Drive (Quantum) Safe! --Towards Post-Quantum Security for Vehicle-to-Vehicle Communications

Real World Crypto 2022
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joint work with Sarah McCarthy
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615,000

THE NUMBER OF MOTOR VEHICLE CRASHES PER YEAR THAT COULD BE PREVENTED USING V2V TECHNOLOGY[1]

[1] U.S. Department of Transportation, https://www.nhtsa.gov/technology-innovation/vehicle-vehicle-communication

20-30%

REDUCTION IN CONGESTION[2]

[2] On a segment of Interstate 5 freeway in the Orange County area, https://www.westernite.org/annualmeetings/15_Las_Vegas/Papers/7C-Shah.pdf

5%

REDUCTION IN CO_2 EMISSIONS[3]

[3] F. Outay, F. Kamoun, F. Kaisser, D. Alterri, A. Yasar, 2019. V2V and V2I communications for traffic safety and CO2 emission reduction: A performance evaluation. *Procedia Computer Science*, *151*, pp.353-360.

BY 2025, THERE WILL BE 100 MILLION CONNECTED CARS GLOBALLY[4]

[4] According to Communications Service Provider TIM, via https://www.ericsson.com/en/connected-vehicles

[5] S. Dongre and H. Rahbari. Message sieving to mitigate smart gridlock attacks in V2V. In Proceedings of the ACM Conference on Security and Privacy in Wireless & Mobile Networks (WiSec), 2021

BY 2025, THERE WILL BE 100 MILLION CONNECTED CARS GLOBALLY[4]

…BUT WILL THEY BE SECURE

…EVEN AGAINST QUANTUM ATTACKERS?

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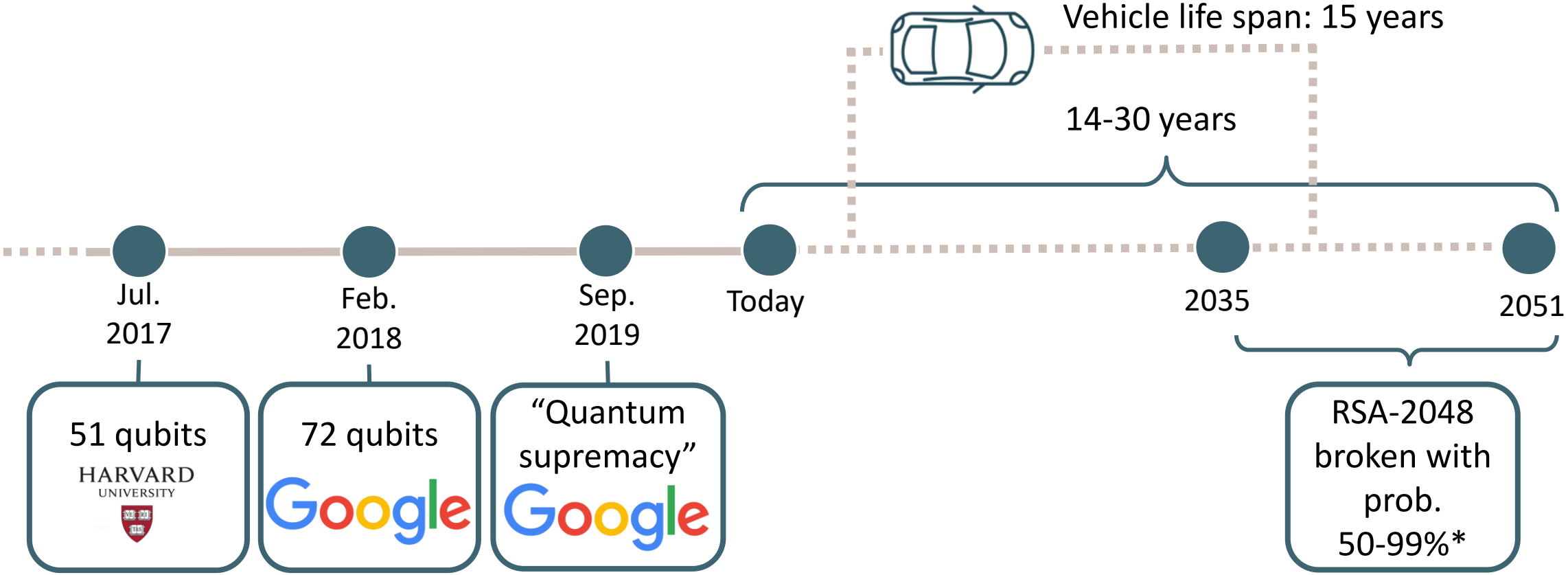
Urgency of PQ Transition for Vehicle-to-Vehicle Communication



*Global Risk Institute, Canada,2019

Outline

- Introduction to **Secure** Vehicle-to-Vehicle (V2V) Communication
- **Challenges** of Quantum-Secure V2V Communication
- Suggestion of **Standard-Compliant** Classical – Post-Quantum **Hybrid Solutions**

*All icons from flaticom.com using premium account.

Introduction to V2V Communication

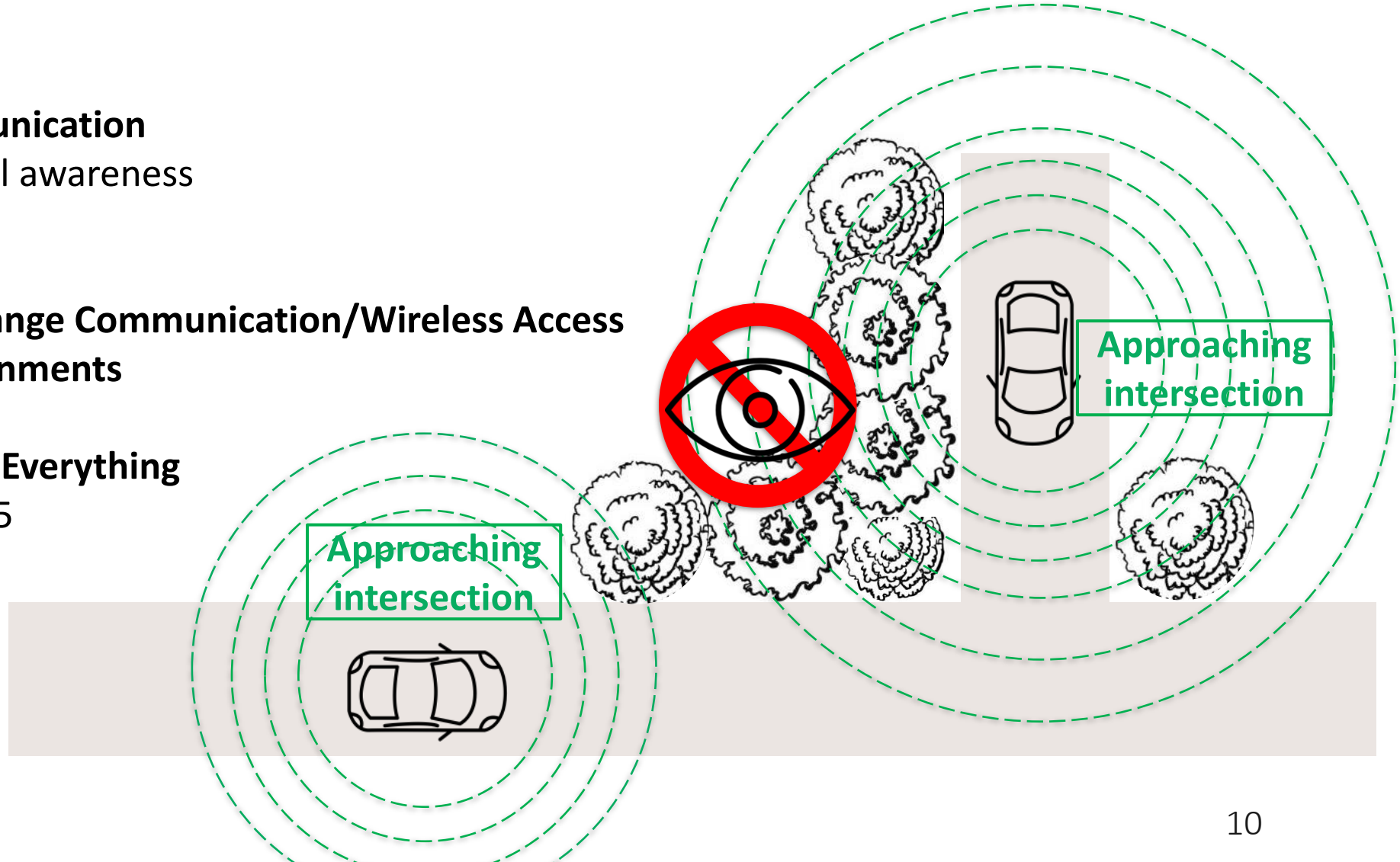
V2V Communication

Direct wireless communication

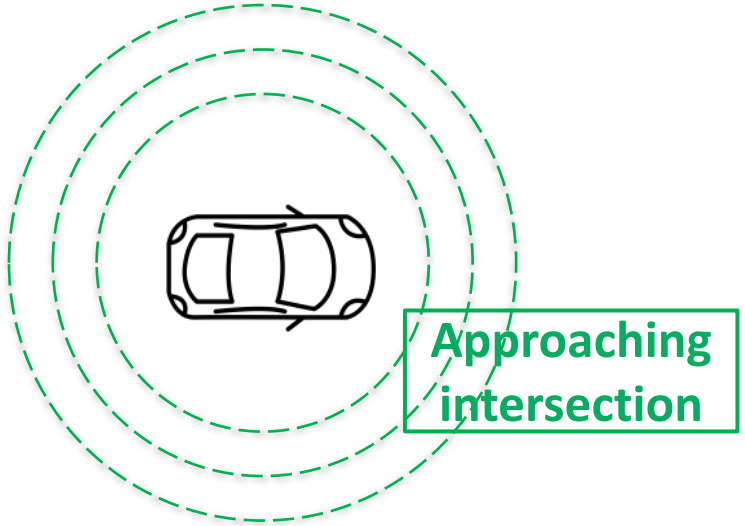
- Increases situational awareness

Described in

- **Dedicated Short Range Communication/Wireless Access in Vehicular Environments**
  IEEE 802.11p
- **Cellular Vehicle-to-Everything**
  3GPP Release 14/15



Basic Safety Messages (BSMs)



Every vehicle broadcasts 10 BSMs per second within transmission range

Direction

Speed

Time

Location

Brake and acceleration status

Introduction to **Secure** V2V Communication

IEEE 1609.2 Standard

Secure wireless communication

- secure transmission of messages
- cryptographic operations
- certificate management

Security goal

"to protect messages from attacks such as eavesdropping, spoofing, alteration, and replay."[6]

[6]IEEE Standard for Wireless Access in Vehicular Environments—Security Services for Applications and Management Messages, IEEE Standard 1609.2, 2016.

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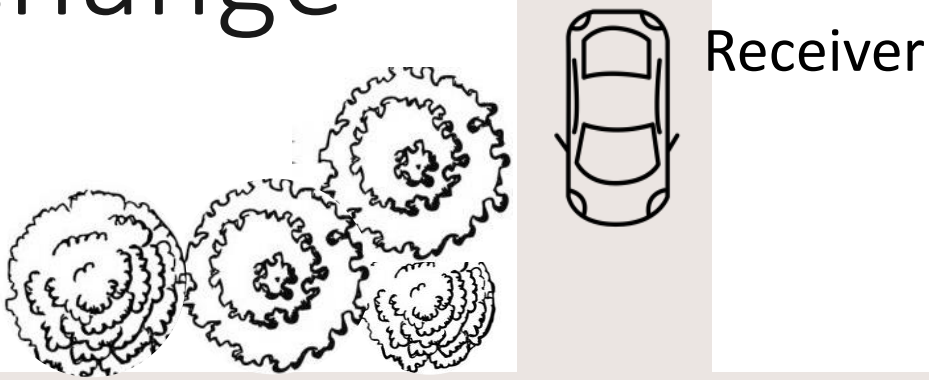
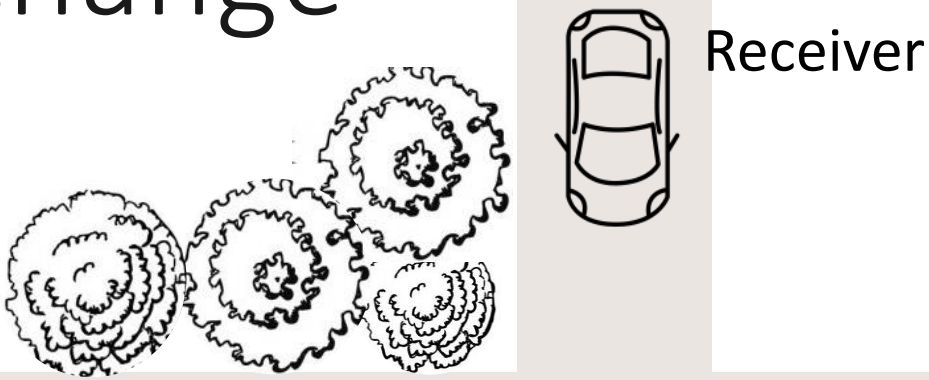
Secure BSM Exchange (IEEE 1609.2)



Secure BSM Exchange (IEEE 1609.2)

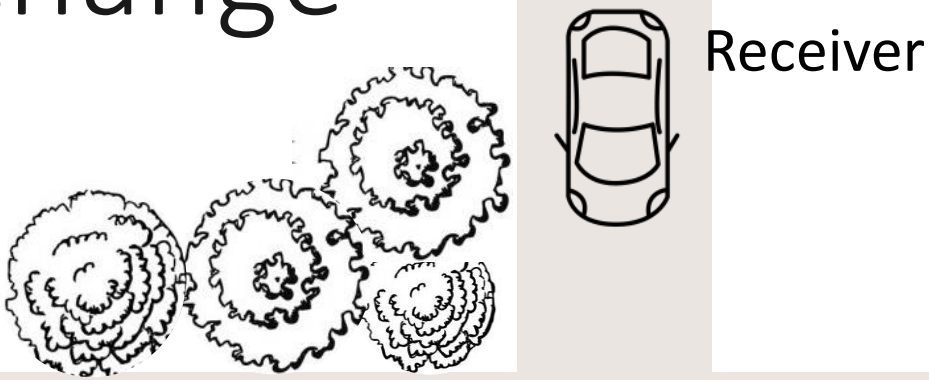


Receiver

Sender

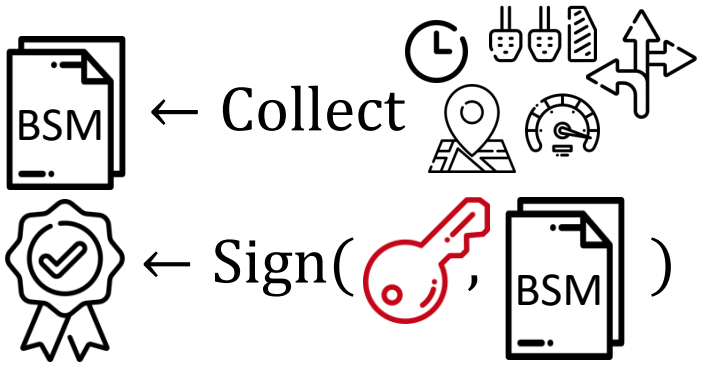
← Collect

Secure BSM Exchange (IEEE 1609.2)



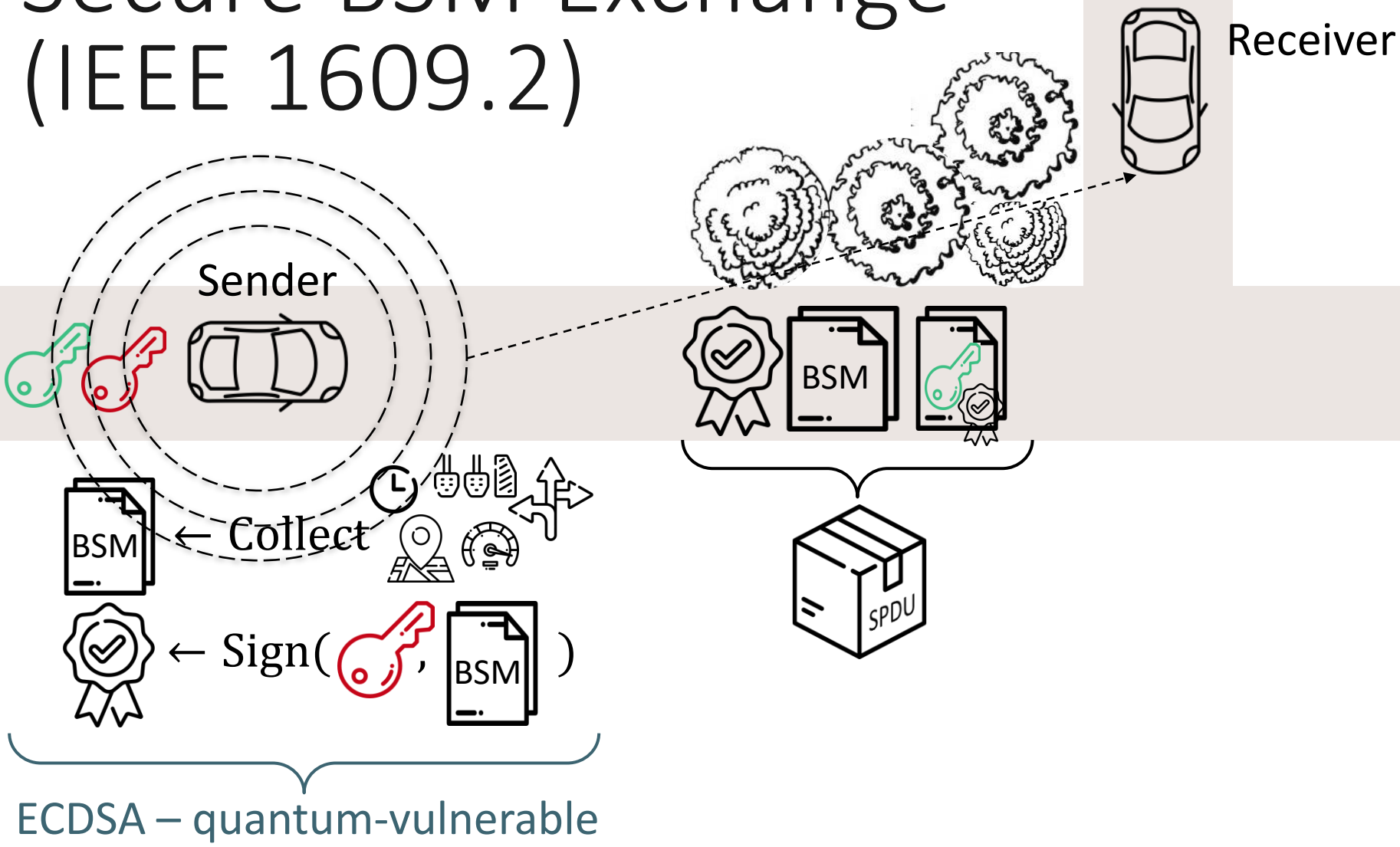
Receiver

Sender



ECDSA – quantum-vulnerable

Secure BSM Exchange (IEEE 1609.2)



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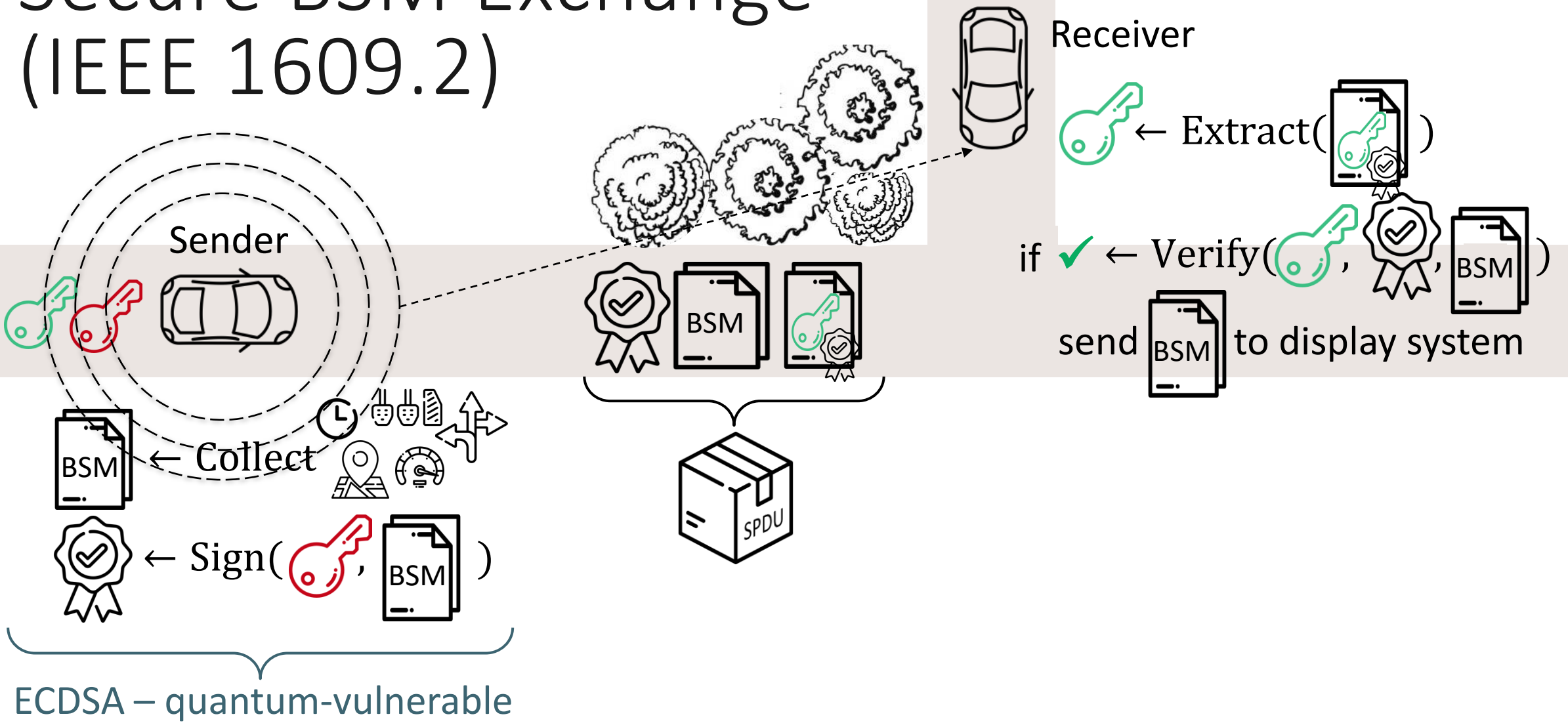

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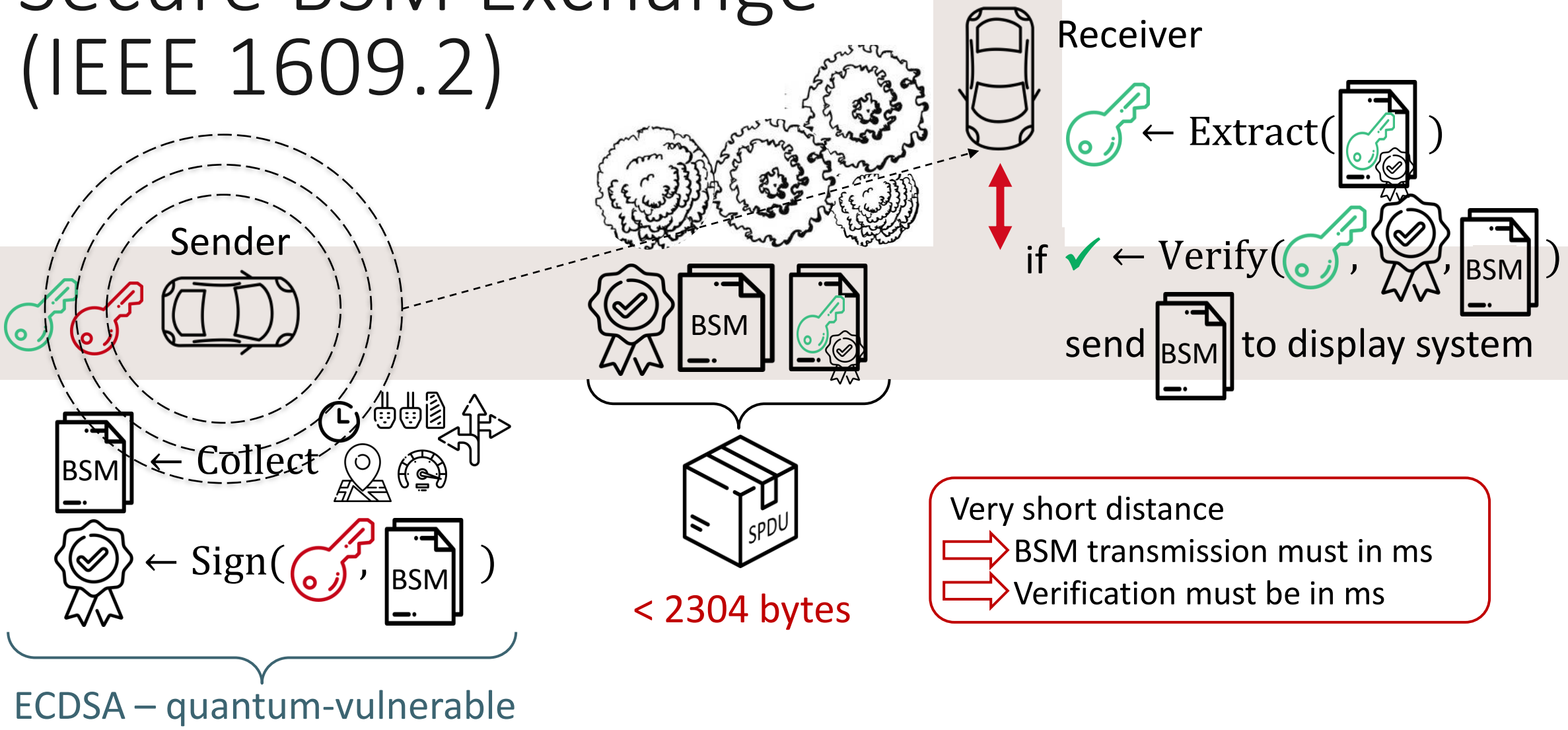
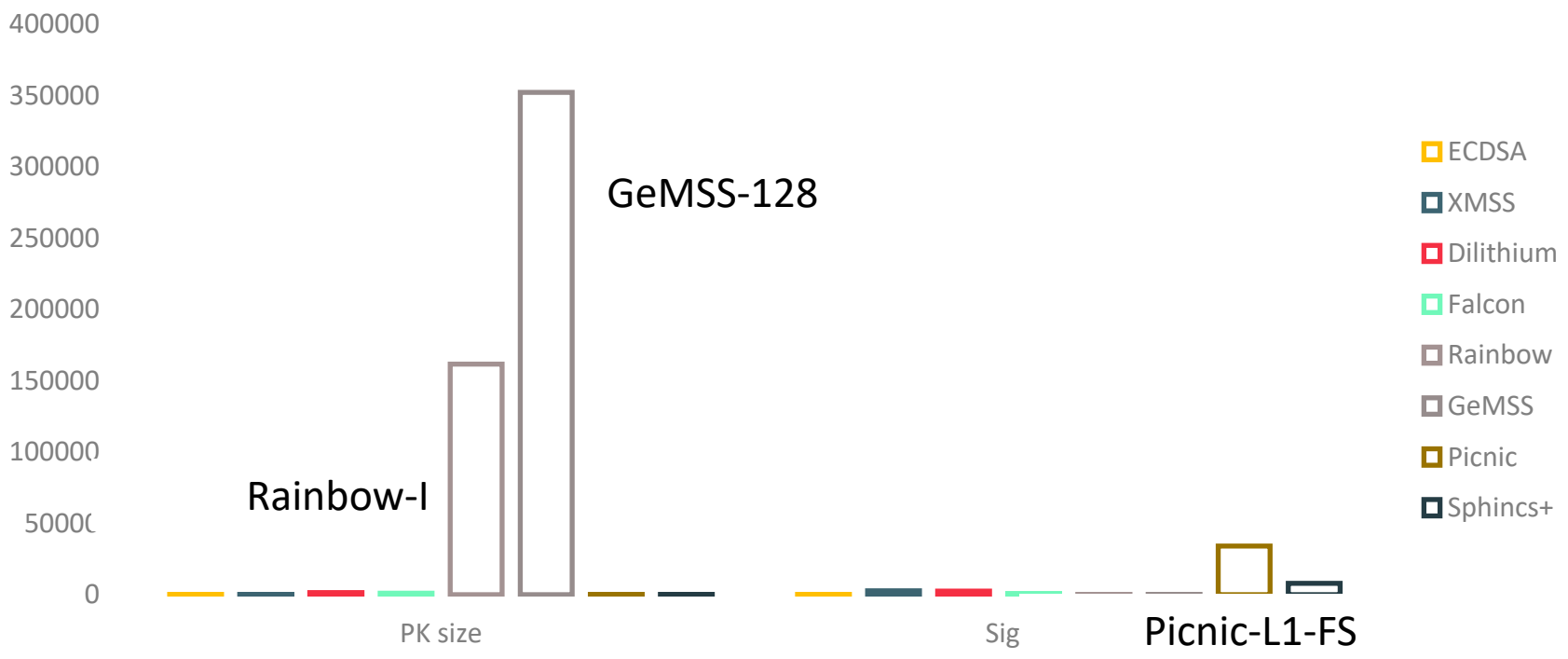
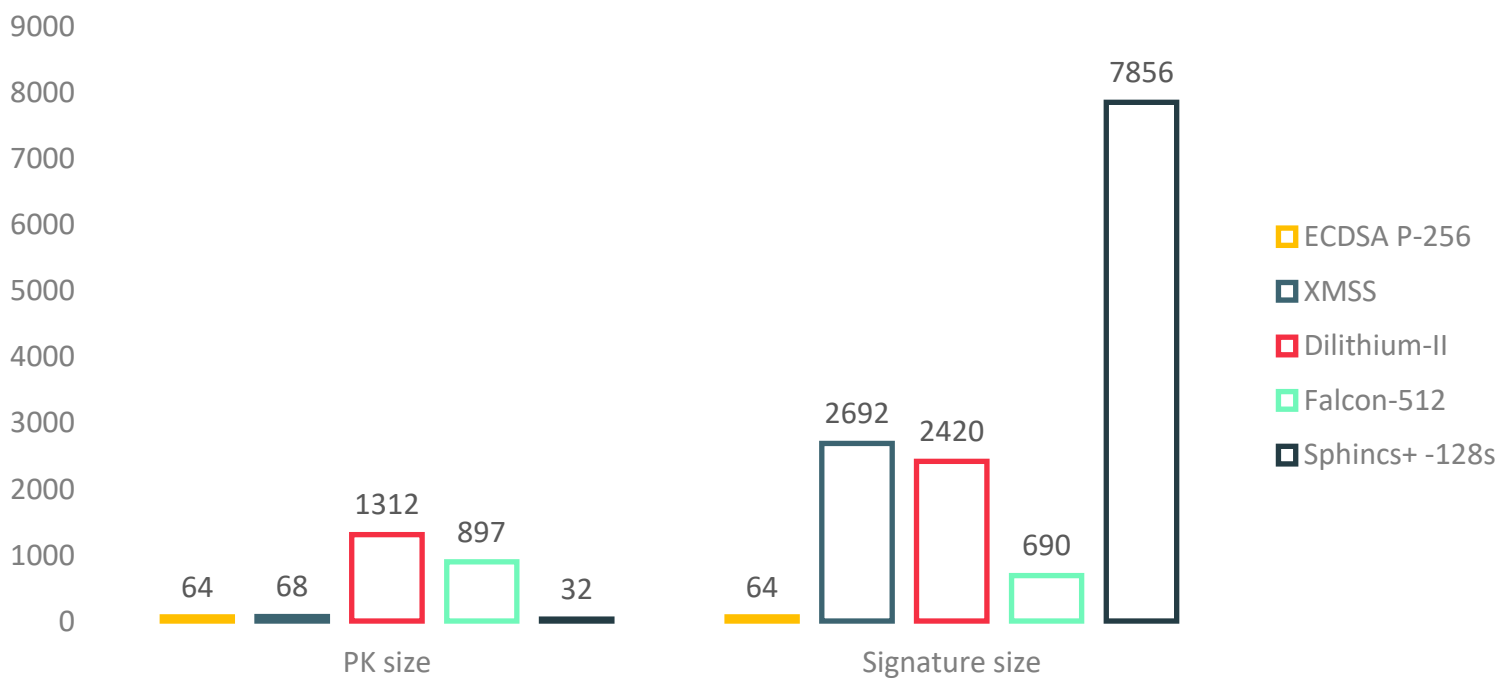


Challenges of PQ V2V Communication

Sizes of PQ Signature Candidates



Sizes of PQ Signature Candidates
(w/o Rainbow, GeMSS, Picnic)



Danger of BSM loss?

Explicit vs Implicit Certs

CA cert

Including $\mathrm{pk}_{\mathrm{CA}}$

$= \mathrm{Sign}_{\mathrm{CA}}(\mathrm{sk}_{\mathrm{CA}},$ [illegible] $)$

User explicit cert

Including pk_{U}, ID of issuing CA

$= \mathrm{Sign}_{\mathrm{CA}}(\mathrm{sk}_{\mathrm{CA}},$ [illegible] $)$

CA cert

Including $\mathrm{pk}_{\mathrm{CA}}$

$= \mathrm{Sign}_{\mathrm{CA}}(\mathrm{sk}_{\mathrm{CA}},$ [illegible] $)$

User implicit cert

Including reconstruction value R_{U}, ID of issuing CA

Explicit vs Implicit Certs

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Including reconstruction value $\mathrm{R_U}$, ID of issuing CA

Goal:

$| \quad | + |\mathrm{pk_U}| \geq |R_U|$

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User implicit cert

Including reconstruction value R_{U}, ID of issuing CA

Goal:

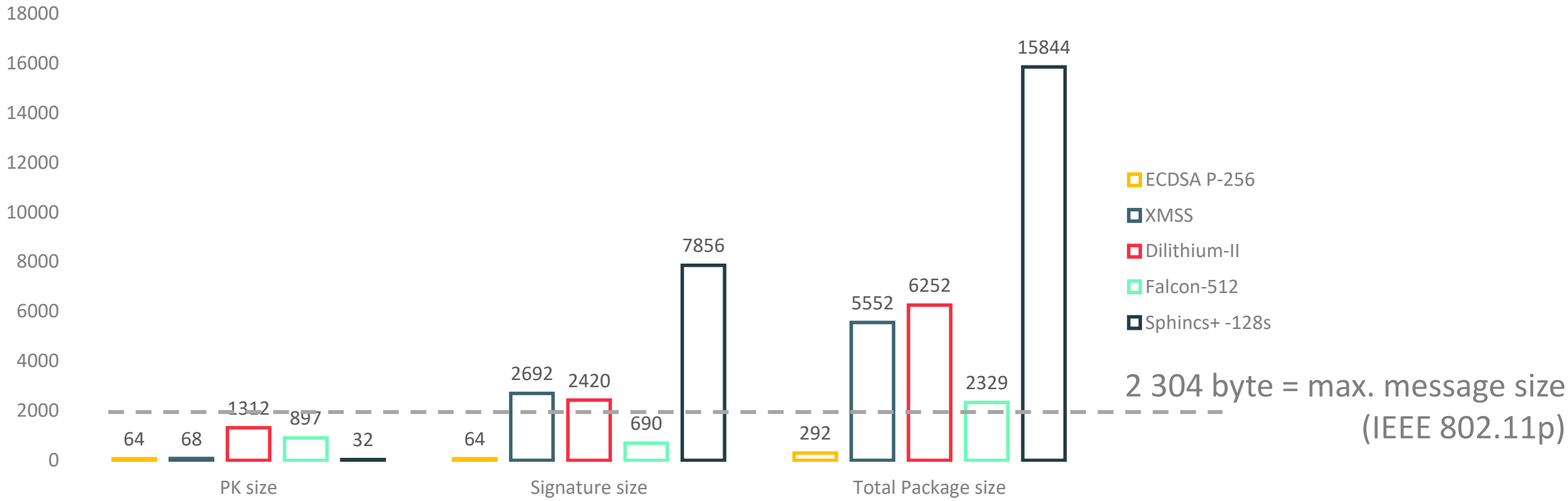
$| \quad | + |\mathrm{pk}_{\mathrm{U}}| \geq |R_U|$

Construction from elliptic curves:
Elliptic curve Qu-Vanstone scheme

Construction from lattice/PQC:
???*

*The Need for Being Explicit When Communicating; N. Bindel & S. McCarthy; Cfail 2021

Total Package Sizes of Selected PQ Signature Candidates



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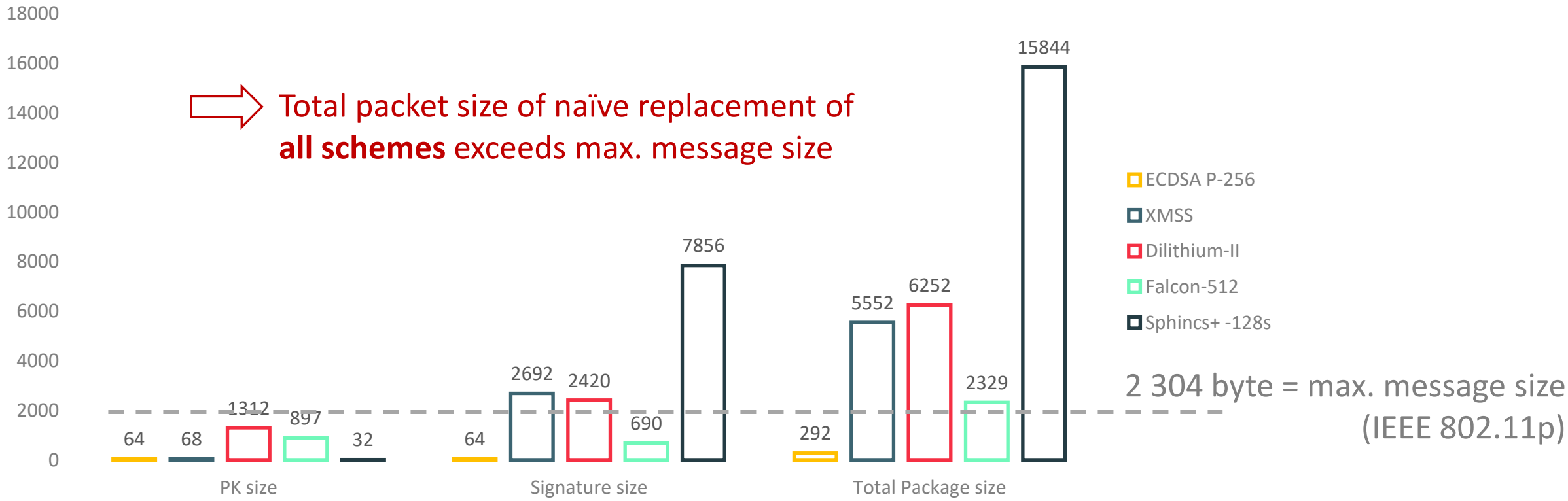

Standard-Compliant Classical-PQ Hybrid Solutions

Hybrid Approach Idea

Suggested by most standardization agencies, e.g. NIST, ETSI, IETF

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S_1 - PQ

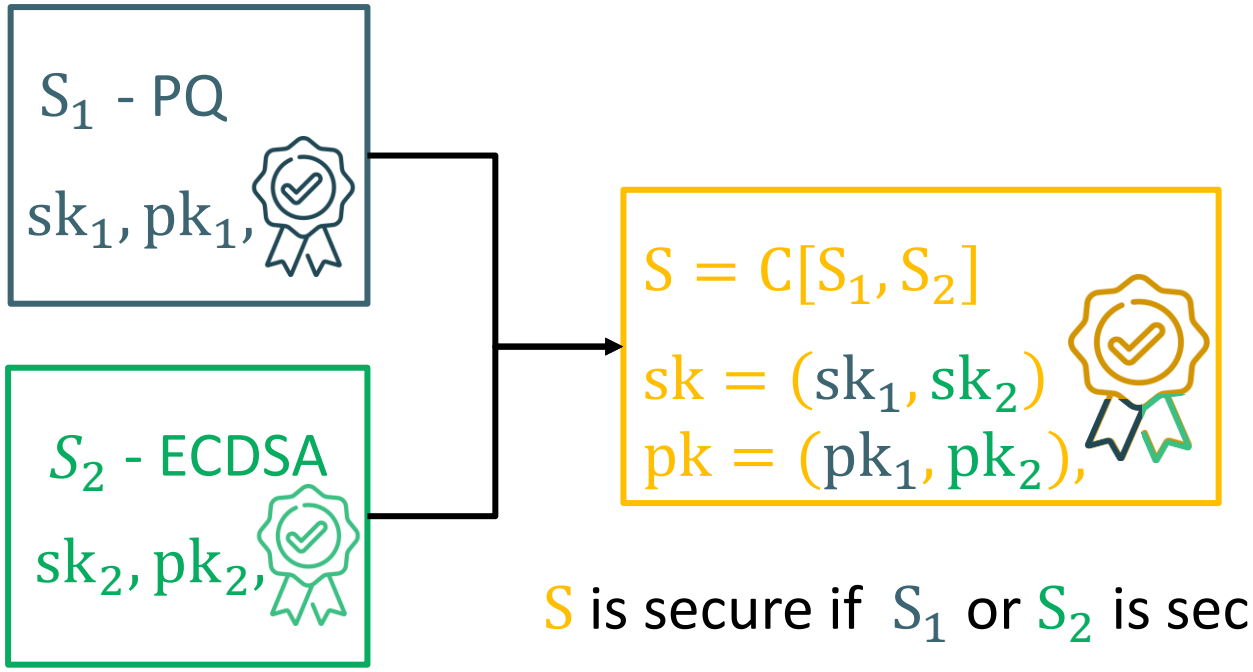
$\mathrm{sk}_1, \mathrm{pk}_1,$

S_2 - ECDSA

$\mathrm{sk}_2, \mathrm{pk}_2,$

Hybrid Approach Idea

Suggested by most standardization agencies, e.g. NIST, ETSI, IETF



S is secure if S_1 or S_2 is secure.

(SIMPLIFIED) TRUE HYBRID

Sender S

Receiver R

$\mathrm{Cert_S} = ($, $)$

$h = \mathrm{Hash}(\mathrm{Cert_S})$

PQ (Falcon)

ECDSA

Hybrid

$\mathrm{sk} = (\mathrm{sk_S^c}, \mathrm{sk_S^{pq}})$

$\mathrm{pk} = (\mathrm{pk_S^c}, \mathrm{pk_S^{pq}})$

(SIMPLIFIED) TRUE HYBRID

PQ (Falcon)

ECDSA

Hybrid

$sk = (sk_S^c, sk_S^{pq})$

$pk = (pk_S^c, pk_S^{pq})$

Sender S

$Cert_S = ($  ,  $)$

$h = Hash(Cert_S)$

Repeat every 5 BSMs:

$SPDU_1 = (BSM_1,$  ,  ,  $)$

Receiver R

$SPDU_1 \longrightarrow$ Verify  using pk_S^c from 

(SIMPLIFIED) TRUE HYBRID

PQ (Falcon)

ECDSA

Hybrid

$sk = (sk_S^c, sk_S^{pq})$

$pk = (pk_S^c, pk_S^{pq})$

Sender S

Receiver R

$Cert_S = ($, $)$

$h = Hash(Cert_S)$

Repeat every 5 BSMs:

$SPDU_1 = (BSM_1,$, , $)$

$\xrightarrow{SPDU_1}$ Verify using pk_S^c from

$SPDU_{2,3,4,5} = (BSM_i,$, $h)$

$\xrightarrow{SPDU_{2,3,4,5}}$ Verify using pk_S^c from and pk_S^{pq} from

(SIMPLIFIED) TRUE HYBRID

PQ (Falcon)

ECDSA

Hybrid

$$sk = (sk_S^c, sk_S^{pq})$$
$$pk = (pk_S^c, pk_S^{pq})$$

Sender S

Receiver R

$$Cert_S = (\, , \,)$$

$$h = Hash(Cert_S)$$

Repeat every 5 BSMs:

$$\underbrace{SPDU_1 = (BSM_1, \, , \, , \,)}_{\textbf{1 835 byte < 2 304 byte}}$$

$SPDU_1$ → Verify using pk_S^c from

$$SPDU_{2,3,4,5} = (BSM_i, \underbrace{\, , \, }_{\textbf{730 byte}}, h)$$

$SPDU_{2,3,4,5}$ → Verify using pk_S^c from and pk_S^{pq} from

Comparison of Resulting SPDUs

Design	SPDU 1	SPDU 2	SPDU 3	SPDU 4	SPDU 5
Pure ECDSA	248	144	144	144	144
True hybrid w/ Falcon	1,835	834	834	834	834

Classical and PQ security guarantees

Comparison of Resulting SPDUs

Design	SPDU 1	SPDU 2	SPDU 3	SPDU 4	SPDU 5
Pure ECDSA	248	144	144	144	144
True hybrid w/ Falcon	1,835	834	834	834	834

Classical and PQ security guarantees

Security threat due to packet loss
>>
Security threat due to signature forgeries by quantum attackers

(SIMPLIFIED) PARTIALLY PQ HYBRID

Idea:

- ECDSA pk valid for one week, changed every 5 min

⇨ sk cannot be computed even by QC

ECDSA cert

pk_S^c

$= \mathrm{sign}^{\mathrm{ECDSA}}(\mathrm{pk}_S^c)$ by a CA

PQ cert

pk_S^c

$= \mathrm{sign}^{\mathrm{PQ}}(\mathrm{pk}_S^c)$ by a CA

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PQ cert

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Idea:

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- CA's (pk,sk) valid long enough to be vulnerable

⇨ CA's signature potentially forged by QC

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Idea:

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⇨ sk cannot be computed even by QC

- CA's (pk,sk) valid long enough to be vulnerable

⇨ CA's signature potentially forged by QC

⇨ Enough to protect integrity of ECDSA keys with PQ signatures

(SIMPLIFIED) PARTIALLY PQ HYBRID

Sender S

$\mathrm{Cert_S} = (\, , \,)$

$\mathrm{h} = \mathrm{Hash}(\mathrm{Cert_S})$

$\mathrm{h^c} = \mathrm{Hash}(\,)$

$\mathrm{C_1}, \ldots, \mathrm{C_4} = \mathrm{Fragment}(\,)$

Repeat every 5 BSMs:

$\mathrm{SPDU_1} = (\mathrm{BSM_1}, \, , \, , \mathrm{C_1})$ $\xrightarrow{\mathrm{SPDU_1}}$ Verify using $\mathrm{pk_S^c}$ from

$\mathrm{SPDU_{2,3,4}} = (\mathrm{BSM_2}, \, , \mathrm{C}_i, \mathrm{h^c})$

$\xrightarrow{\mathrm{SPDU_{2,3,4}}}$ Verify using $\mathrm{pk_S^c}$ from

Check $\mathrm{pk_S^c}$ from = $\mathrm{pk_S^c}$ from

Receiver R

ECDSA cert

$\mathrm{pk_S^c}$

$= \mathrm{sign^{ECDSA}}(\mathrm{pk_S^c})$ by a CA

PQ cert

$\mathrm{pk_S^c}$

$= \mathrm{sign^{PQ}}(\mathrm{pk_S^c})$ by a CA

(SIMPLIFIED) PARTIALLY PQ HYBRID

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Repeat every 5 BSMs:

$\mathrm{SPDU_1} = (\mathrm{BSM_1}, \, , \, , \mathrm{C_1})$ —$\mathrm{SPDU_1}$→ Verify using $\mathrm{pk_S^c}$ from

$\mathrm{SPDU_{2,3,4}} = (\mathrm{BSM_2}, \, , \mathrm{C}_i, \mathrm{h^c})$

—$\mathrm{SPDU_{2,3,4}}$→ Verify using $\mathrm{pk_S^c}$ from

Check $\mathrm{pk_S^c}$ from = $\mathrm{pk_S^c}$ from

$\mathrm{SPDU_5} = (\mathrm{BSM_i}, \, , \mathrm{h})$

—$\mathrm{SPDU_5}$→ Verify using $\mathrm{pk_S^c}$ from

Receiver R

ECDSA cert

$\mathrm{pk_S^c}$

$= \mathrm{sign^{ECDSA}}(\mathrm{pk_S^c})$ by a CA

PQ cert

$\mathrm{pk_S^c}$

$= \mathrm{sign^{PQ}}(\mathrm{pk_S^c})$ by a CA

Comparison of Resulting Sizes

Design	SPDU 1	SPDU 2	SPDU 3	SPDU 4	SPDU 5
Pure ECDSA					
True hybrid w/ Falcon					
Partially PQ hybrid w/ Falcon					
Partially PQ hybrid w/ Dilithium					
Partially PQ hybrid w/ Sphincs+					
Partially PQ hybrid w/ XMSS					

Comparison of Resulting Sizes

Design	SPDU 1	SPDU 2	SPDU 3	SPDU 4	SPDU 5	max. #vehicles
Pure ECDSA						183
True hybrid w/ Falcon						31
Partially PQ hybrid w/ Falcon						107
Partially PQ hybrid w/ Dilithium						54
Partially PQ hybrid w/ Sphincs+						21
Partially PQ hybrid w/ XMSS						50

Comparison of Resulting Sizes

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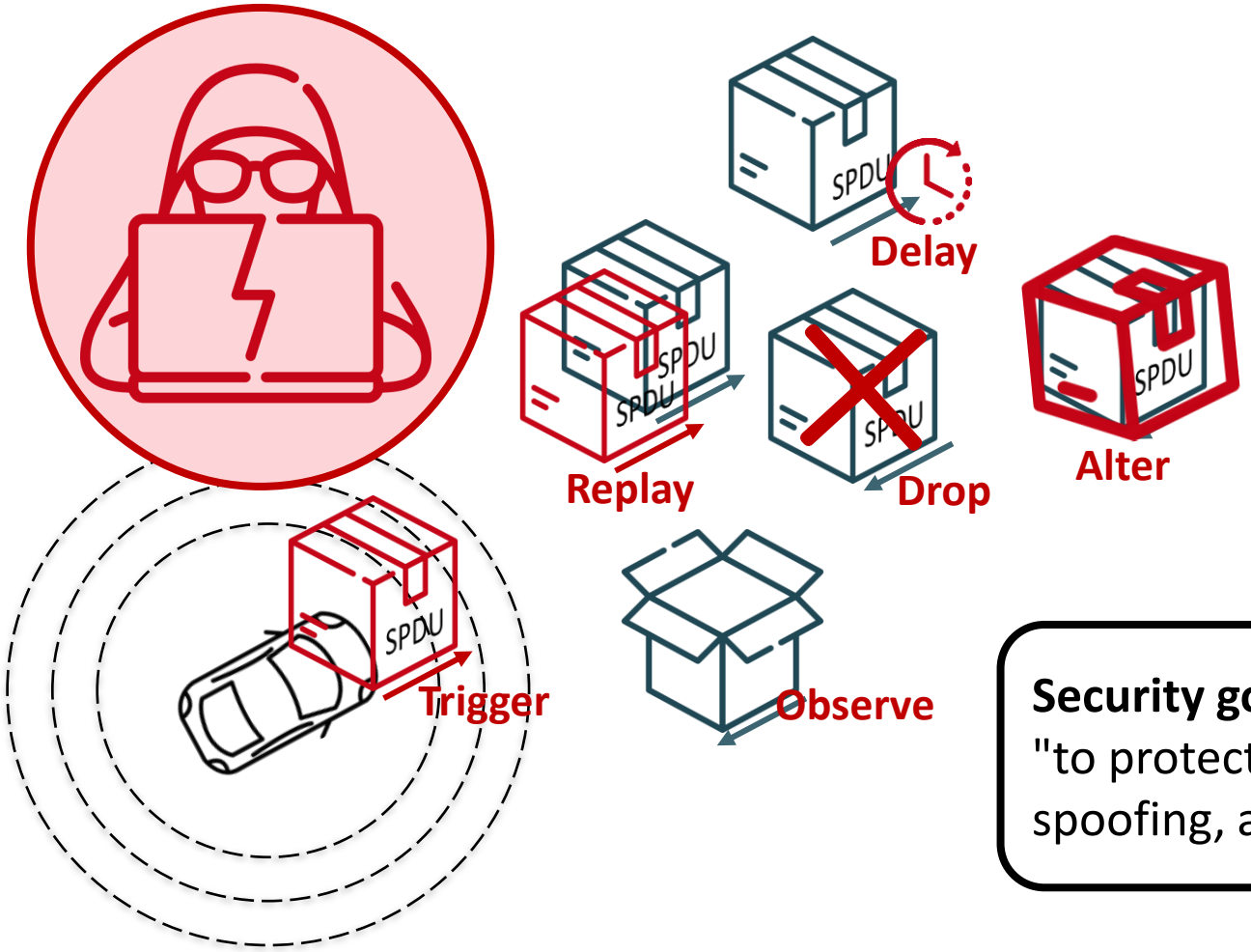
Partially PQ hybrid w/ XMSS						50

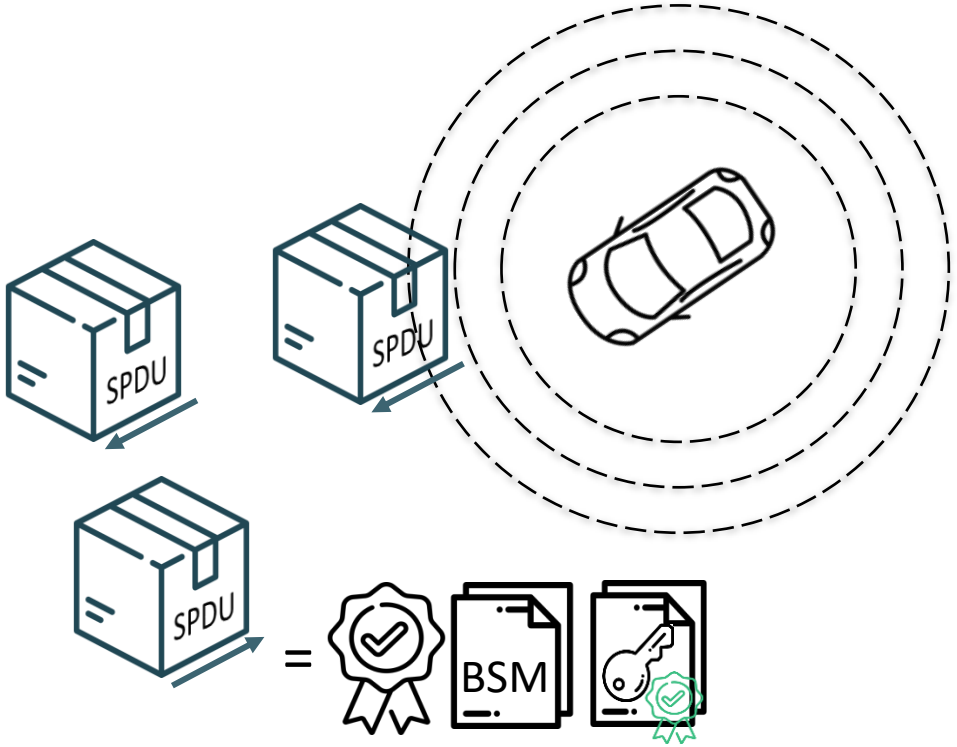
Use clever sieving algorithms to prioritize messages [DR21]

Threat Model and Limitations

Security goal
"to protect messages from attacks such as eavesdropping, spoofing, alteration, and replay.“ (IEEE 1609.2)

Threat Model





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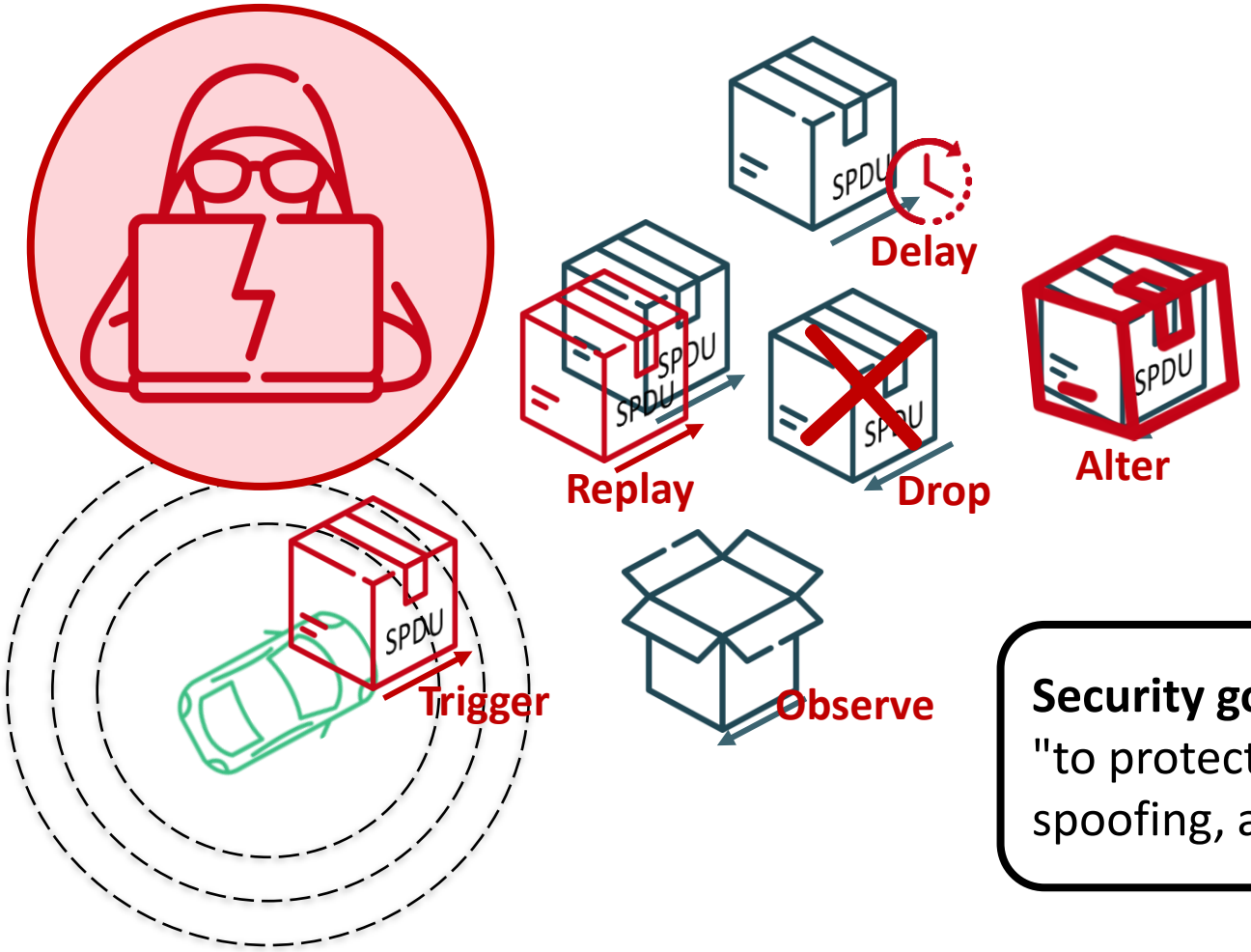
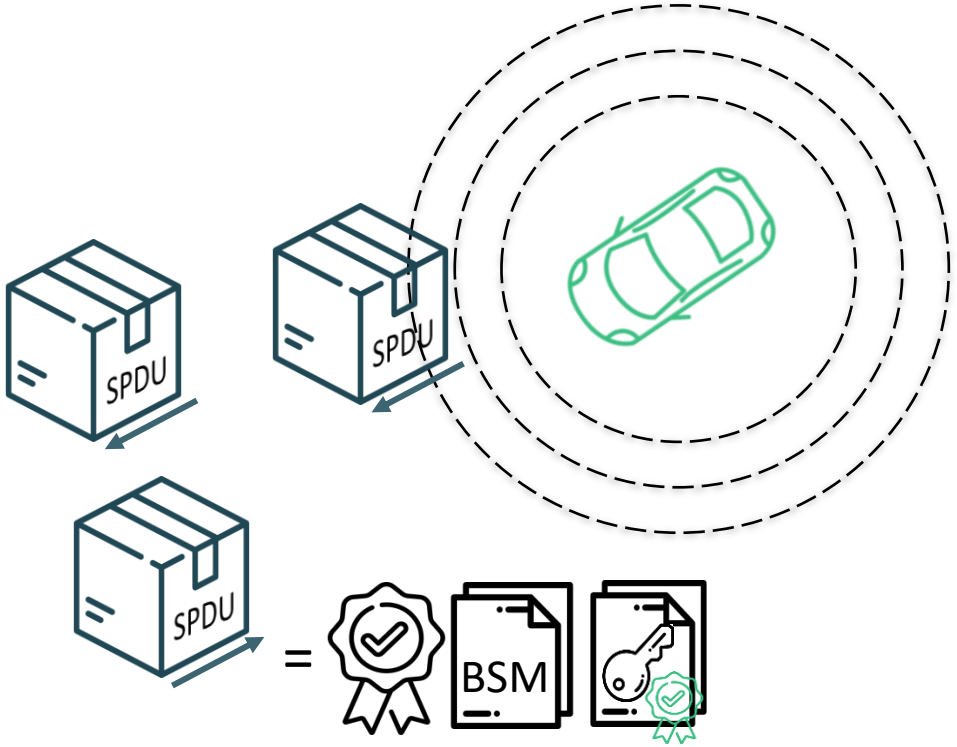


No side-channel attacks



- CA honest
- Immediate verify of cert

Security goal
"to protect messages from attacks such as eavesdropping, spoofing, alteration, and replay.“ (IEEE 1609.2)

Summary

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- **Naive swap** of ECDSA with PQ signatures is **not possible** under current standards.

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- Enabled by **careful analysis of quantum power** and **tailoring** of PQ extension to the application.

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THANK YOU.

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[BMRT21] N. Bindel, S. McCarthy, H. Rahbari, G. Twardokus. Drive (Quantum) Safe! --Towards Post-Quantum Security for Vehicle-to-Vehicle Communications. Forth coming. 2021

[KPD+18] P. Kampanakis, P. Panburana, E. Daw, D. Van Geest . The Viability of Post-quantum X.509 Certificates. Cryptology ePrint Archive: Report 2018/063.

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