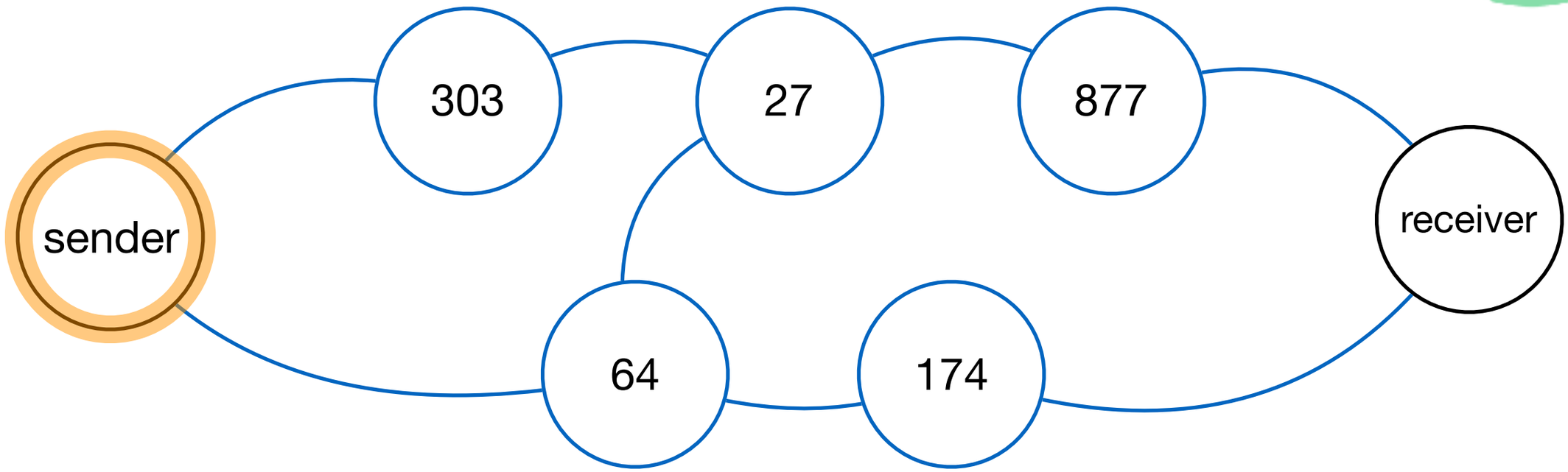


- Each PLUS-aware hop XORs random value per node to PCF type 4 value.
- Value at receiver indicates which path was taken without identifying path.

- Red path: 1207

Path Tracing



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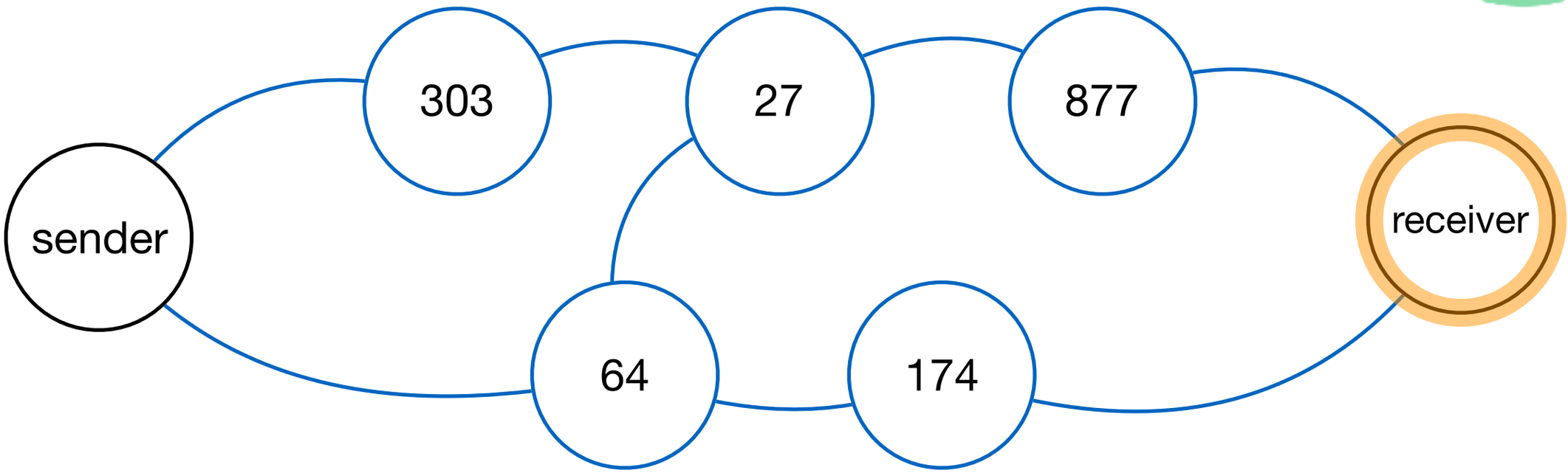
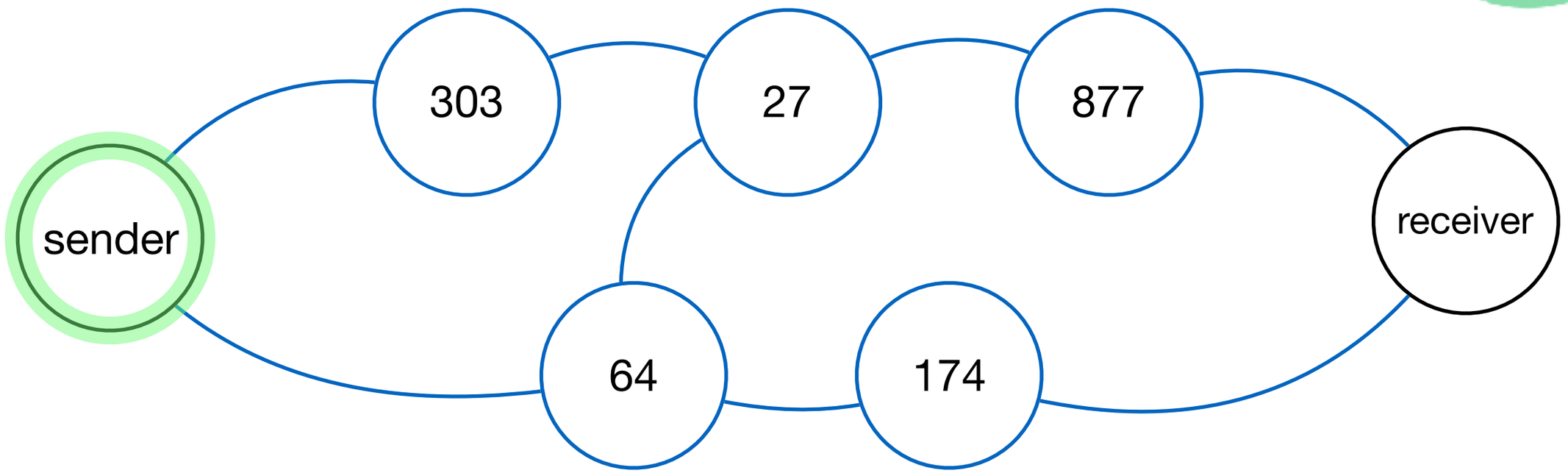
Path Tracing



- Each PLUS-aware hop XORs random value per node to PCF type 4 value.
- Value at receiver indicates which path was taken without identifying path.

- Red path: 1207
- Orange path: 238

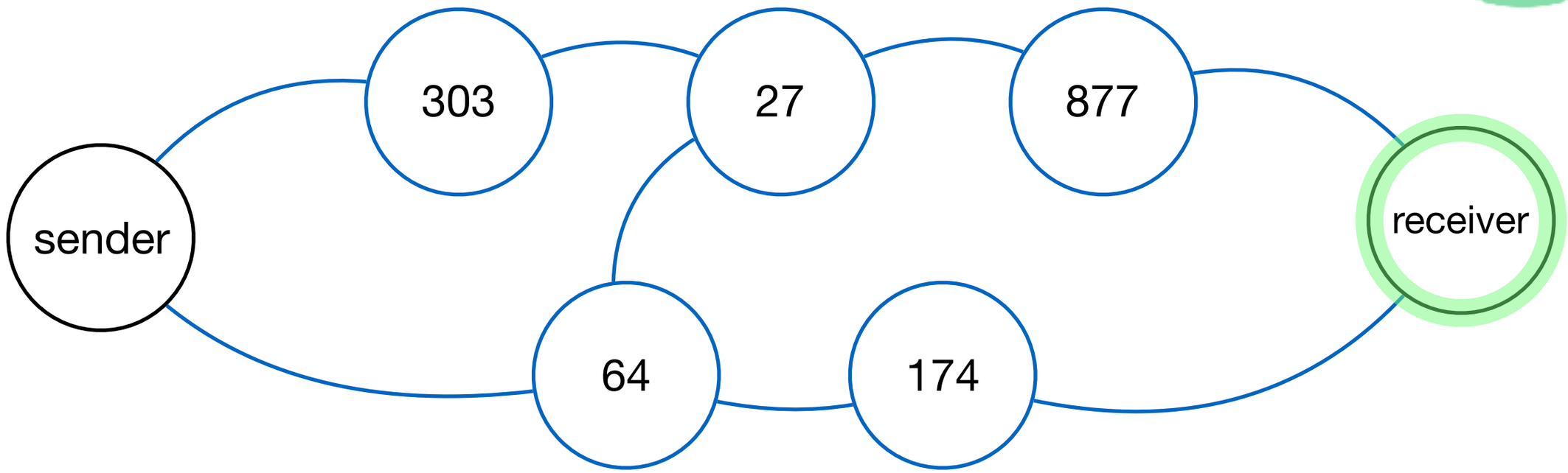
Path Tracing



- Each PLUS-aware hop XORs random value per node to PCF type 4 value.
- Value at receiver indicates which path was taken without identifying path.

- Red path: 1207
- Orange path: 238

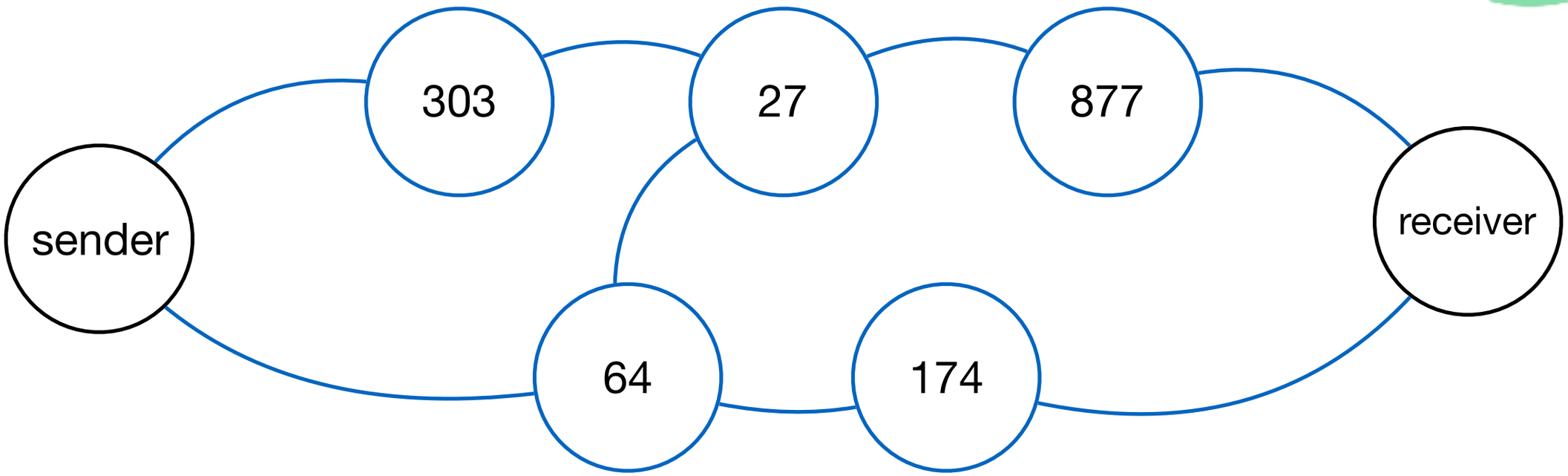
Path Tracing



- Each PLUS-aware hop XORs random value per node to PCF type 4 value.
- Value at receiver indicates which path was taken without identifying path.

- Red path: 1207
- Orange path: 238
- Green path: 968

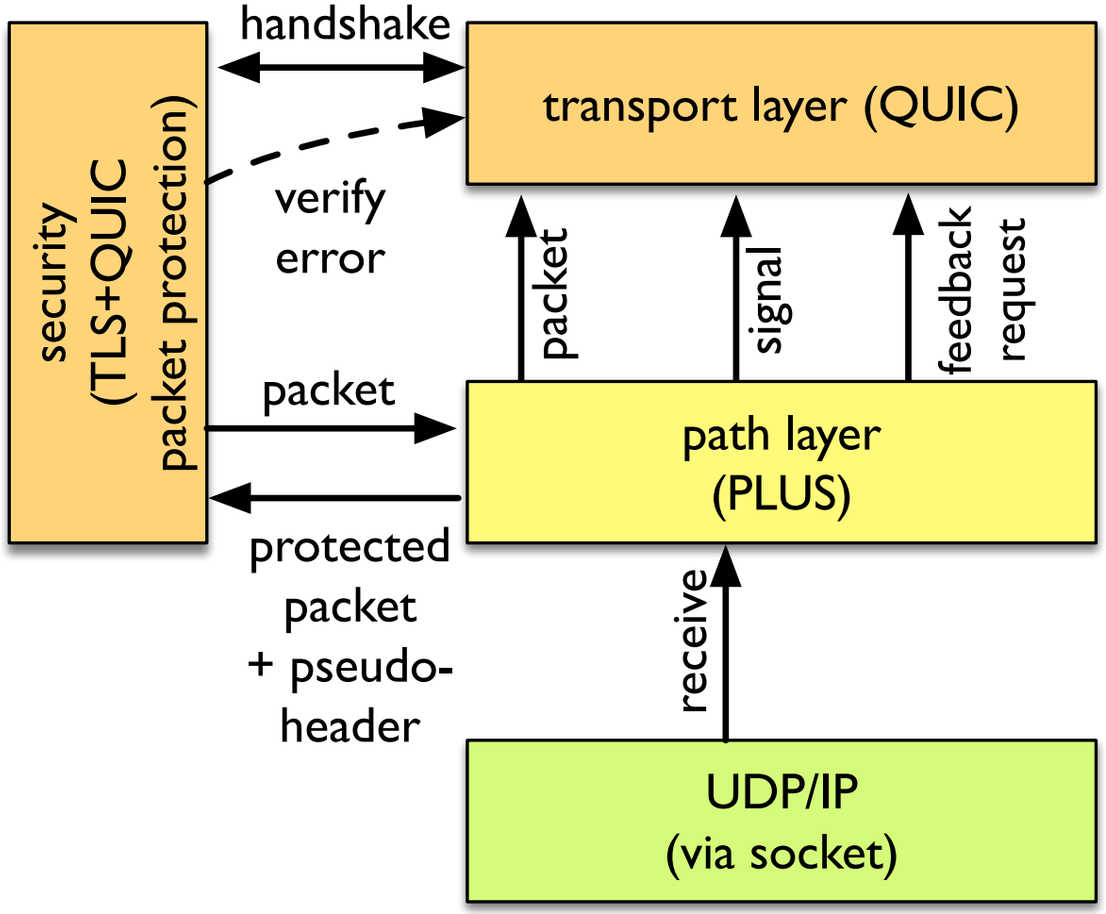
Path Tracing



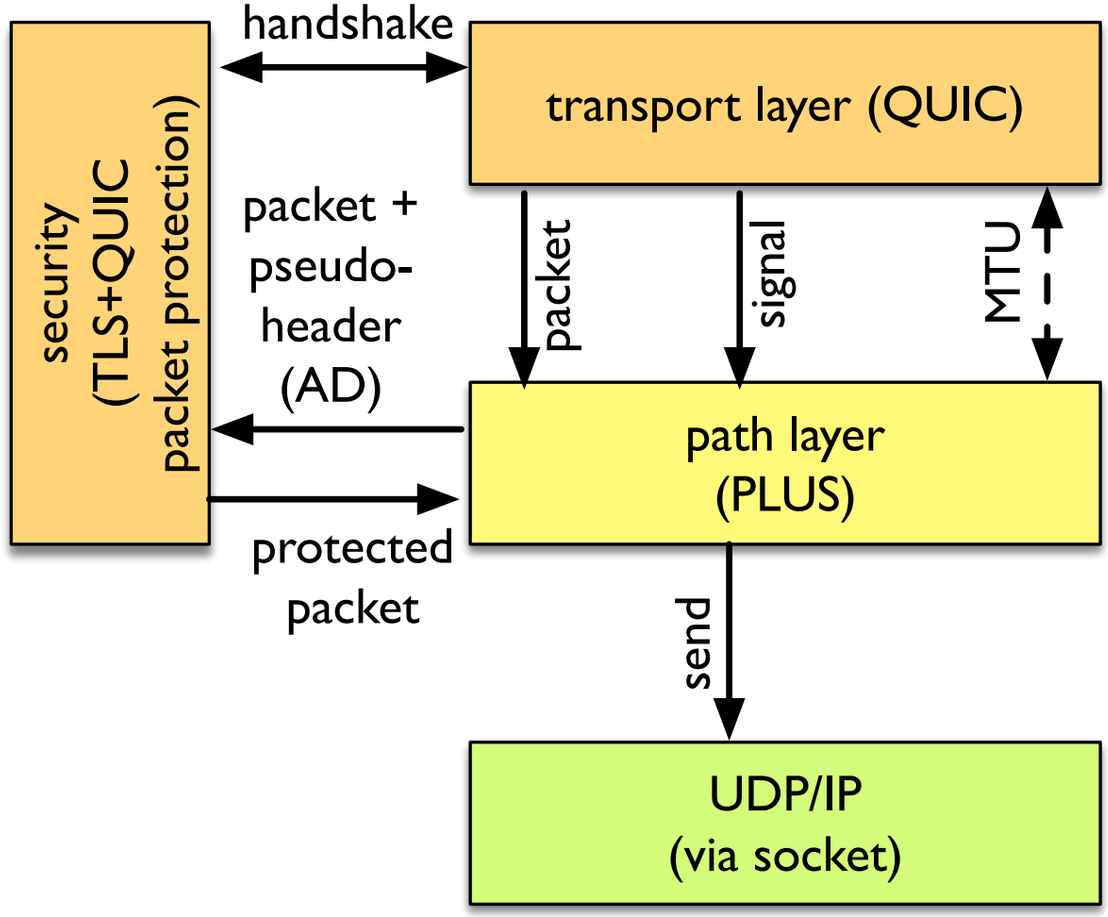
- Each PLUS-aware hop XORs random value per node to PCF type 4 value.
- Value at receiver indicates which path was taken without identifying path.

- Red path: 1207
- Orange path: 238
- Green path: 968

Transport interfaces to PLUS: pilot implementation work under QUIC

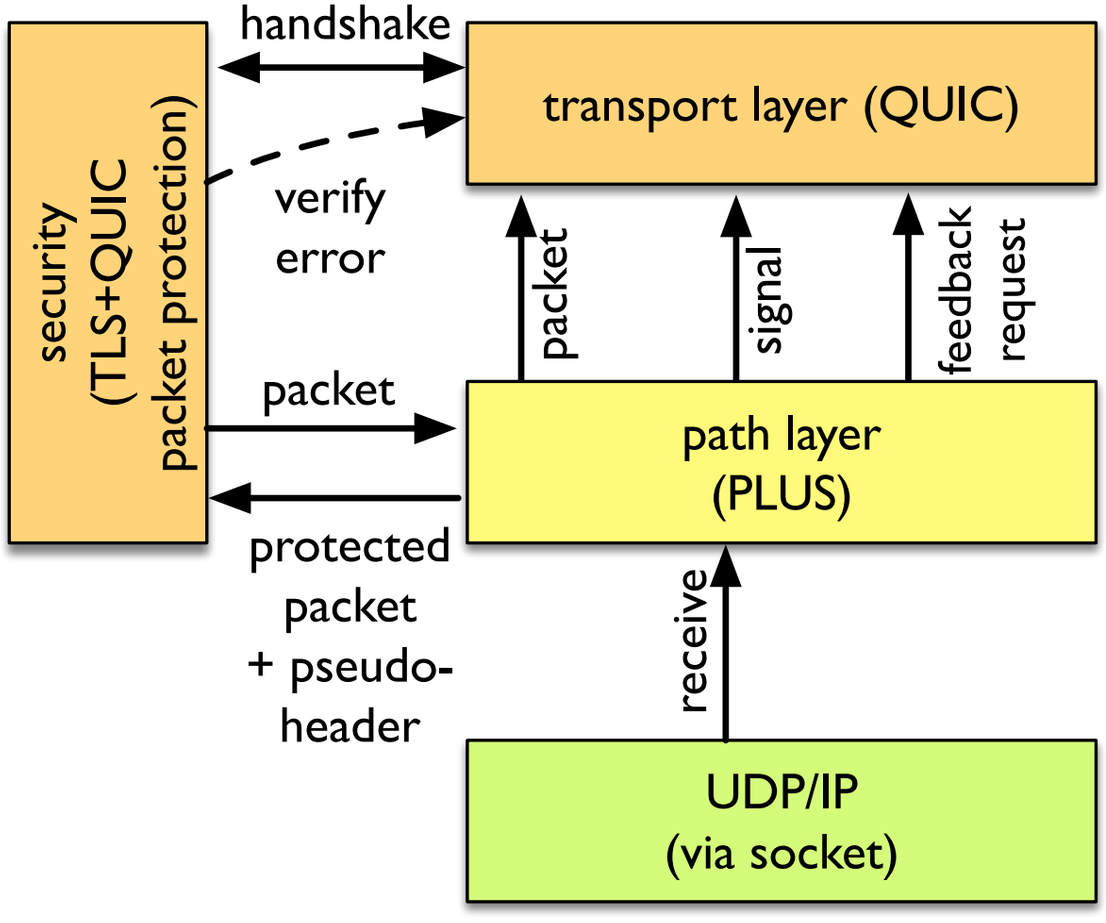


(a) receiver-side interfaces

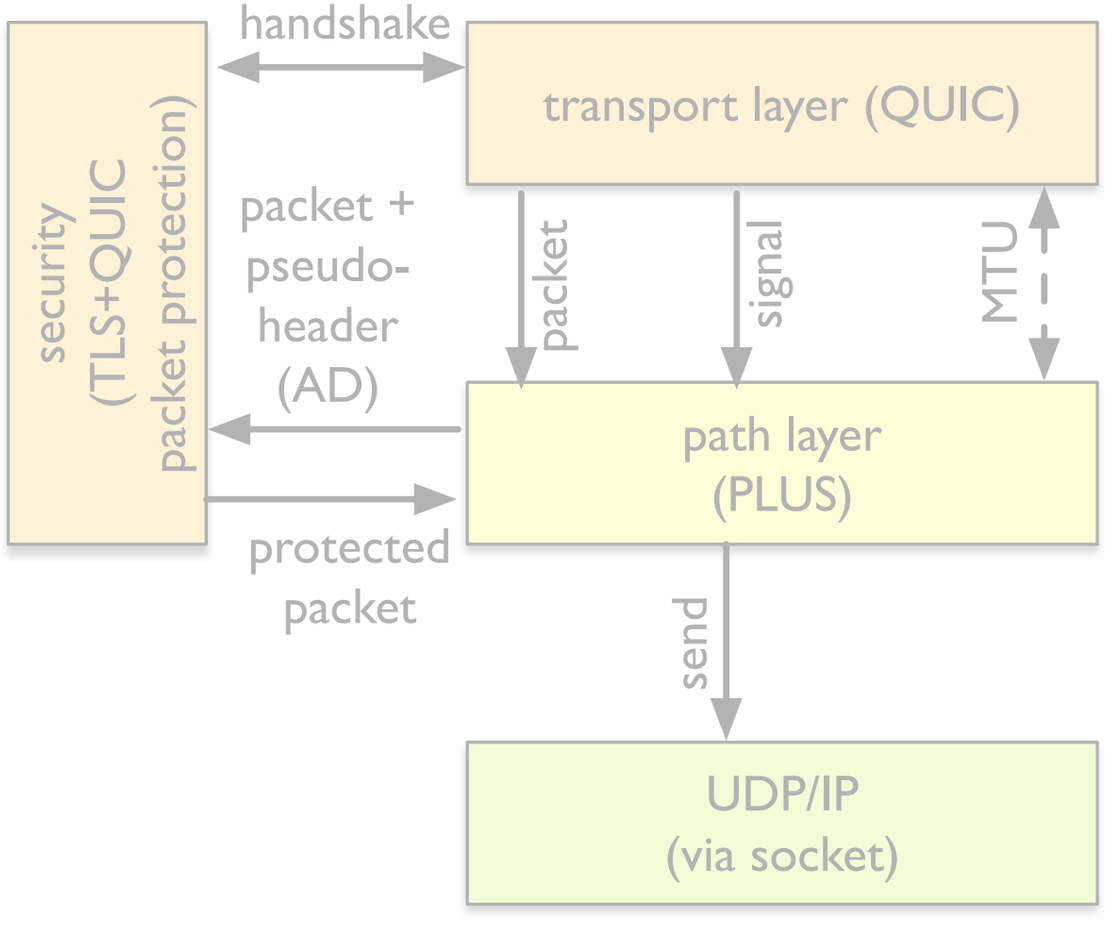


(b) sender-side interfaces

Transport interfaces to PLUS: pilot implementation work under QUIC

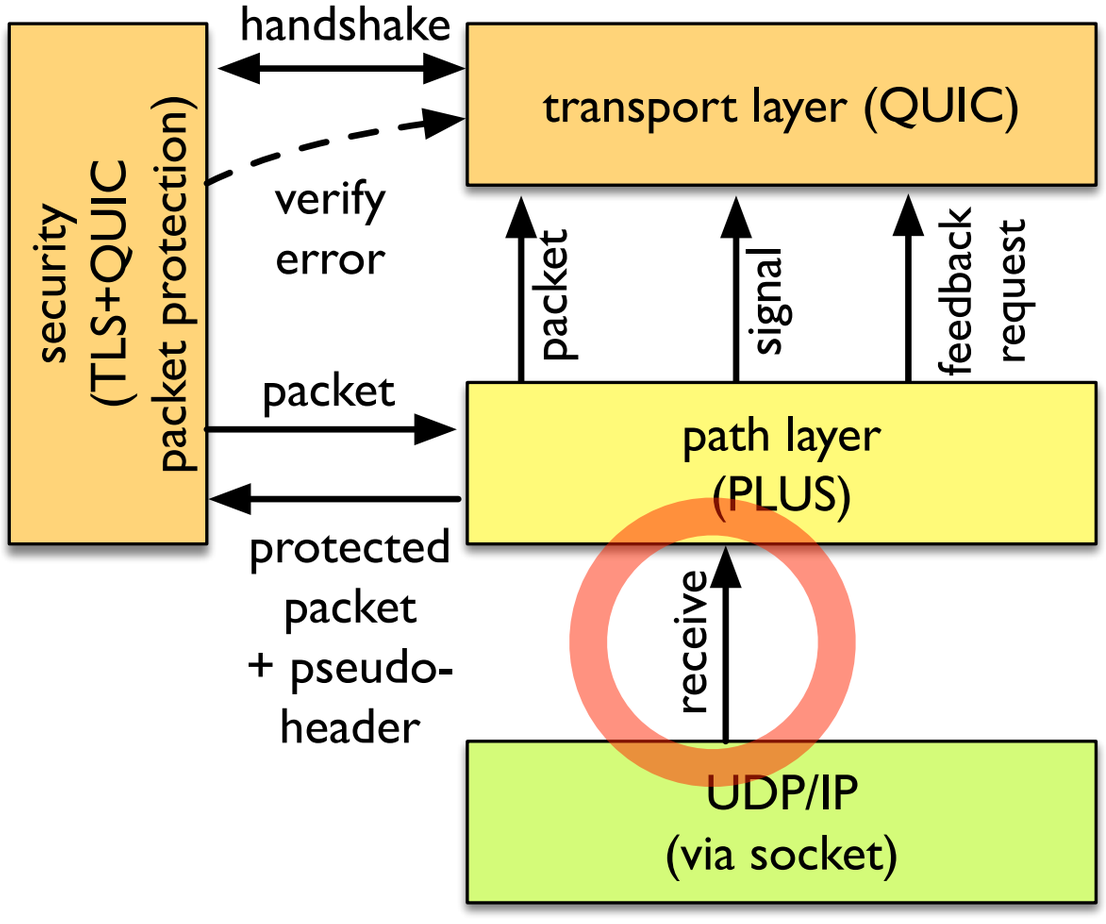


(a) receiver-side interfaces

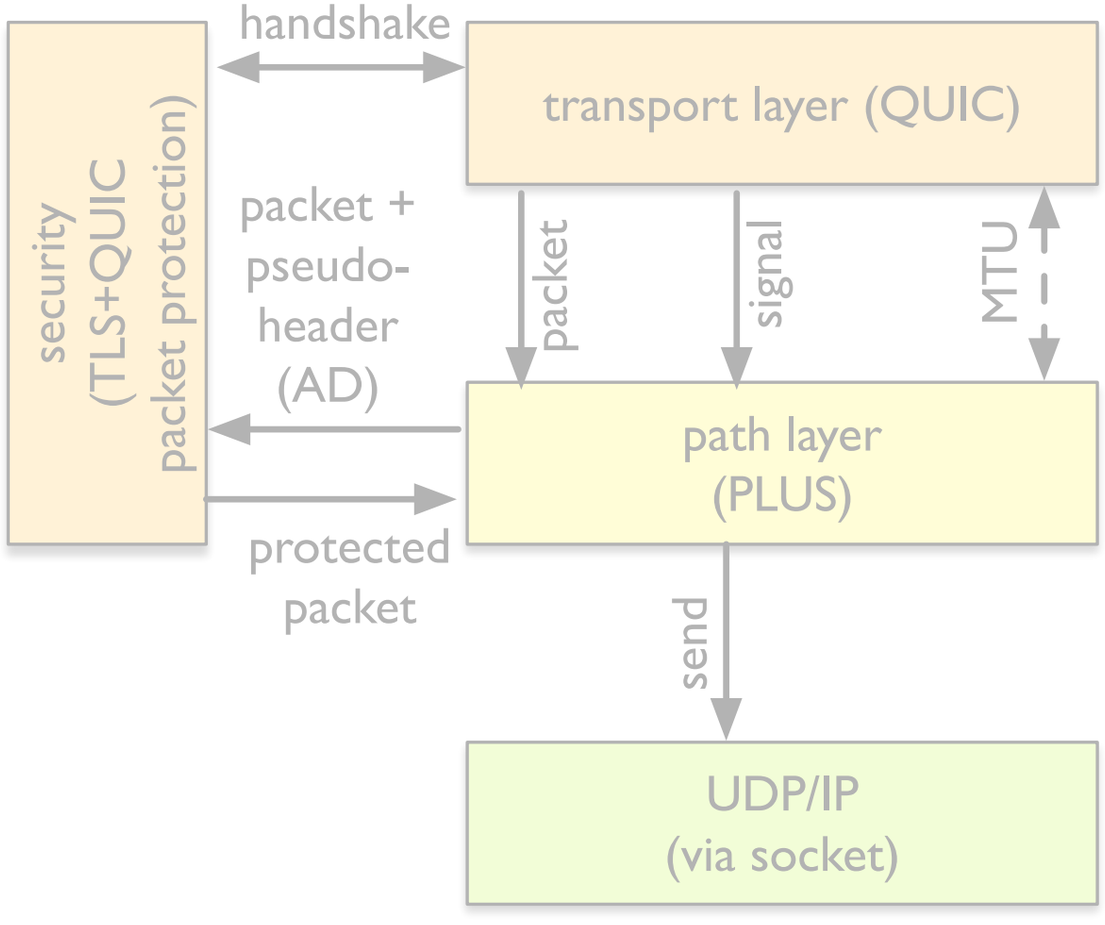


(b) sender-side interfaces

Transport interfaces to PLUS: pilot implementation work under QUIC

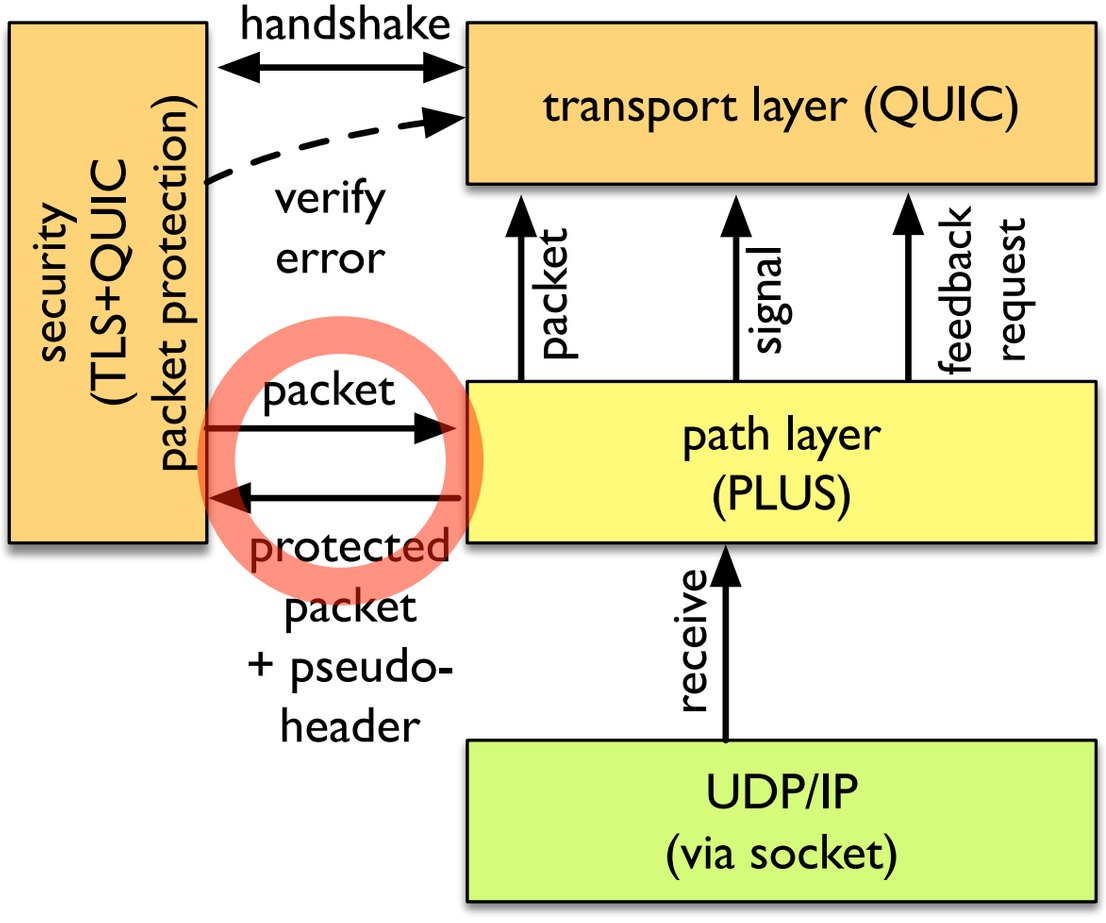


(a) receiver-side interfaces

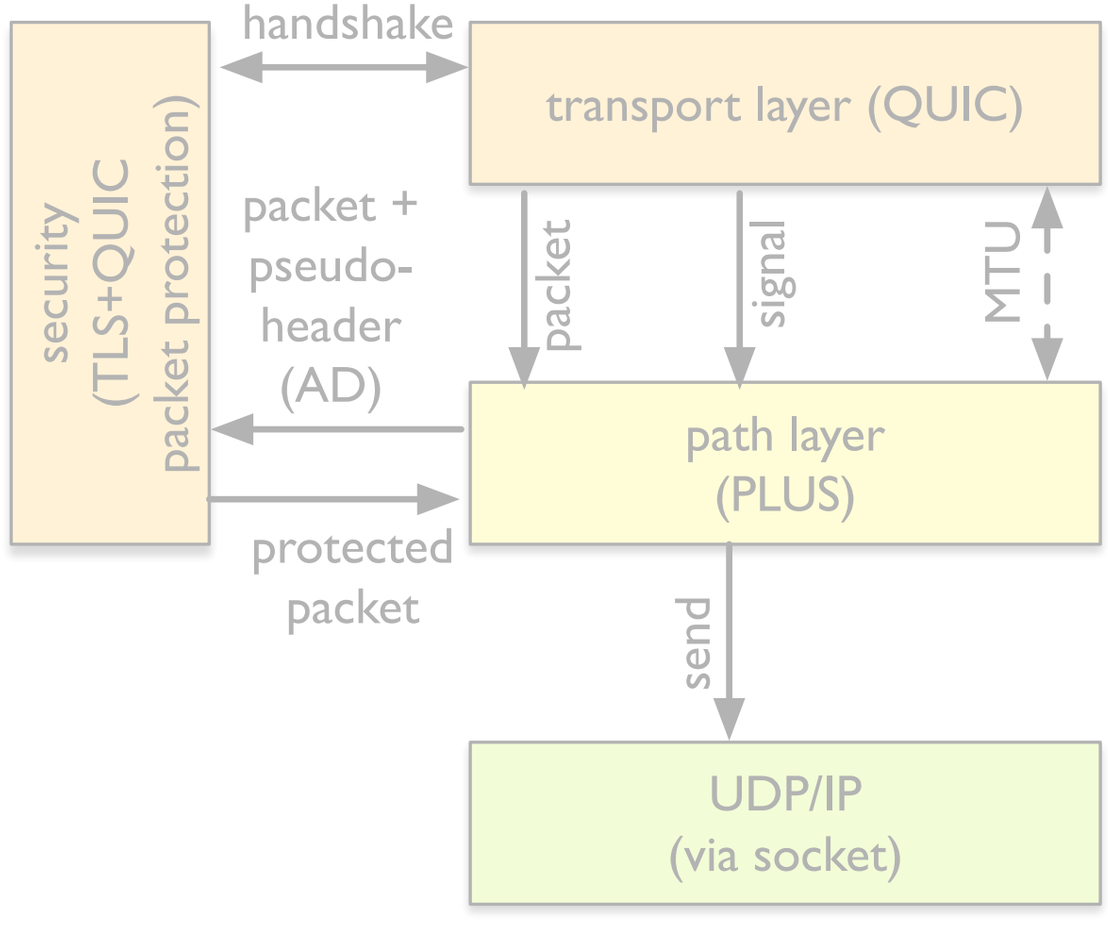


(b) sender-side interfaces

Transport interfaces to PLUS: pilot implementation work under QUIC

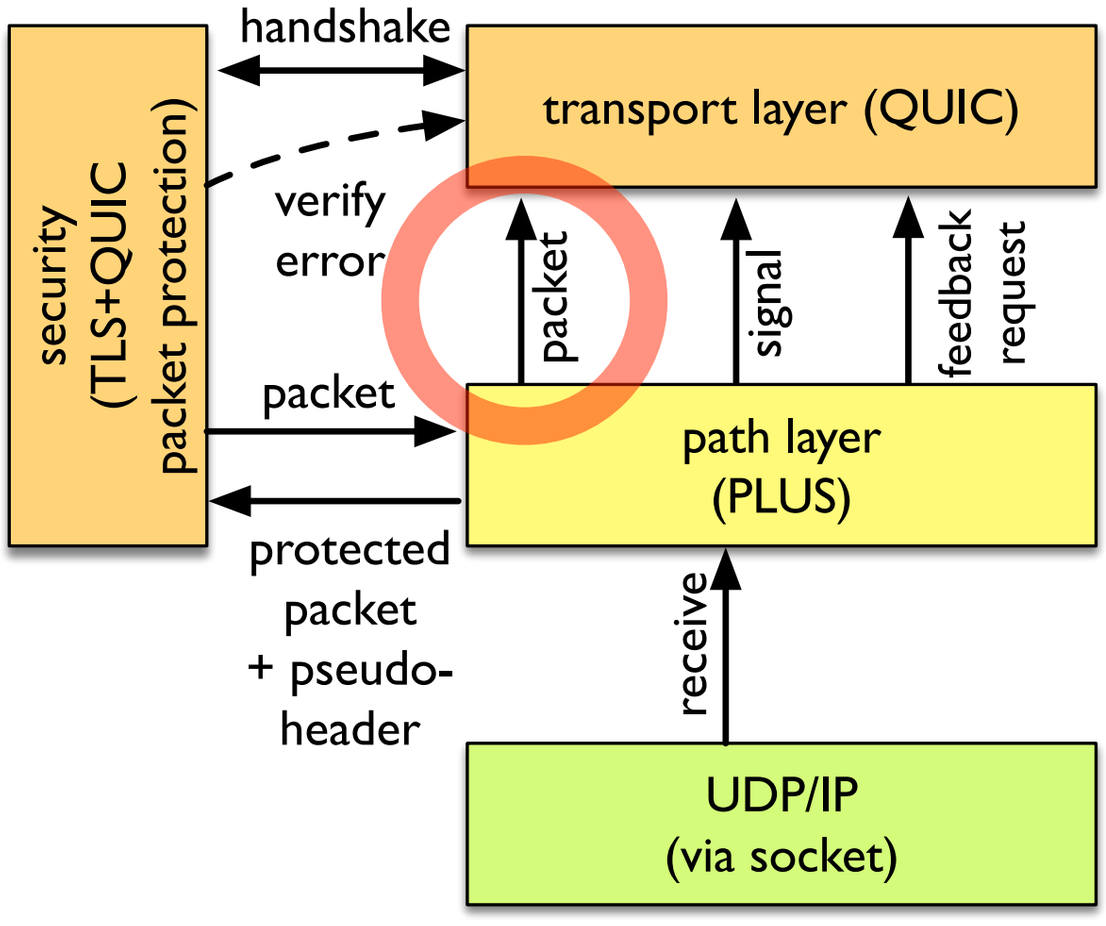


(a) receiver-side interfaces

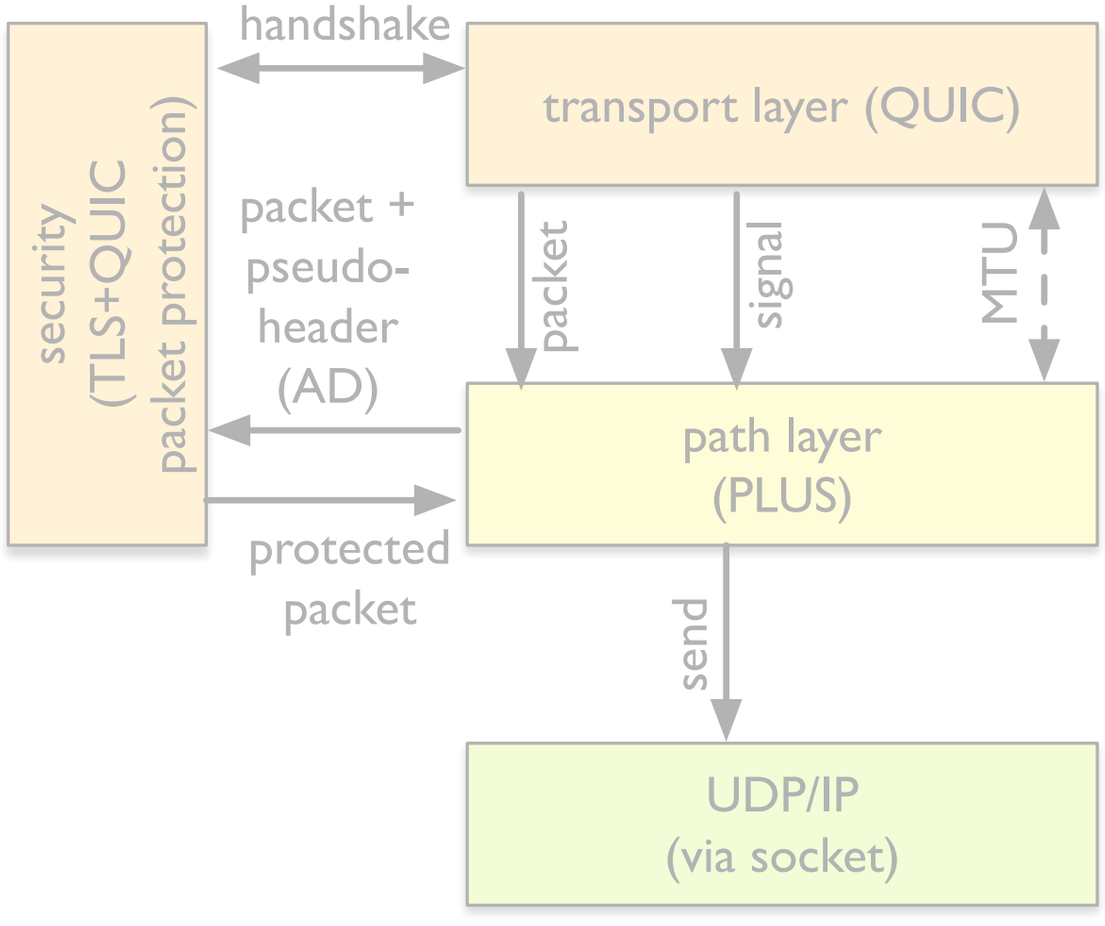


(b) sender-side interfaces

Transport interfaces to PLUS: pilot implementation work under QUIC

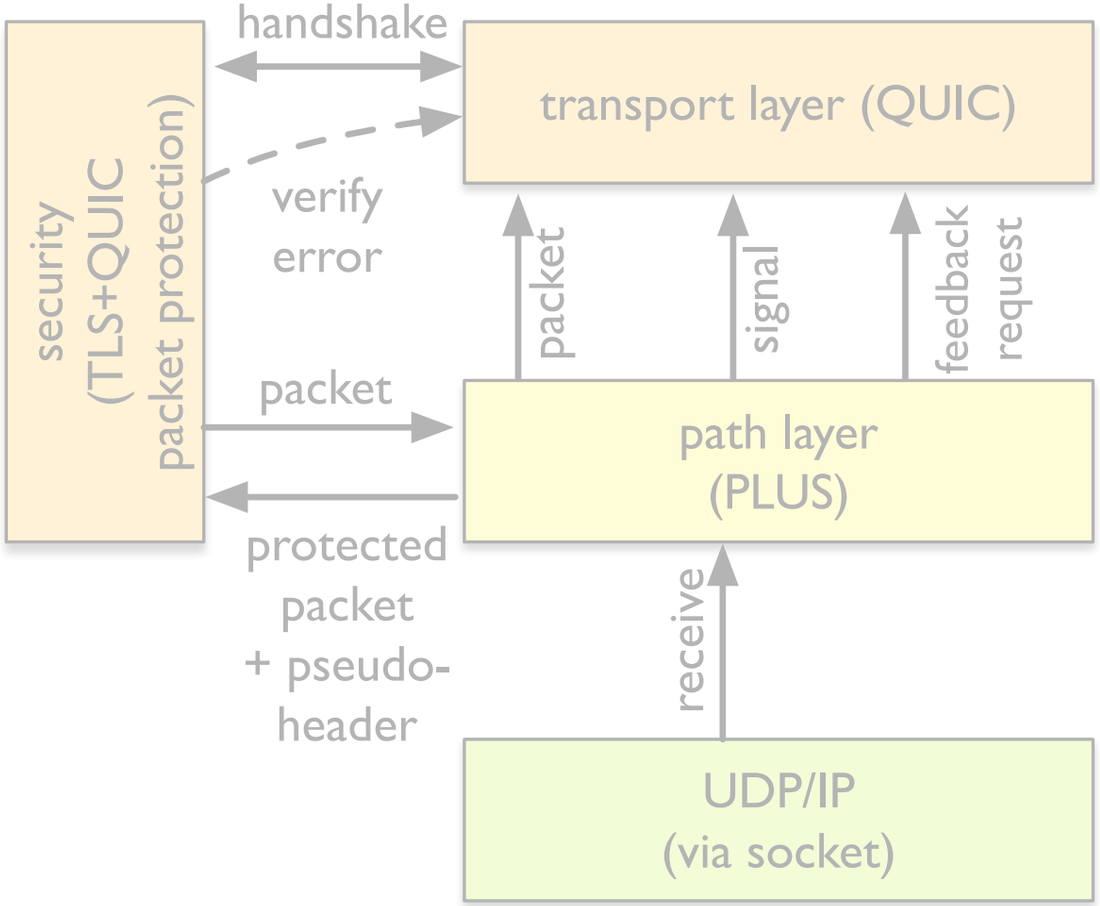


(a) receiver-side interfaces

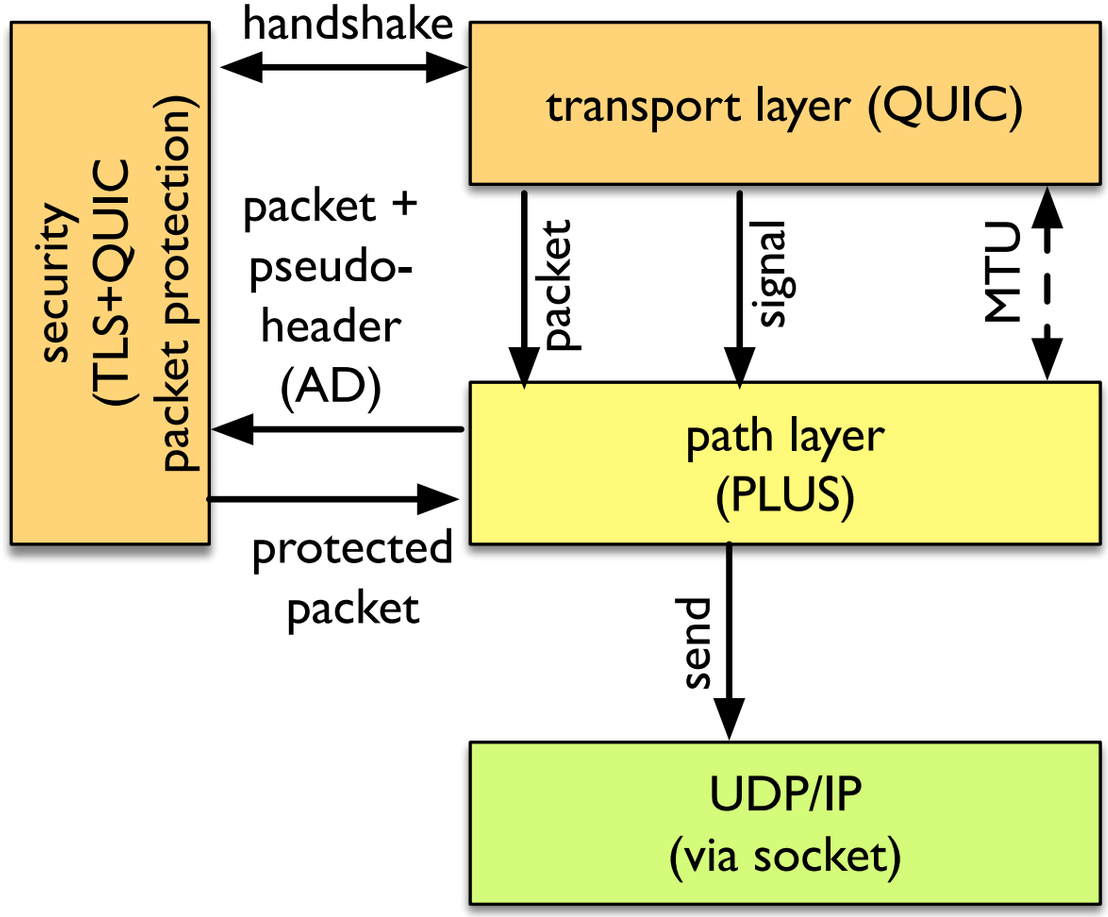


(b) sender-side interfaces

Transport interfaces to PLUS: pilot implementation work under QUIC



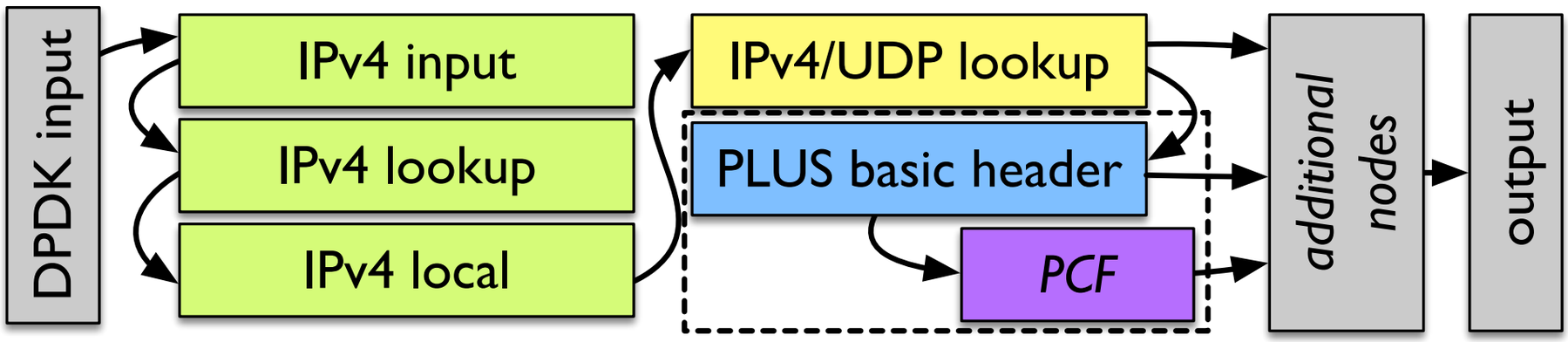
(a) receiver-side interfaces



(b) sender-side interfaces

Building PLUS-aware middleboxes with fd.io VPP

- fd.io VPP: framework for building userspace network devices on any DPDK platform, using *packet vectors* for scalability.
- PLUS middlebox support implemented as VPP nodes
  - Core node handles state machine and basic header flags
  - One extension node per PCF type
  - Modifications to UDP logic to recognize PLUS magic



PLUS and QUIC

- Both PLUS and QUIC propose encryption and UDP encapsulation to enable transport evolution.
- PLUS proposes additional explicit signaling to replace information that encryption removes.
  - Declarative and advisory, but better than inference.

- Many basic PLUS features appear in QUIC in diminished form:
  - QUIC's PN is a PSN, but without echo
  - QUIC's CID is a CAT, but not on every packet
- Additional QUIC features proposed based on PLUS experience:
  - No PSE, but latency spin bit proposed to replace it for passive RTT

Conclusions

- Adding a ***path layer*** to the Internet architecture to enable ***explicit cooperation*** between endpoints and middleboxes can support transport protocol evolution while replacing manageability and measurability lost through encryption.

- PLUS provides a testbed for experimenting with explicit cooperation approaches.