BLERP: BLE Re-Pairing Attacks and Defenses

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FRANCE 2030
EURECOM
ORSHIN

Bluetooth Low Energy (BLE)

BLE is a standardized wireless protocol for short-range data exchange

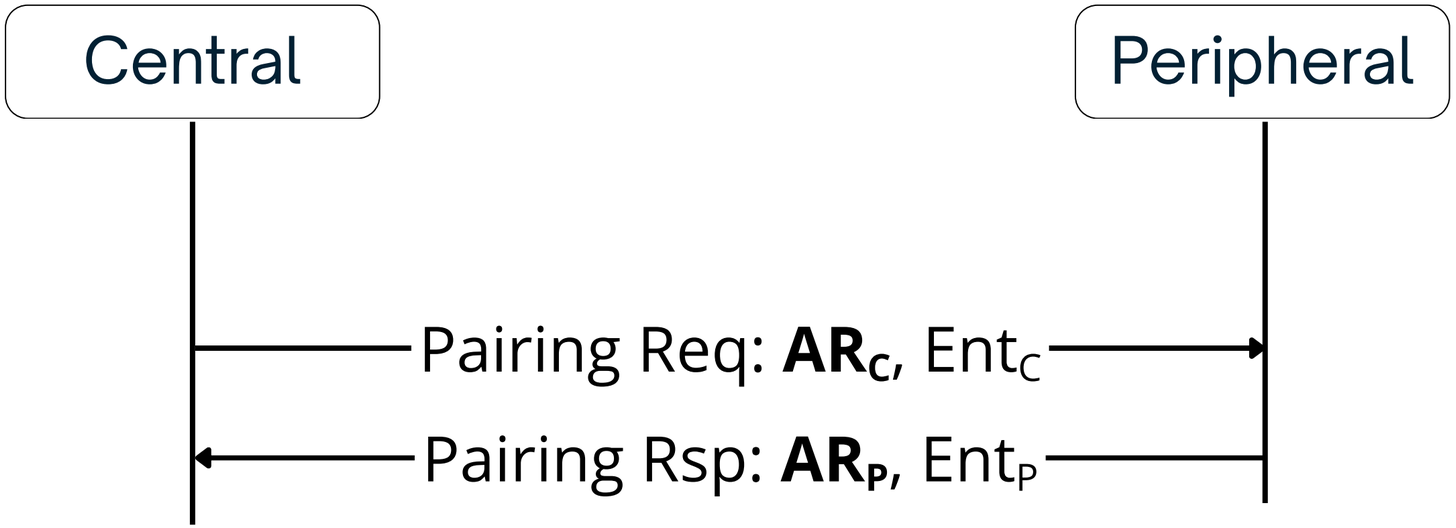
Used daily by **billions of heterogeneous devices** (⌚ 📱 💻)

Connection roles

- **Central**: scans for advertisements, starts connections → 📱 💻
- **Peripheral**: advertises presence, responds to connections → ⌚

BLE Pairing

- Establish a long-term Pairing Key (PK)
- Allows negotiating features
  - Security Level (SC, MitM, bond, …) → AR
  - Key Entropy (7-16 bytes)



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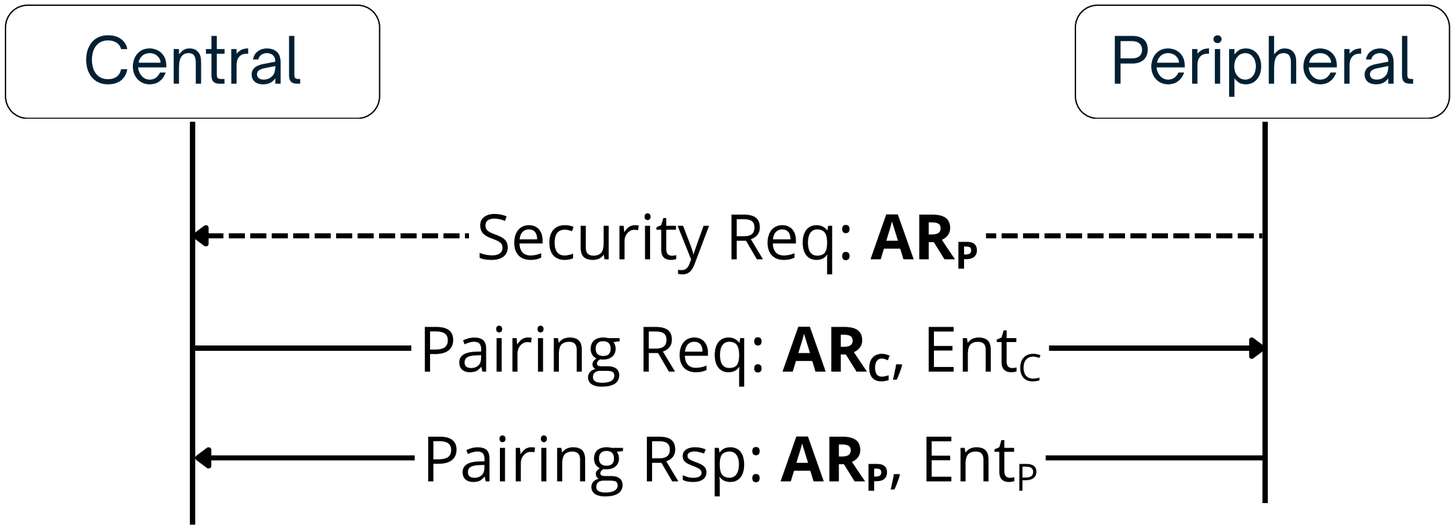

BLE Session Establishment

- Short-term key establishment protocol
- Encrypts the connection between paired devices

Focus on BLE Pairing Security

Prior attacks on BLE pairing

- **KNOB**, **Invalid Curve**, **Crackle** → force weak key
- **Method Confusion**, **NiNo** → bypass authentication

Threat model

- Dolev-Yao adversary
- Target initial pairing → devices connect for the first time
- **Re-pairing** is **not considered**

What about BLE Re-Pairing?

The standard allows re-pairing and **overwriting a PK**

Limited existing research

- **BLURtooth**: Cross-Transport Key Derivation (AsiaCCS’ 22)
  - First mention of *re-pairing* between BR/EDR and BLE
  - Only mention of *re-pairing* in the literature

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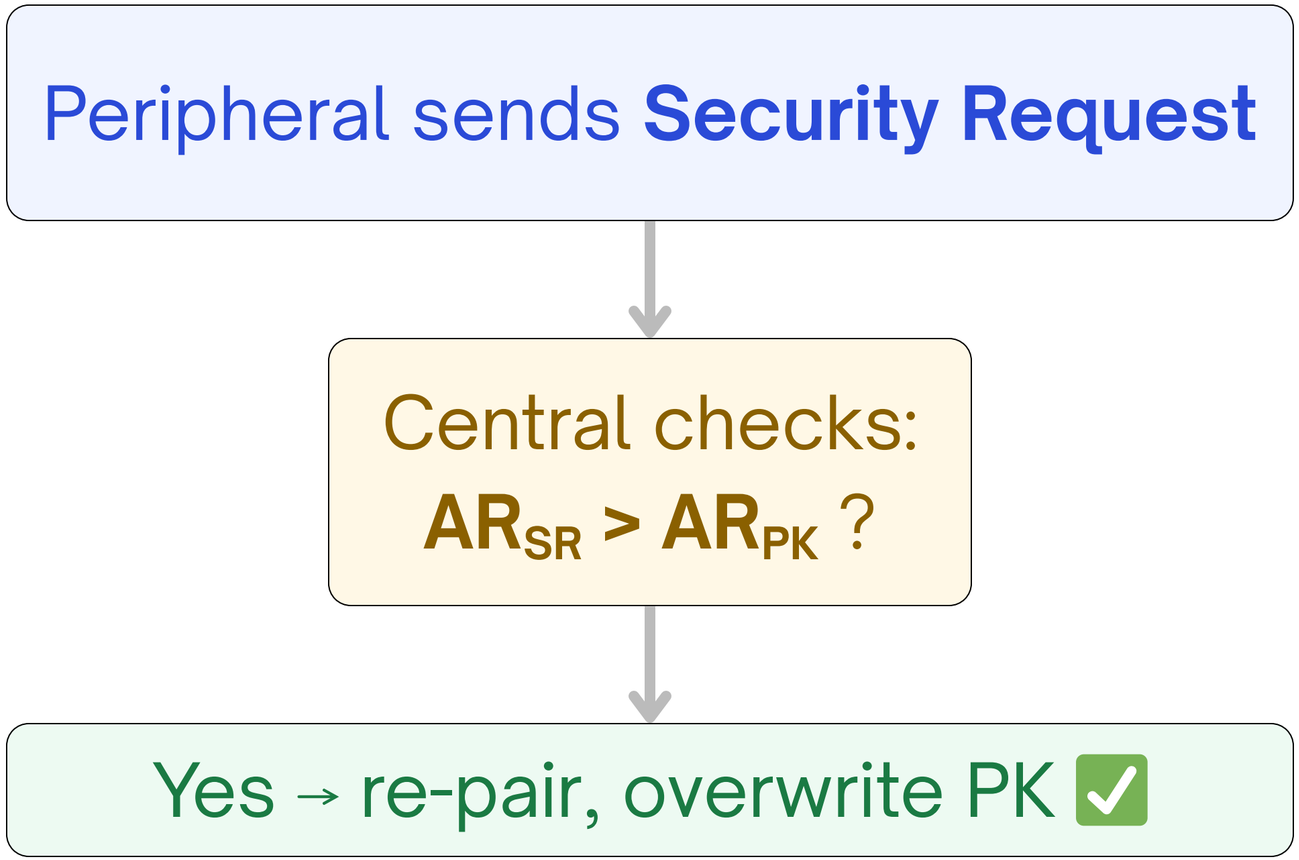
How secure is BLE re-pairing?

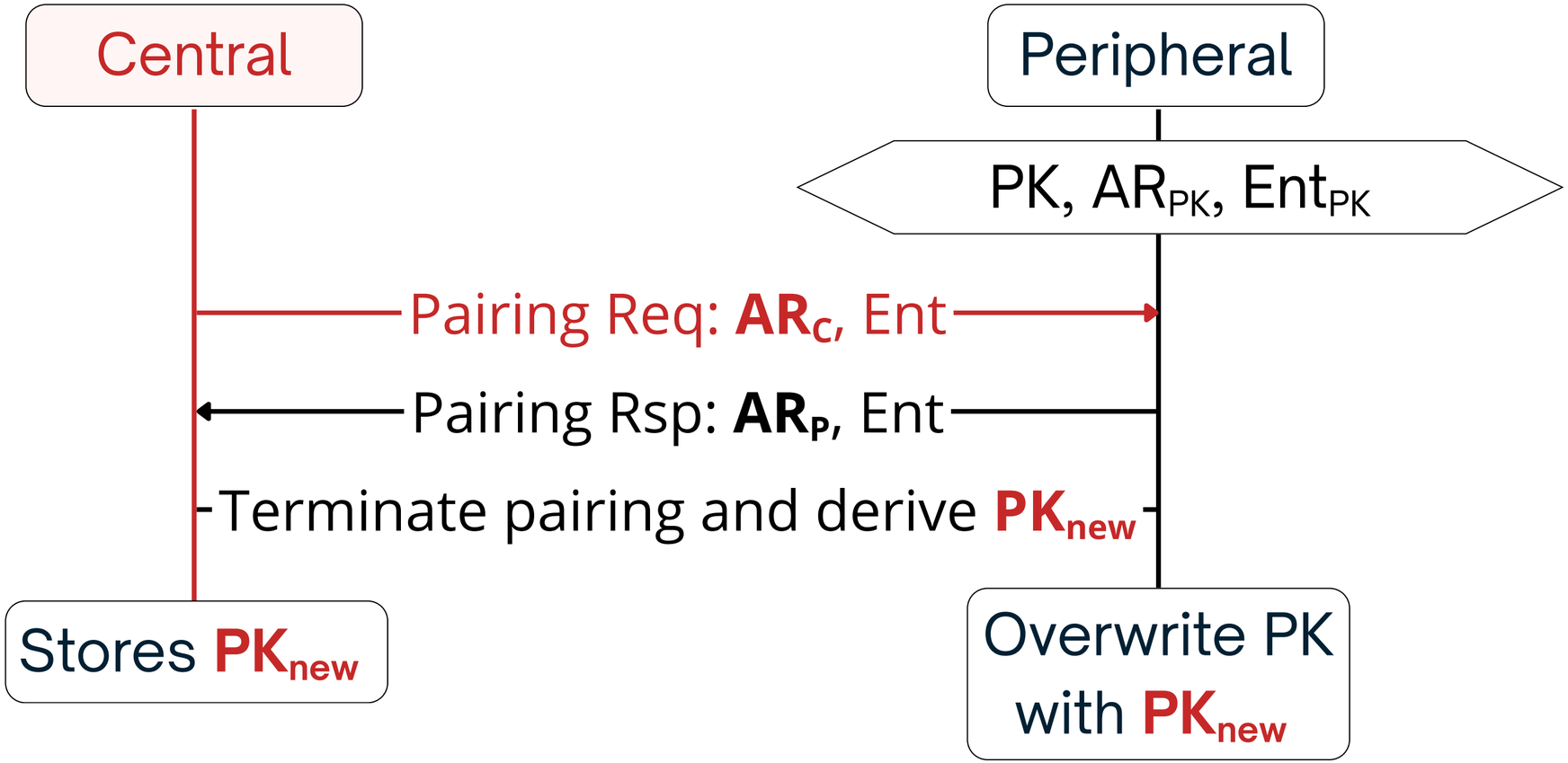
Our Contributions

1. Four new BLE re-pairing attacks
2. Four new protocol-level vulnerabilities affecting the standard
3. Low-cost toolkit to test attacks
4. Evaluation exploiting 22 devices
5. Designed and tested countermeasures
6. Updated BLE threat model to include re-pairing

BLE Re-pairing Logic



BLERP Central Impersonation



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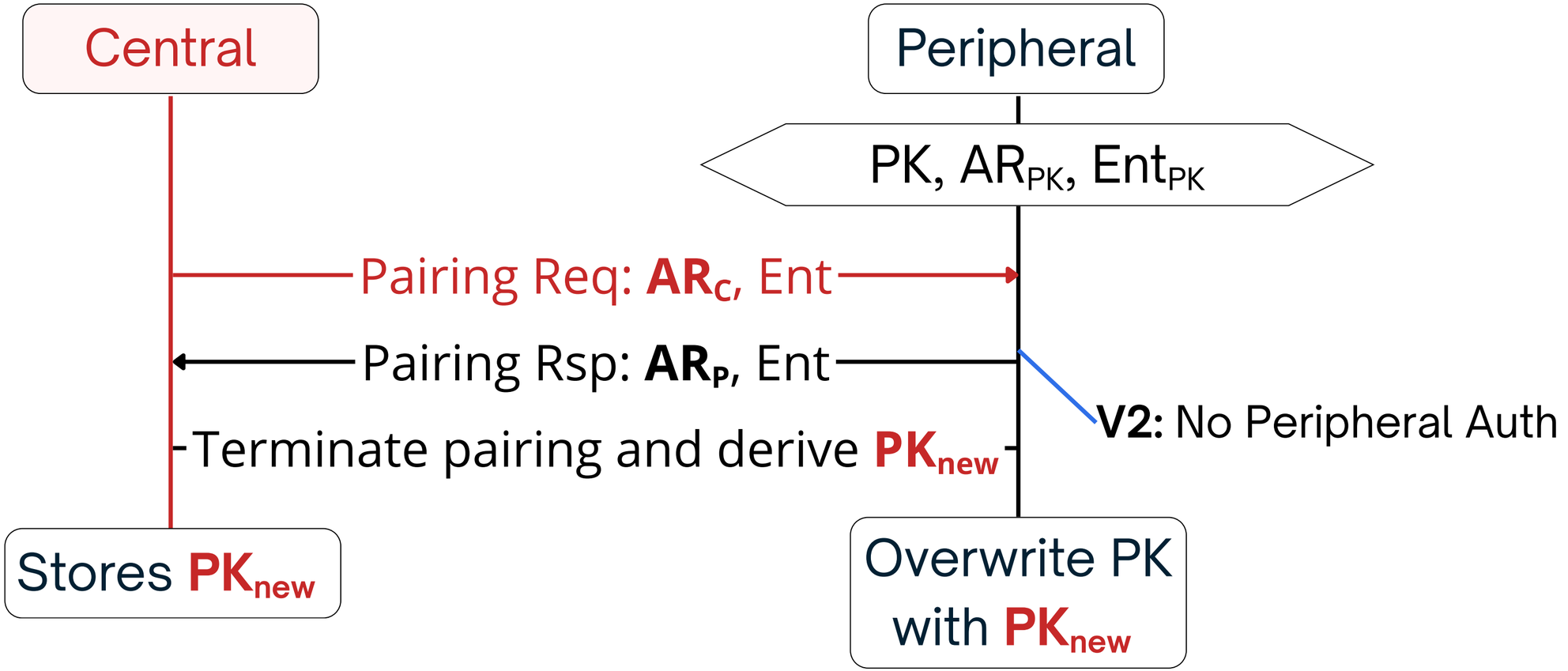

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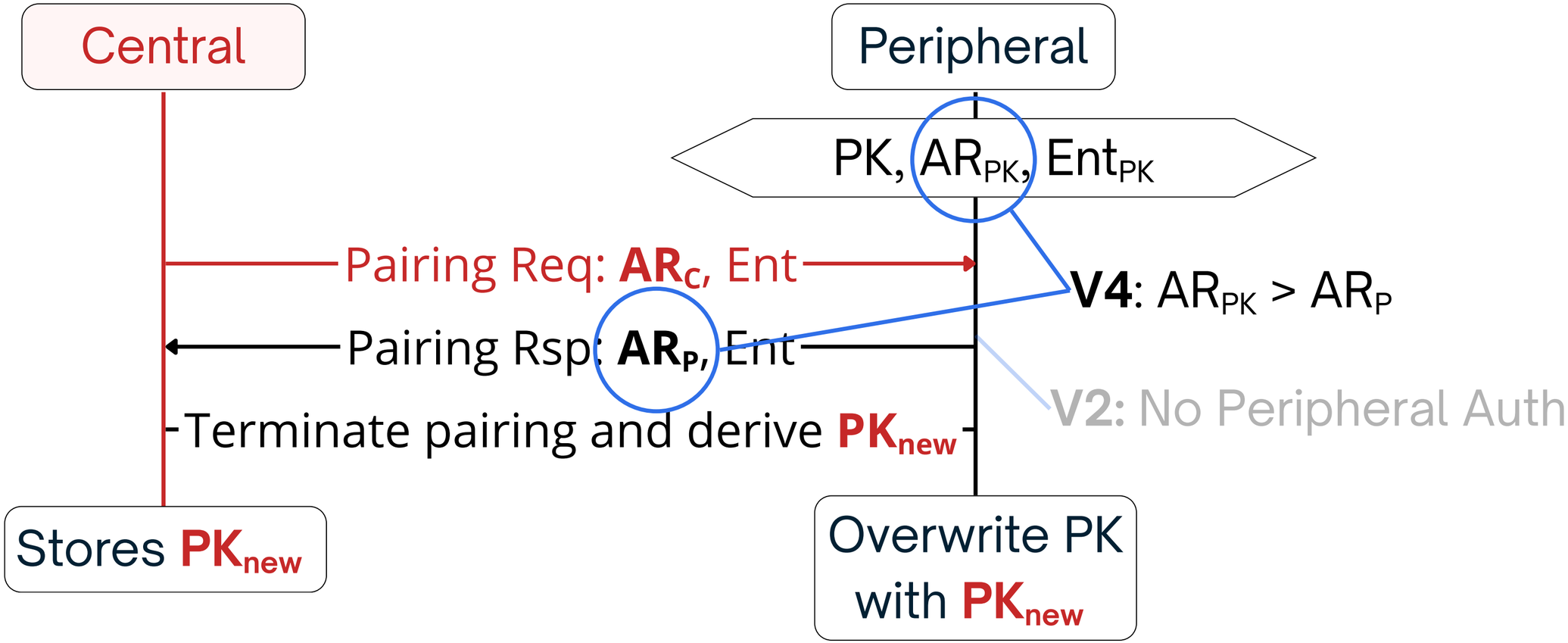
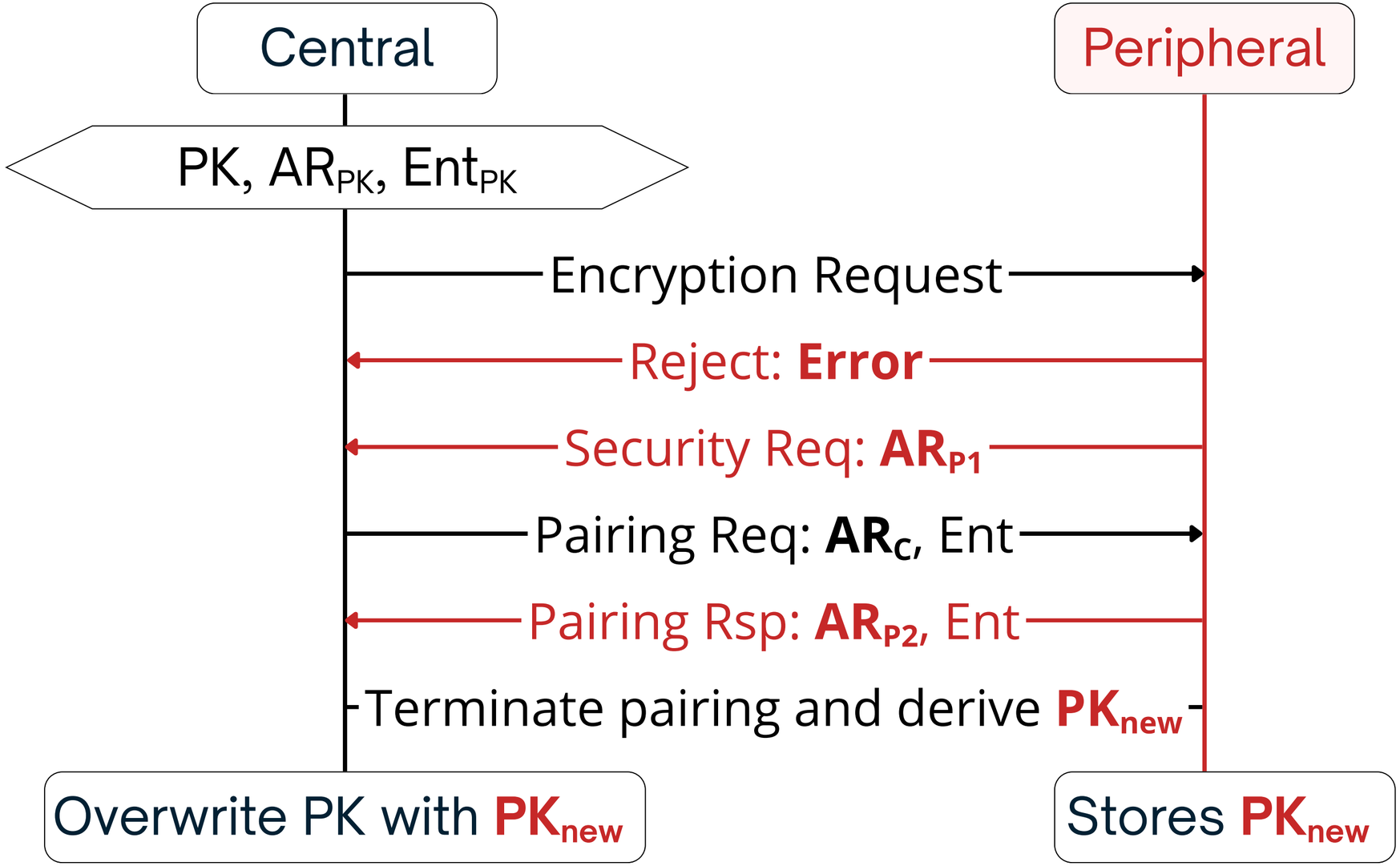


BLERP Peripheral Impersonation



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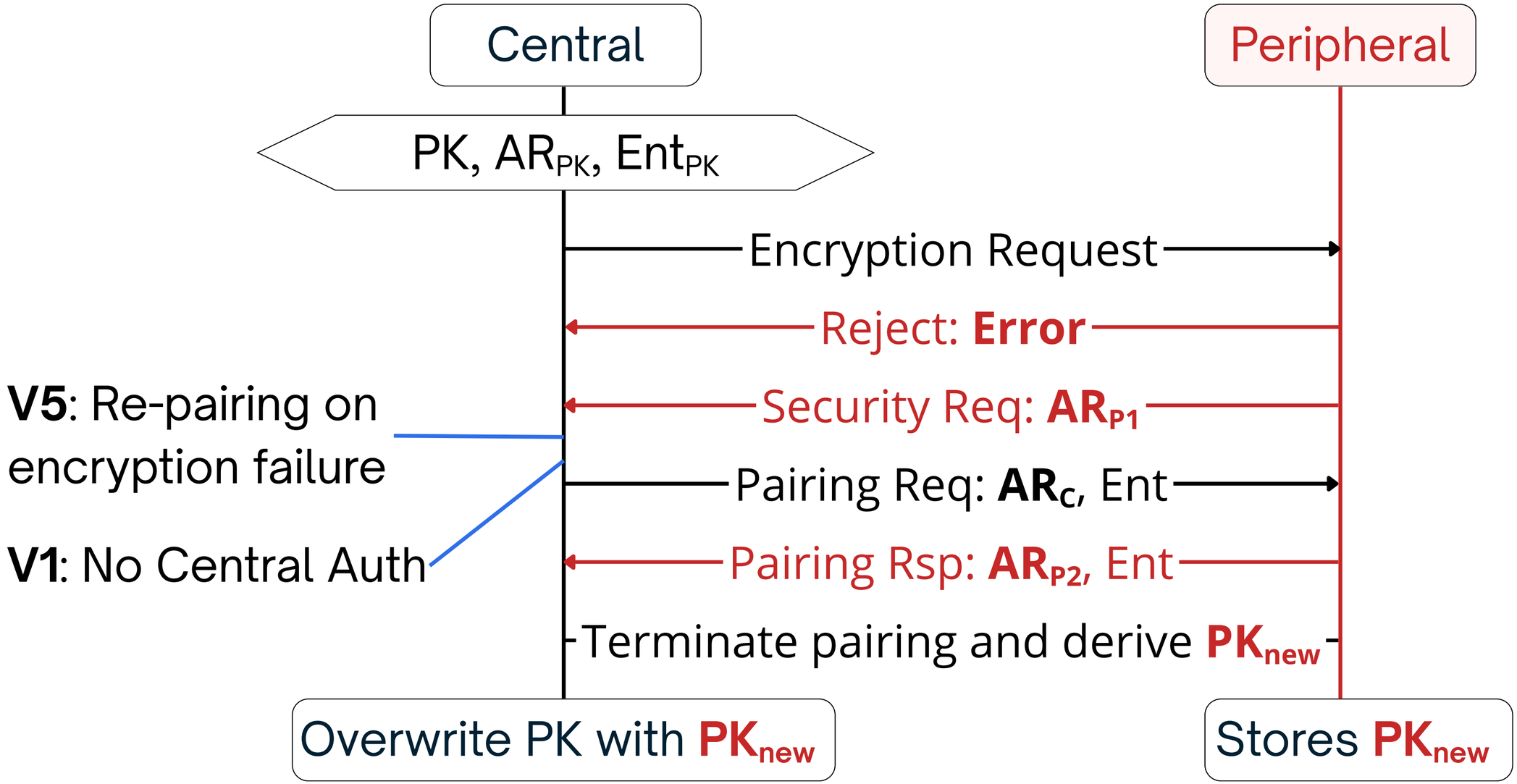

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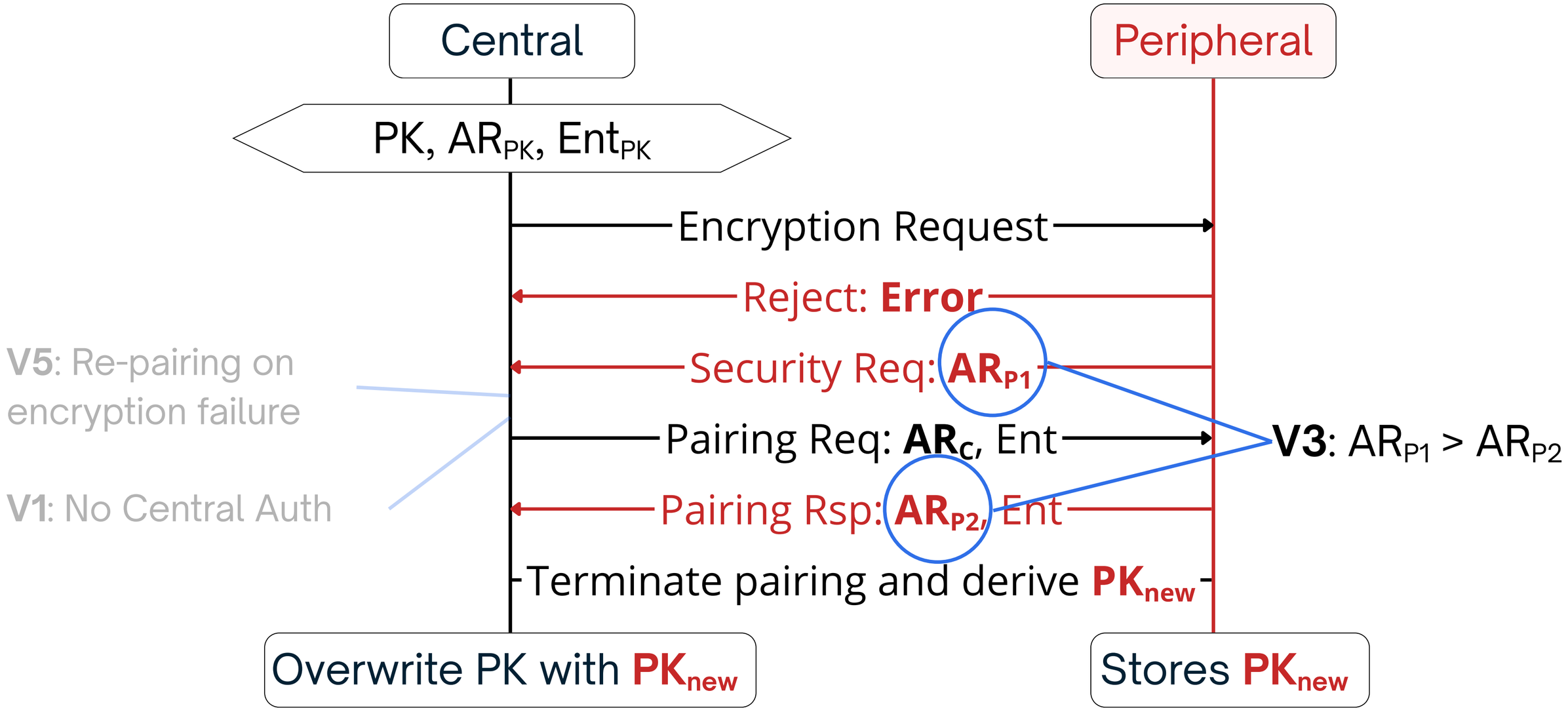

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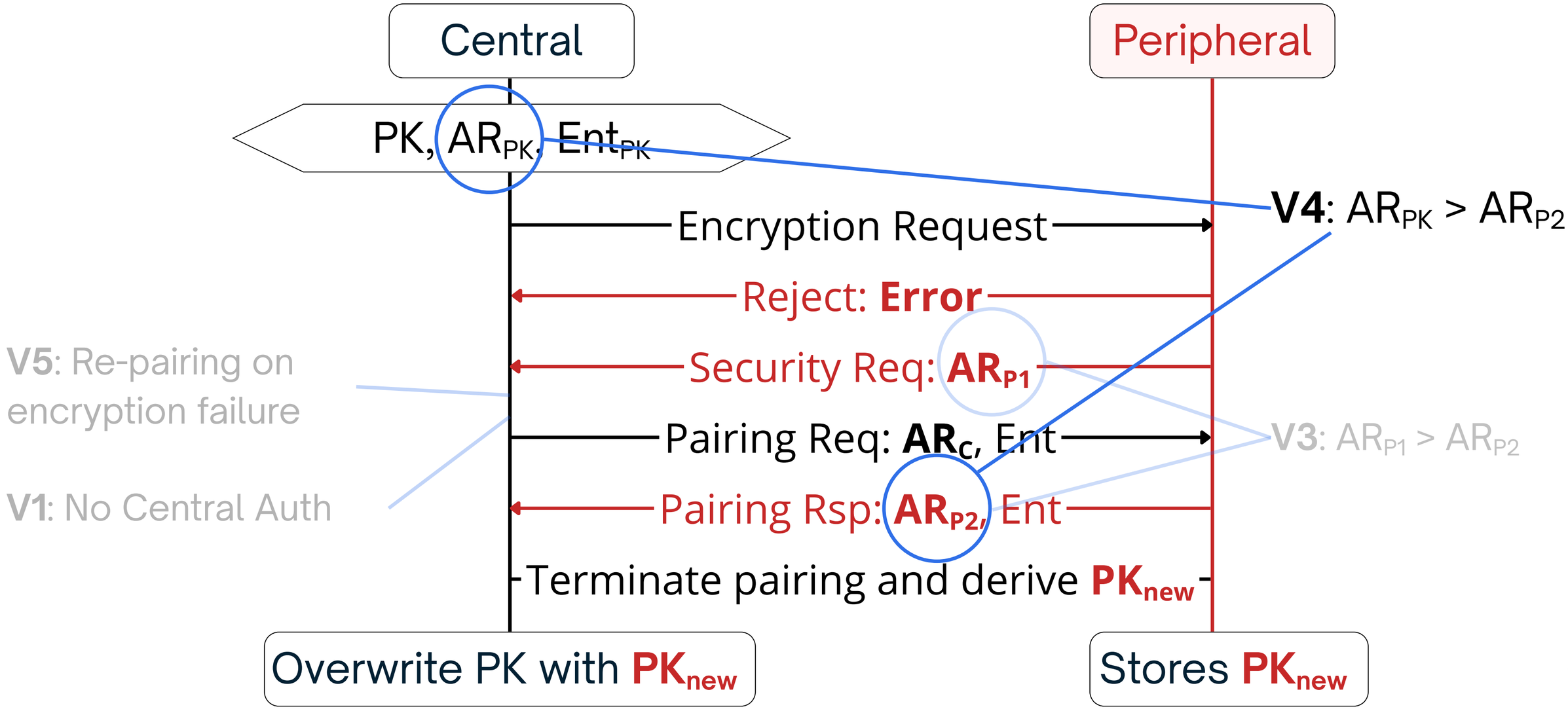
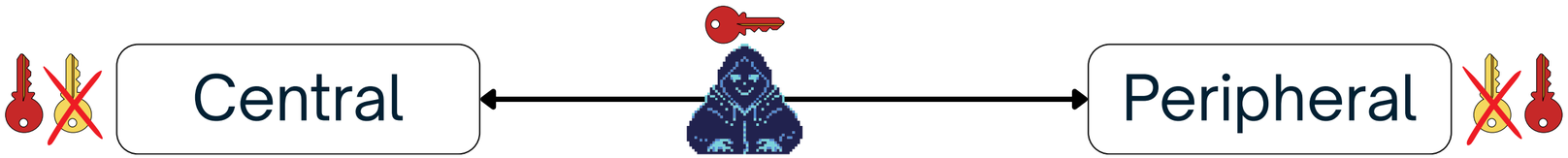
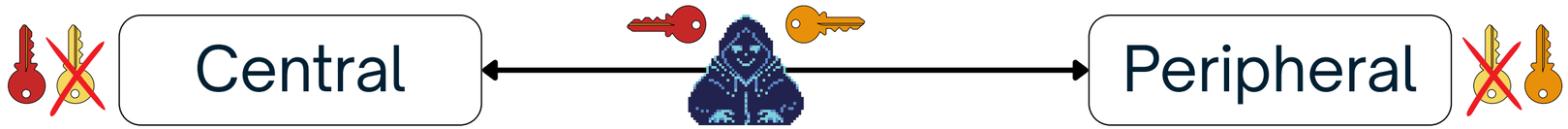


BLERP MitM Attacks

Single-Channel MitM



Double-Channel MitM



BLERP Vulnerabilities

V1: *Unauth. Central Re-pairing* ***(new)***

V2: *Unauth. Peripheral Re-pairing* ***(new)***

V3: *Peripheral Security Level Downgrade* ***(new)***

V4: *Re-pairing Security Level Downgrade* ***(new)***

V5: Re-pairing from failed encryption

V6: Re-pairing Key Entropy Downgrade

Evaluation Results Summary

22/22	**4.2 – 5.4**	**SC, MitM, …**	**0/1 – Click**
Targets vulnerable to 2+ vulnerabilities	Affected Bluetooth Versions	Regardless of security settings	One or zero user interaction

Apple: Allows re-pairing if $\mathbf{AR_{SR} = AR_{PK}}$

NimBLE: Allows re-pairing with **specific** $\mathbf{AR_{SR}}$ (CVE-2025-62235)

Android: Deletes PK after two encryption errors

Zephyr: Blocks re-pairing downgrade

Evaluation Results

Device	AuthReq	BLEv	V1	V2	V3	V4	V5	V6	PI	CI
MacBook Air	SC, MitM	5.0	●	-	●	●	●	●	●	-
Windows 11	SC	5.2	●	-	●	●	●	●	●	-
Linux 6.10.9	SC	5.2	●	-	●	●	●	●	●	-
Oculus Quest	SC	5.0	●	-	●	●	●	●	●	-
iPhone 15	SC, MitM	5.3	●	-	●	●	●	●	●	-
iPad 2022	SC, MitM	5.2	●	-	●	●	●	●	●	-
Google Pixel 8	SC	5.3	●	-	●	●	●	●	●	-
Realme X2 Pro	SC	5.0	●	-	●	●	●	●	●	-
Xiaomi Mi 11 Lite	SC	5.1	●	-	●	●	●	●	●	-
Samsung Galaxy A15	SC	5.3	●	-	●	●	●	●	●	-
TCL 43P638	SC	5.0	●	-	●	●	●	●	●	-

Evaluation Results

Device	AuthReq	BLEv	V1	V2	V3	V4	V5	V6	PI	CI
NimBLE	SC, MitM	5.4	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴
NimBLE SC-Only	SC, MitM	5.4	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🔴
Zephyr	LSC	5.4	🔴	🔴	🟢	🟢	🔴	🟢	🔴	🔴
BTstack	SC, MitM	5.2	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🔴
ESP32-C3	SC, MitM	5.0	🔴	🔴	🔴	🔴	🟢	🔴	🟢	🔴
Xbox Joystick	SC	5.0	-	🔴	-	🔴	-	🔴	-	🔴
Logitech MX Anywhere 3S	SC	5.1	-	🔴	-	🔴	-	🔴	-	🔴
Logitech MX Keys S	SC, MitM	5.1	-	🔴	-	🔴	-	🔴	-	🔴
Logitech MX Master 3	LSC	4.2	-	🔴	-	🔴	-	🔴	-	🔴
Garmin Vivoactive 5	SC, MitM	5.0	-	🔴	-	🟢	-	🔴	-	🔴

BLERP Defenses

Hardened re-pairing (backward-compatible)

- Security Level enforcement
- Disconnect on encryption error

Authenticated re-pairing (protocol re-design)

- Key chaining
- Transcript hashing

Conclusion

Contributions

6 vulnerabilities • 4 attacks • 2 defenses

• BLERP toolkit • 22 devices tested • threat model update

Takeaways

Vendors → harden stacks, update threat model

Bluetooth SIG → re-design their security protocols