nQUIC: Noise-Based Packet Protection

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Facebook

Nick Sullivan
Cloudflare

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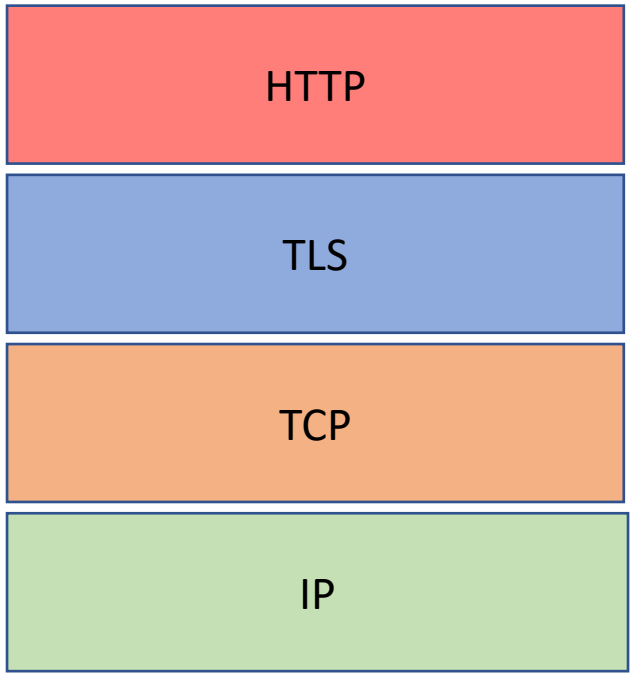
Johns Hopkins University

[*]Work done while at NCC Group

[†]Work done while at Cloudflare

The Traditional HTTPS Stack



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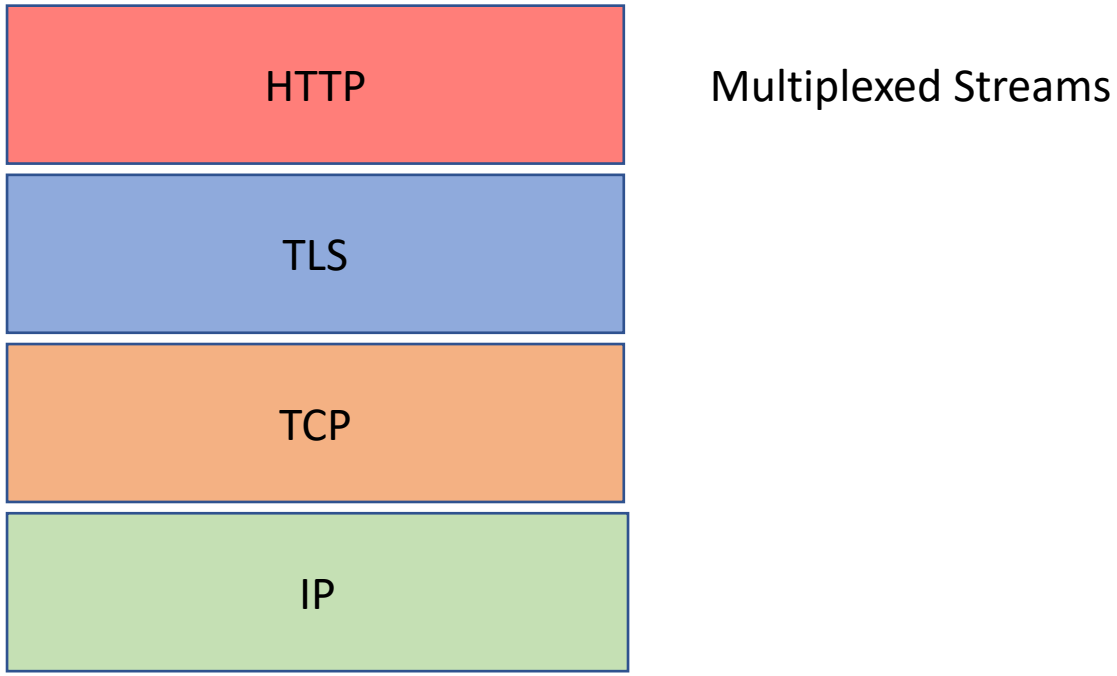

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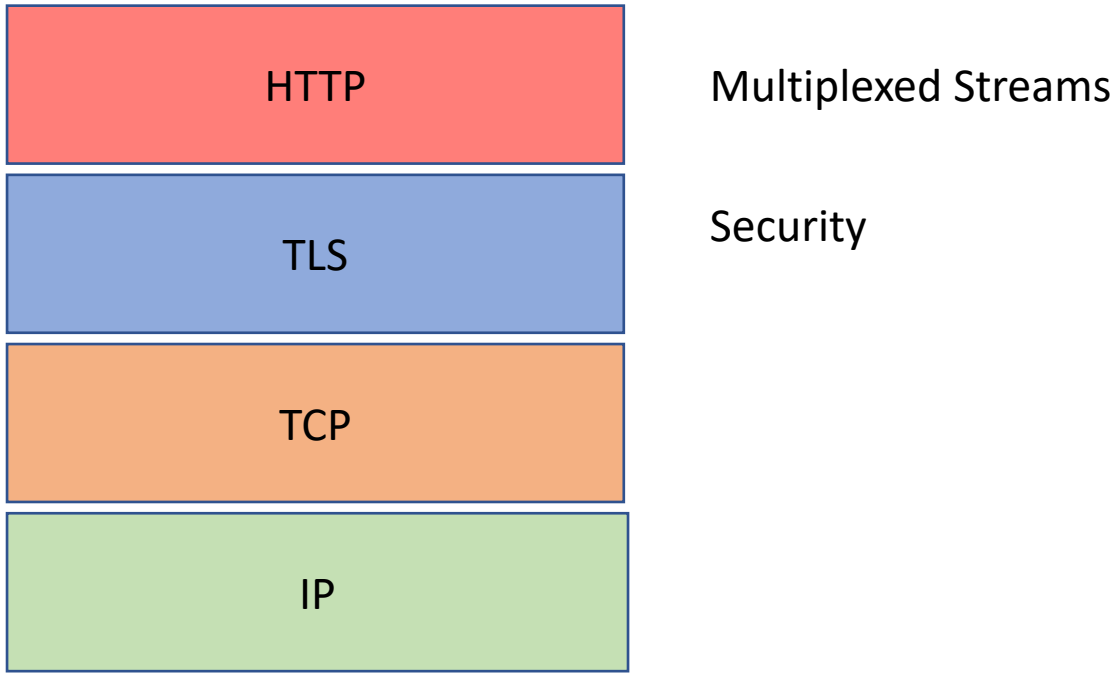

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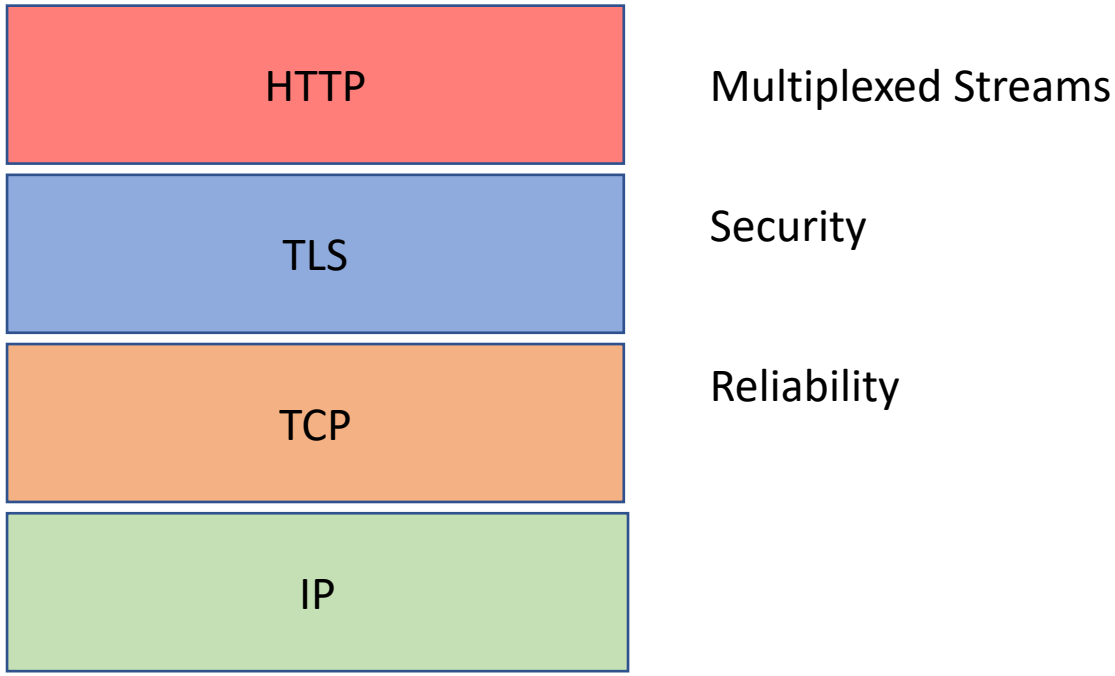

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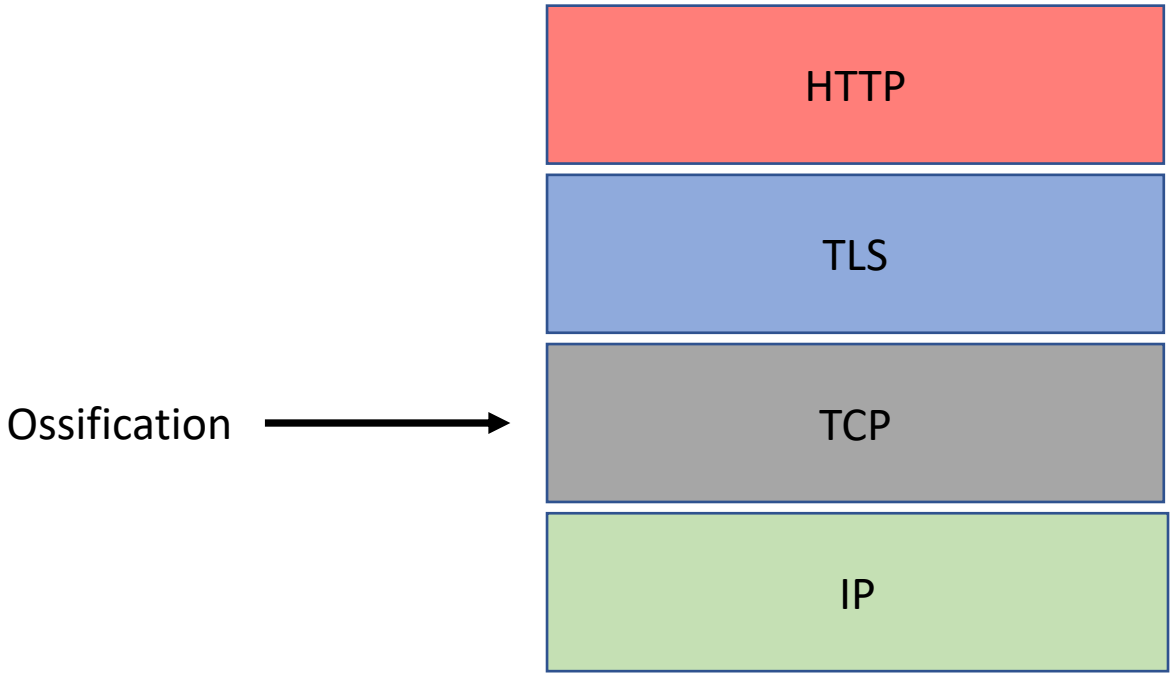
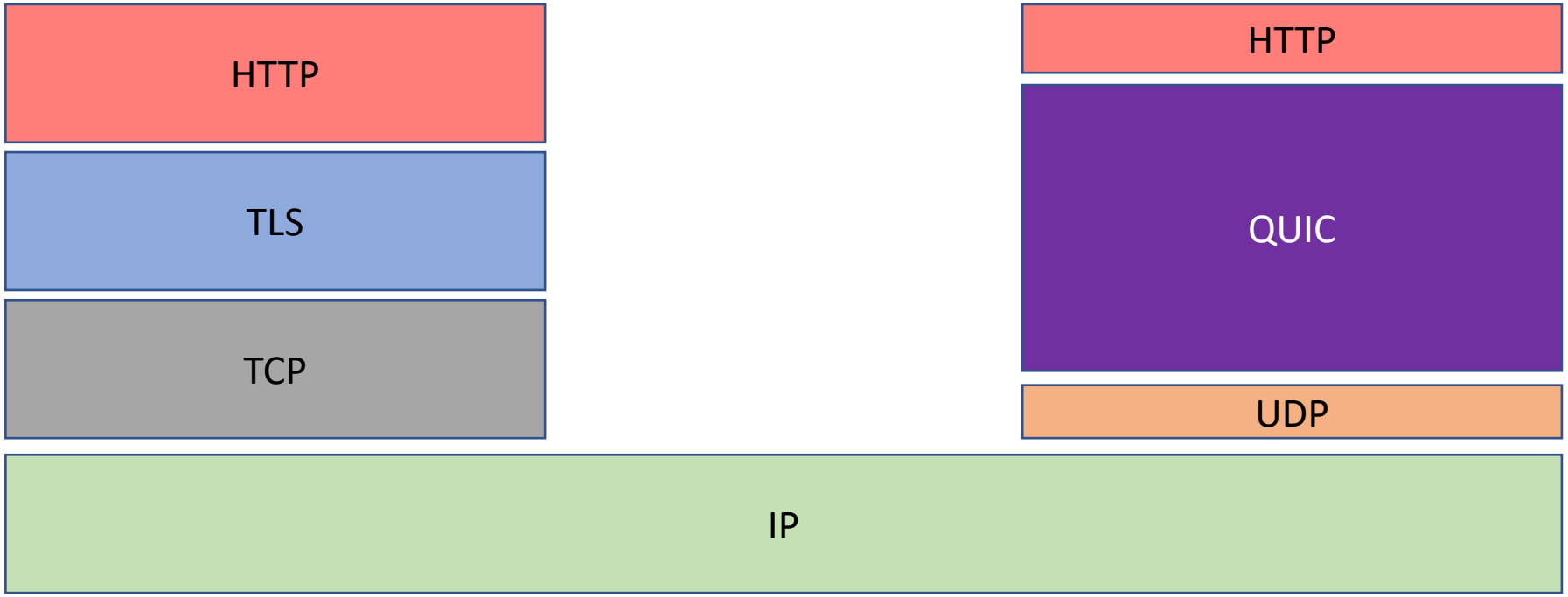


The QUIC way of doing things



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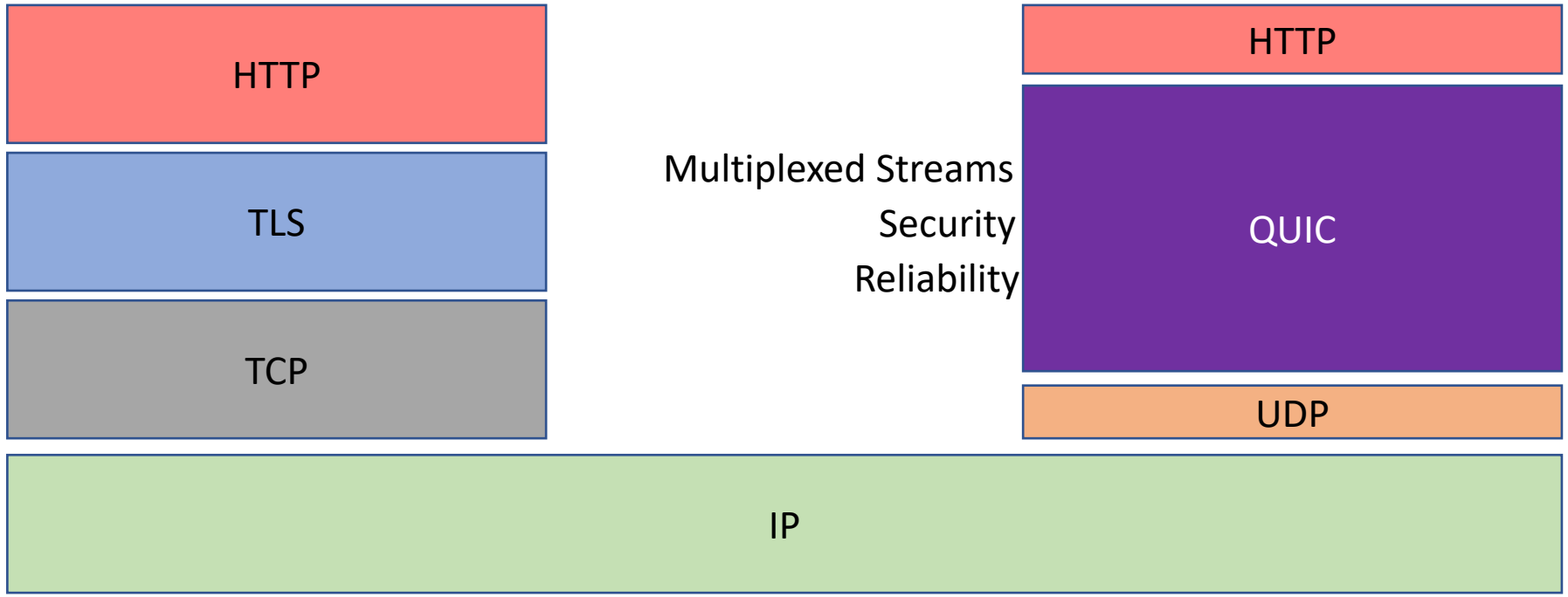
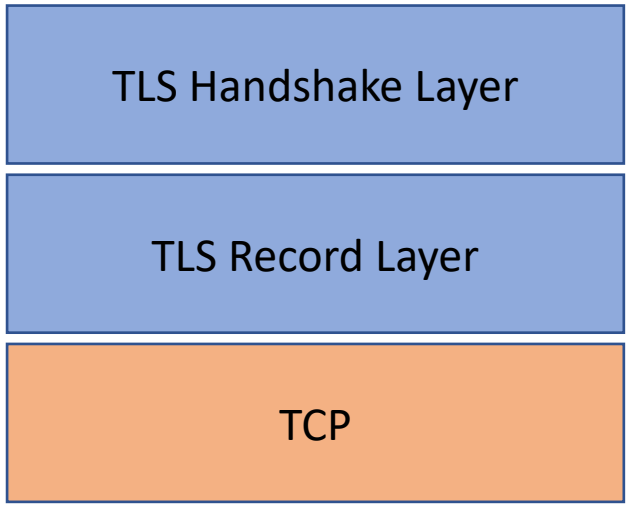


Securing Protocols with TLS

Securing Protocols with TLS: TCP



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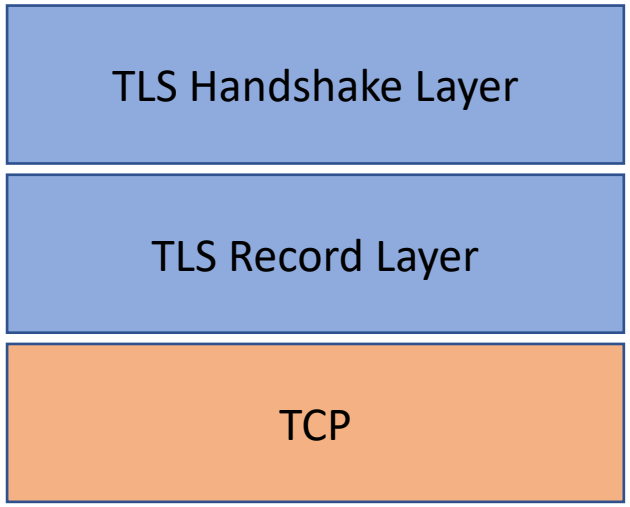

Handshake messages, Application data, TLS alerts

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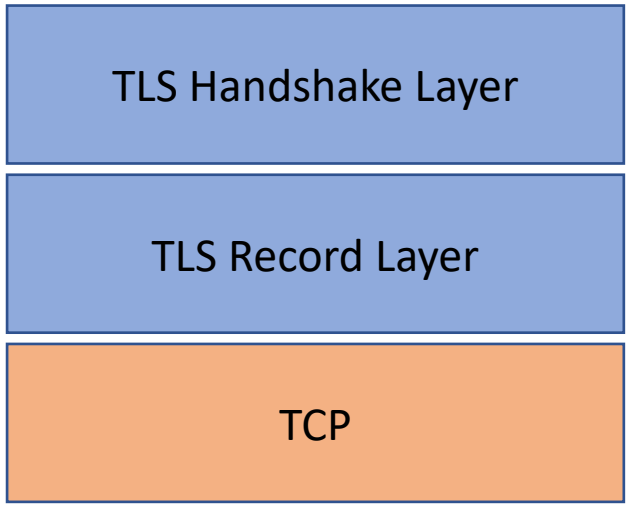

Handshake messages, Application data, TLS alerts

Applies cryptographic protection

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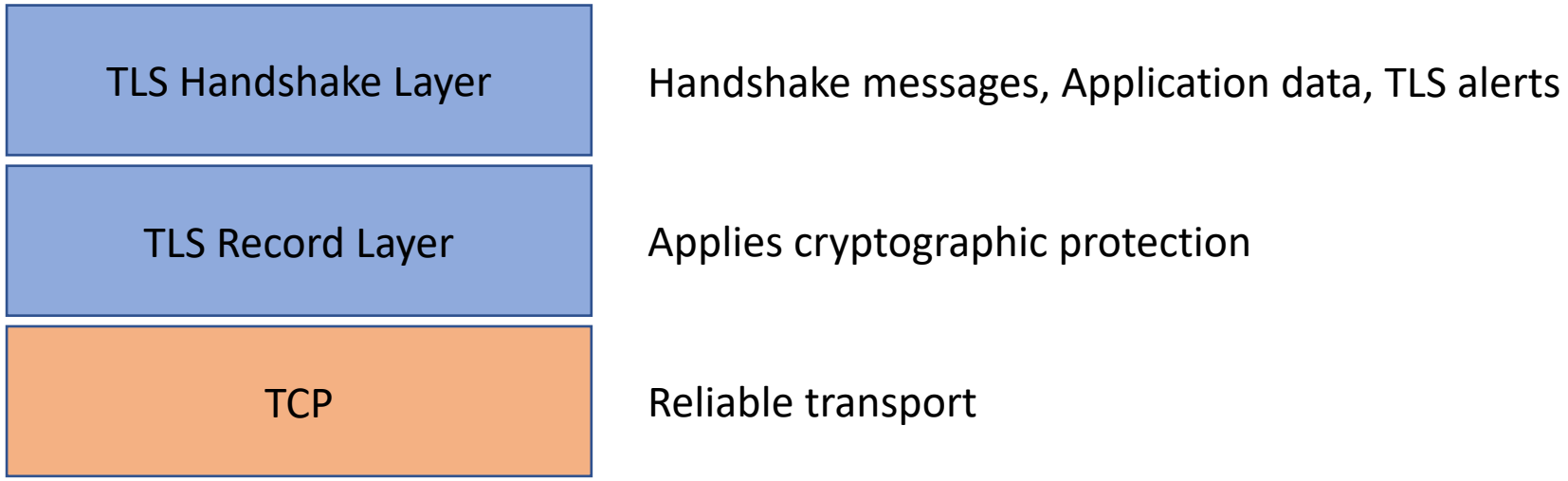

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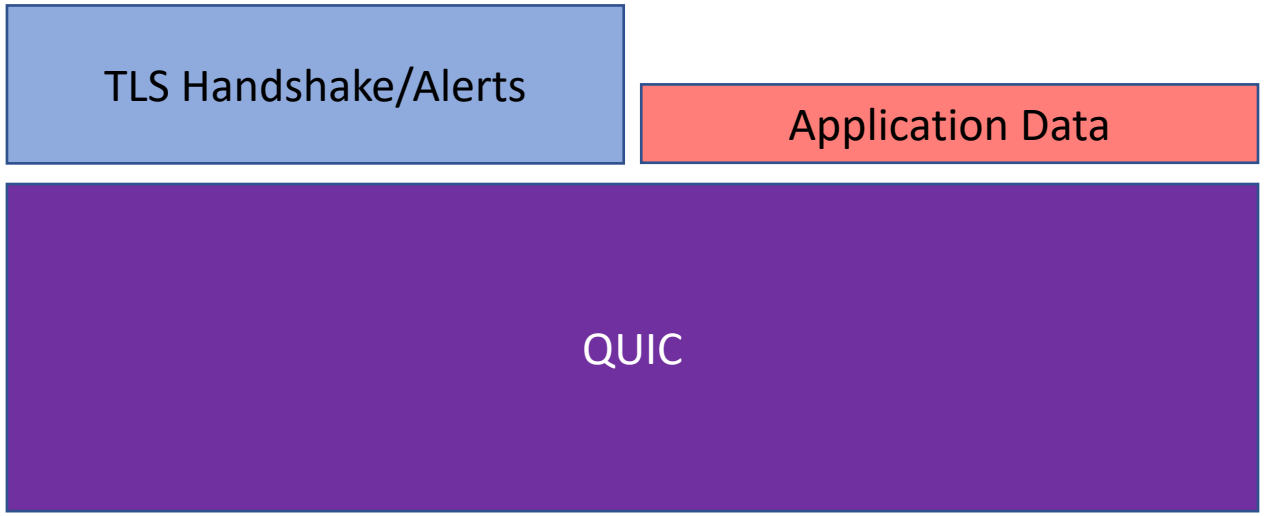

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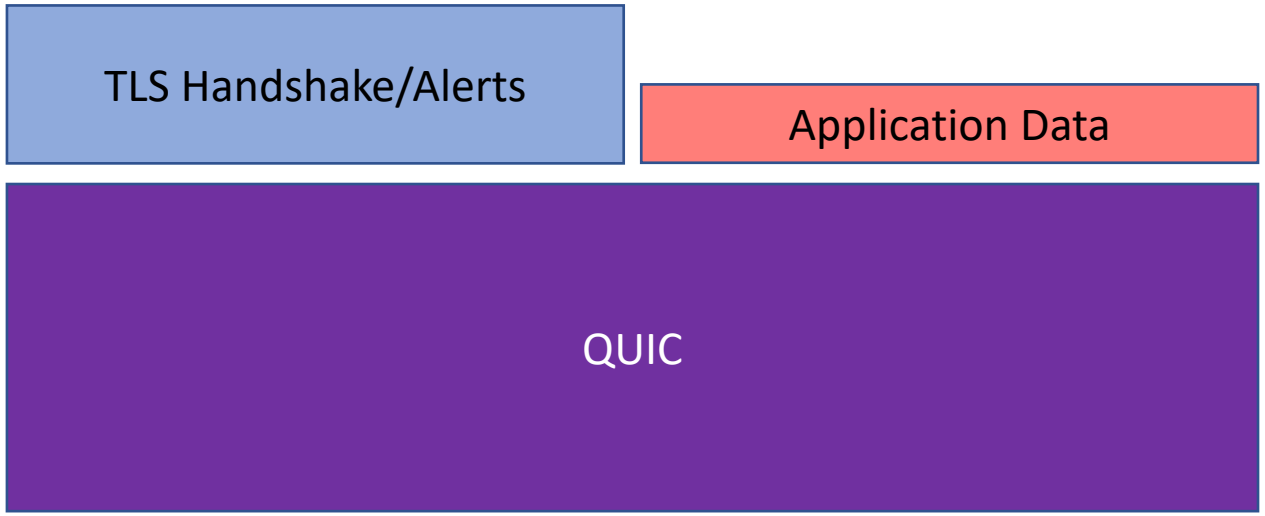

Supplies both packet protection and reliable transport

Handshake Modularity

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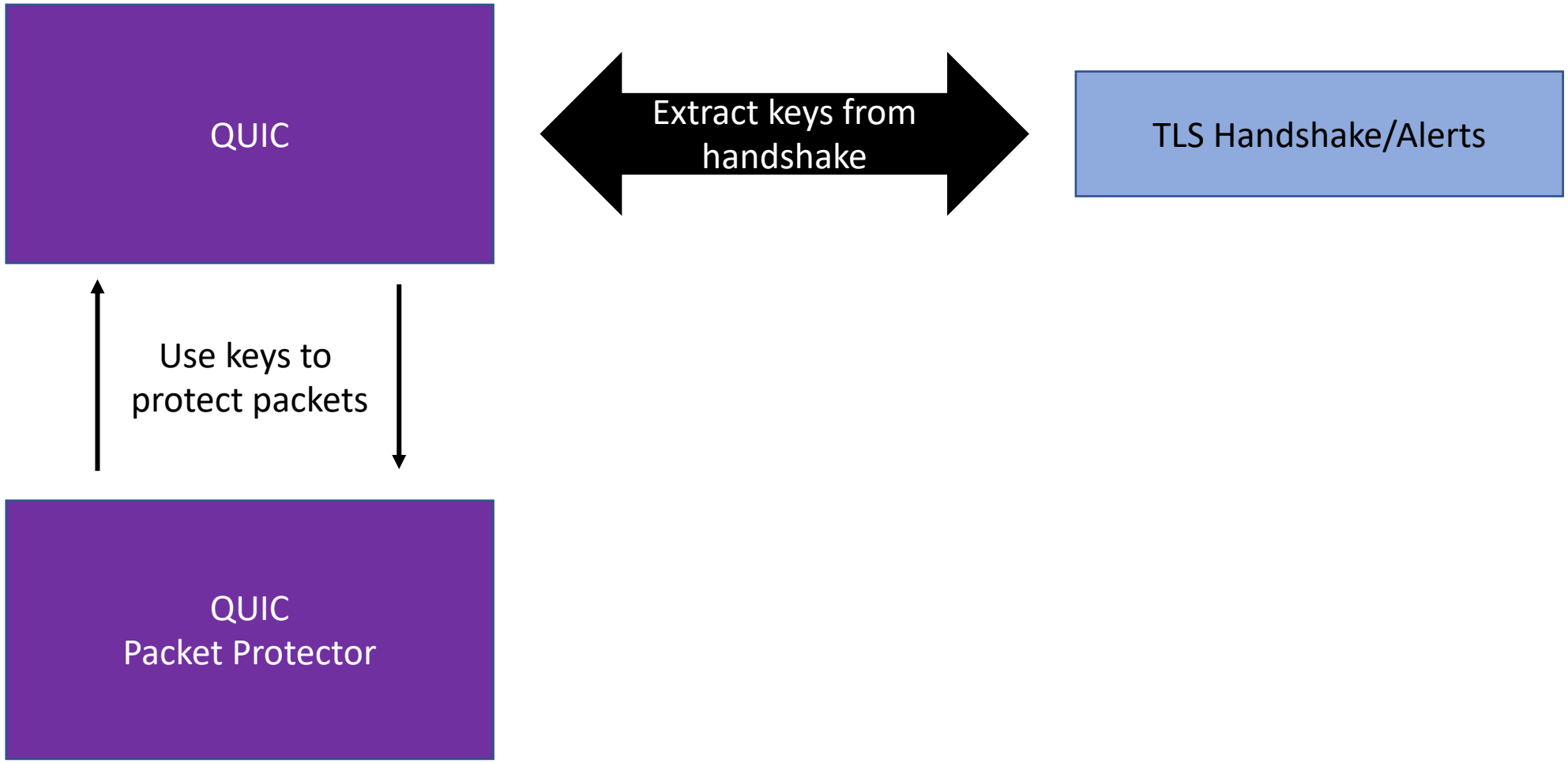

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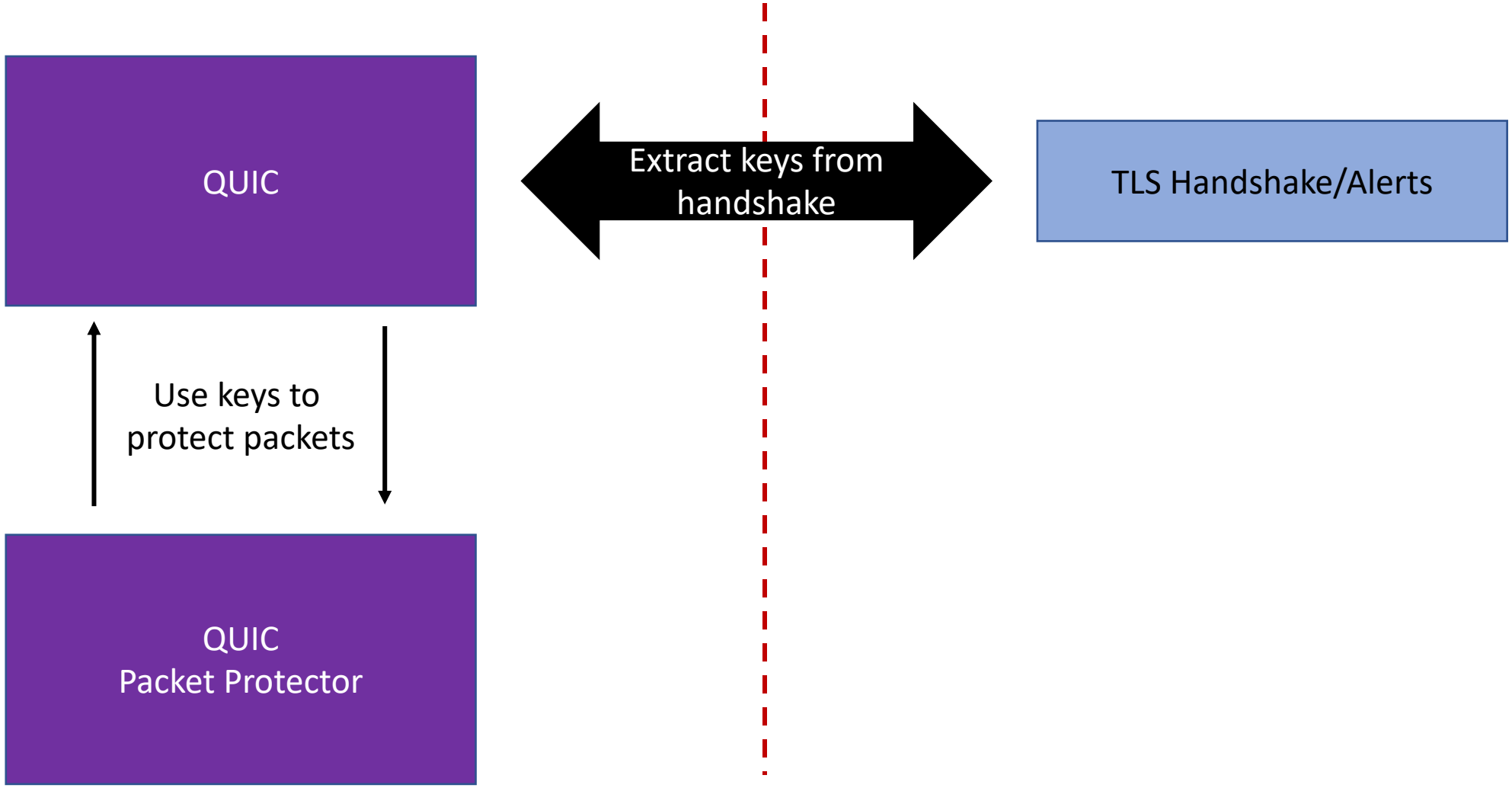

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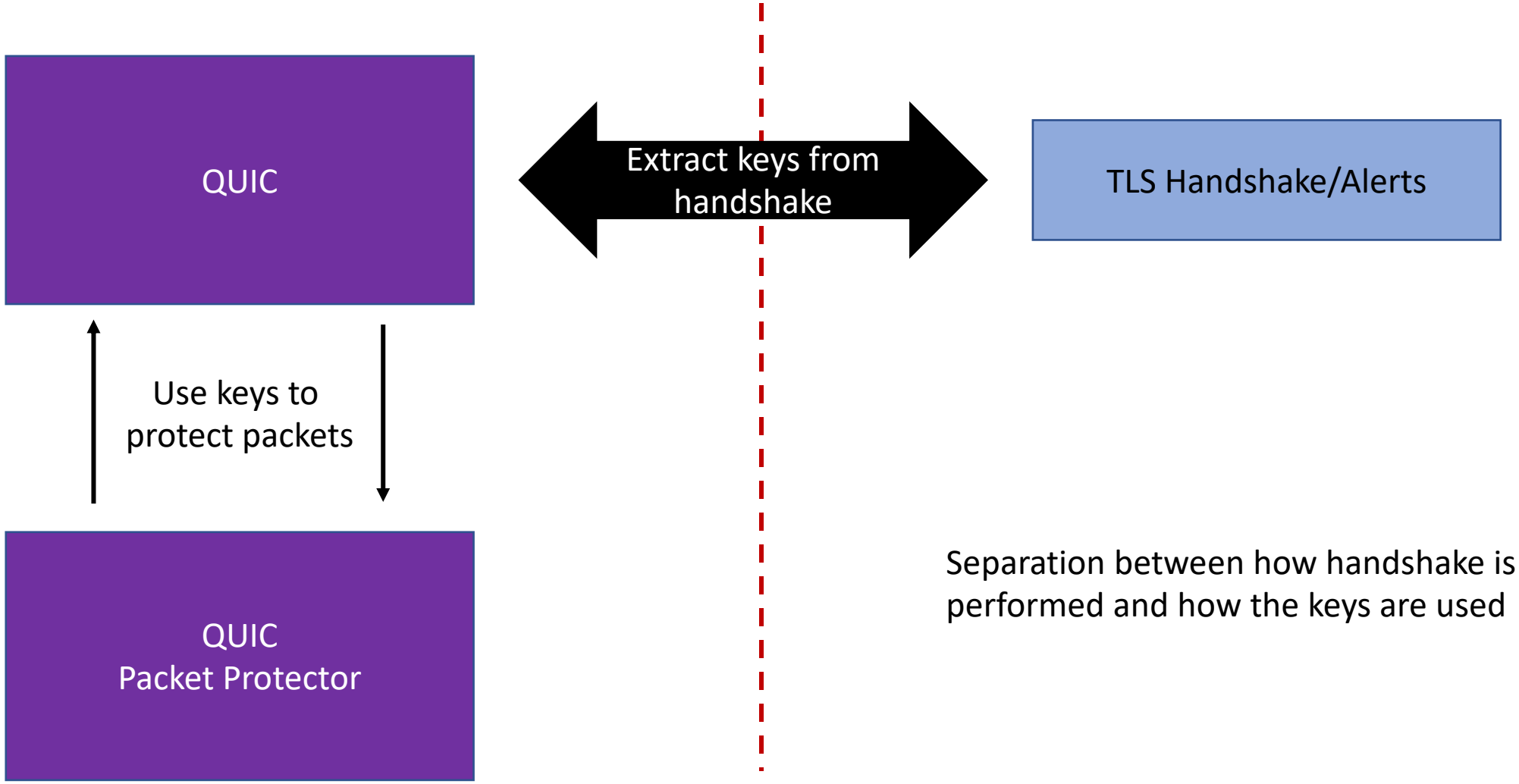

Separation between how handshake is performed and how the keys are used

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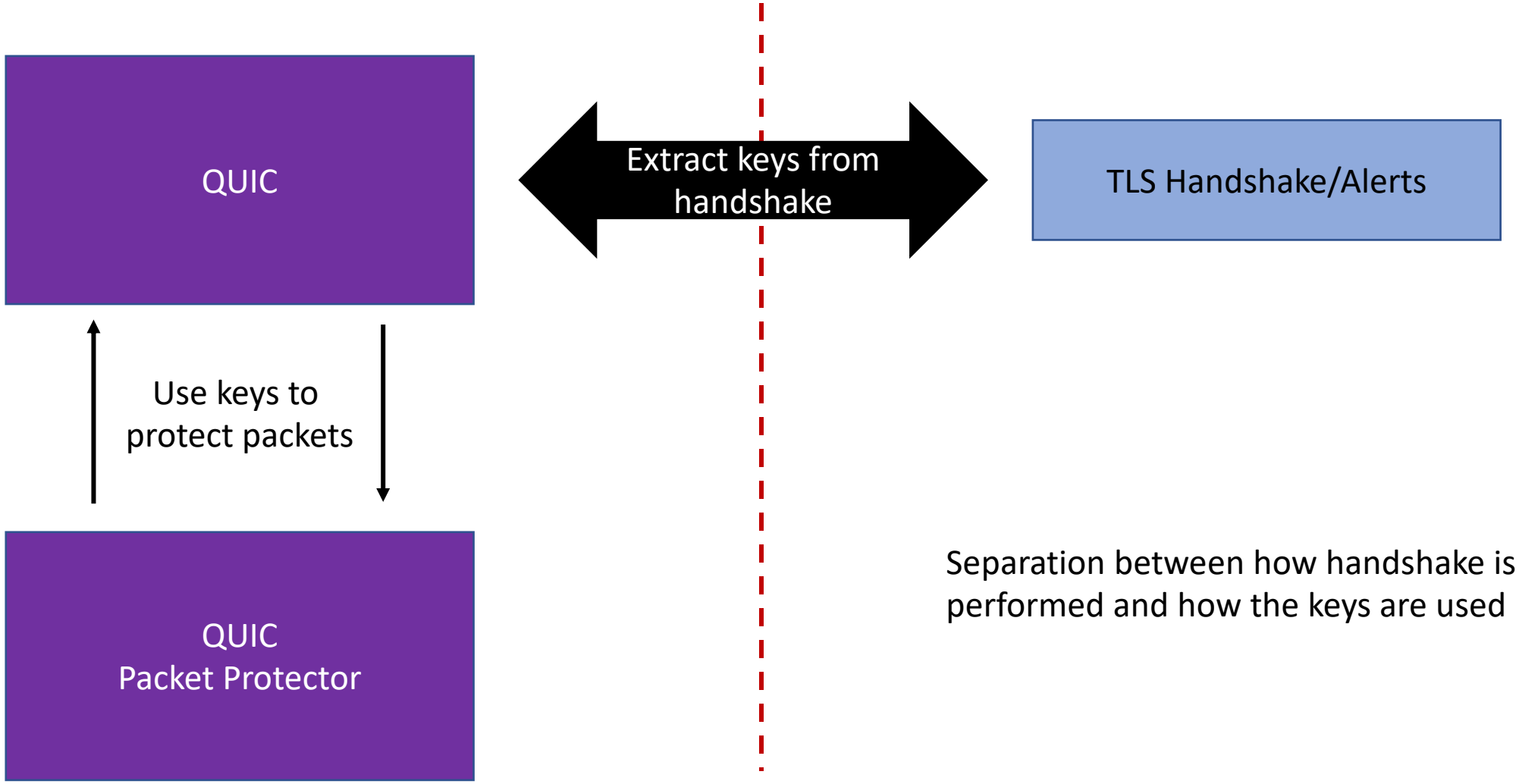

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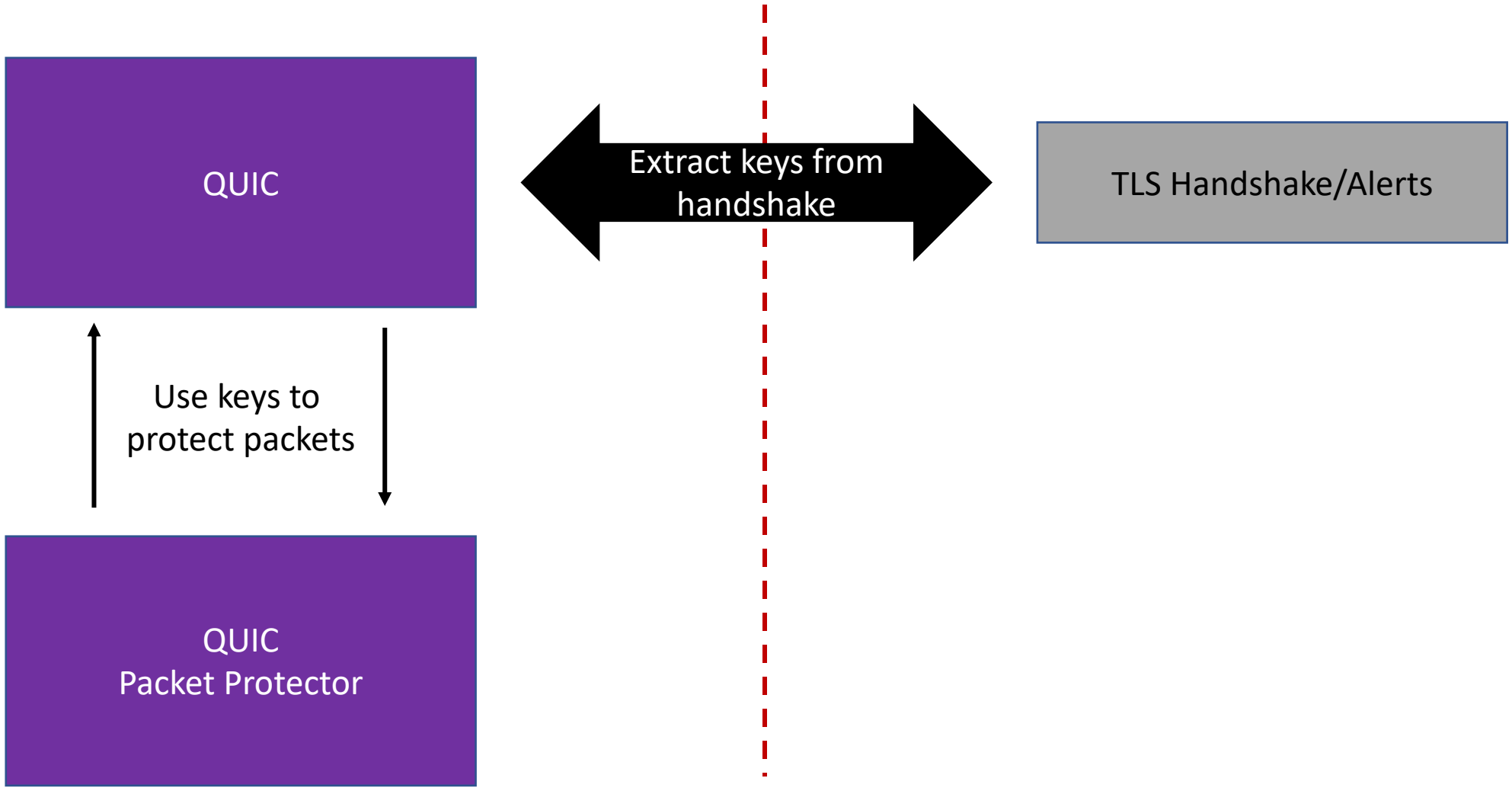

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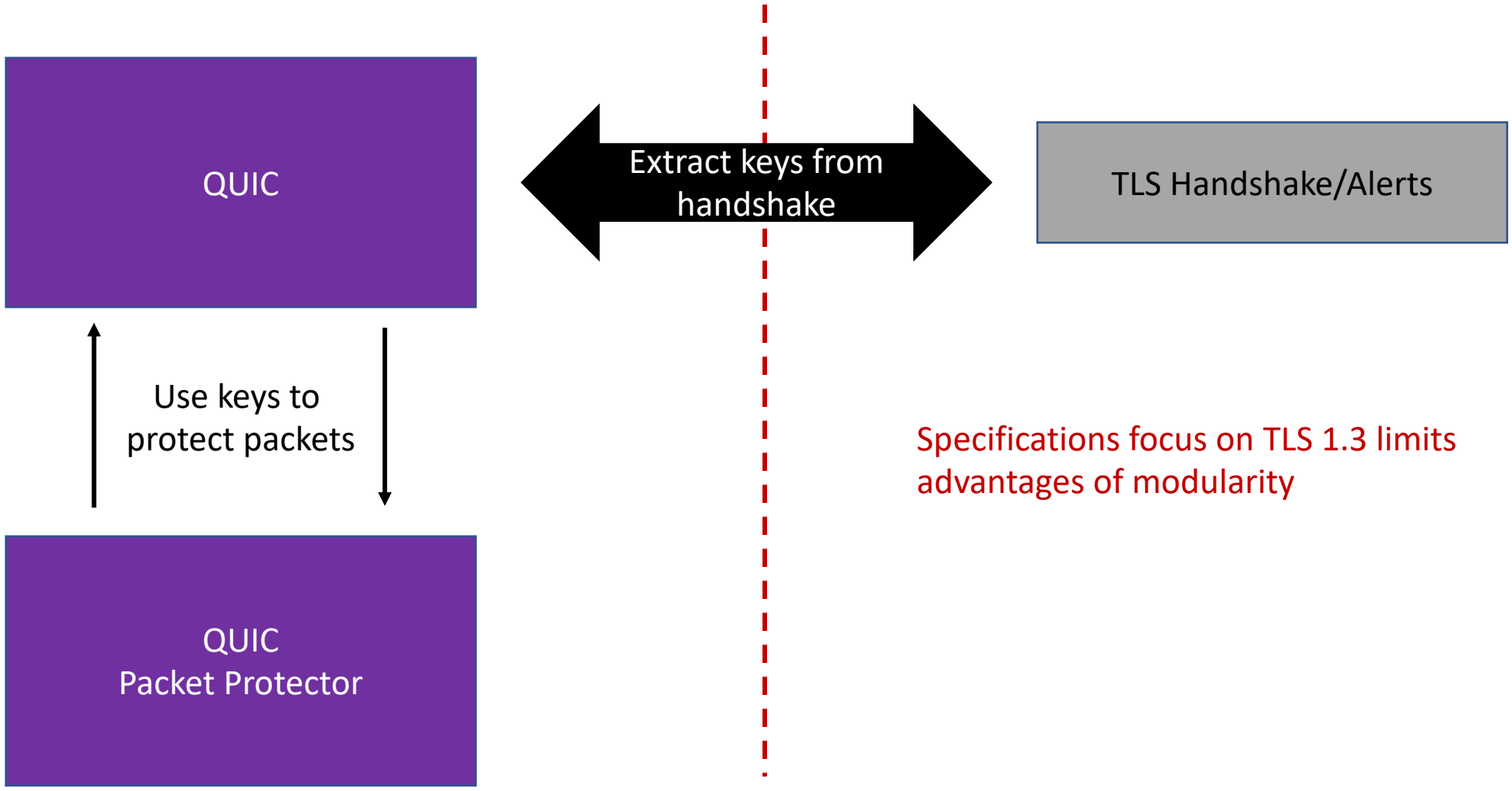

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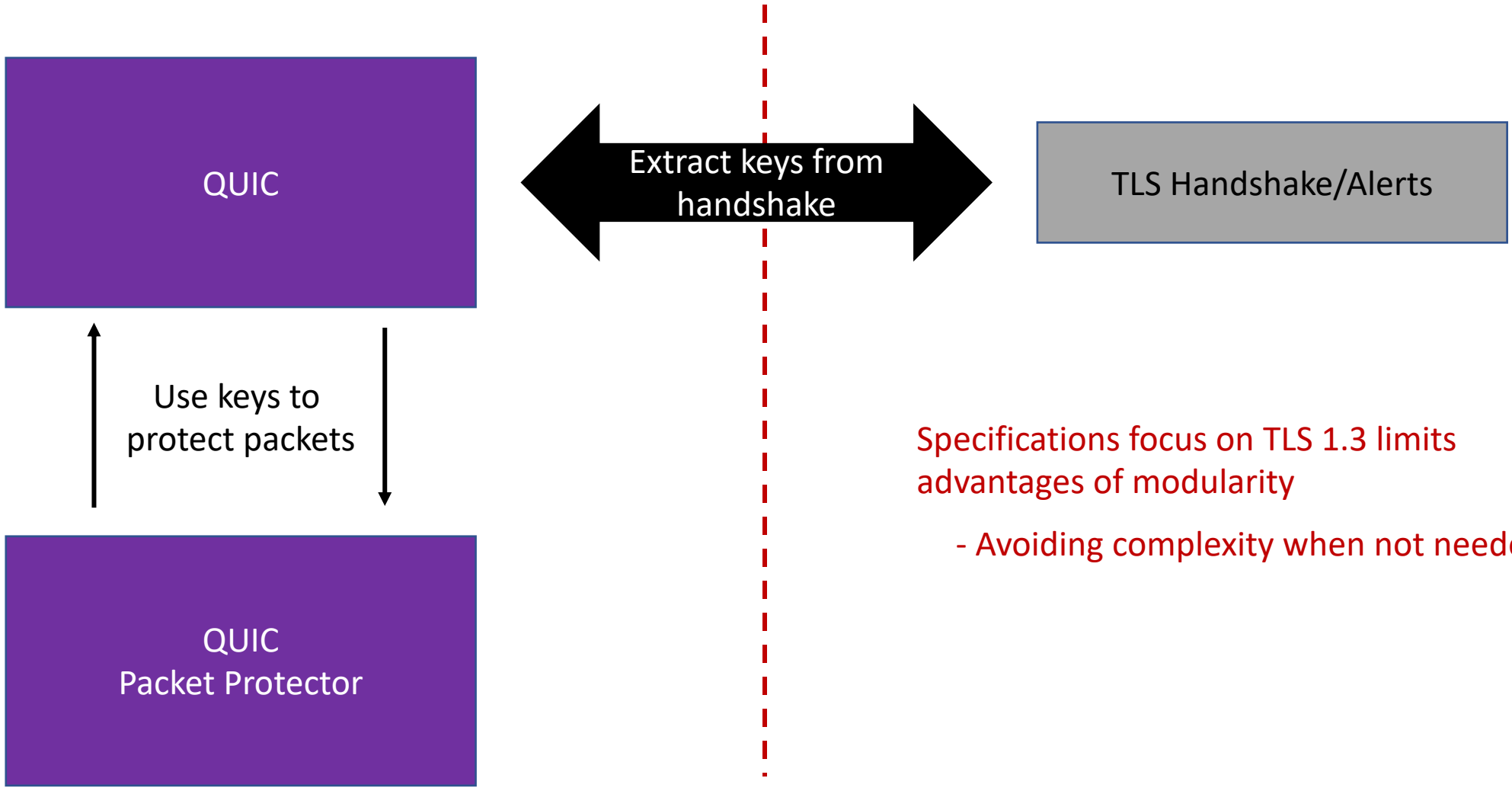

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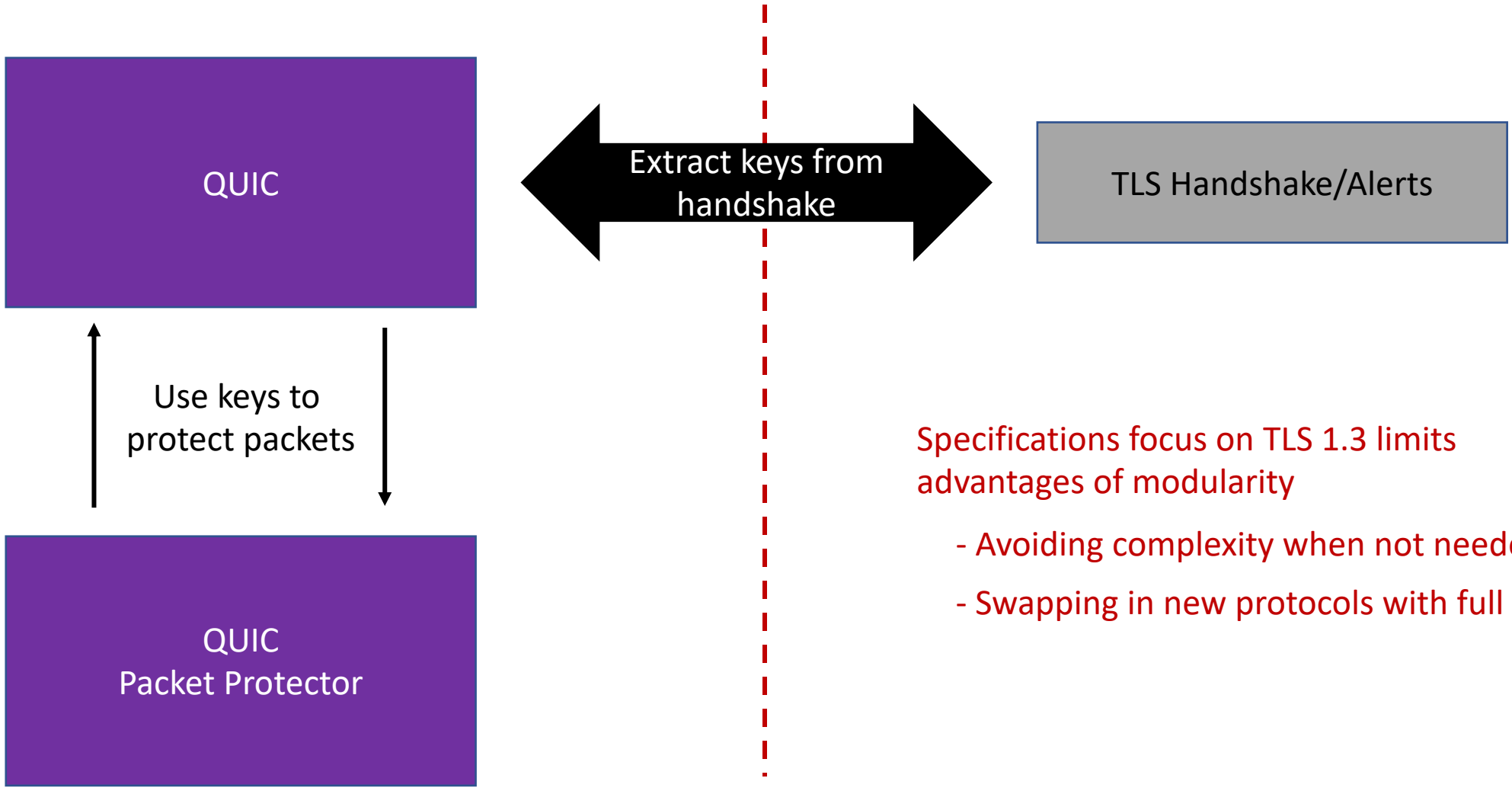

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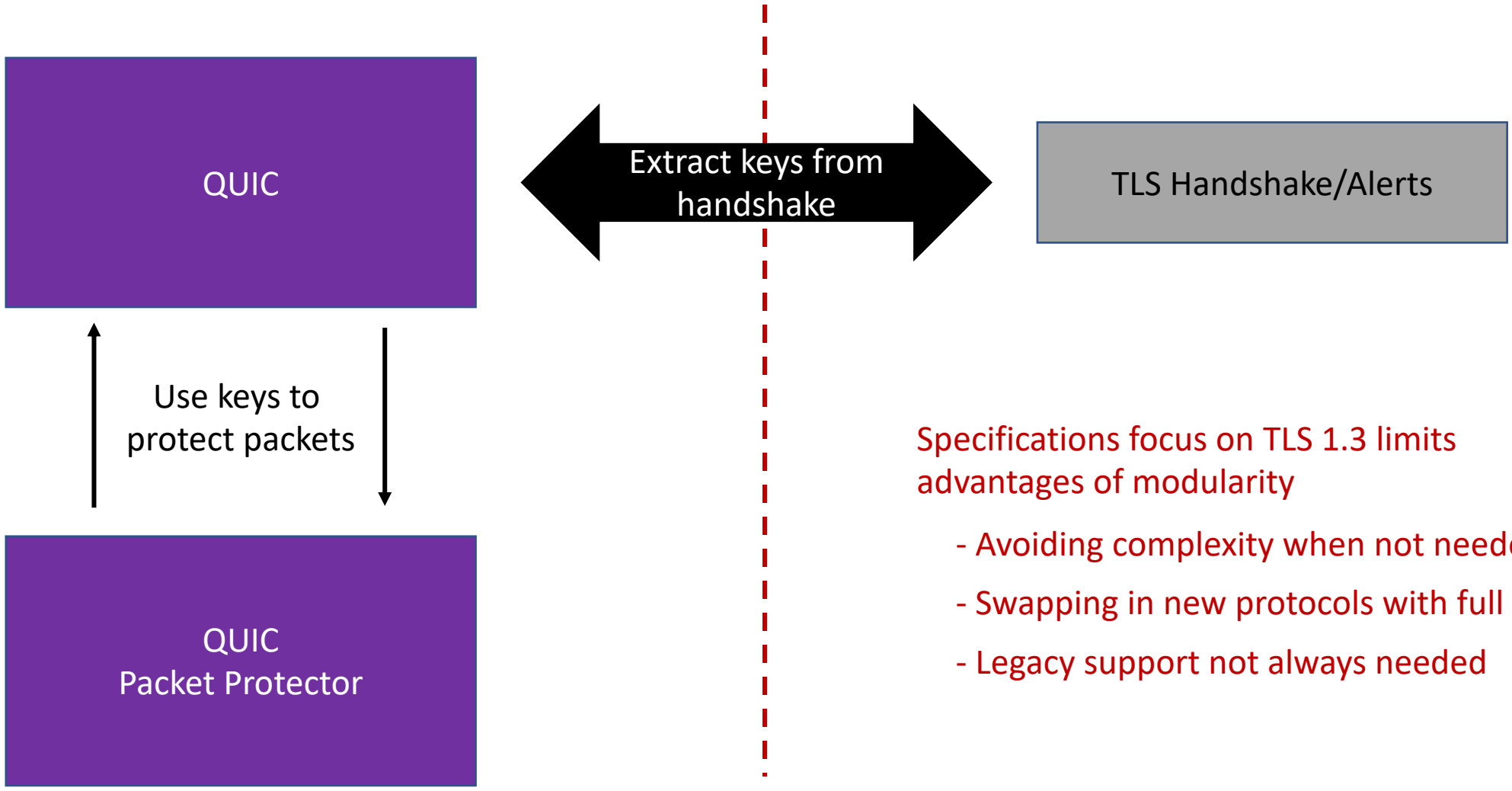

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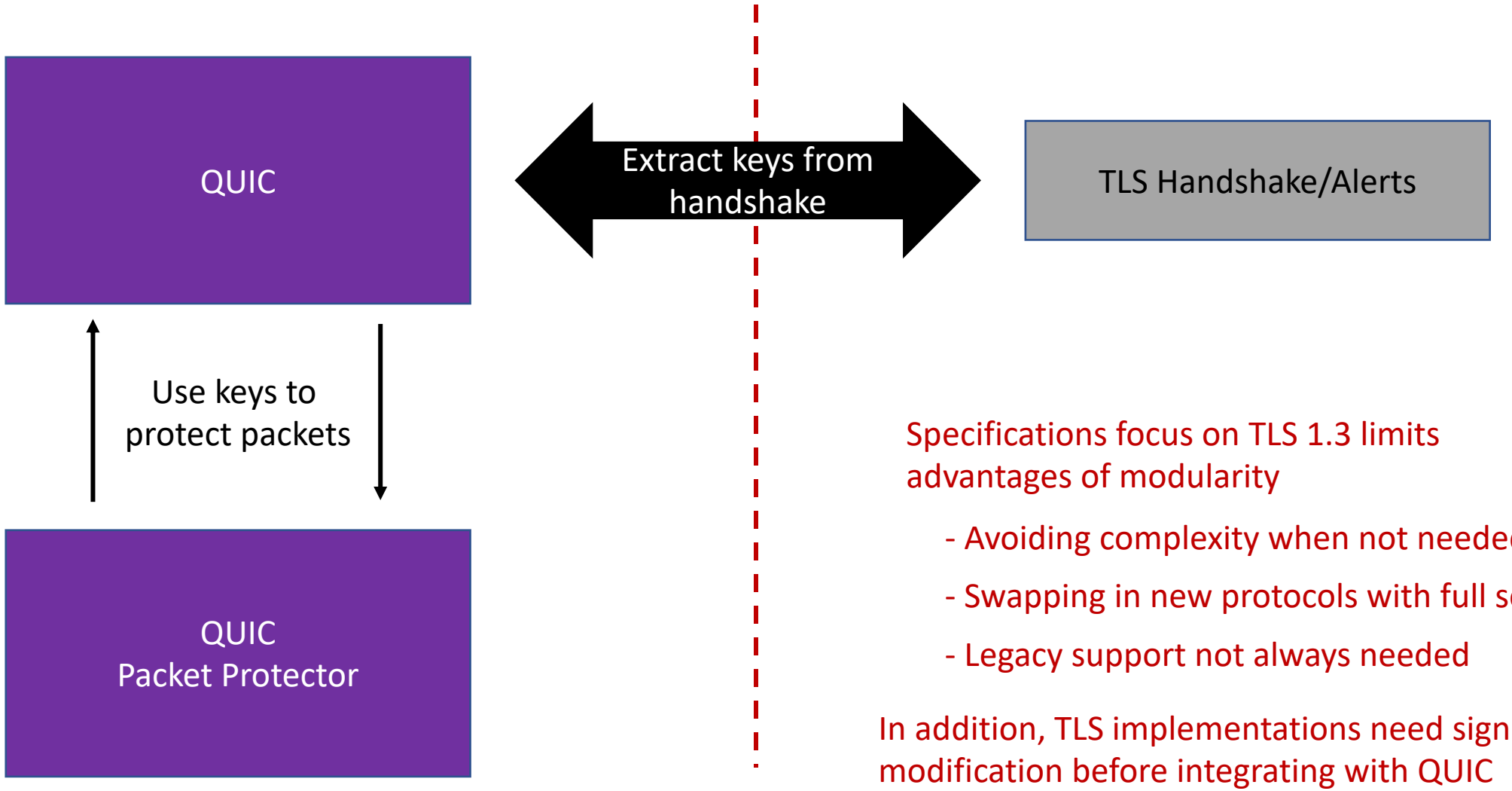

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In addition, TLS implementations need significant modification before integrating with QUIC

Are there circumstances we can do better than TLS 1.3?

What is Noise

A *framework* for specifying Cryptographic Handshakes

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A variety of protocols can be specified using the simple Noise language

These protocols can vary in their guarantees and complexity

However, once a protocol is selected, the handshake proceeds in a straightforward fashion

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The Noise language consists of tokens, which combine into message patterns, when combine into handshake patterns

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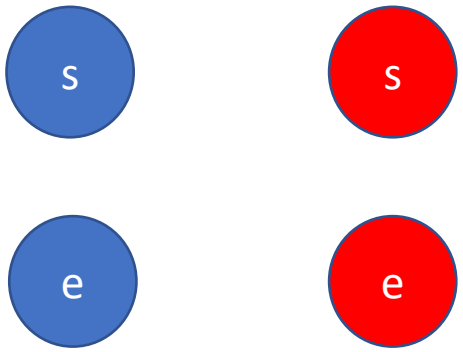

Public Key Tokens

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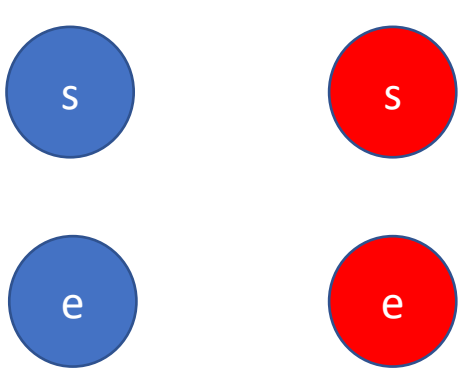

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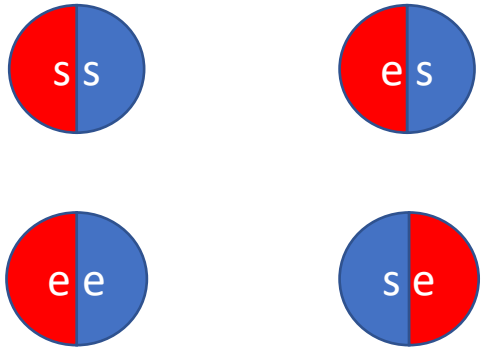

DH Tokens

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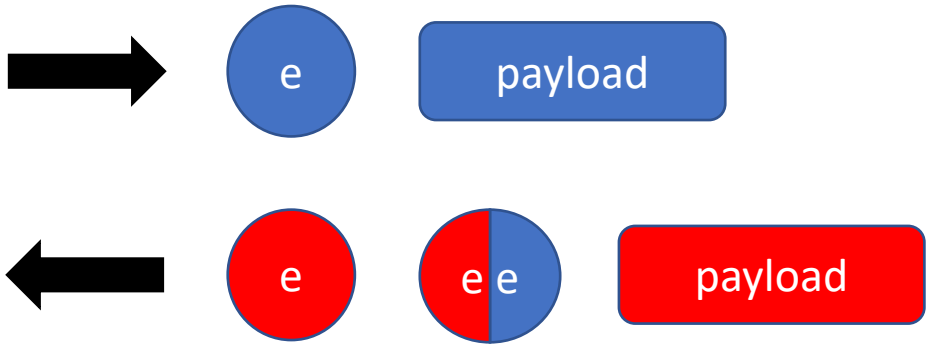
Here is a basic example handshake pattern



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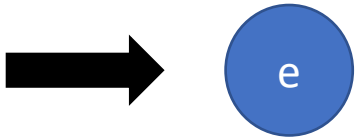

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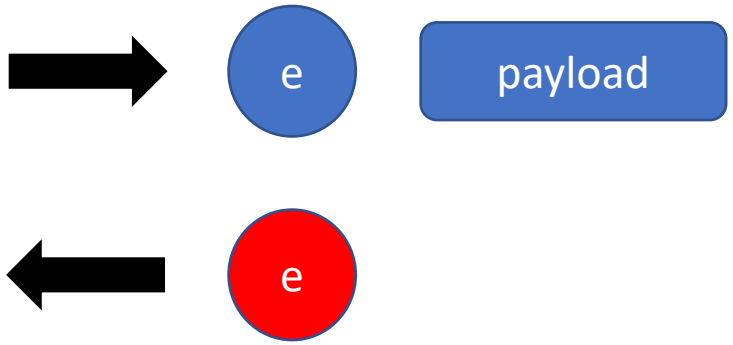

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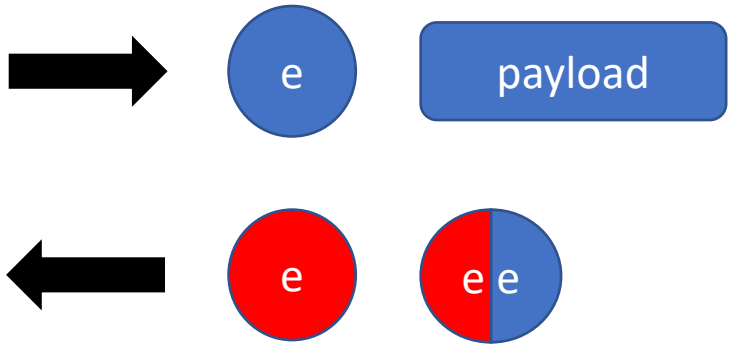

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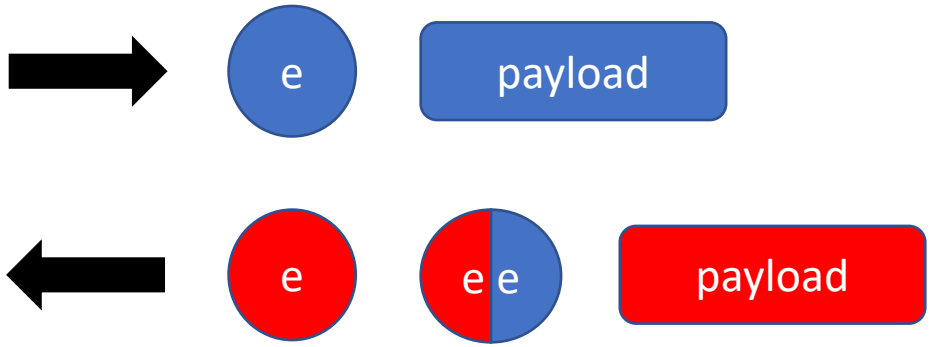

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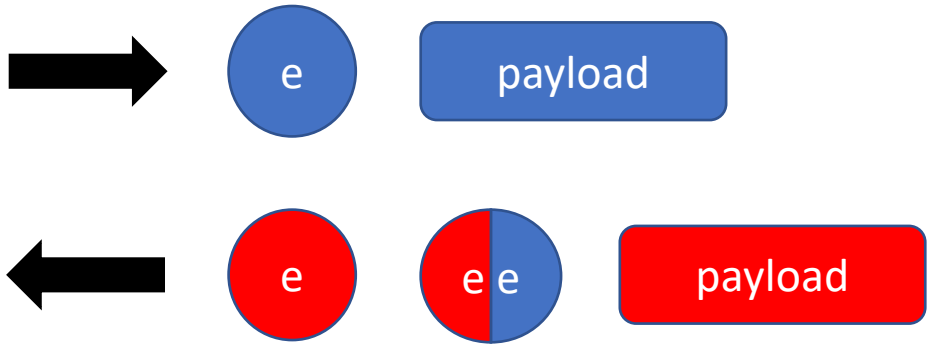

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Noise does additional processing to mix all handshake data into the derived key

Noise vs TLS

- Once a handshake pattern is selected, noise follows a simple linear state machine

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- Noise is easy to prove secure
- Noise is generally implemented as a “build your own protocol” library
- Noise lacks cryptographic agility

Peer Authentication and Pinning

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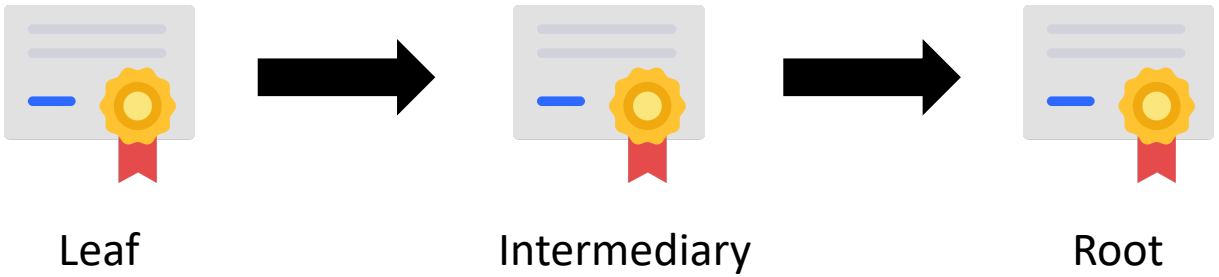

Chain of Trust

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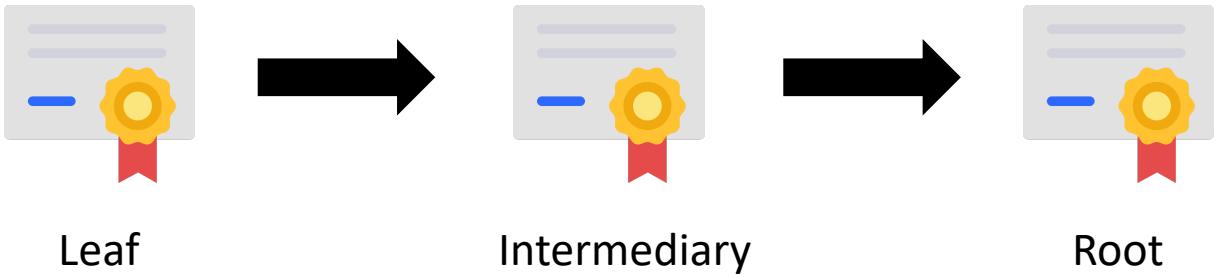

Chain of Trust

However this is not necessary in a centrally managed setting

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$$n \quad \text{vs} \quad \frac{n!}{2 \cdot (n-2)!}$$

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This applies to cases where:

- Public keys or Certificate Chains are obtained out-of-band
- Peers are bootstrapped with keys
- Public keys are managed by a trusted key management service

nQUIC

Motivated by simplicity while still satisfying the following requirements:

1. Authenticated Key Exchange
2. Authentication of Transport Parameters
3. Authenticated Version Negotiation
4. Authenticated Negotiation of Application Protocol
5. Address Validation

nQUIC

Motivated by simplicity while still satisfying the following requirements:

1. Authenticated Key Exchange
   Feature of Noise
2. Authentication of Transport Parameters
   Can be placed in the payload field
3. Authenticated Version Negotiation
   Can be placed in the payload field
4. Authenticated Negotiation of Application Protocol
   ALPN data can be placed in transport parameters
5. Address Validation
   Handled by QUIC address validation tokens

nQUIC’s Noise Pattern

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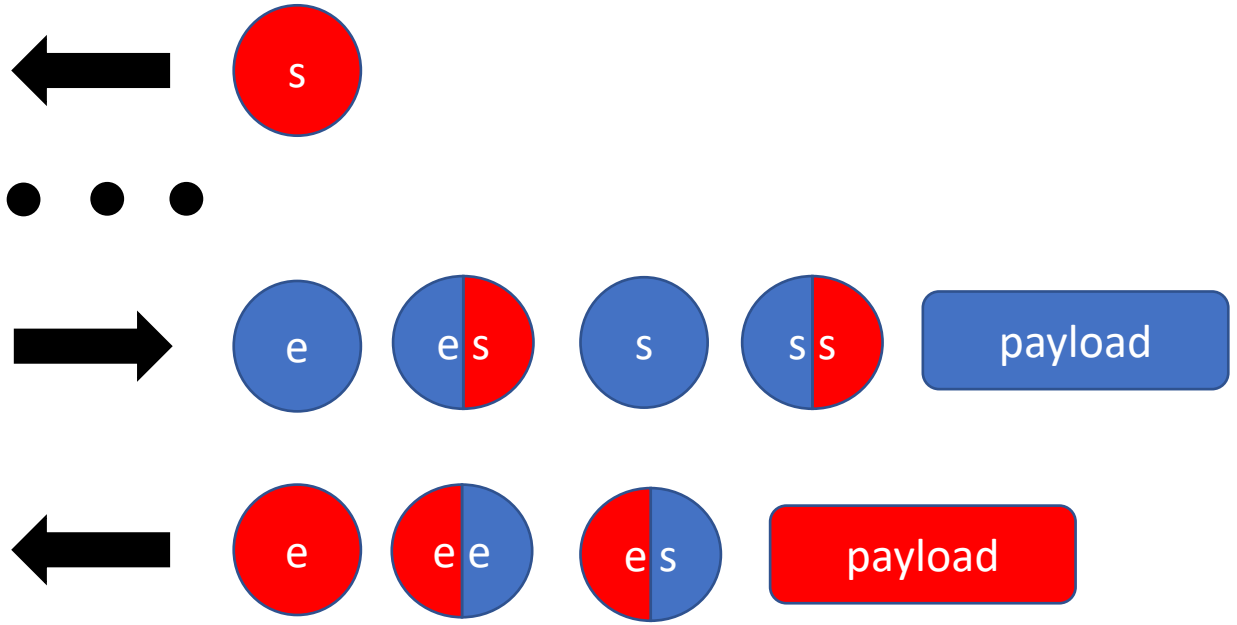
Encrypts transport parameters

nQUIC's Noise Pattern

In order to achieve this we selected the IK pattern:



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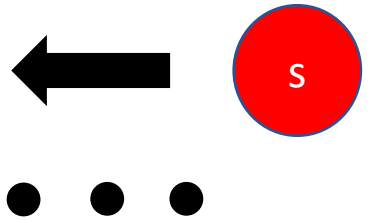
Server shares static key in advance



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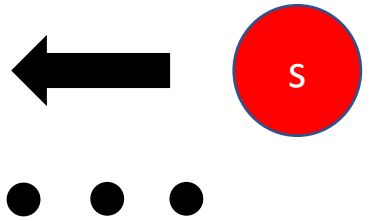

Client payload secured by client ephemeral and server static keys

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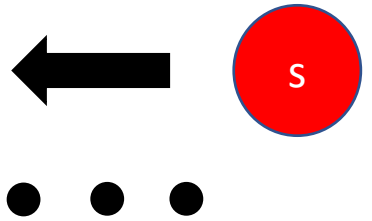

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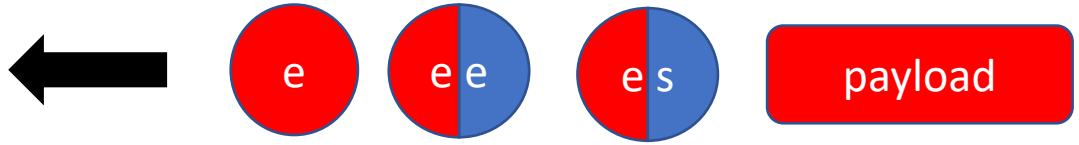
Server payload secured by both parties ephemeral keys



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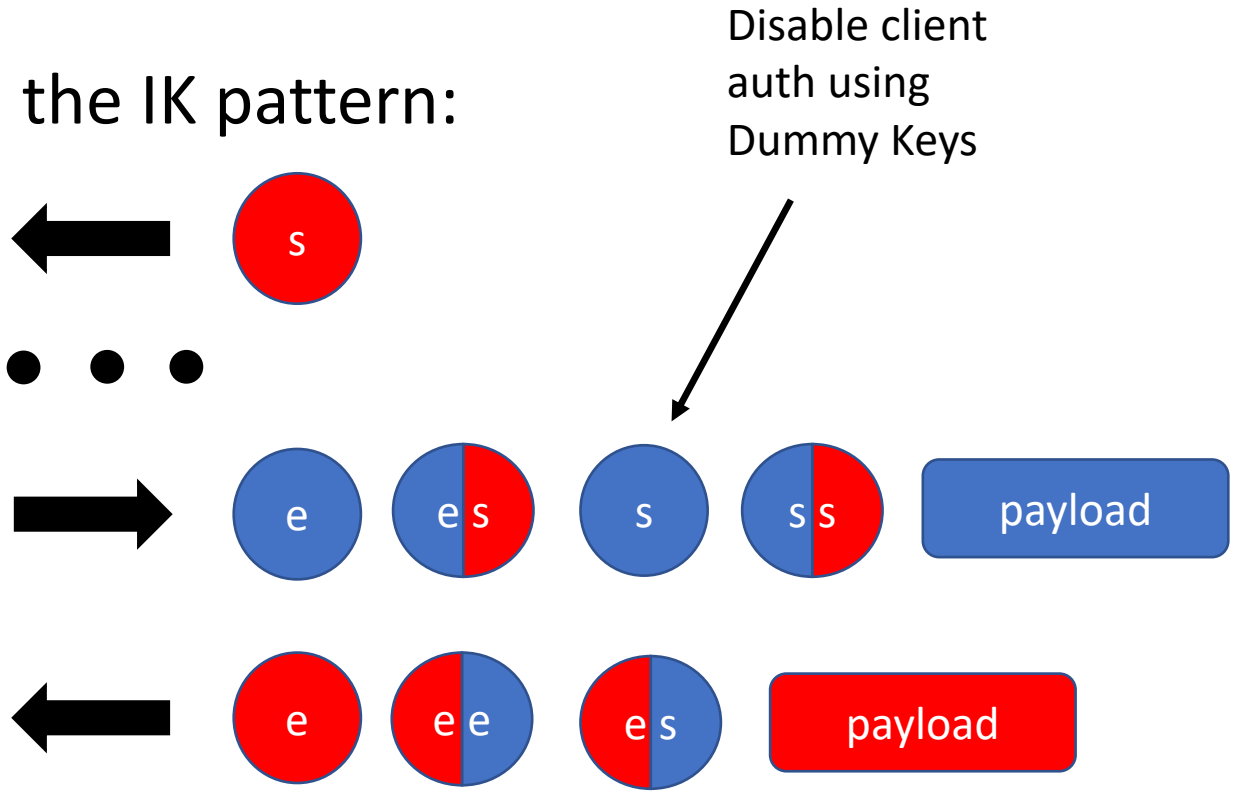

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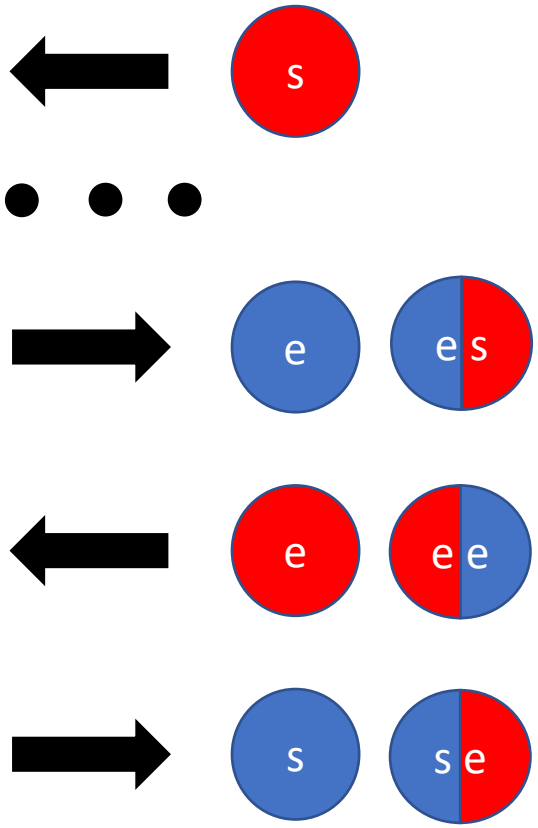
The XK Pattern also sends server static key beforehand, but is 3 rounds

XK



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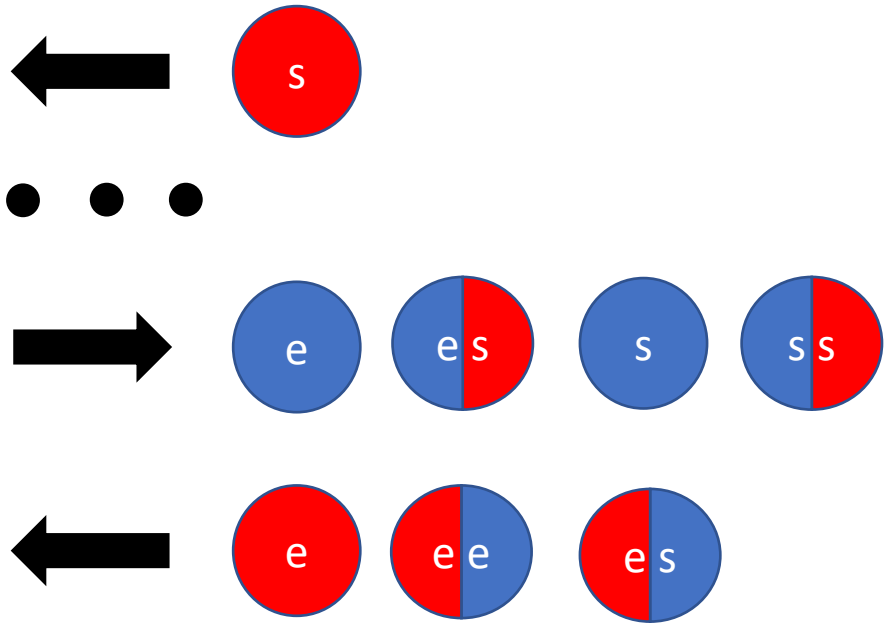
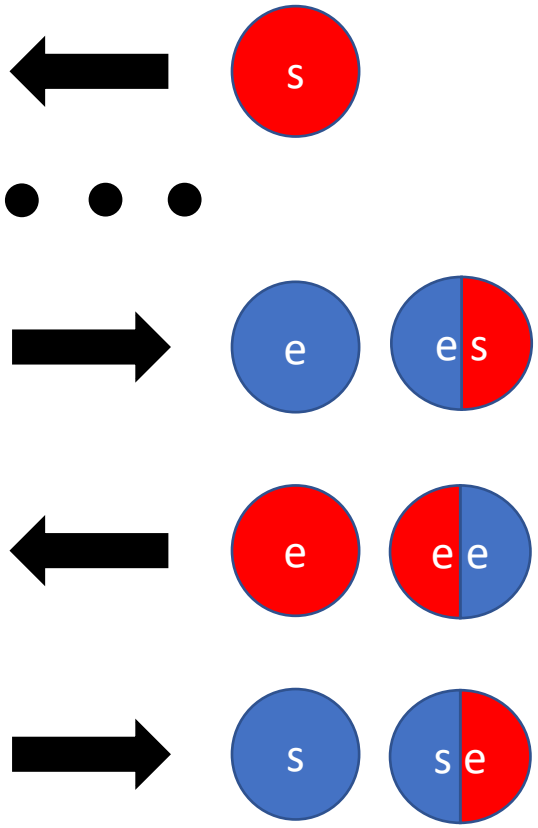
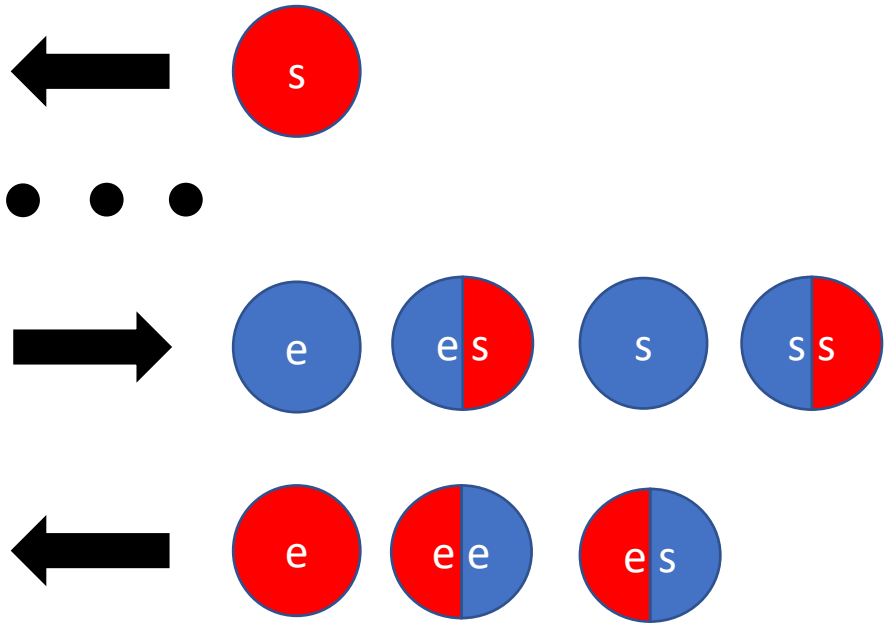


XK



- More rounds

IK



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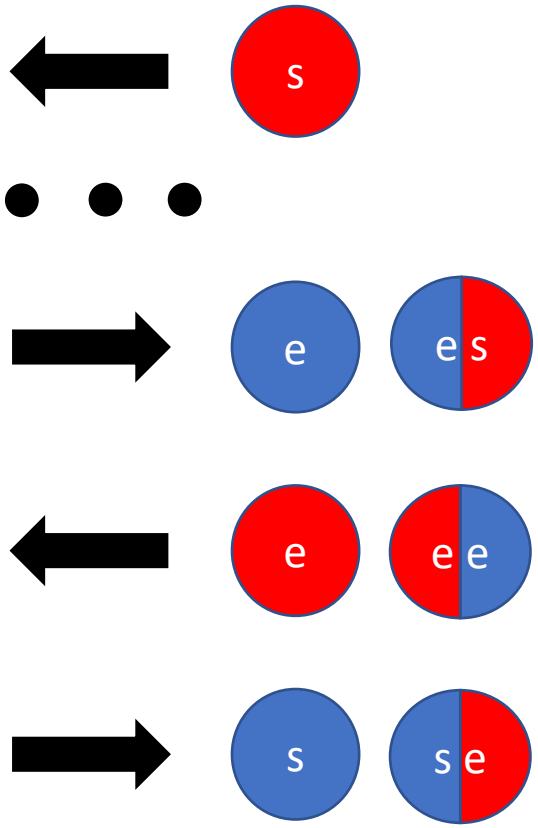

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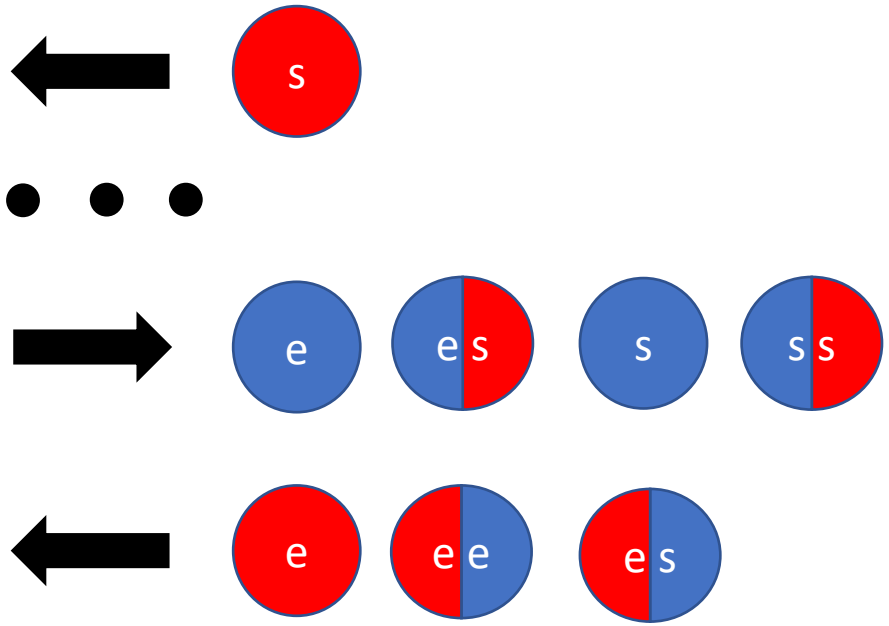

- More DHs

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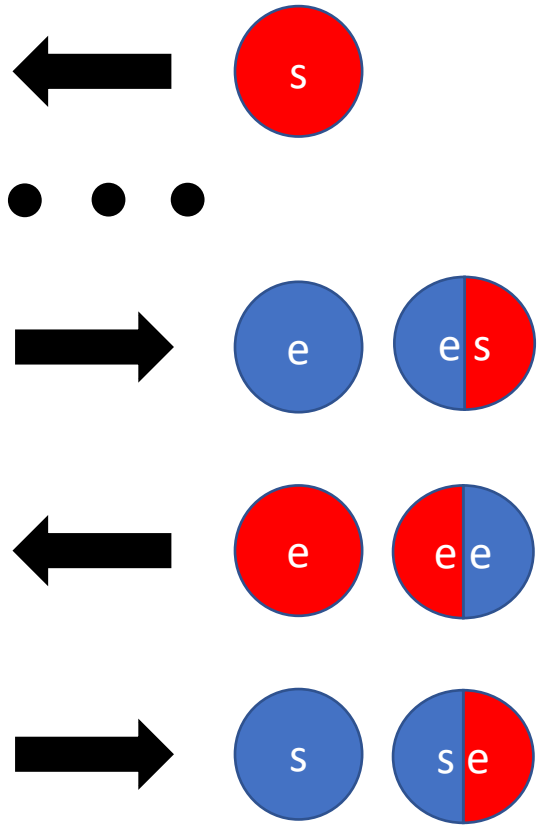

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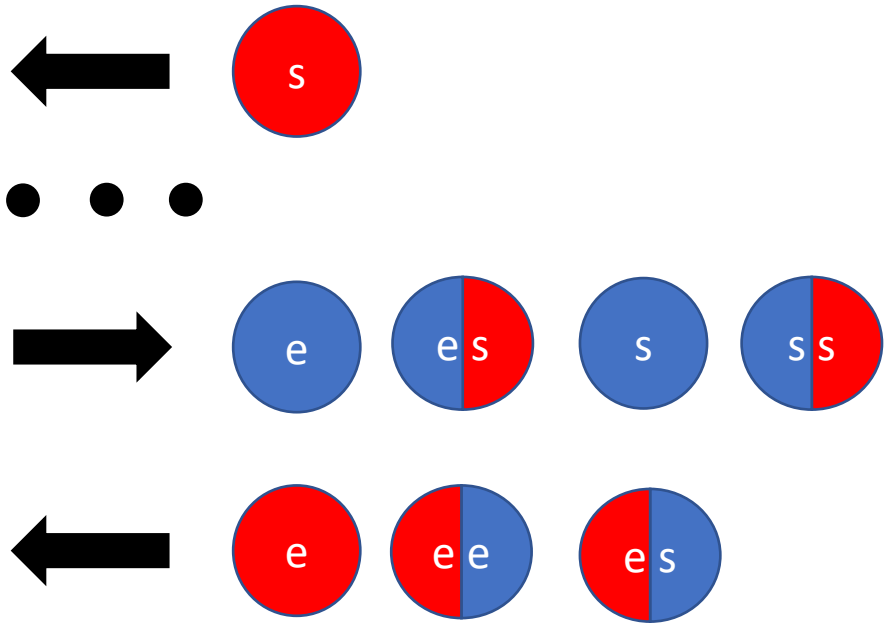

- More DHs
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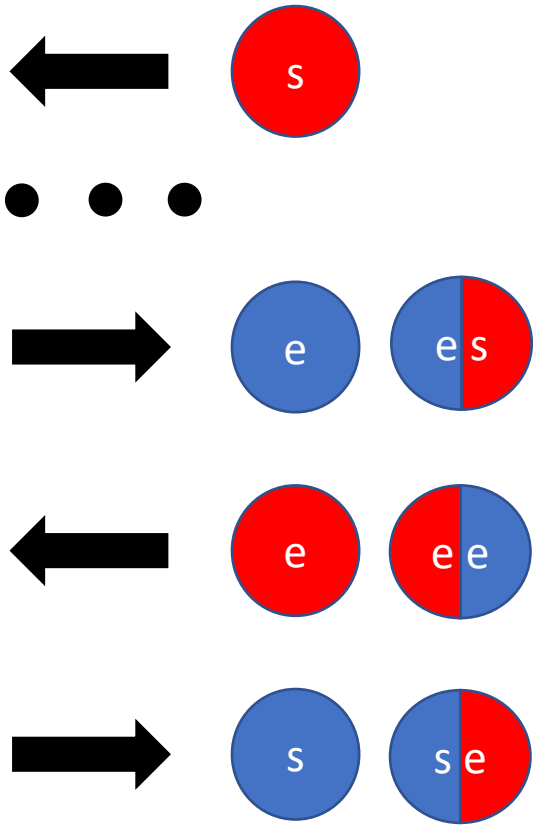

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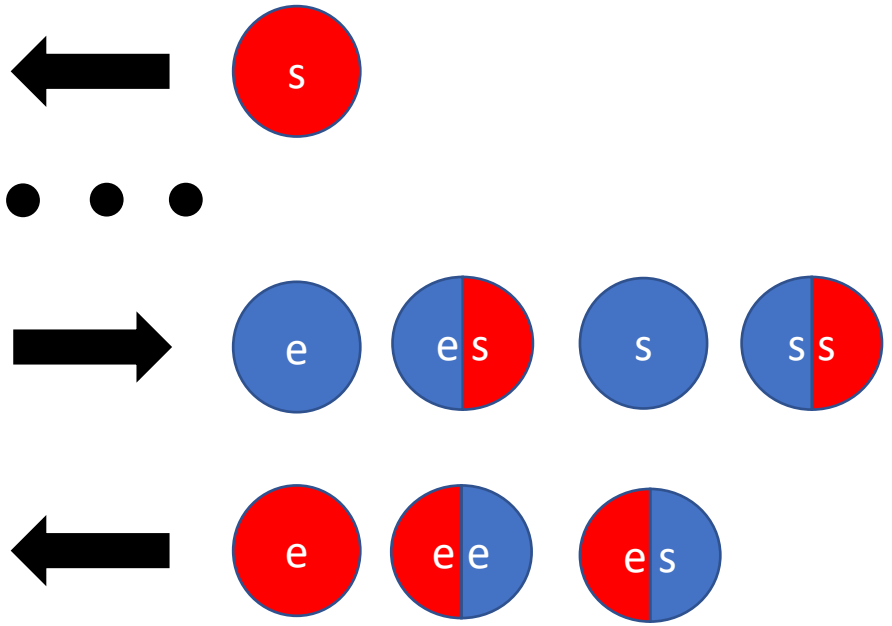

- More DHs
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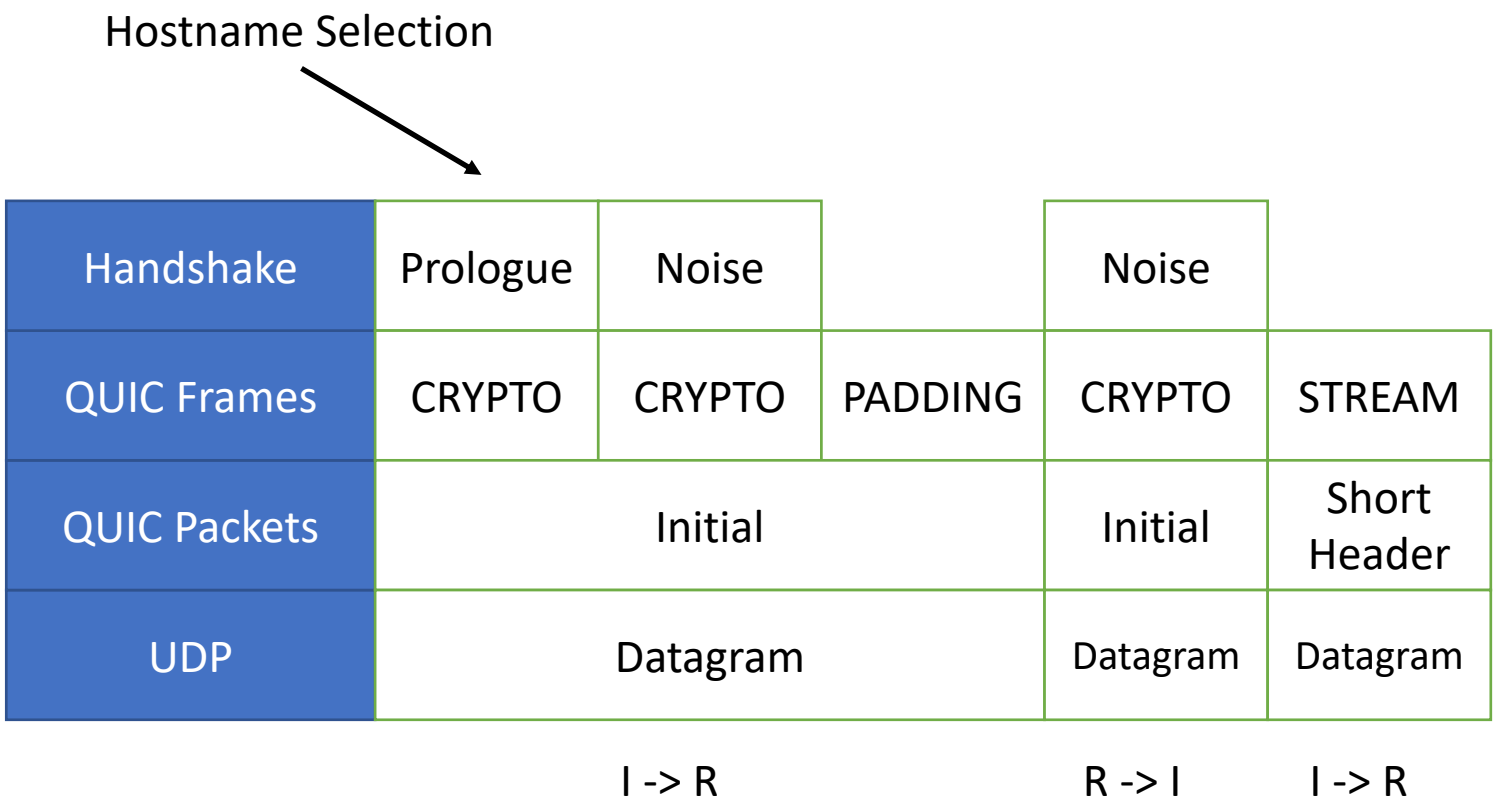
Ultimately, we found network latency to be the most serious constraint

Anatomy of nQUIC

Handshake	Prologue	Noise		Noise	
QUIC Frames	CRYPTO	CRYPTO	PADDING	CRYPTO	STREAM
QUIC Packets	Initial			Initial	Short Header
UDP	Datagram			Datagram	Datagram
	I -> R			R -> I	I -> R

Anatomy of nQUIC



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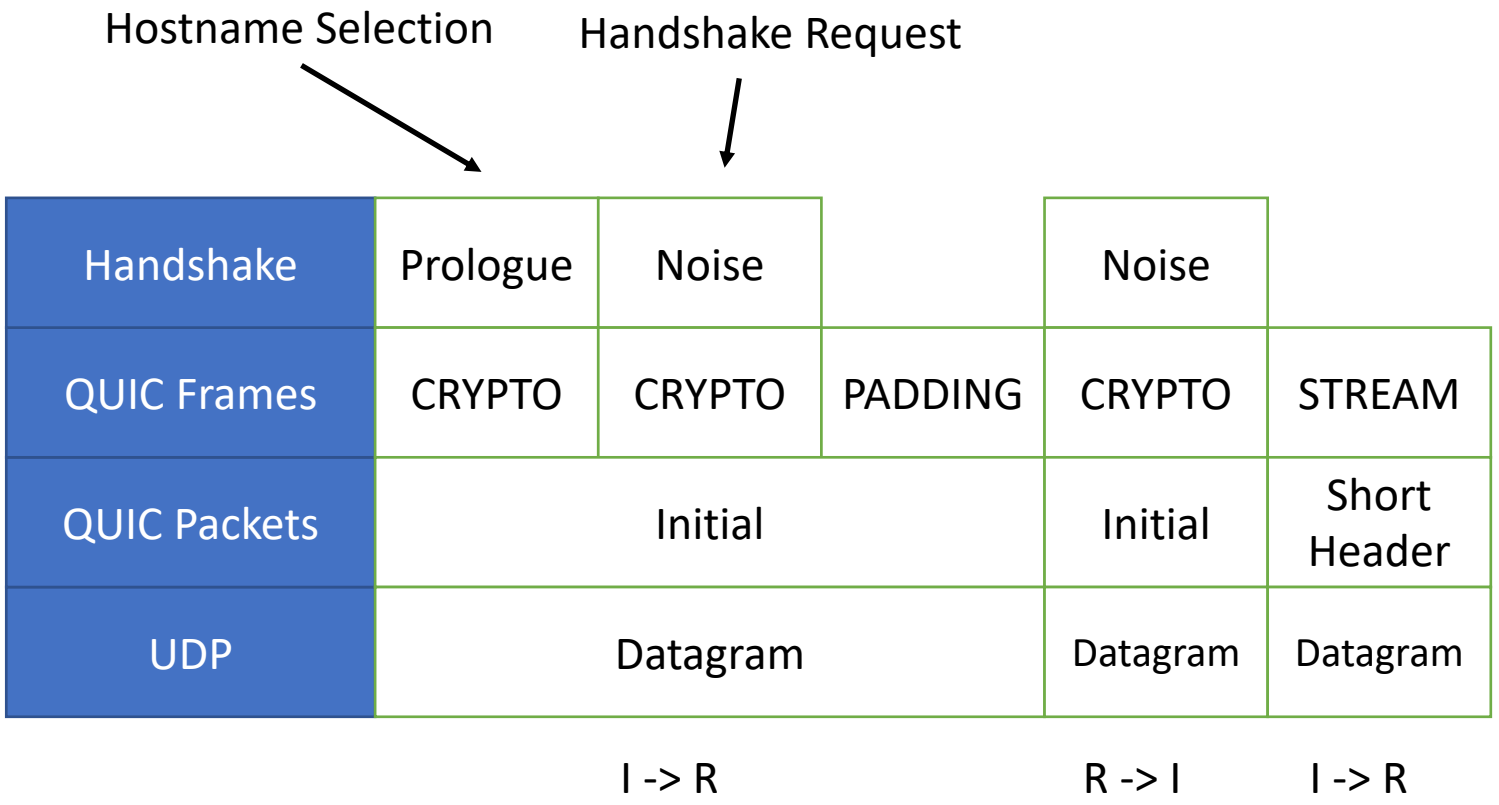

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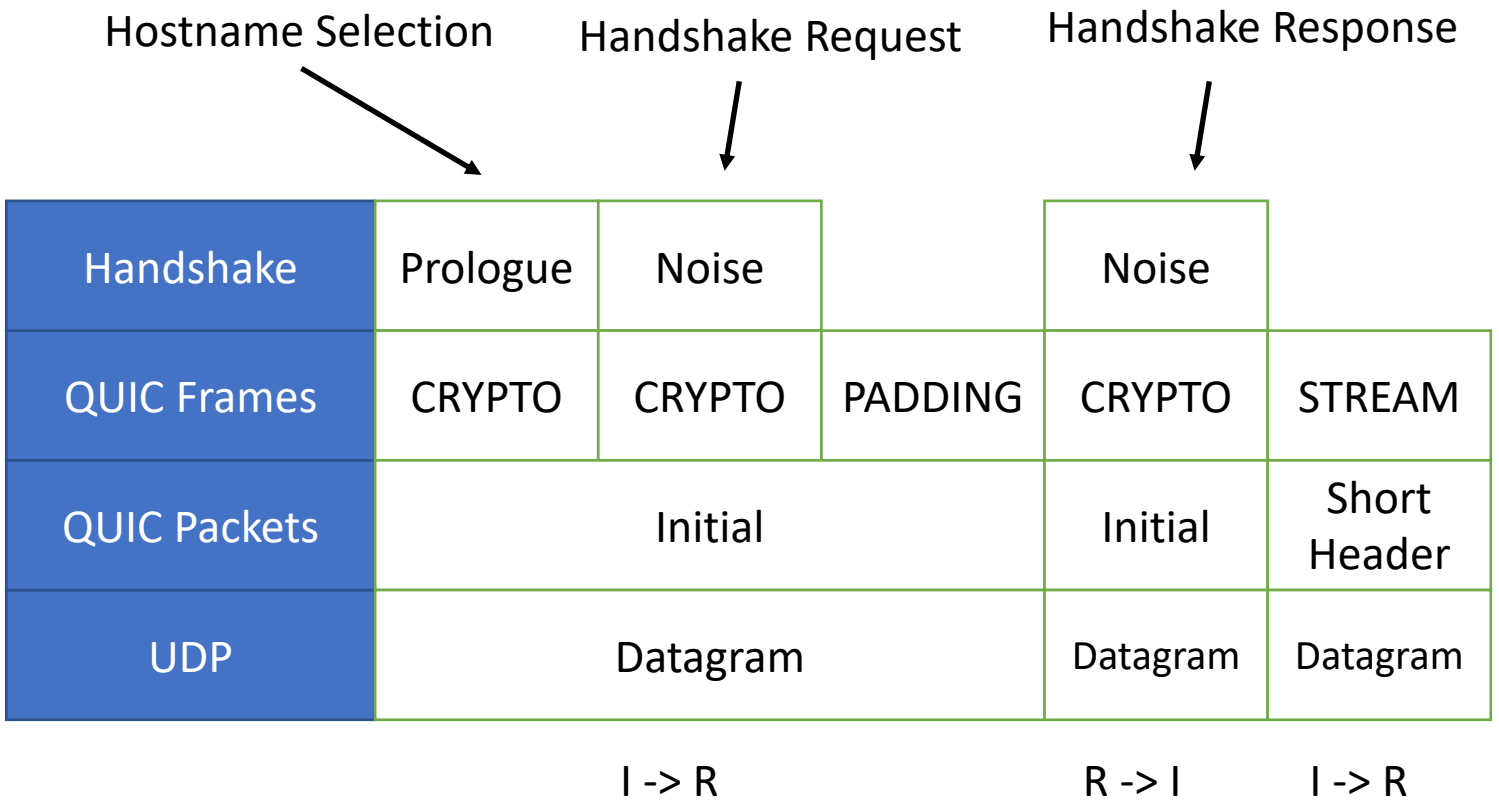

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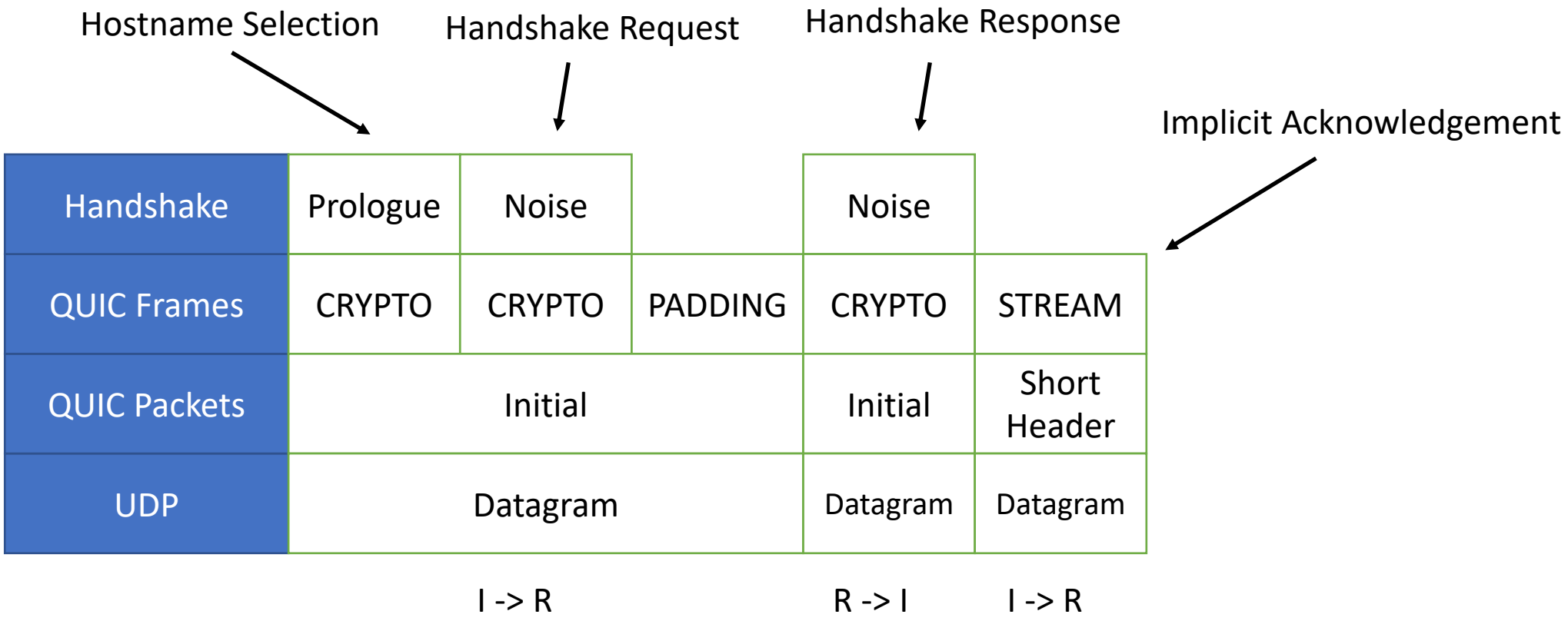

Hostname Selection

Problem: A server may be responsible for multiple endpoints, only one of which has the correct key.

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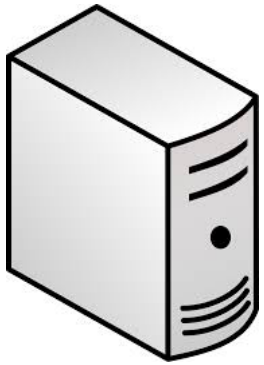

Has key pinning for A

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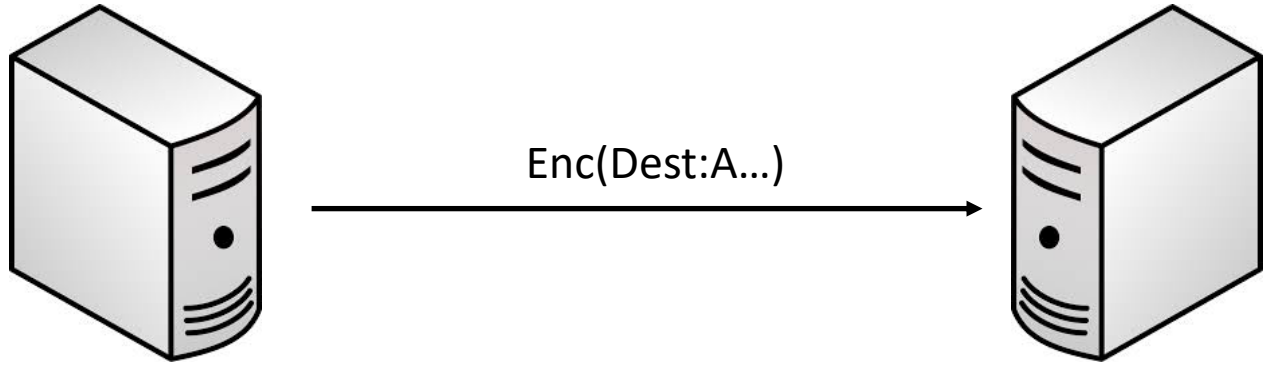

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Load Balancer or Server hosting multiple endpoints on same machine

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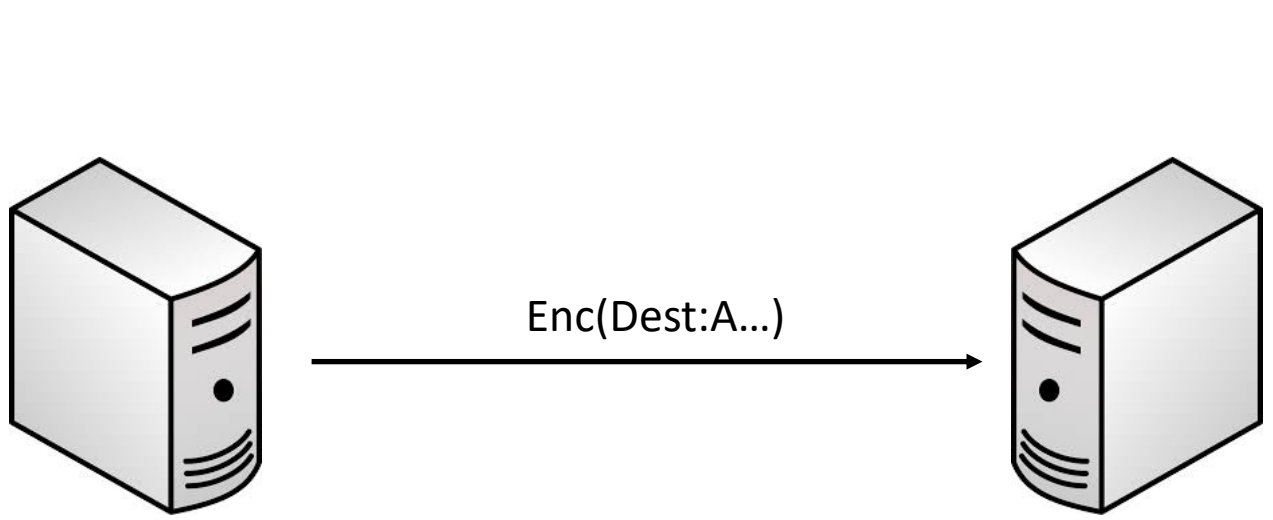

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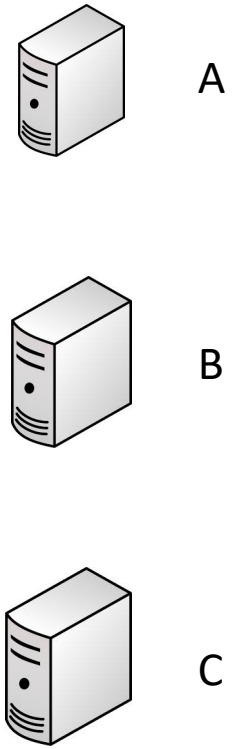

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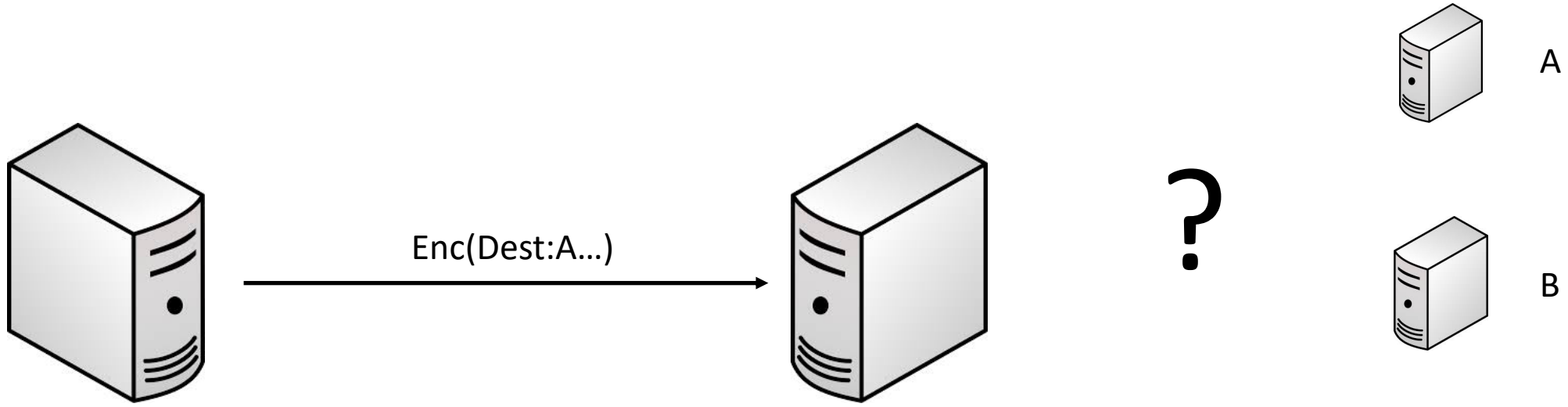

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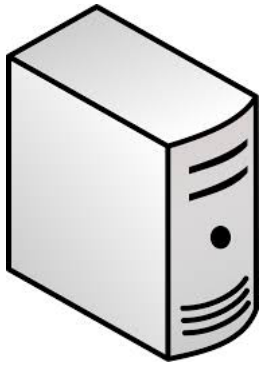
Hostname Selection

For TLS, SNI solves this by including the server id as part of the TLS negotiation



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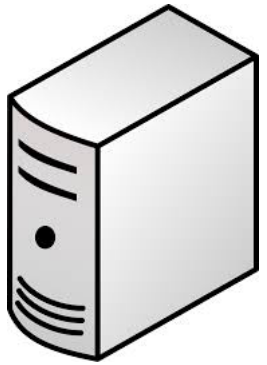

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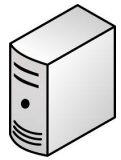
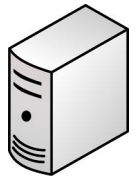
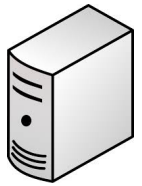


A



B



C

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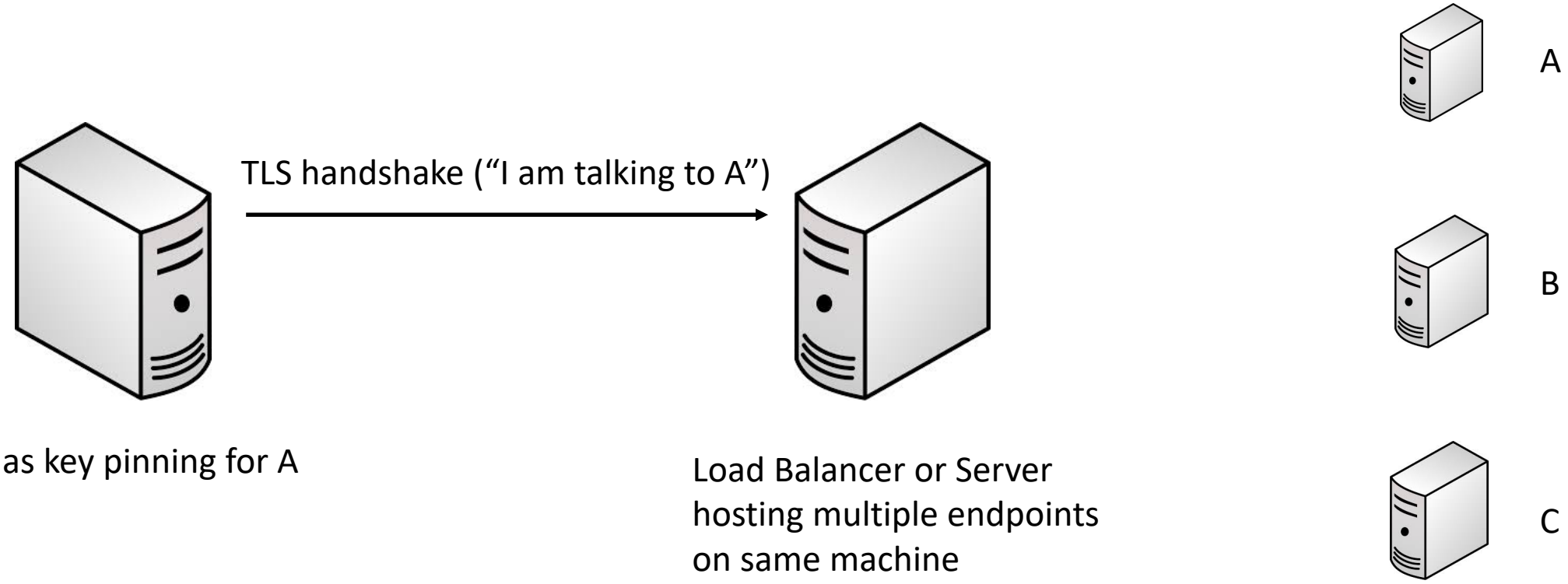

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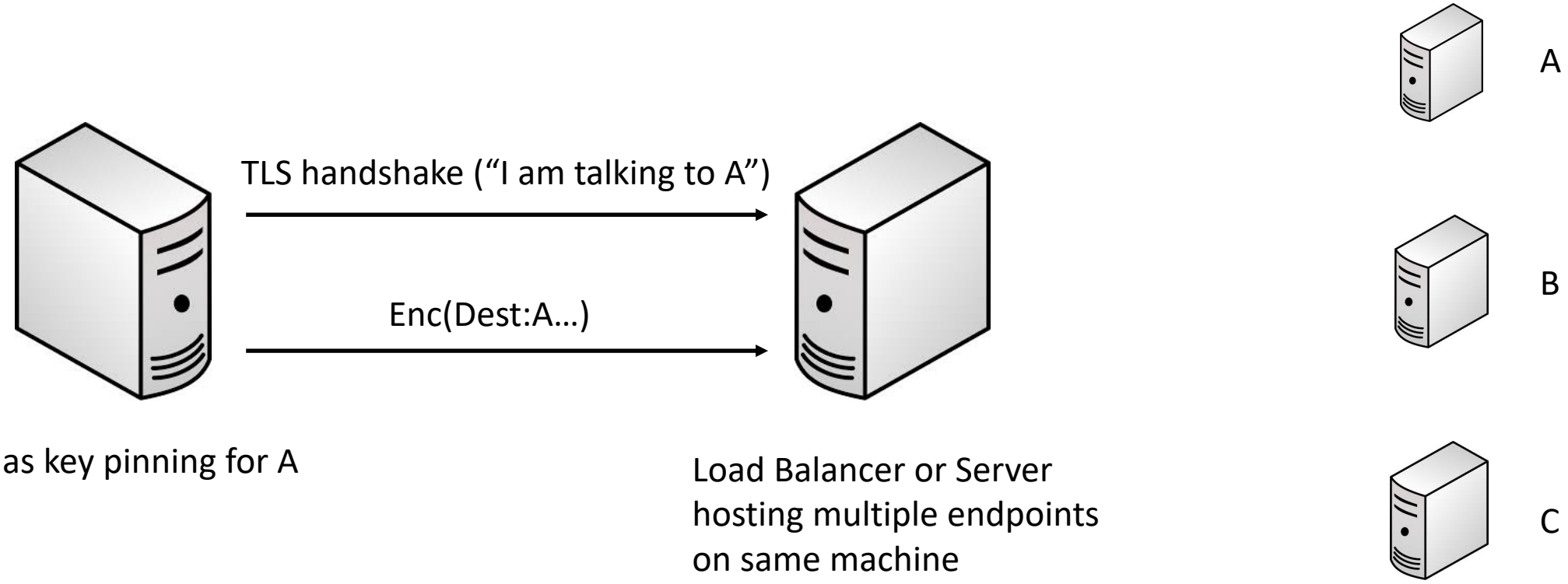

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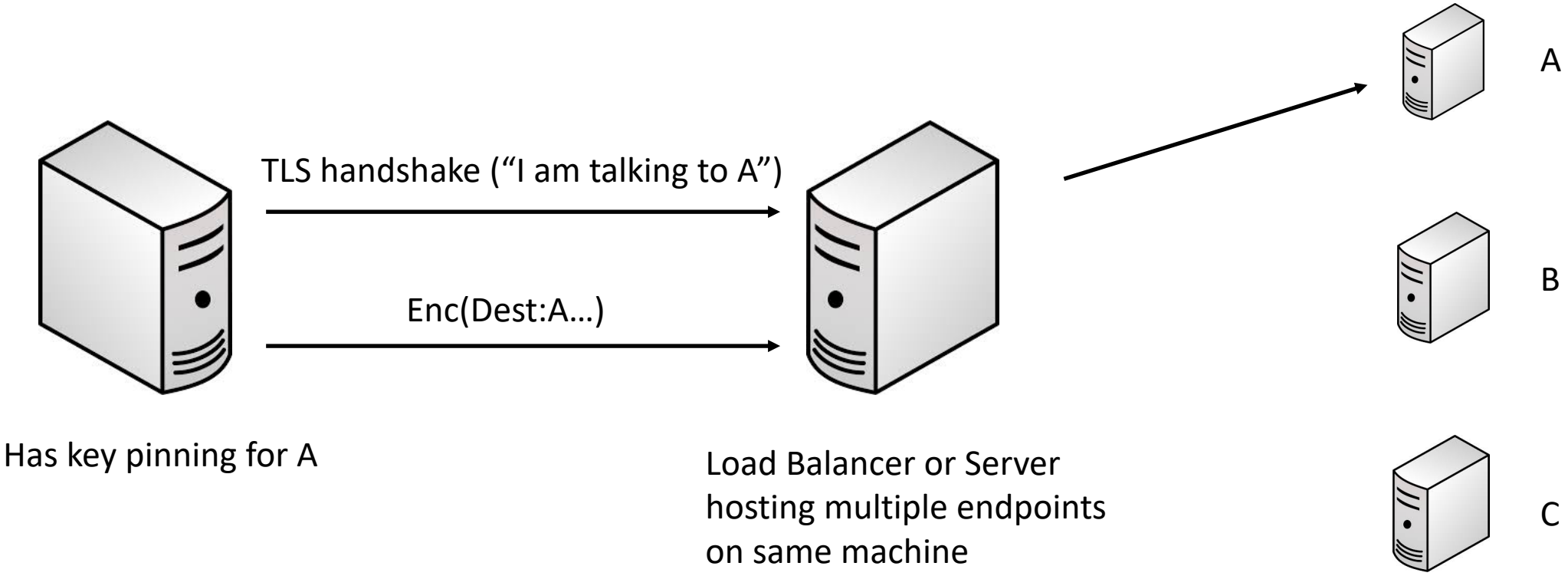

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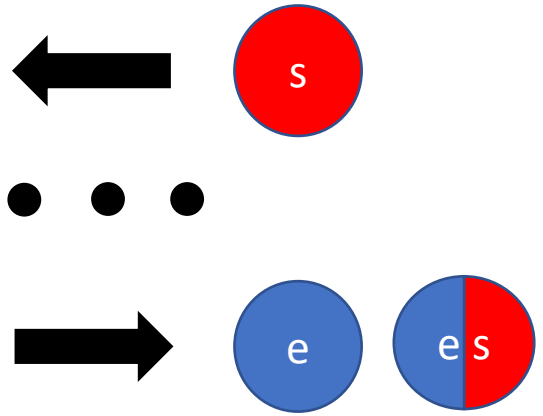
- Noise has a Prologue field that requires both parties to initialize the handshake with the same value
- We can use this field to support SNI
- If we need to hide this data from the forwarding server we can encrypt it using the N pattern:



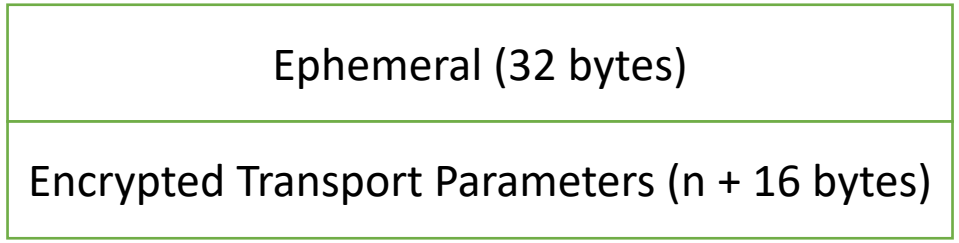
Handshake Request

- Indicates the start of the cryptographic handshake
- Transmits encrypted client transport parameters
- Optionally presents client’s Identity

Ephemeral (32 bytes)
Client Static (32 + 16 bytes)
Encrypted Transport Parameters (n + 16 bytes)

Handshake Response

- Completes Negotiation of Transport Keys
- Transmits encrypted server transport parameters
- Proves server’s identity



After this step, final keys are derived and passed to QUIC packet protector

Implicit Acknowledgement

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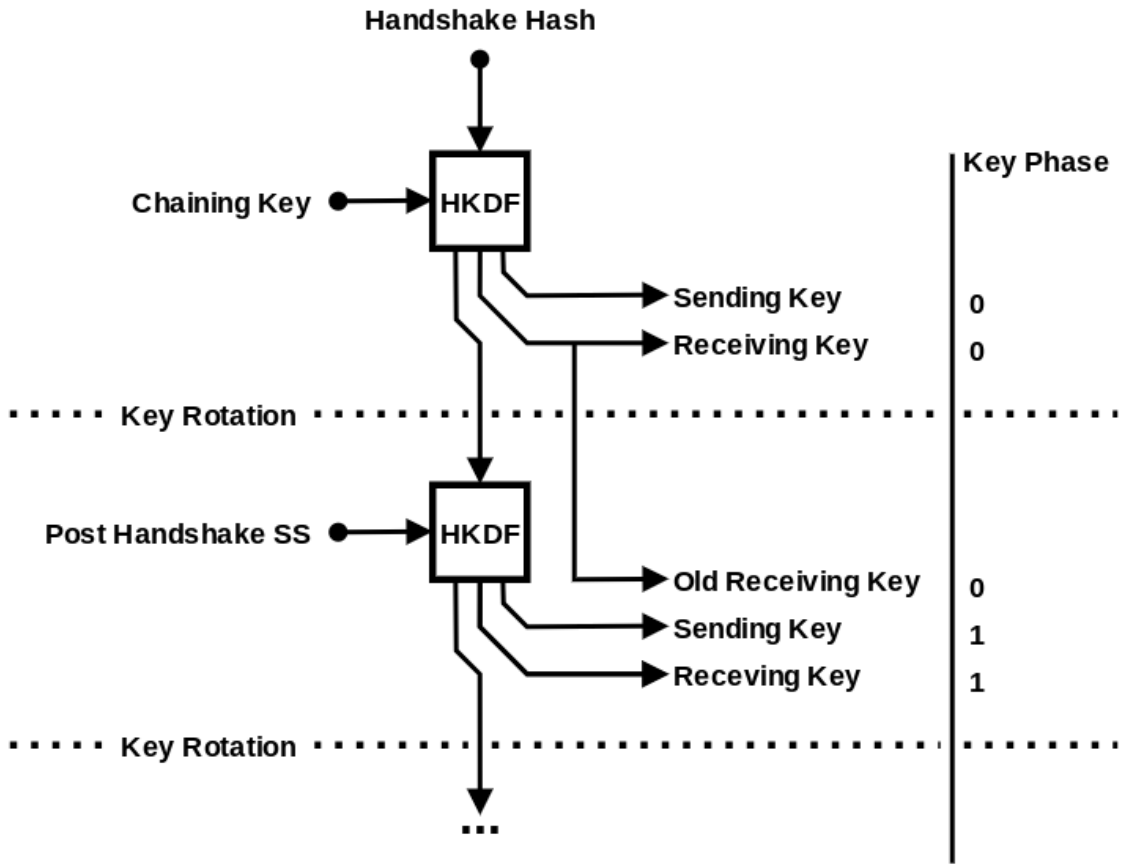
Implicit Acknowledgement

- In order to avoid replay or Key Compromise attacks, client must immediately send a packet encrypted under transport keys upon completing the handshake
- Only after this does the server consider the handshake finished
- If application data is not available a PADDING or PING frame is sent
- Clients ACK frames are not sufficient for this

Ratcheting in nQUIC



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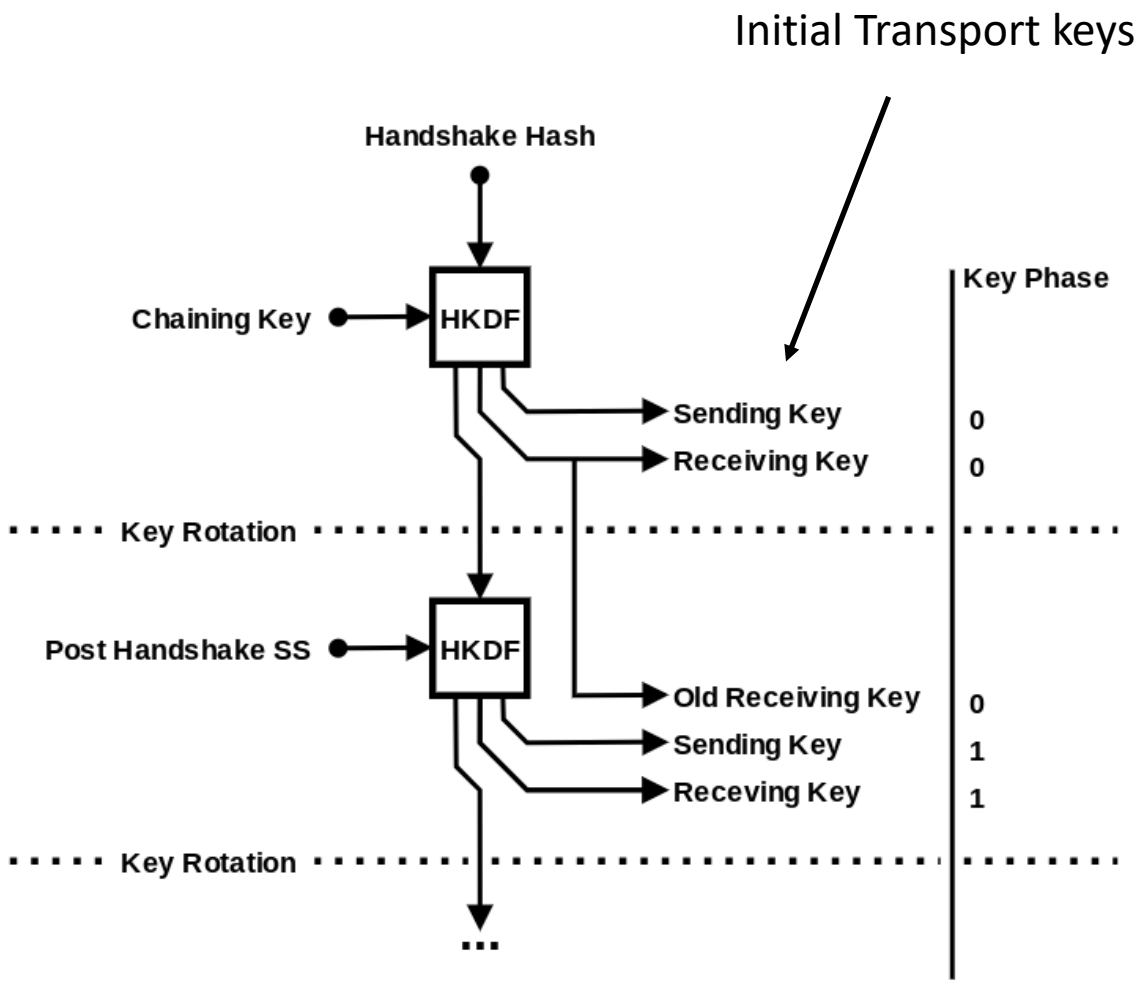

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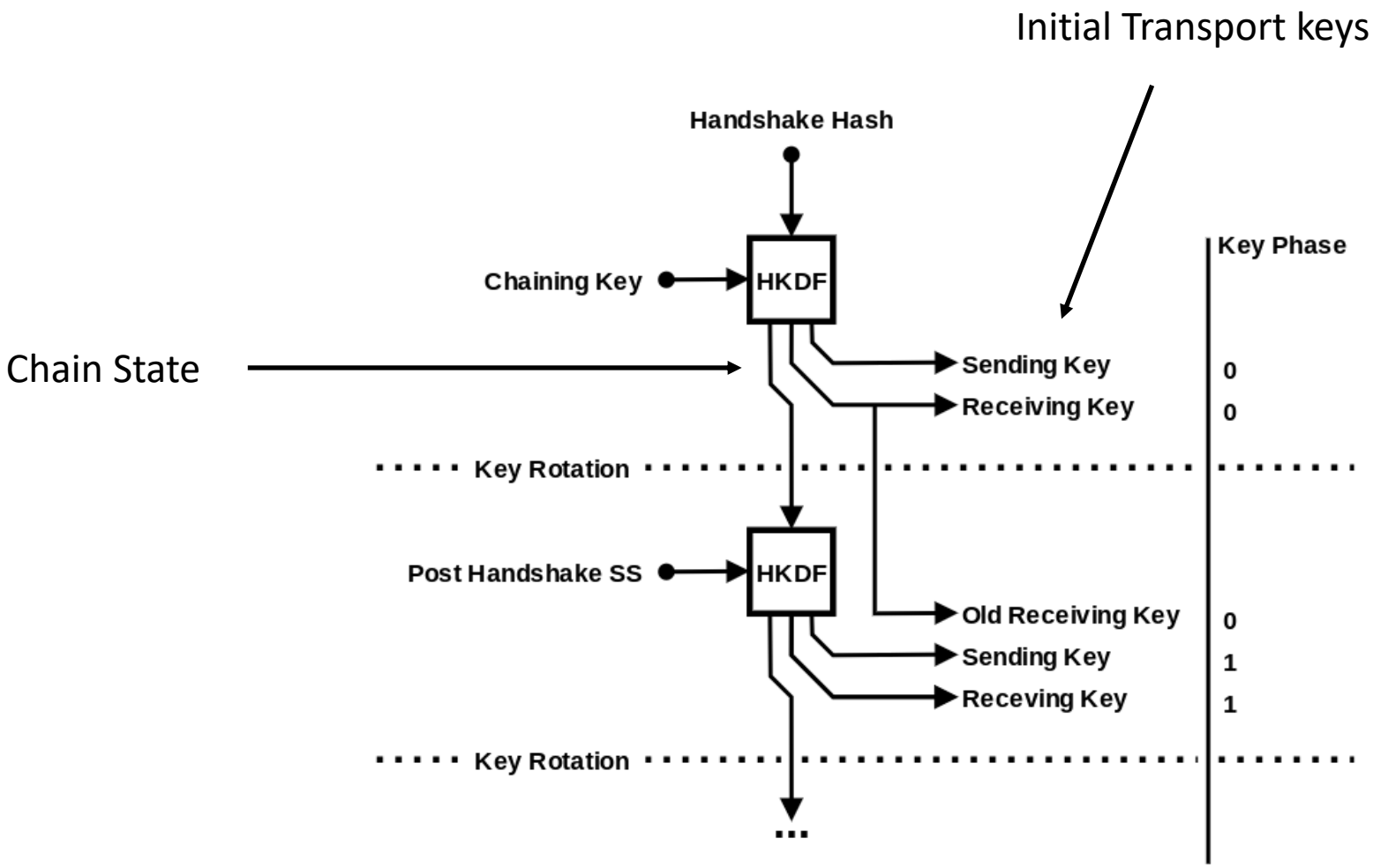

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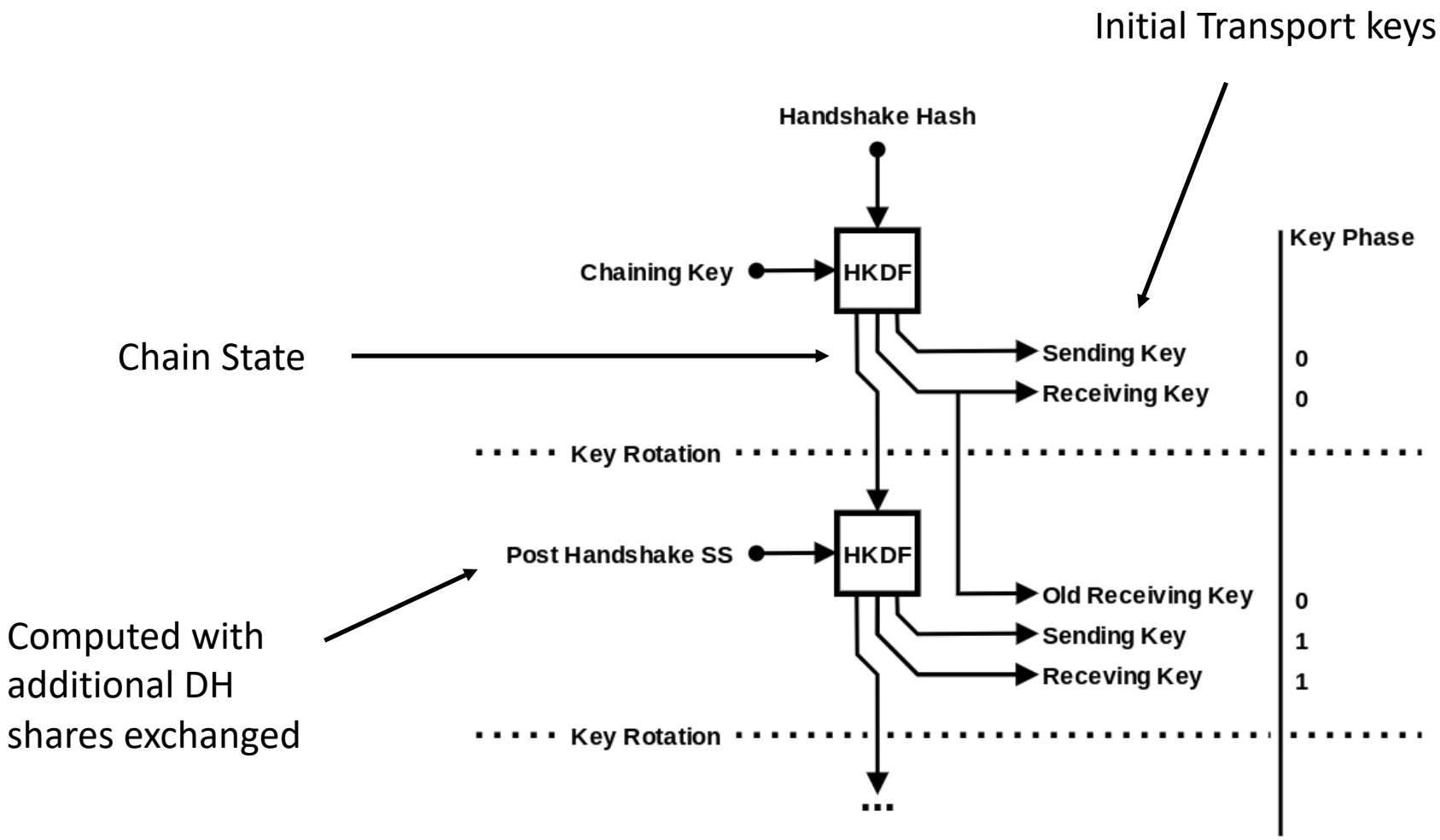

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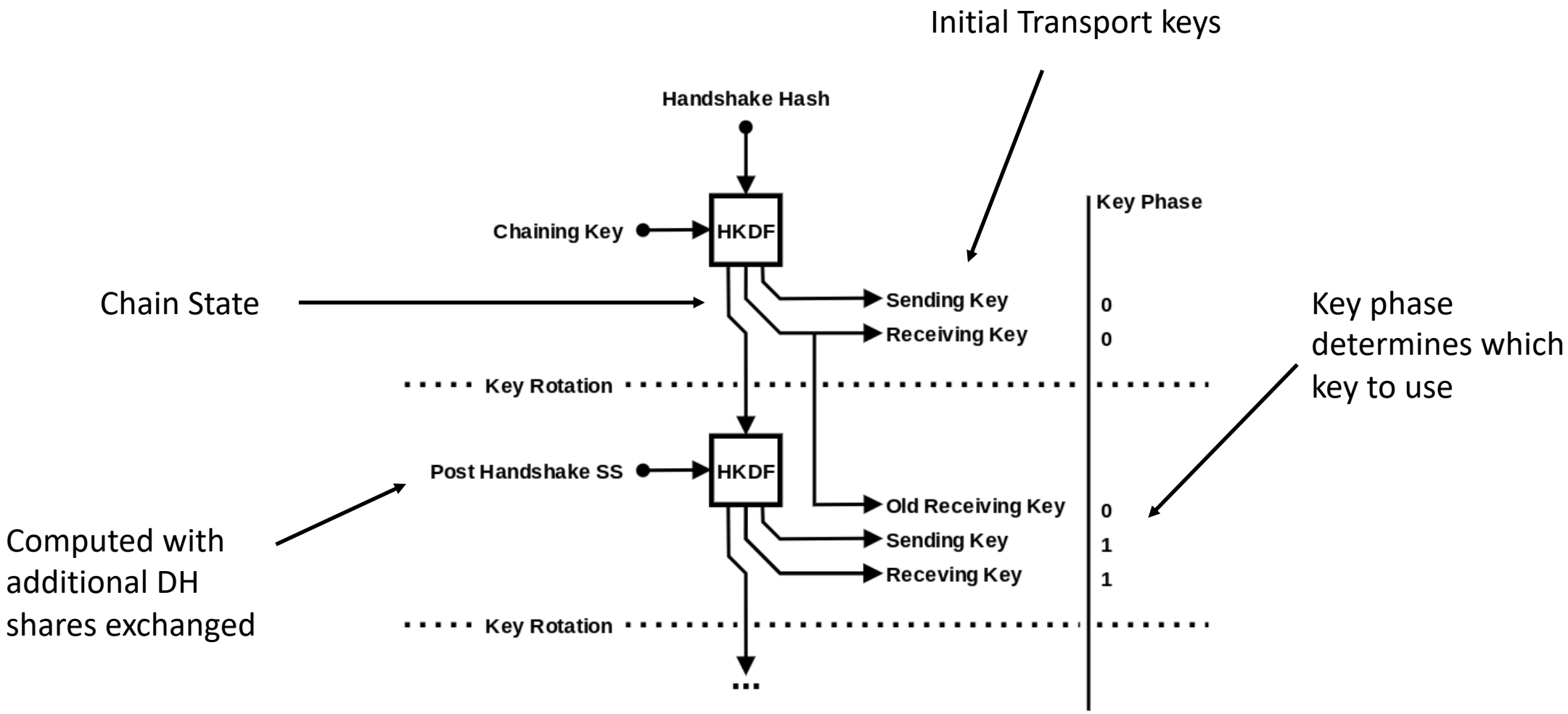

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- nQUIC is intended to be a minimal update to QUIC-TLS
- Potentially can be specified as a new QUIC version compatible with existing RFCs
- Since versions with the upper 16 bits clear are reserved for future IETF use we chose 0xff00000b for nQUIC

Cost Comparison

C_{key} be the cost of a key generation operation
C_{dh} be the cost of a key exchange operation
C_{sign} be the cost of a signing operation
C_{verif} be the cost of a signature verification operation

Figure 5: nQUIC Key Exchange Cost Comparison

Authentication	Client Cost	Server Cost
server	$1C_{key} + 4C_{dh}$	$1C_{key} + 4C_{dh}$
mutual	$1C_{key} + 4C_{dh}$	$1C_{key} + 4C_{dh}$

Figure 6: QUIC-TLS Key Exchange Cost Comparison

Authentication	Client Cost	Server Cost
server	$1C_{key} + 1C_{dh} + XC_{verif}$	$1C_{key} + 1C_{dh} + 1C_{sign}$
mutual	$1C_{key} + 1C_{dh} + XC_{verif} + 1C_{sign}$	$1C_{key} + 1C_{dh} + YC_{verif} + 1C_{sign}$
psk	None	None
psk_dhe	$1C_{key} + 2C_{dh}$	$1C_{key} + 2C_{dh}$

Performance Evaluation

The key difference in nQUIC and QUIC-TLS is the handshake

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These libraries where significantly smaller than the QUIC libraries they were based on

Performance Evaluation

Implementation	Encryption	Hash	Handshake Time (s)	Handshake Bandwidth (B)
ninn (nQUIC)	AES-GCM-256	SHA-256	0.00135	1496
quinn (QUIC-TLS)	AES-GCM-256	SHA-384	0.00193	3426
quic-go (QUIC-TLS)	AES-GCM-256	SHA-384	0.02949	3230
quic-go (QUIC-TLS PSK)	AES-GCM-256	SHA-384	0.02689	2036
nquic-go (nQUIC)	AES-GCM-256	SHA-256	0.01023	1463

Conclusion

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Supporting a variety of handshake protocols will help avoid ossification and allow for scenario specific optimizations

Questions?

- Thank you!