MobiCom 2023

Exploiting Contactless Side Channels in Wireless Charging Power Banks for User Privacy Inference via Few-shot Learning

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Introduction

USB Cables

Cable-based Power Banks

Wireless Chargers

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Cable-based Power Banks

Wireless Chargers

Charger-Surfing (USENIX-SEC'20)

WIGHT (Oakland'22)

GhostTalk (NDSS'22)

Cour *et al.* (CCS'21)

Wu *et al.* (ACSAC'21)

EM-Surfing (TDSC'22)

Dai *et al.* (Oakland'23)

Wireless Charging Power Banks

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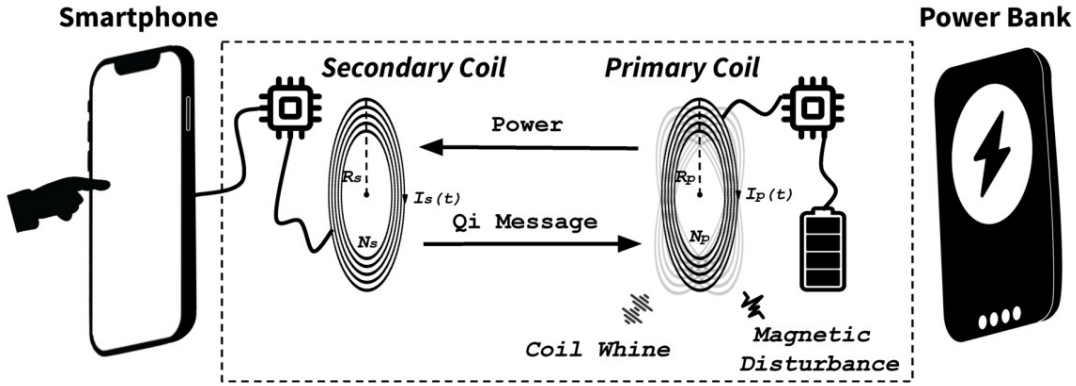
Is this contactless charging accessory safe?

Wireless Charging Power Banks

Wireless Charging Power Banks

Charging Principles



Is this contactless charging accessory safe?

Wireless Charging Power Banks

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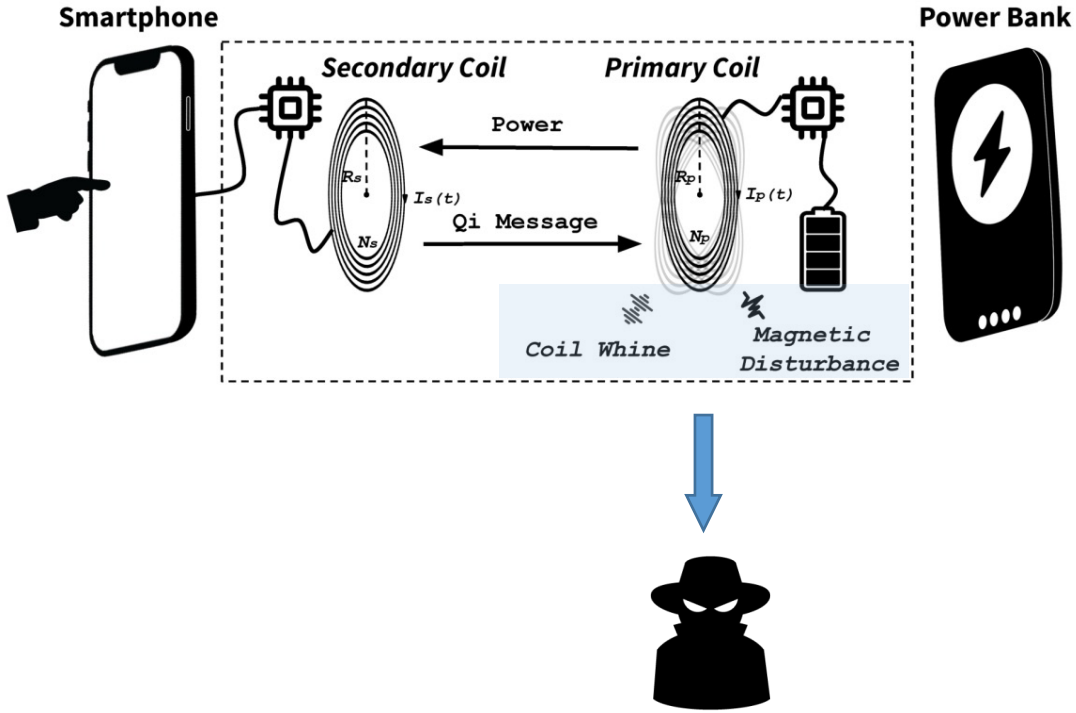
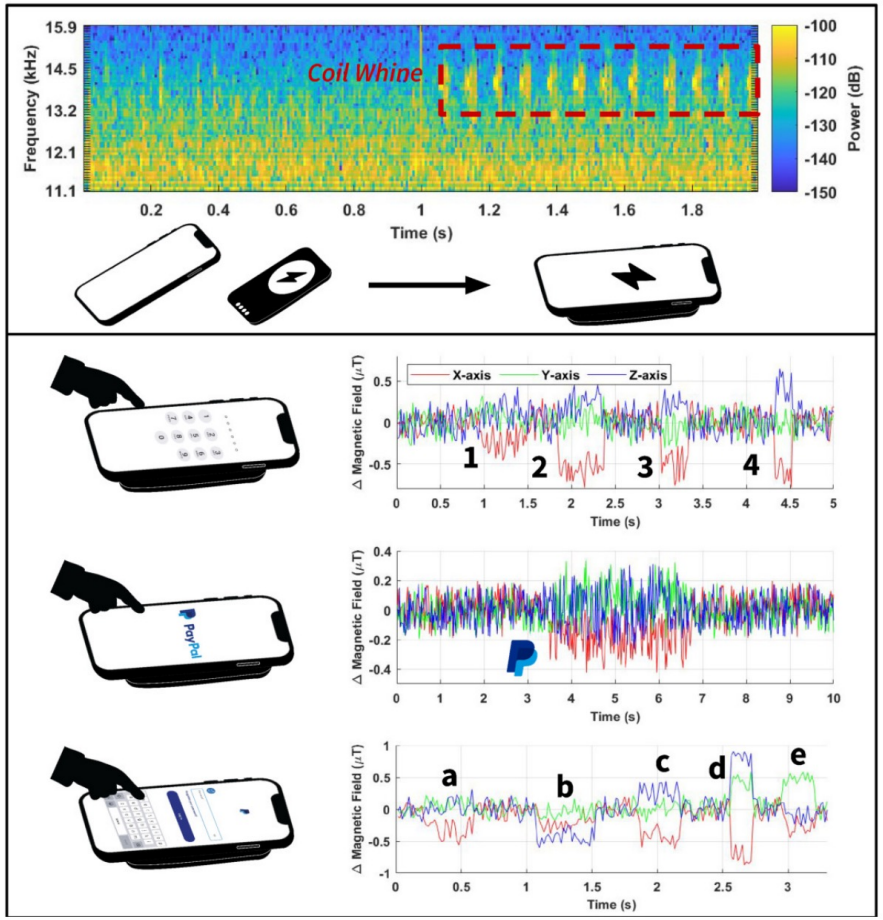


Is this contactless charging accessory safe?

Motivating Example & Physical Phenomena



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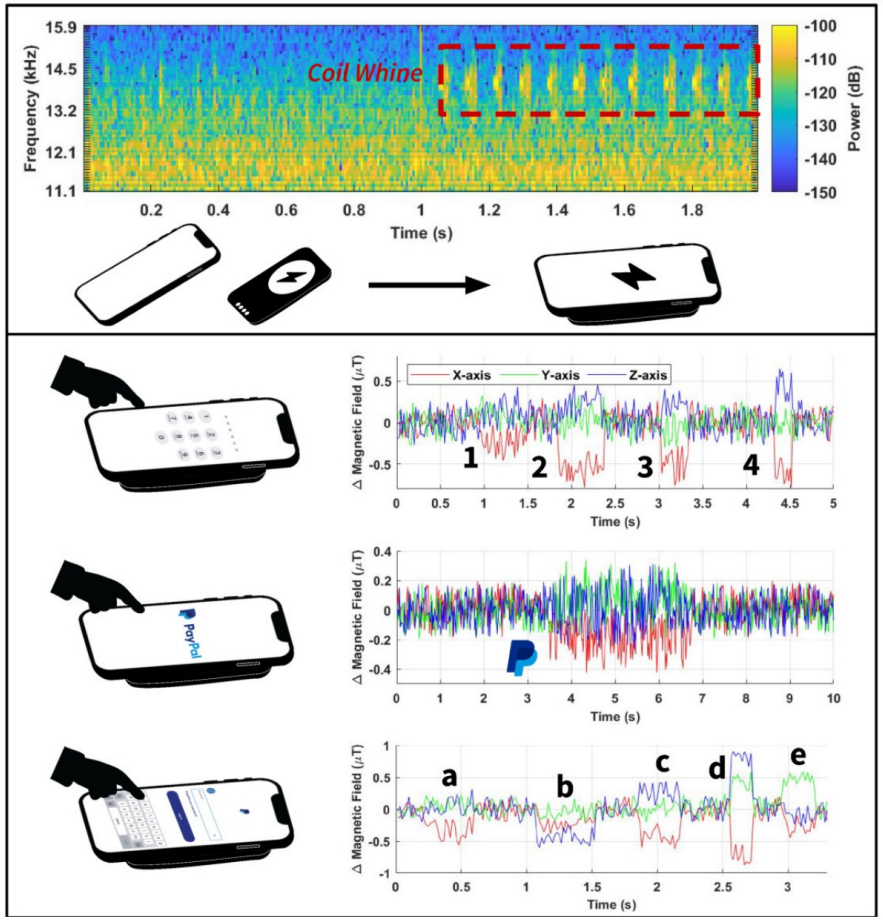
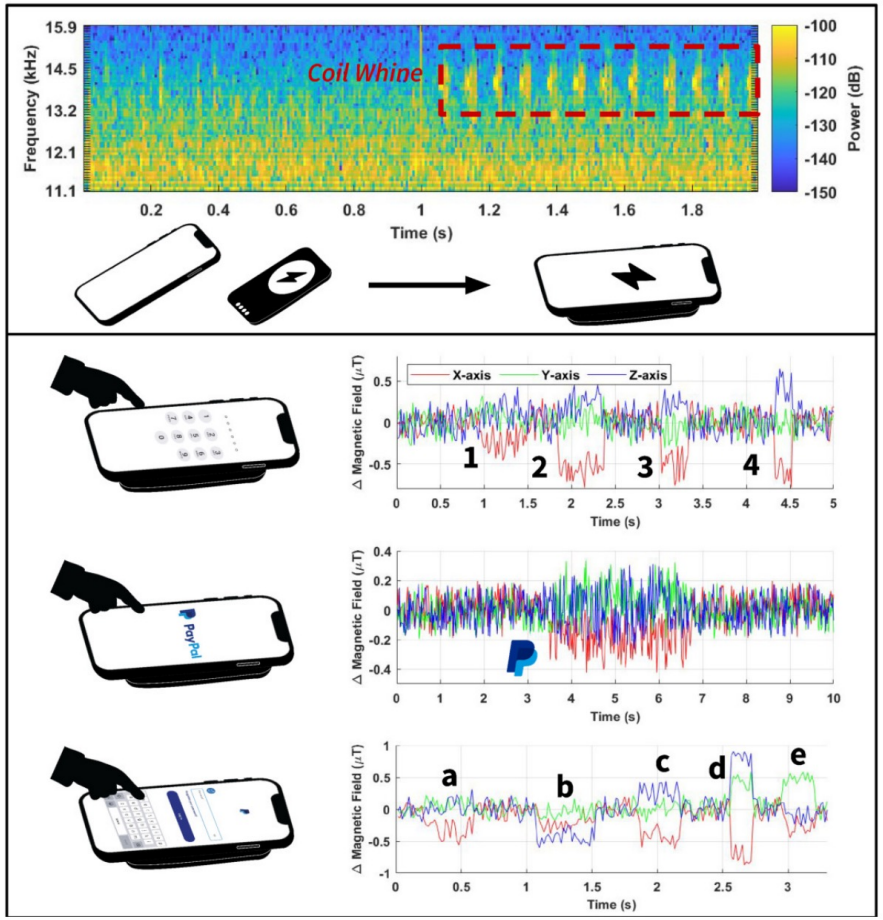


Coil Whine

Vibration and deformation of the coil

- Maxwell stress tensor
- Magnetostriction
- Lorentz force

Motivating Example & Physical Phenomena



Coil Whine

Vibration and deformation of the coil

- Maxwell stress tensor
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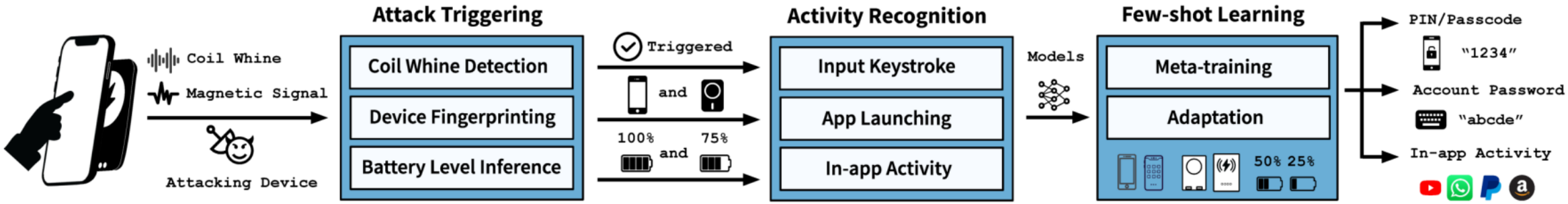
Magnetic Field Disturbance

Perturbations of ambient magnetic field

- Load changes (Charging smartphone)
- Touchscreen characteristics
- Finger-coupling effects

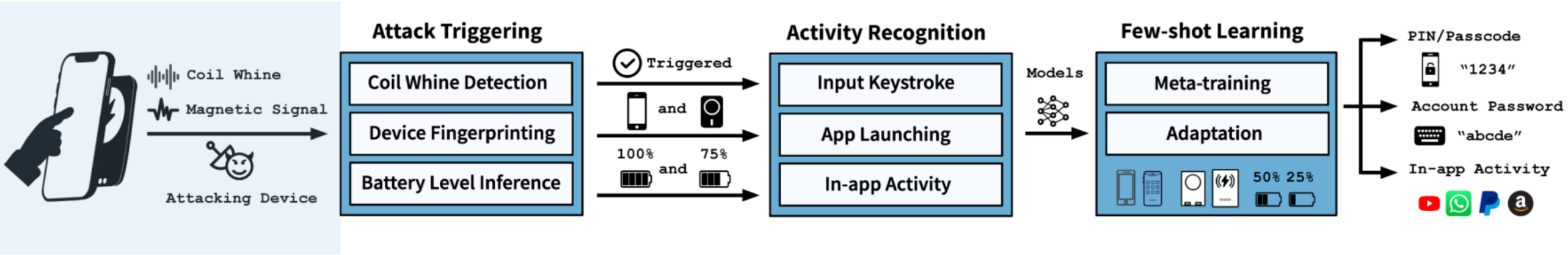
BankSnoop – A Contactless Side-Channel Attack Framework



Comparison with Prior Works

Attacks	Attack surface	Contactless	No need to Compromise devices	No prior knowledge of devices	Fine-grained user privacy	Domain adaptive
Cour et al. (CCS'21)	Current in power line	✗	✗	✗	✗	✗
Wu et al. (ACSAC'21)	Inductive current	✓	✓	✗	✗	✗
EM-Surfing (TDSC'22)	Inductive voltage	✗	✗	✗	✓	✗
Charger-Surfing (Security'20)	Current in USB cable	✗	✗	✗	✓	✗
GhostTalk (NDSS'22)	Current in USB cable	✗	✗	✗	✓	✗
BankSnoop (Our work)	*Coil whine and Magnetic field*	✓	✓	✓	✓	✓

Attacking Device & Scenarios



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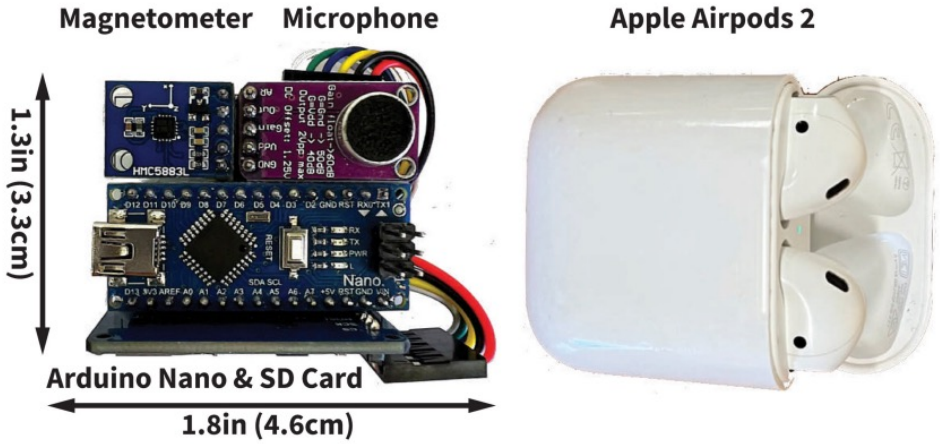

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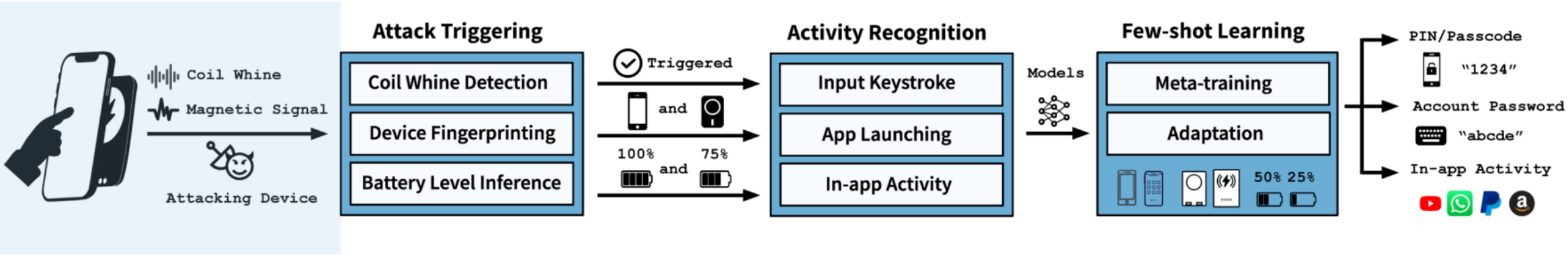

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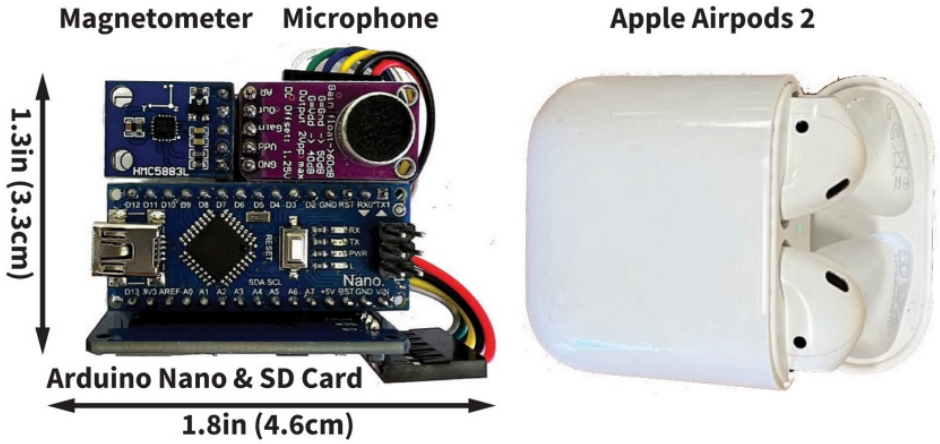
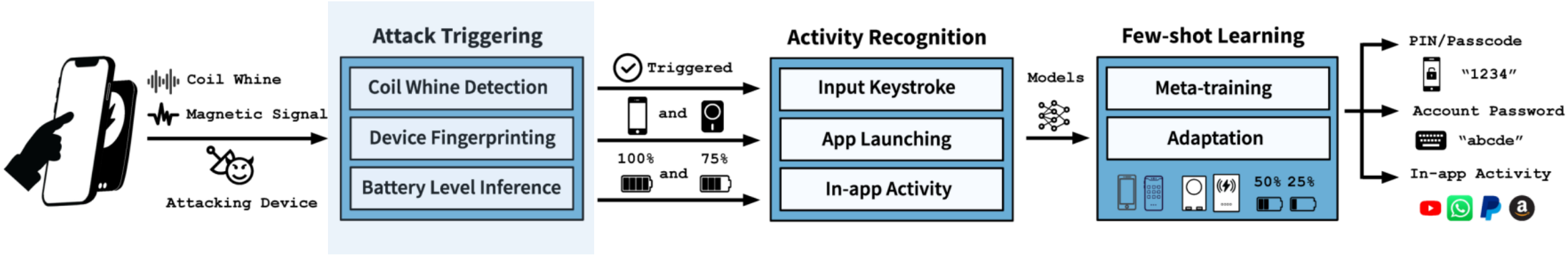


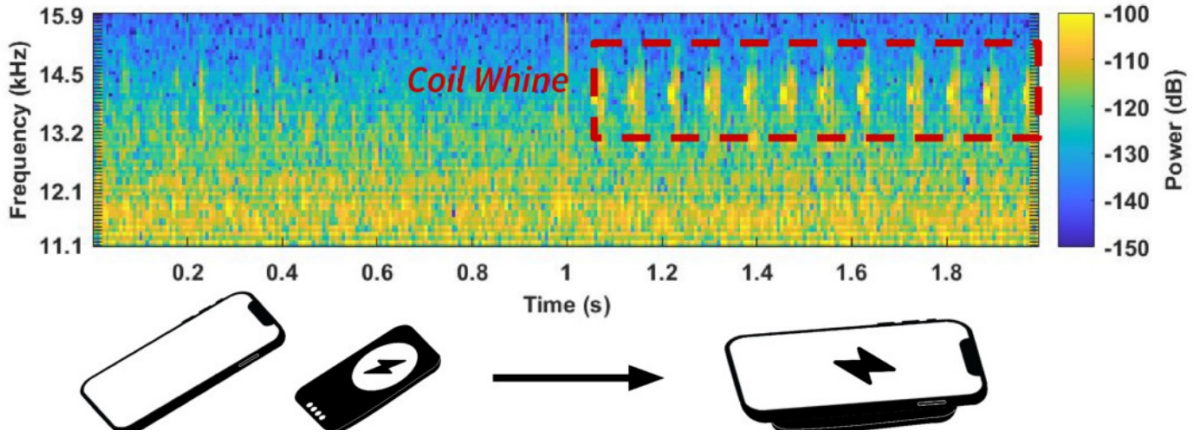
Attack Scenarios

Underneath table

Near the devices

Attack Triggering – Coil Whine Detection





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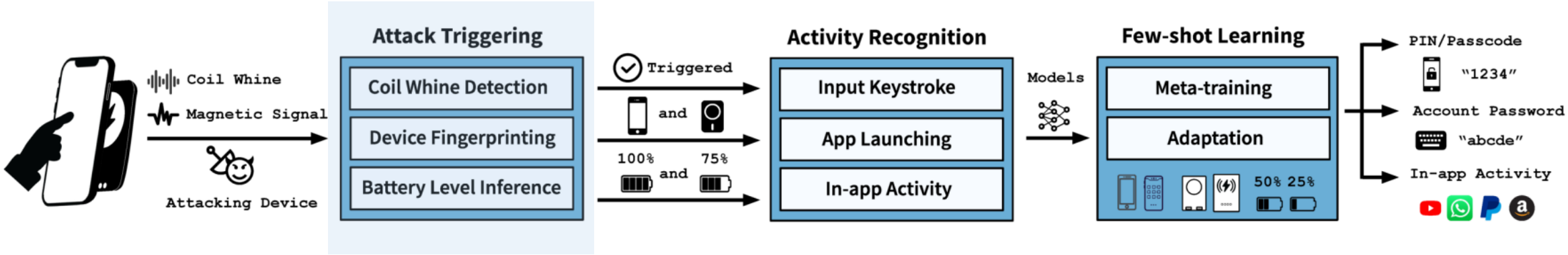
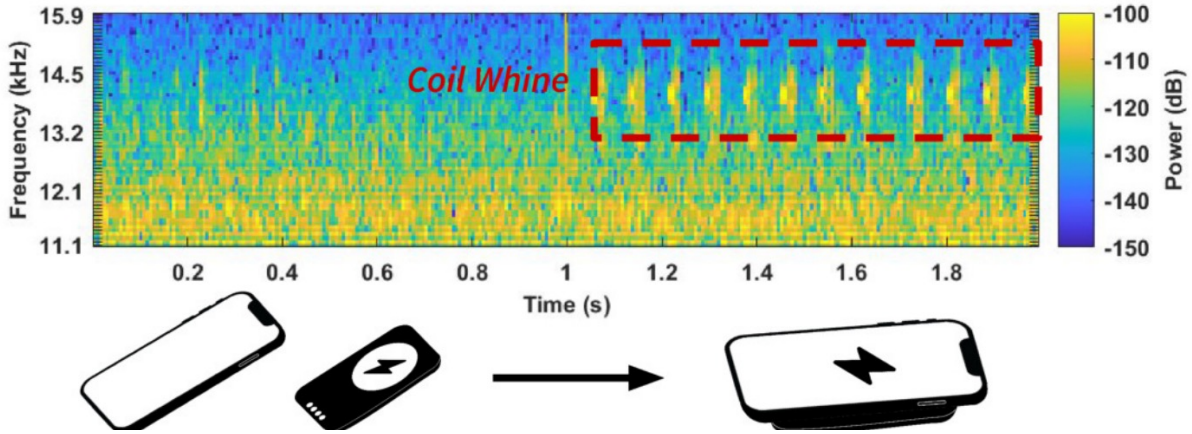
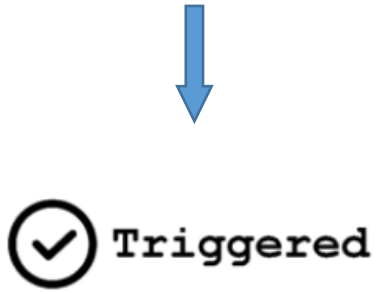
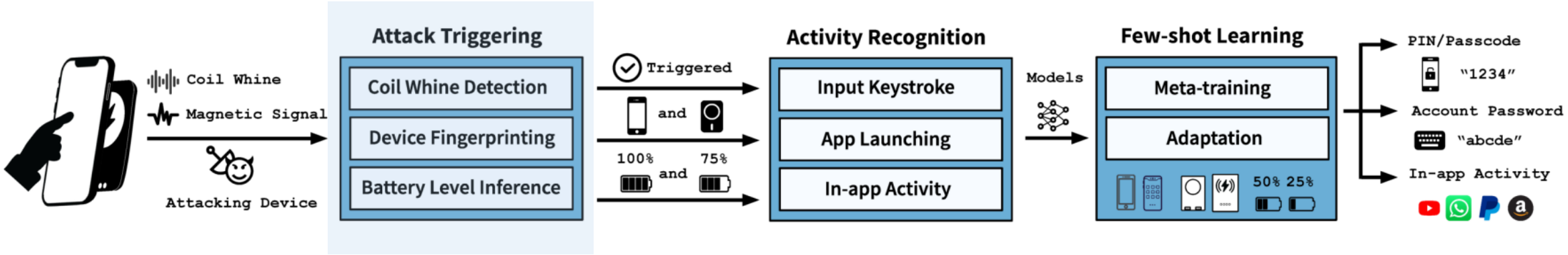






Attack Triggering – Device Fingerprinting



Power Banks

- P_1 : EGO MAGPOWER 2
- P_2 : Anker MagGo
- P_3 : Apple MagSafe Battery Pack
- P_4 : Belkin BOOSTCHARGE

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Smartphones

- S_1 : iPhone 13 Pro
- S_2 : iPhone 12
- S_3 : iPhone 11
- S_4 : Samsung S10

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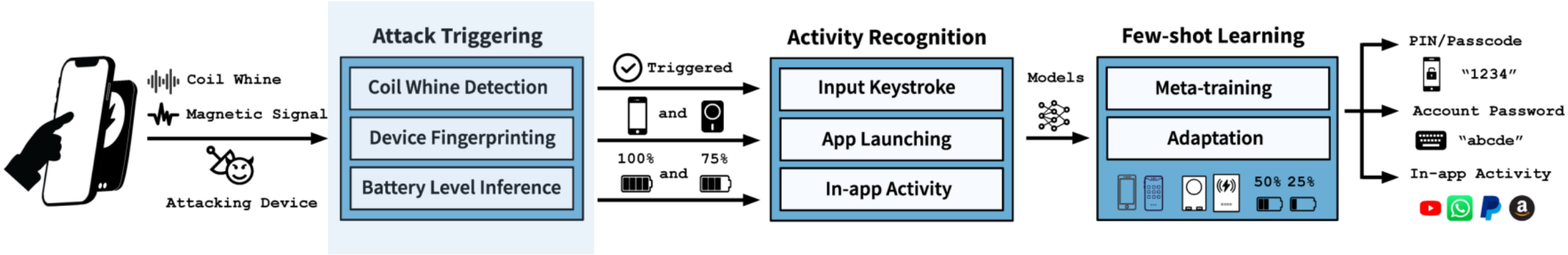

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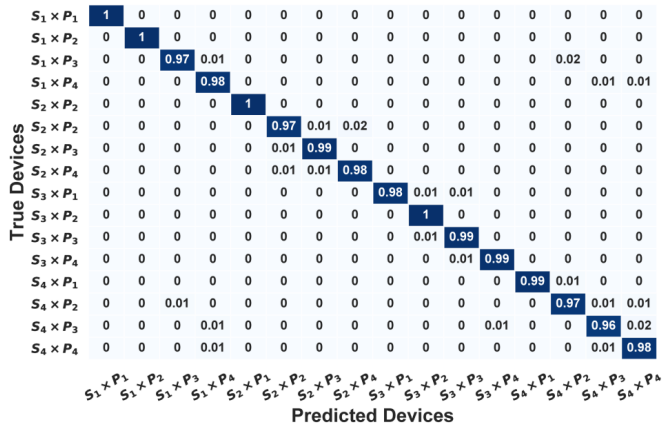
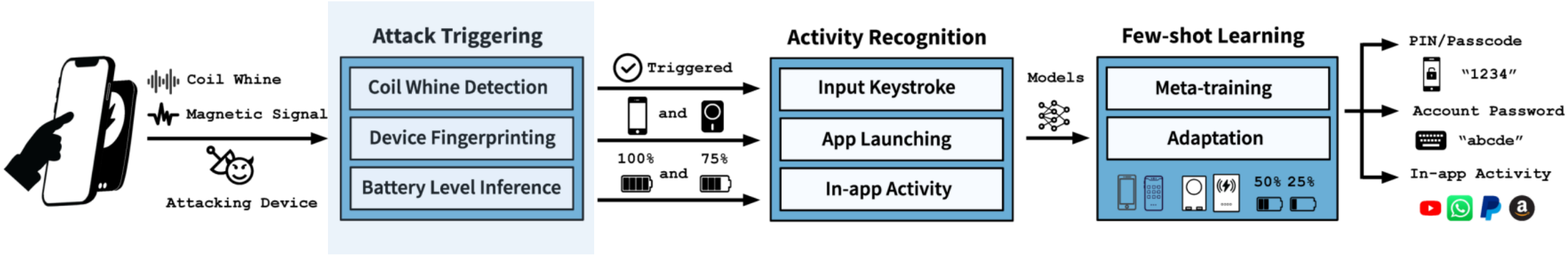
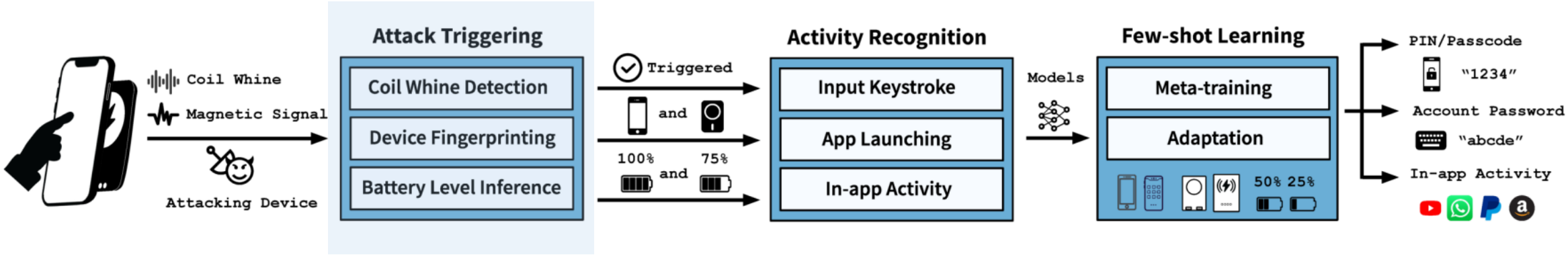


Attack Triggering – Battery Level Inference



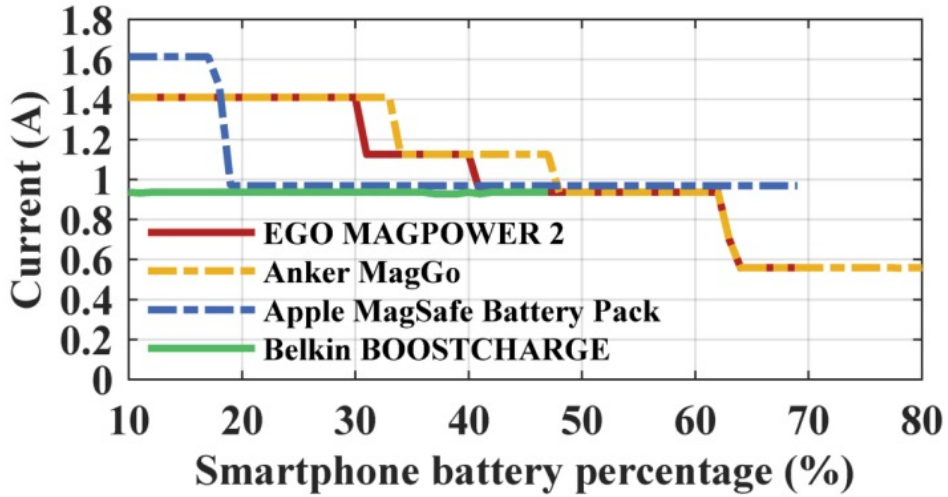
RQ1: Do different power banks present different battery levels in a wireless charging process?

Attack Triggering – Battery Level Inference



RQ1: Do different power banks present different battery levels in a wireless charging process?

Answer to RQ1: Different power banks present different charging patterns, and some (e.g., EGO MAGPOWER 2, Anker MagGo) present ladder-like battery levels.



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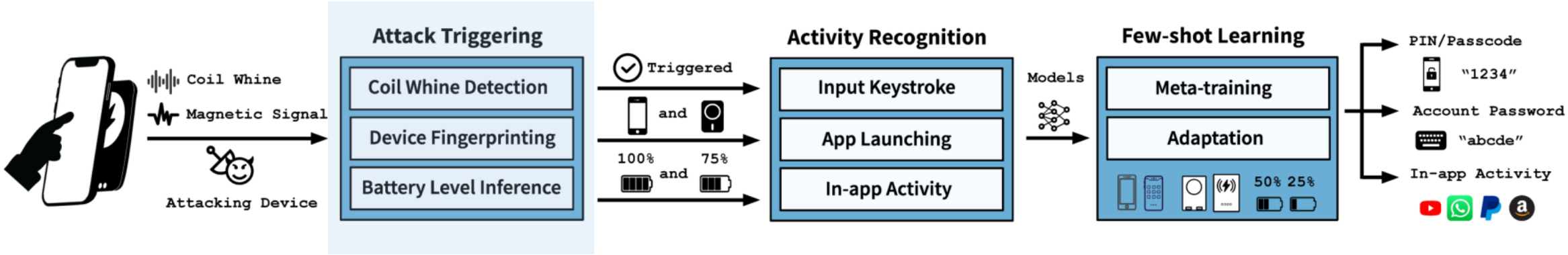
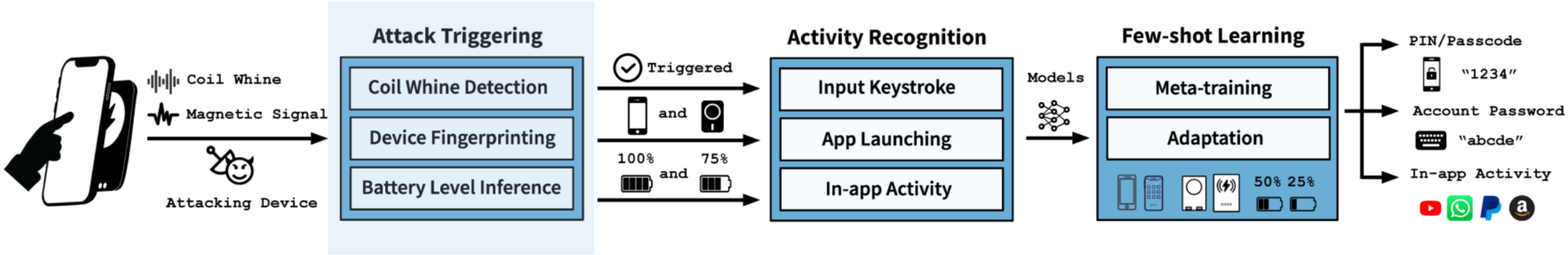


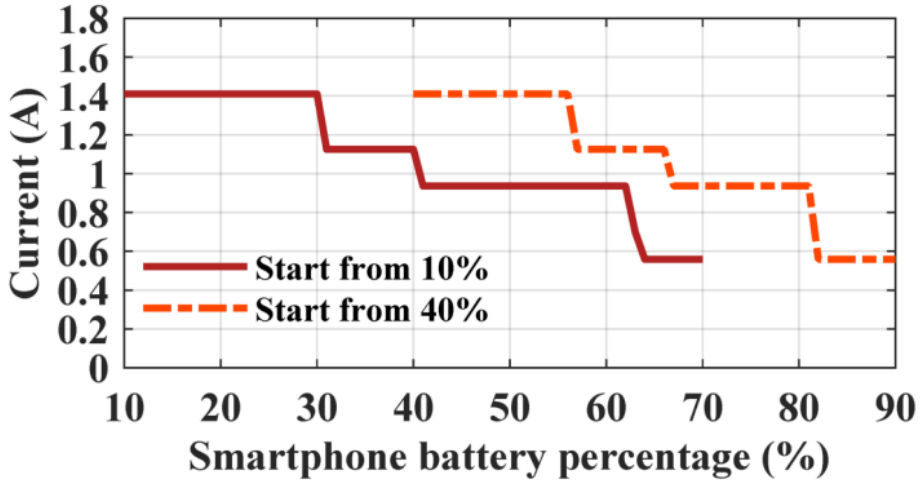
RQ2: Does the initial battery percentage of the smartphone impacts the inductive charging current?

Attack Triggering – Battery Level Inference



RQ2: Does the initial battery percentage of the smartphone impacts the inductive charging current?

Answer to RQ2: The inductive charging current in the secondary coil depends on the battery level of the power bank regardless of the smartphone's initial battery percentage.



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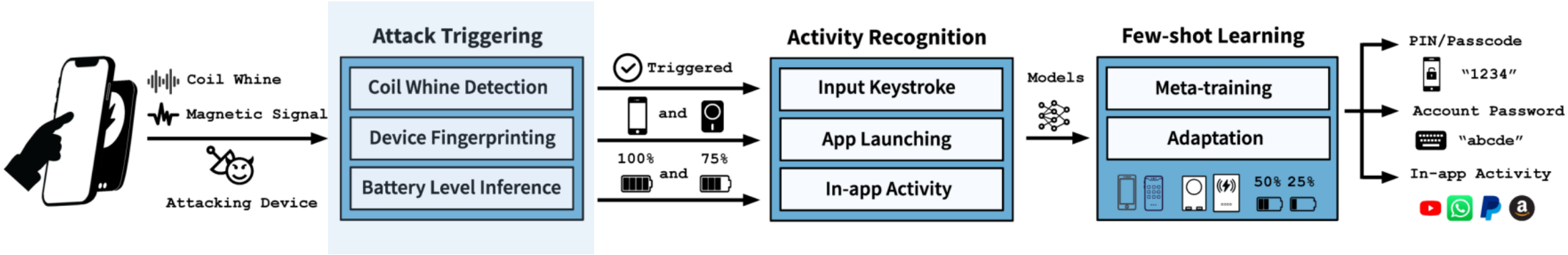
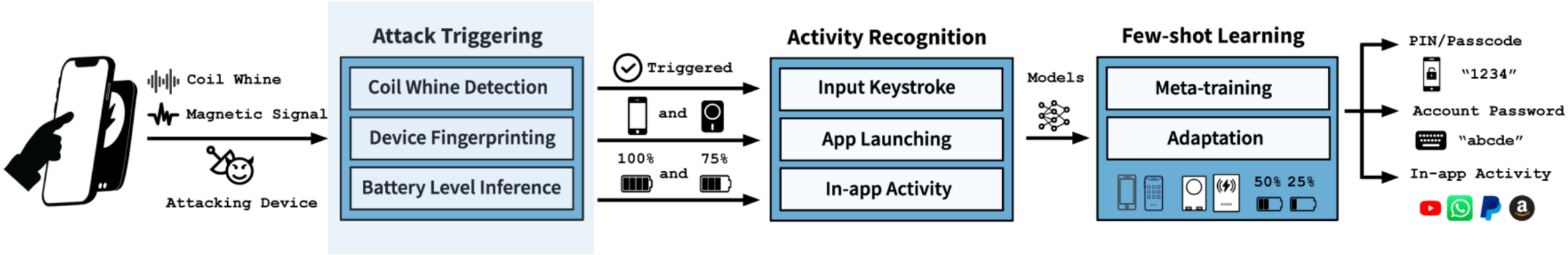


RQ3: Can CDFs of magnetic field strength differences distinguish the battery levels of a power bank?

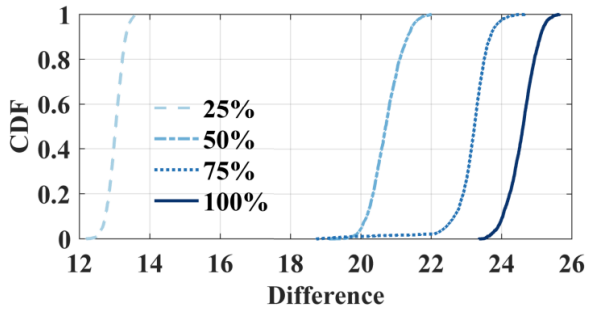
Attack Triggering – Battery Level Inference



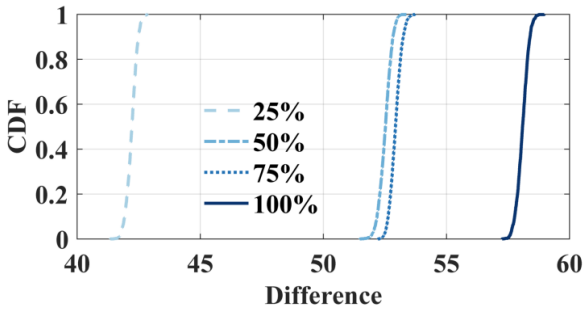
RQ3: Can CDFs of magnetic field strength differences distinguish the battery levels of a power bank?

$$Mag_s(t) = \sqrt{Mag_x^2(t) + Mag_y^2(t) + Mag_z^2(t)}$$

Answer to RQ3: We can use CDFs of the magnetic field strength differences as the measurement to distribute different battery levels of a wireless charging power bank.

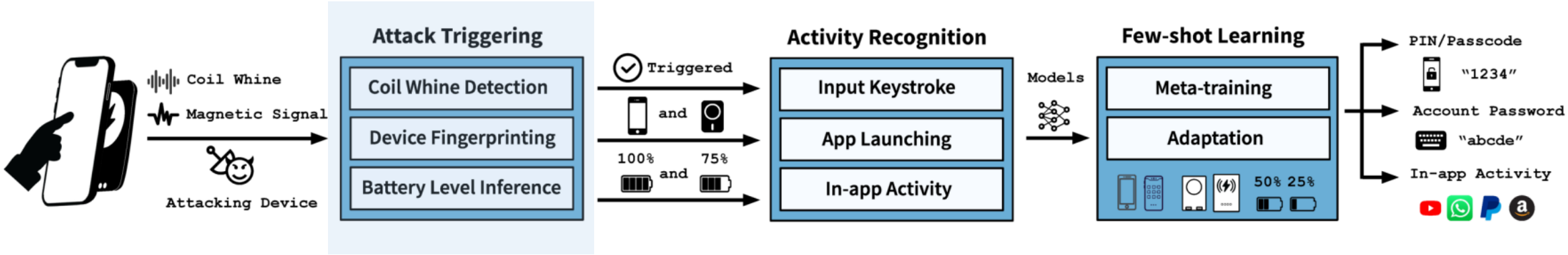


(a) EGO MAGPOWER 2.



(b) Anker MagGo.

Attack Triggering – Battery Level Inference



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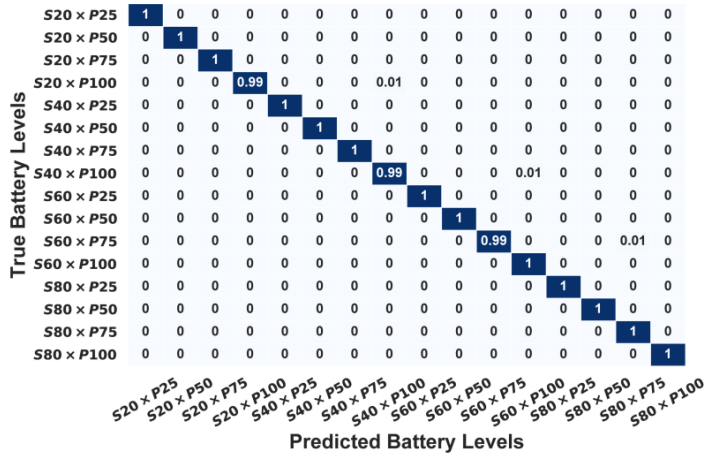
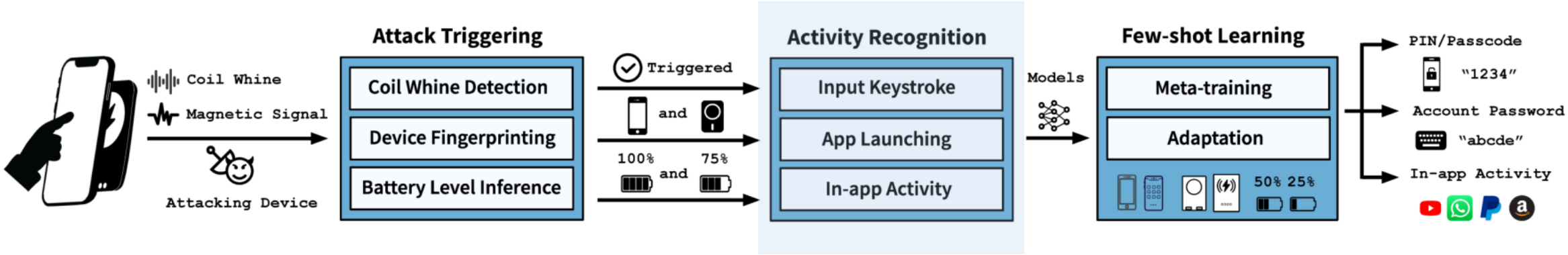
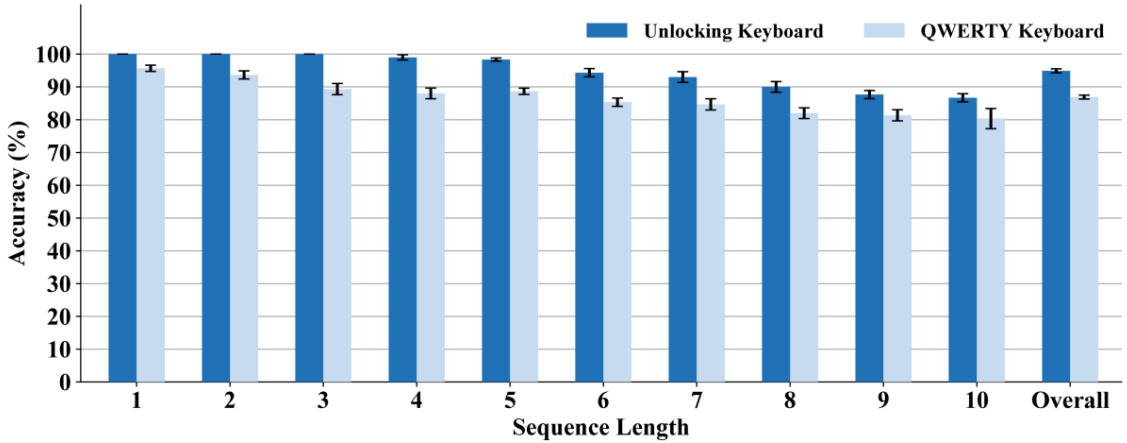


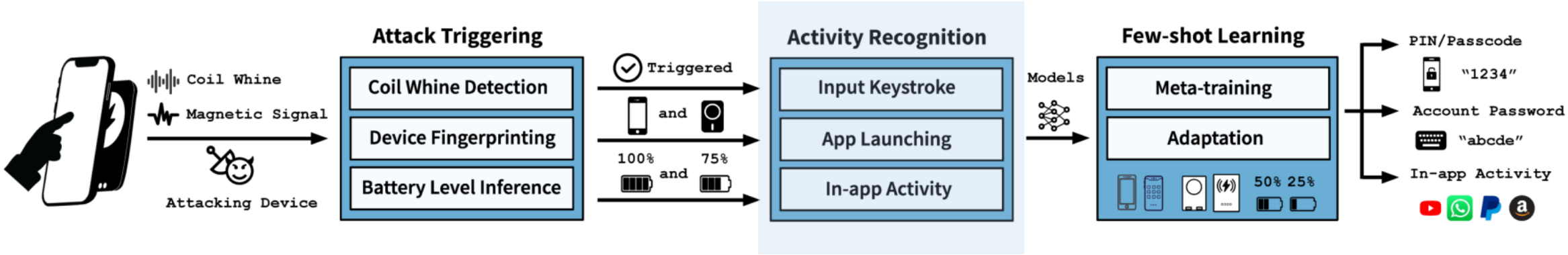
Activity Recognition – Input Keystroke



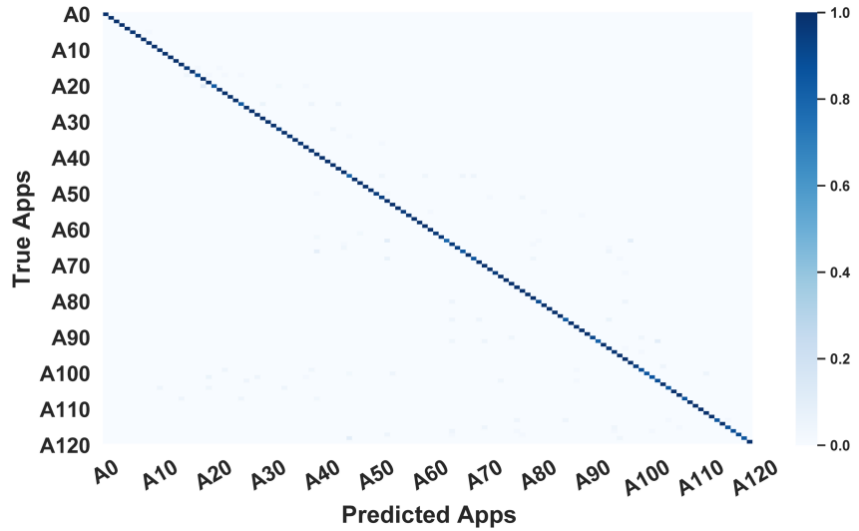
Input Keystrokes



Activity Recognition – App Launching



Launching Apps



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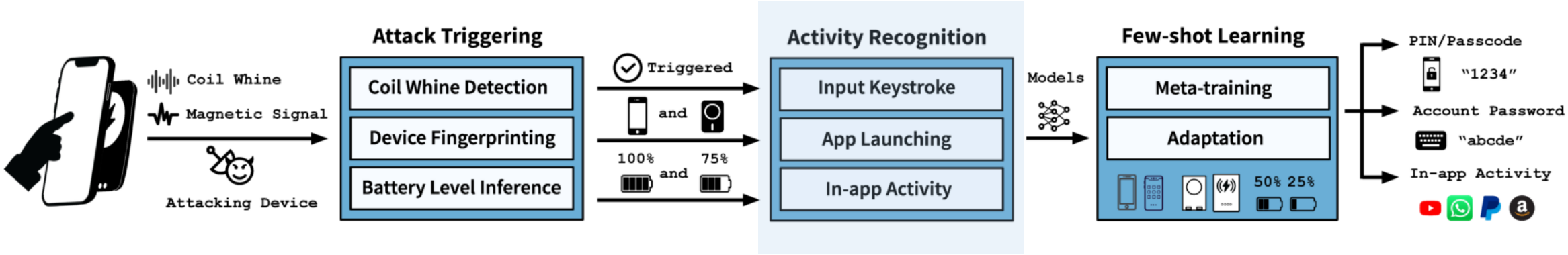
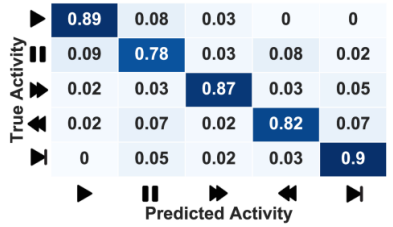
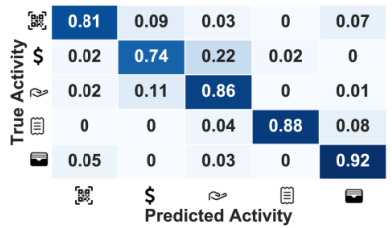


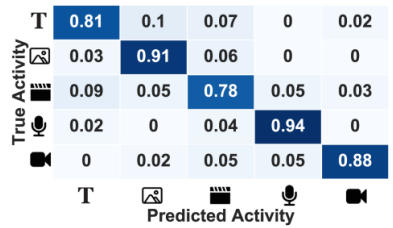
In-App Activities



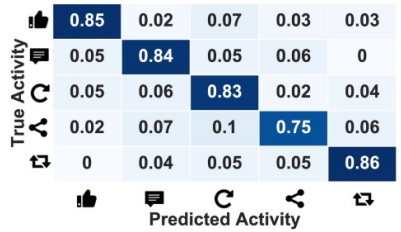
(a) YouTube



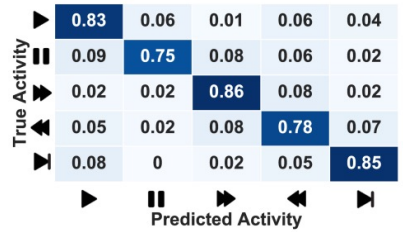
(b) PayPal



(c) WhatsApp

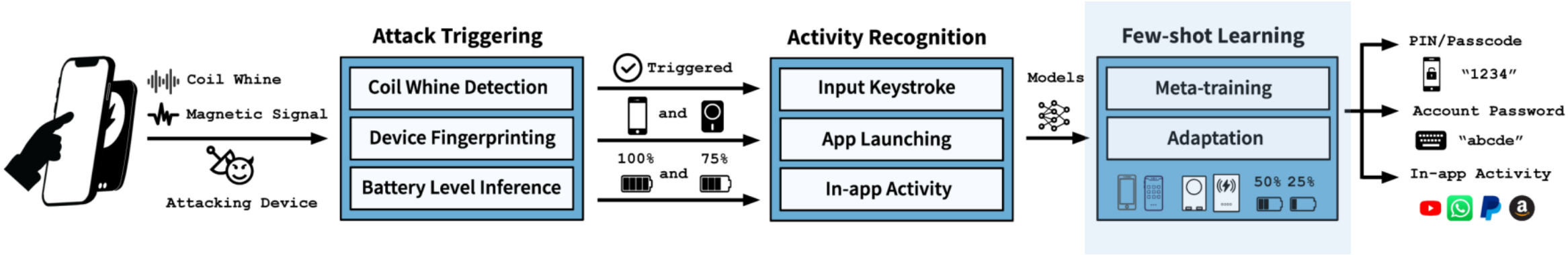


(d) Facebook



(e) Spotify

Few-Shot Learning – Fast Adaptation



Algorithm 1: Meta-training for magnetic classifier

Input: $\mathcal{D}_S$: source dataset. f: magnetic signal classifier. α and β: learning rate hyperparameters.

Output: f_{θ^*}: trained magnetic signal classifier with optimized parameters θ^*.

$\theta \leftarrow \theta_0$, $f_\theta \leftarrow f_{\theta_0}$ ▷ random initialize f_θ with parameters θ_0

while *not finished* **do**

  $\mathcal{T} \leftarrow$ generate a batch of tasks from $\mathcal{D}_S$

  for *each task* $\mathcal{T}_i \in \mathcal{T}$ **do**

    $\mathcal{S}_{\mathcal{T}_i} \leftarrow K \times N$ support samples from $\mathcal{T}_i$

    $\mathcal{S}_{\mathcal{Q}_i} \leftarrow K \times N$ query samples from $\mathcal{T}_i$ $(\mathcal{S}_{\mathcal{T}_i} \cap \mathcal{S}_{\mathcal{Q}_i} = \phi)$

    Evaluate $\nabla_\theta \mathcal{L}_{\mathcal{T}_i}(f_\theta)$ with $\mathcal{S}_{\mathcal{T}_i}$ and loss $\mathcal{L}_{\mathcal{T}_i}(f_\theta, \mathcal{S}_{\mathcal{T}_i})$

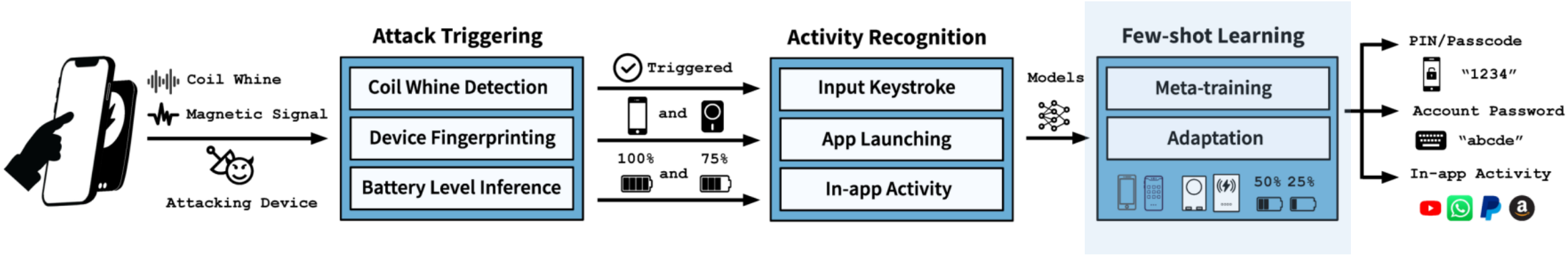
    $\theta'_{\mathcal{T}_i} \leftarrow \theta_0 - \alpha \nabla_\theta \mathcal{L}_{\mathcal{T}_i}(f_{\theta_0}, \mathcal{S}_{\mathcal{T}_i})$ ▷ obtain task-specific parameters $\theta'_{\mathcal{T}_i}$ of $\mathcal{T}_i$ using gradient descent.

    Evaluate $\mathcal{L}_{\mathcal{T}_i}(f_{\theta'_{\mathcal{T}_i}})$ with query set $\mathcal{S}_{\mathcal{Q}_i}$.

  $\theta^* \leftarrow \theta_0 - \beta \nabla_\theta \sum_{\mathcal{T}_i \in \mathcal{T}} \mathcal{L}_{\mathcal{T}_i}(f_{\theta'_{\mathcal{T}_i}}, \mathcal{S}_{\mathcal{Q}_i})$ ▷ obtain the optimized parameters θ^* that minimizes all task losses

Output classifier f_{θ^*} with optimized parameters θ^*

Few-Shot Learning – Fast Adaptation



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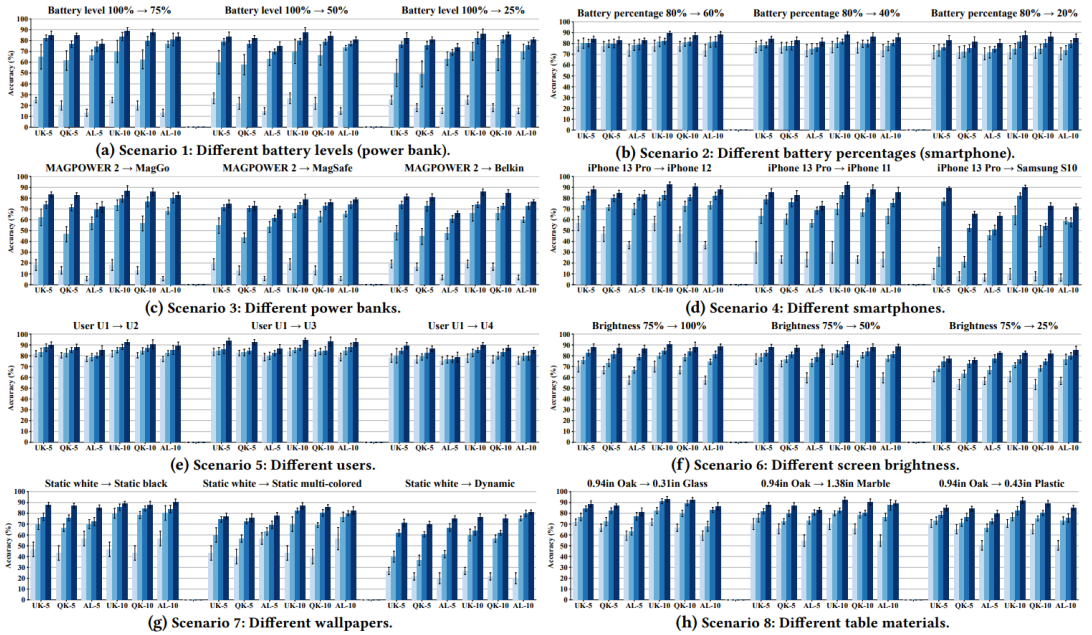
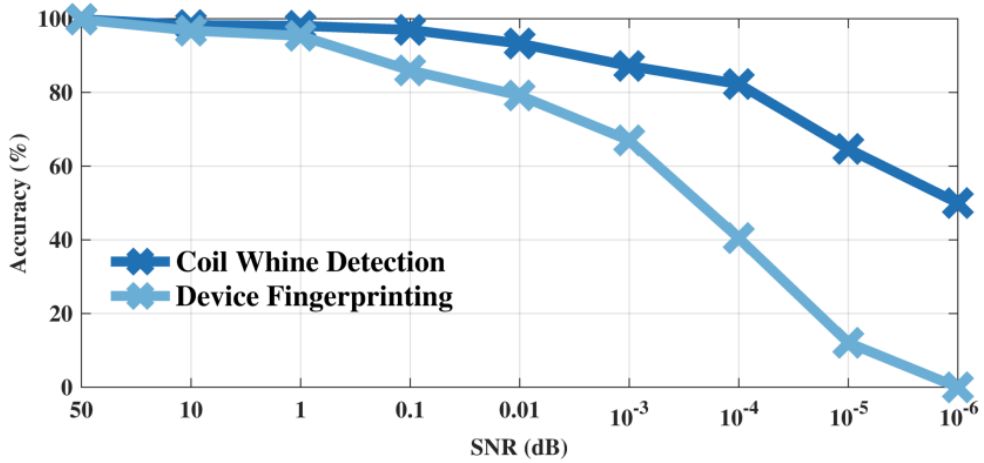
  $\theta^* \leftarrow \theta_0 - \beta \nabla_\theta \sum_{\mathcal{T}_i \in \mathcal{T}} \mathcal{L}_{\mathcal{T}_i}(f_{\theta'_{\mathcal{T}_i}}, \mathcal{S}_{\mathcal{Q}_i})$ ▷ obtain the optimized parameters θ^* that minimizes all task losses
Output classifier f_{θ^*} with optimized parameters θ^*



(a) Scenario 1: Different battery levels (power bank).
(b) Scenario 2: Different battery percentages (smartphone).
(c) Scenario 3: Different power banks.
(d) Scenario 4: Different smartphones.
(e) Scenario 5: Different users.
(f) Scenario 6: Different screen brightness.
(g) Scenario 7: Different wallpapers.
(h) Scenario 8: Different table materials.

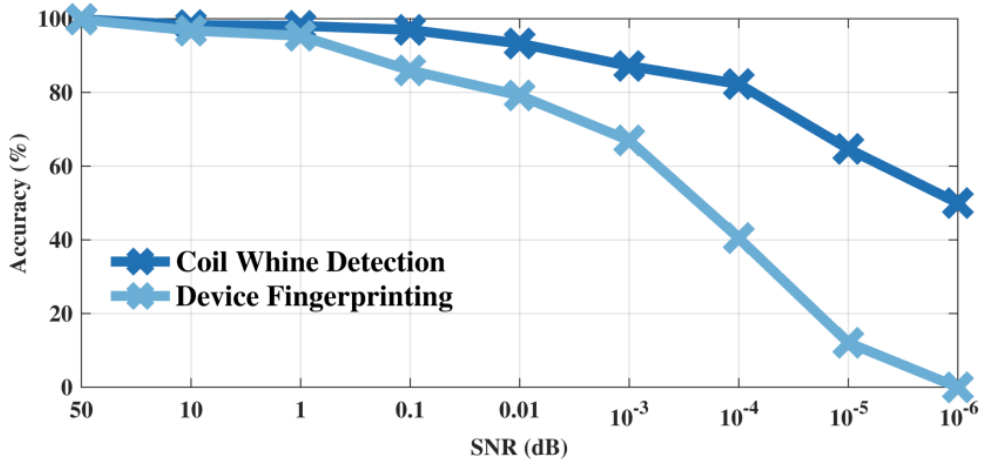
Analysis of Other Impact Factors

Environmental Noise

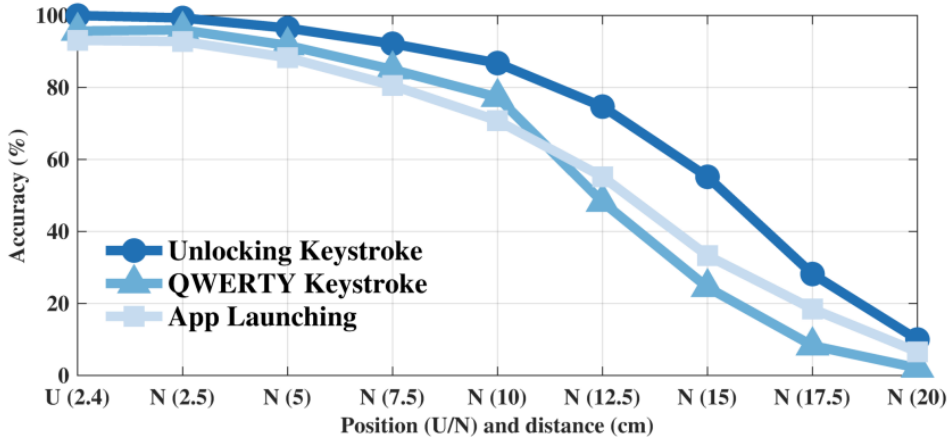


Analysis of Other Impact Factors

Environmental Noise



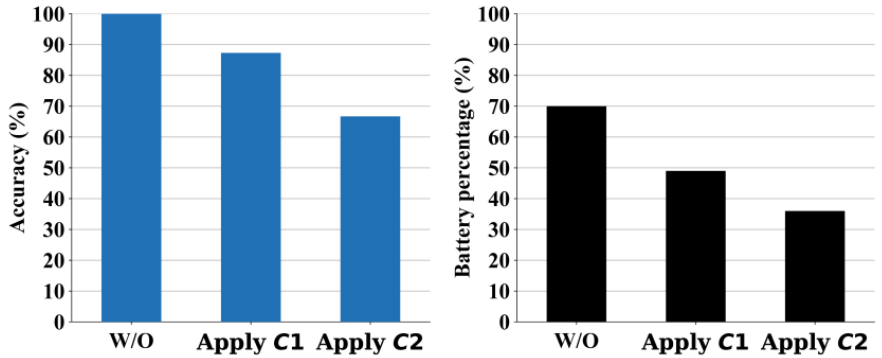
Position and Distance



Countermeasures

Countermeasure 1: Shield magnetic field.

Countermeasure 2: Signal obfuscation.



(a) Recognition accuracy. (b) Battery after charging.

Conclusion

- **A novel contactless side-channel attack**

Conclusion

- **A novel contactless side-channel attack**
- **A new attack framework**

Conclusion

- **A novel contactless side-channel attack**
- **A new attack framework**
- **Comprehensive evaluation with fast adaptation**

Thank you!

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I will be on the 2024 job market!

Read the paper