Thwarting Smartphone SMS Attacks at the Radio Interface Layer

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Feb 28th, 2023

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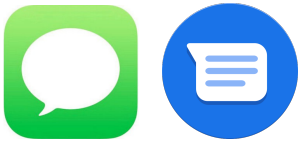
Short Message Service (SMS)



- Introduced since December, 1992
- Defined in 3GPP TS 23.040 [3gp]

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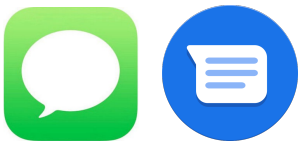

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- Text-based messaging

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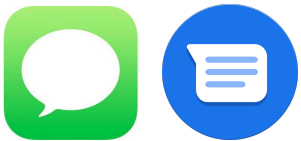

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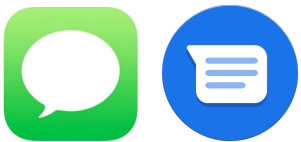

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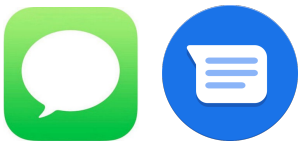

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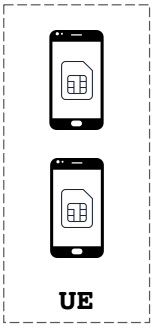
- Alerts & notifications
- Marketing & advertising
- .....

SMS Transmission Path in Cellular Network



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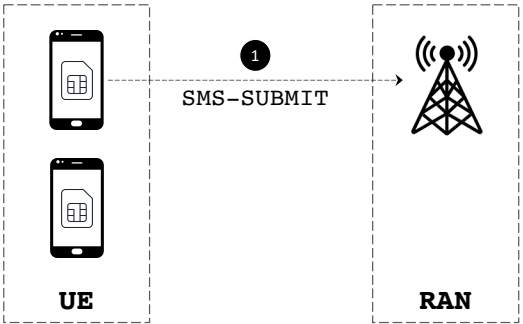

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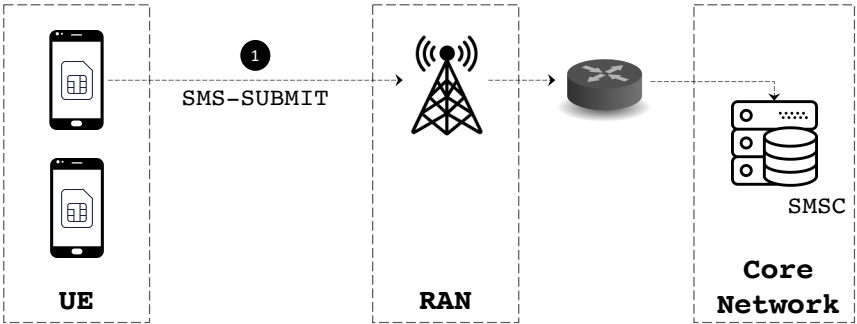

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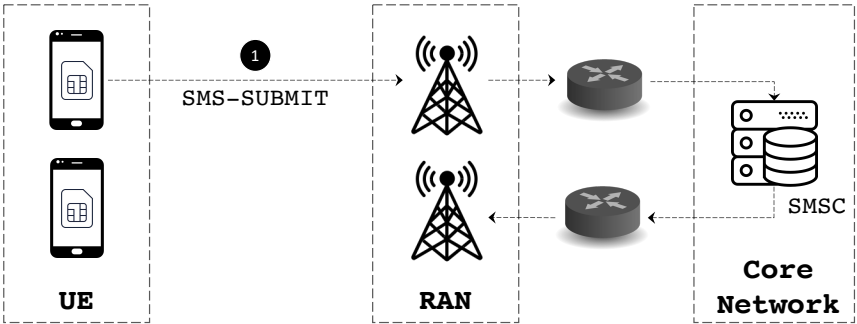

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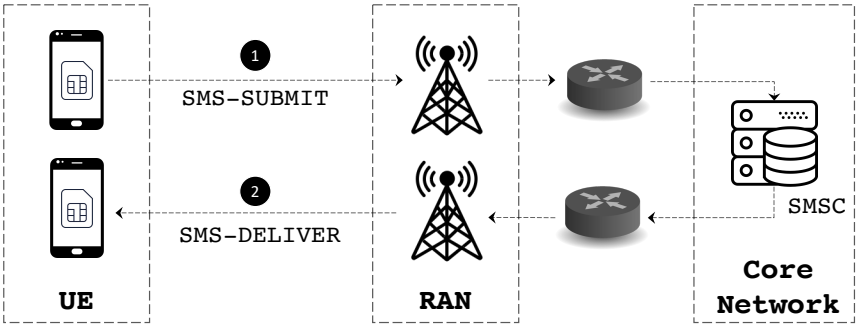
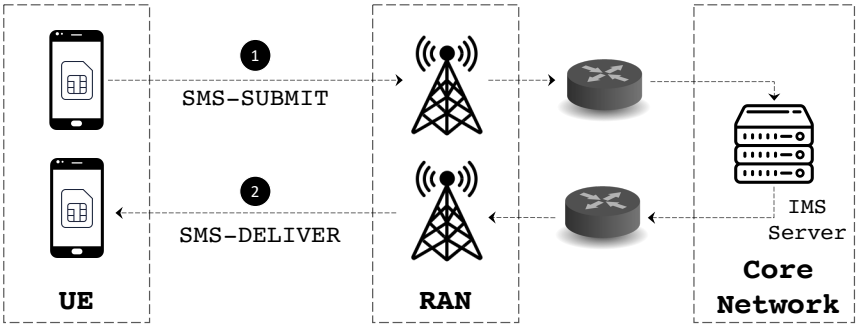


SMSC-Based SMS (2G/3G)

SMS Transmission Path in Cellular Network



IMS-Based SMS (4G+)

Exploiting SMS

- SMS is **not** just a *text-based service*

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- Zero-click exploits exist in various ways to compromise security, privacy and availability without the user's knowledge and consent

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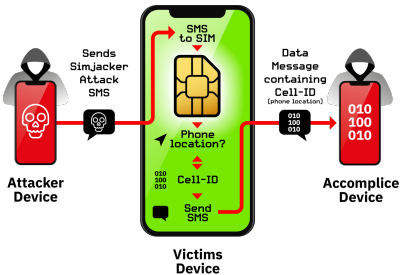

SimJacker Attack [sim]

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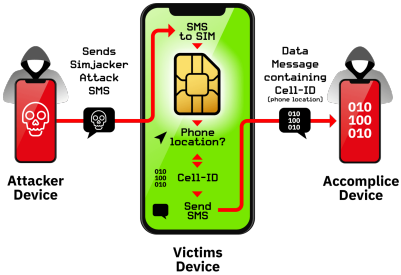


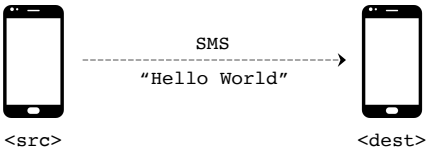
SimJacker Attack [sim]

Contemporary UE operating systems cannot see these SMS attacks, let alone stop them

Exploiting SMS

SMS PDU Payload

Field	SCA	FO	OA/DA	PID	DCS	...	UDL	UD
Value	-	01	<dest>	00	00		0C	C8329BF...



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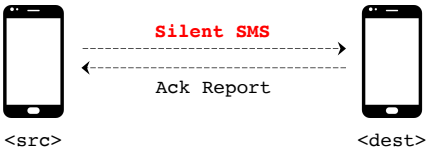
SMS PDU Payload

Field	SCA	FO	OA/DA	PID	DCS	...	UDL	UD
Value	-	01	<dest>	40	00		0C	C8329BF...

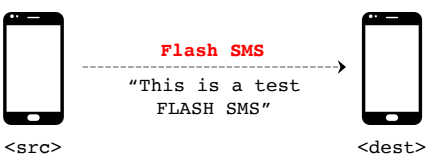


UE will not display silent SMS to user

Exploiting SMS

SMS PDU Payload

Field	SCA	FO	OA/DA	PID	DCS	...	UDL	UD
Value	-	01	<dest>	00	18		0C	C8329BF...



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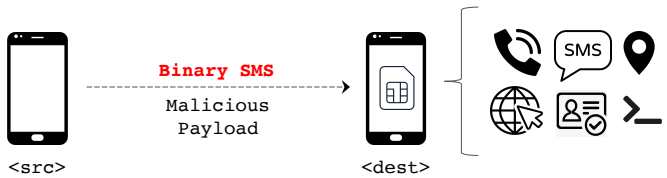
Field	SCA	FO	OA/DA	PID	DCS	...	UDL	UD
Value	-	01	<dest>	7F	F6		0C	<Payload>



Exploiting SMS

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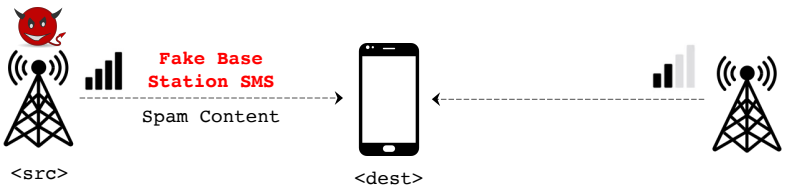
Field	SCA	FO	OA/DA	PID	DCS	...	UDL	UD
Value	-	01	<dest>	00	00		0C	Spam Content



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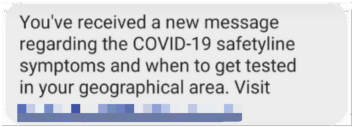

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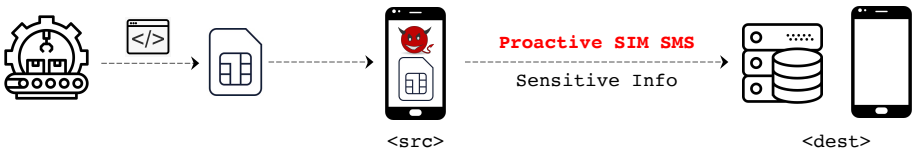
Value	-	01	<dest>	00	00		0C	Sensitive Info



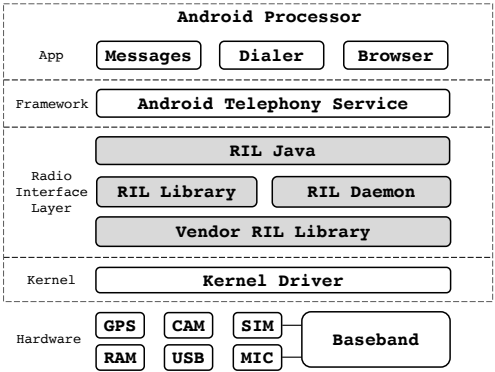
Exploitation Cost

Pre-paid SIM: $5

GSM USB Modem: $15

Total Cost: As low as $20!

Defending Against SMS Attacks



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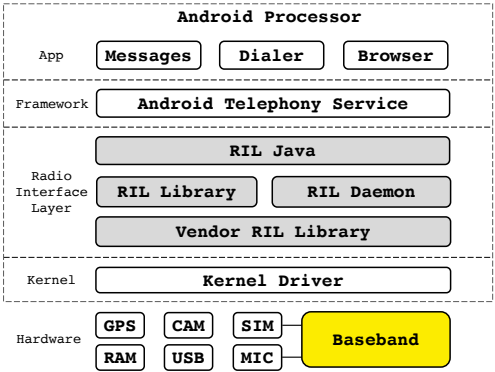

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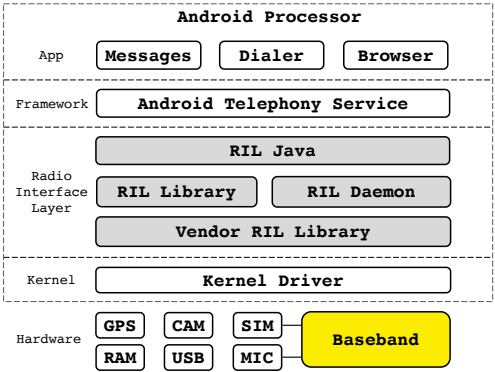

Baseband-Layer Defenses

- FBS Detection in Qualcomm chips [qua]

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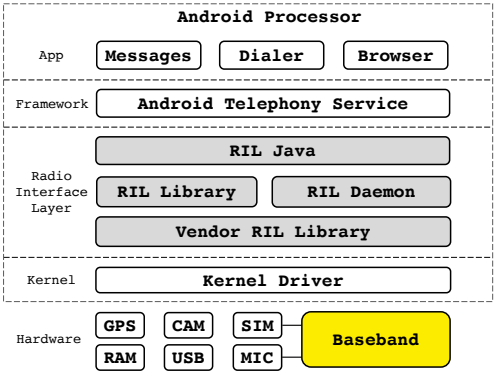

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+ High visibility
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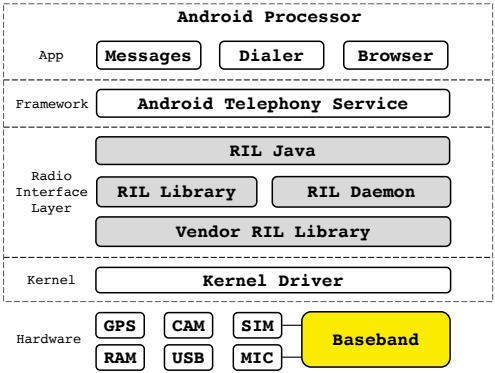

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Cons

– Closed-source
– Integrity-protected
– Highly customized implementation

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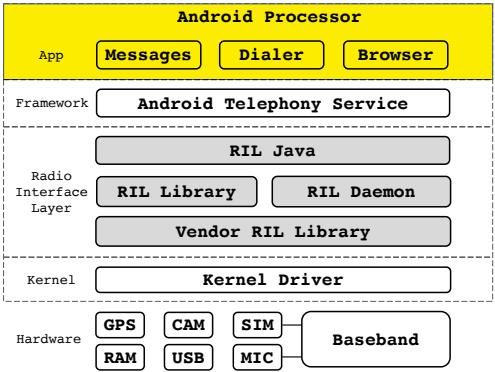

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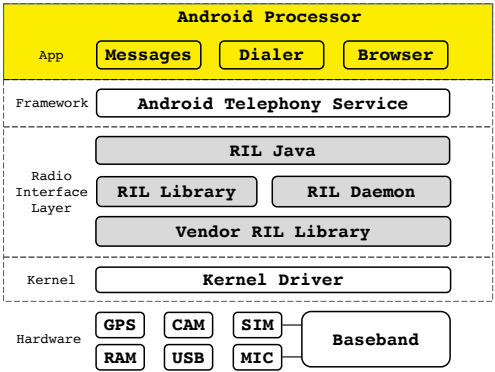

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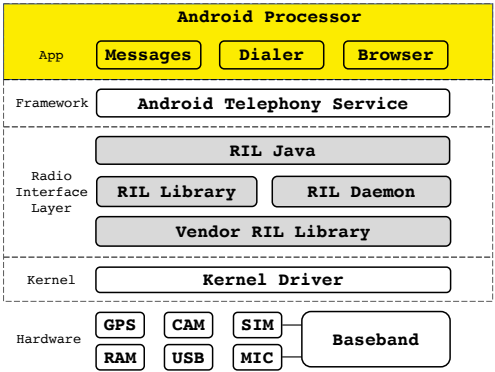

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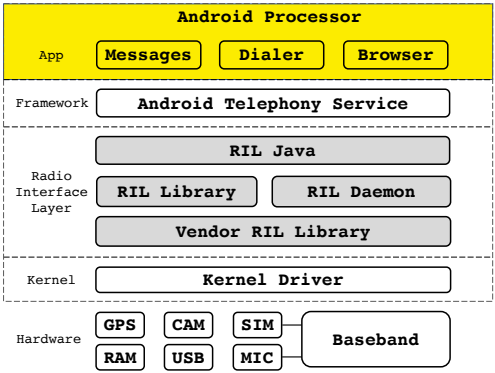

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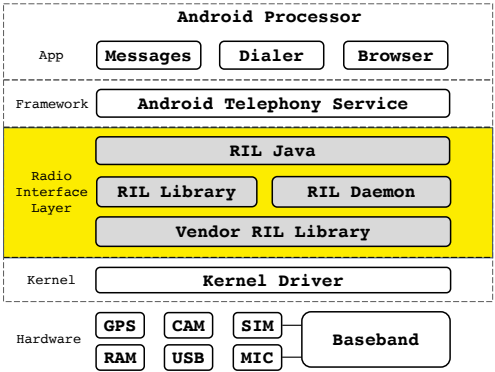
– Low visibility
– Passive detection only
– Root required

RILDefender Overview



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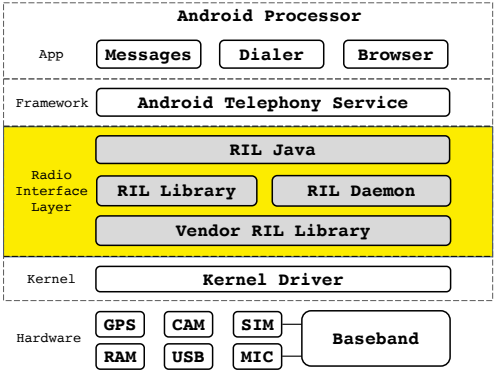

RIL-layer Defenses

- The *first* defense RILDefender
- Deployed at the *Radio Interface Layer* (RIL)

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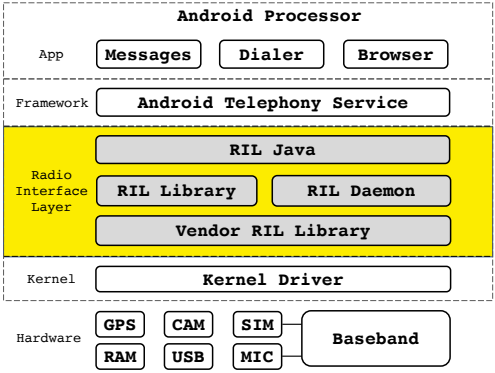

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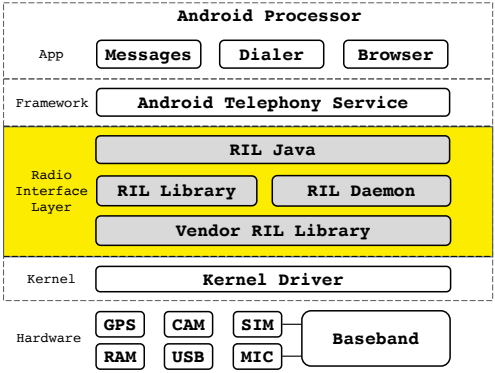

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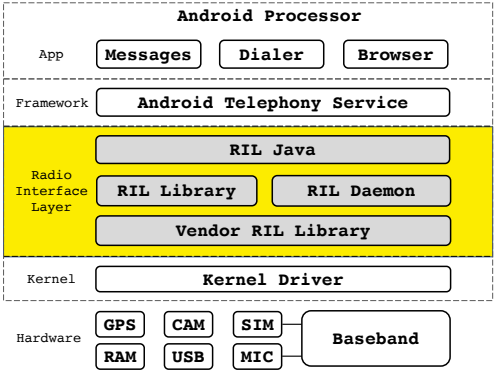

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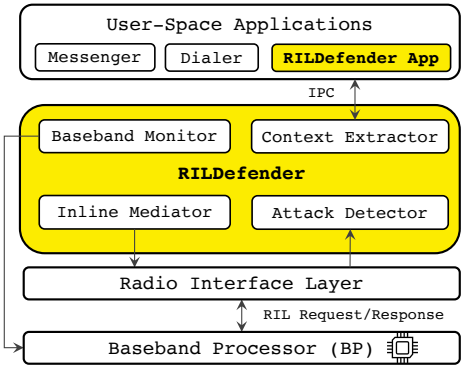
Key Distinctions over Existing Defenses

+ Detection & Prevention capability
+ Vendor-agnostic
+ Extensibility

RILDefender At the Radio Interface Layer



RILDefender Architecture

- Radio Interface Layer
  - Four logical components
- Application Layer
  - The RILDefender app

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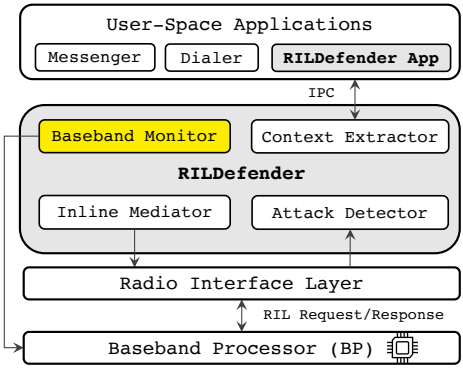

Baseband Monitor

- Monitor baseband-only SMS attacks (one exception)

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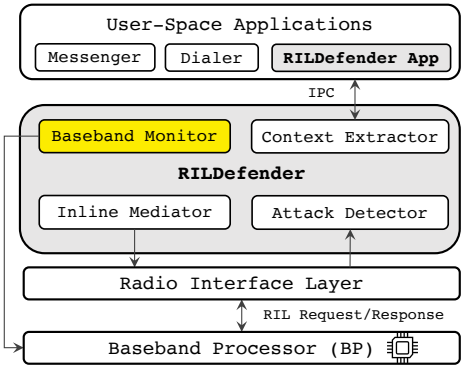
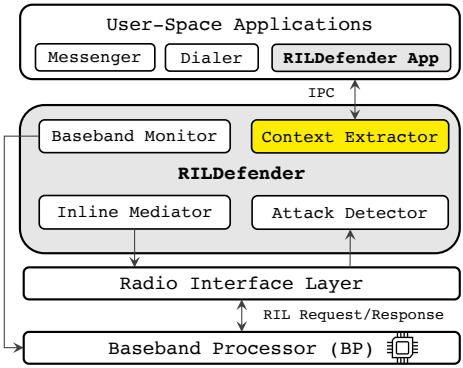


Baseband Monitor

- Monitor baseband-only SMS attacks (one exception)
- Interpret baseband traffic from diagnostic interfaces (e.g., `/dev/diag`)
- Adapted from existing libraries [sno]

RILDefender At the Radio Interface Layer



Context Extractor

- Track context of user-space applications (e.g., SMS sender PID)

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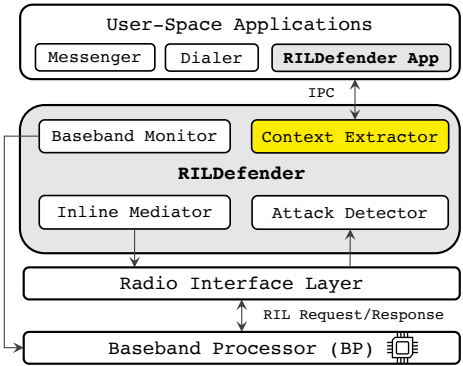
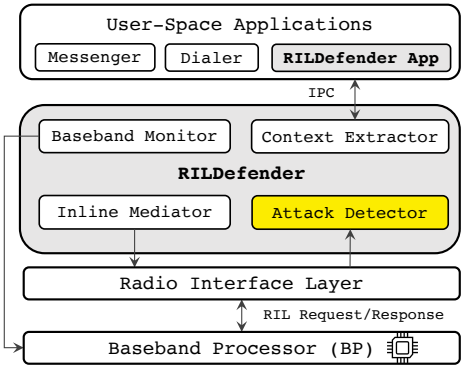


Context Extractor

- Track context of user-space applications (e.g., SMS sender PID)
- Track context of system-level parameters (e.g., signal strengths)
- Interact through IPC calls

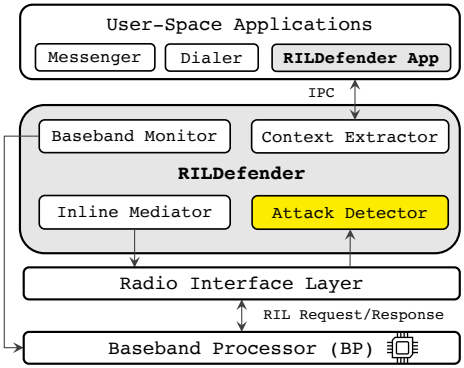
RILDefender At the Radio Interface Layer



Attack Detector

- Instrument the main RIL handler

RILDefender At the Radio Interface Layer



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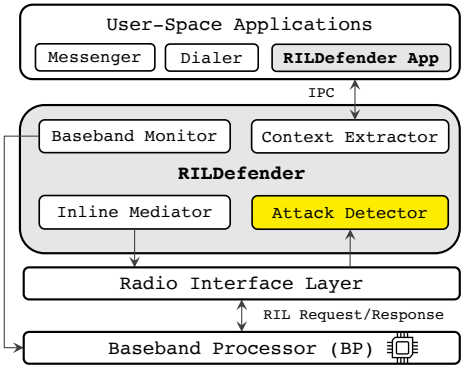

Attack Detector

- Instrument the main RIL handler
- Synthesize SMS payload and information from other component
- Load user-defined attack signature set

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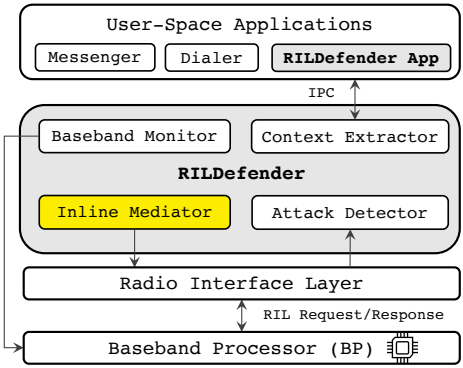
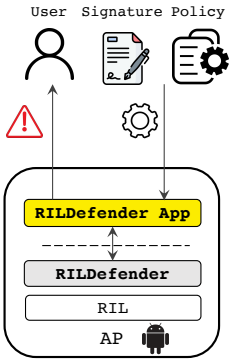


Inline Mediator

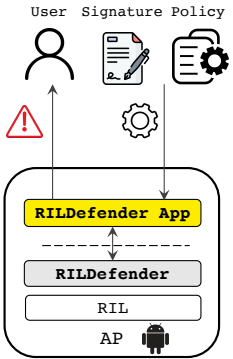
- Instrument the RIL logic for attack prevention
- Interact through specific RIL commands

RILDefender at the Application Layer



RILDefender App

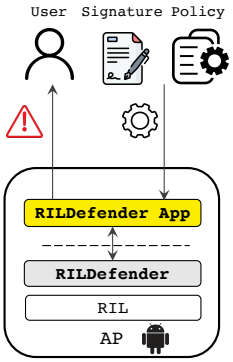
RILDefender at the Application Layer



RILDefender App

- Configure security level for each attack
  - Block and Notify
  - Block without Notify
  - Notify only
  - Allow

RILDefender at the Application Layer



RILDefender App

- Configure security level for each attack
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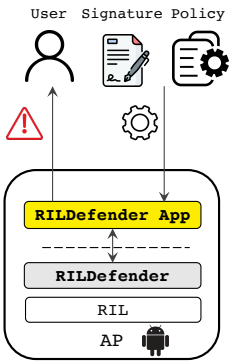
- Receive real-time alerts for attack events

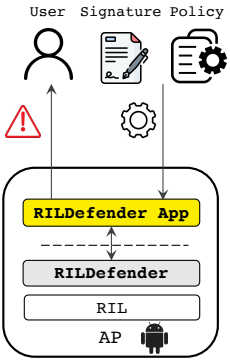
RILDefender at the Application Layer

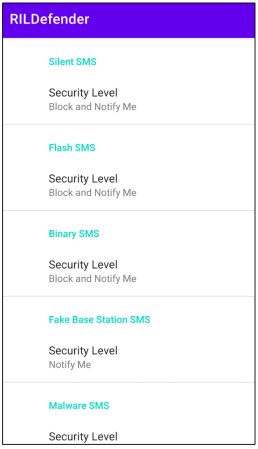


RILDefender App

- Configure security level for each attack
  - Block and Notify
  - Block without Notify
  - Notify only
  - Allow
- Receive real-time alerts for attack events
- Configure user-defined attack signatures

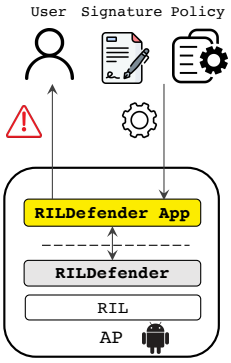
RILDefender at the Application Layer

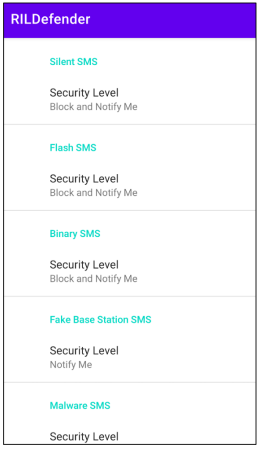




Configuration UI

RILDefender at the Application Layer





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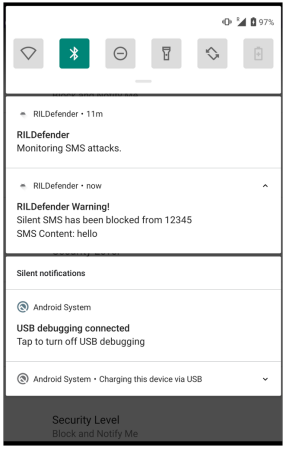

Alert UI

RILDefender at the Application Layer

Category	SMS Feature
SMS Fields	$sms.mti$
	$sms.smsc$
	$sms.oa$
	$sms.da$
	$sms.scts$
	$sms.pid$
	$sms.dcs$
	$sms.udl$
	$sms.ud$
	$sms.proactiveCmd$
SMS Context	$sms.src$
	$sms.ts$
	$bs.\overline{ss}$
	$bs.mcc$
	$bs.mnc$
	$bs.cid$
	$bs.lac$
	$bs.arfcn$
	$bs.rat$
SMS Events	$evnetCount$
	$\{sms_1, ..., sms_n\}$

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SMS Events	$evnetCount$
	$\{sms_1, ..., sms_n\}$

```
<Rule>    → <RuleName>: <Expr>
<Expr>    → { lvalue: <Value>
              opCode: <Op>
              condition: <Cond>
              rvalue: <Value> }
<Value>   → <Feature> | <Const> | <Expr> | List(<Expr>)
<OpCode>  → + | - | * | / | & | | | ^ | && | || | << | >>
<Cond>    → == | != | > | < | >= | <=
<Feature> → sms.mti | sms.smsc | sms.oa | sms.da | sms.ud
            | sms.pid | sms.scts |sms.dcs | sms.udl
            | sms.src | sms.ts | sms.proactiveCmd |
            | bs.ss | bs.mcc | bs.mnc | bs.cid | bs.lac
            | bs.arfcn | bs.rat | eventCount | sms_n
<Const>   → <Integer> | <Float> | <String>
```

YAML-based language to describe SMS attack signatures as propositional logic

Implementation and Experiment Setup

Device	Chipset	OS Ver.	AOSP Build	LoC
Nexus 6	QCOM Snapdragon 805	7.1.1	N6F26Q	3,342
Pixel XL	QCOM Snapdragon 821	10.0.0	QP1A.190711.019	3,462
Pixel 5	QCOM Snapdragon 765G	11.0.0	RQ3A.211001.001	3,476
Pixel 5	QCOM Snapdragon 765G	12.0.0	SQ1A.220205.002	3,476
Pixel 5	QCOM Snapdragon 765G	13.0.0	TP1A.221005.002	3,482

Smartphone UEs and AOSP versions that RILDefender has been implemented on and evaluated

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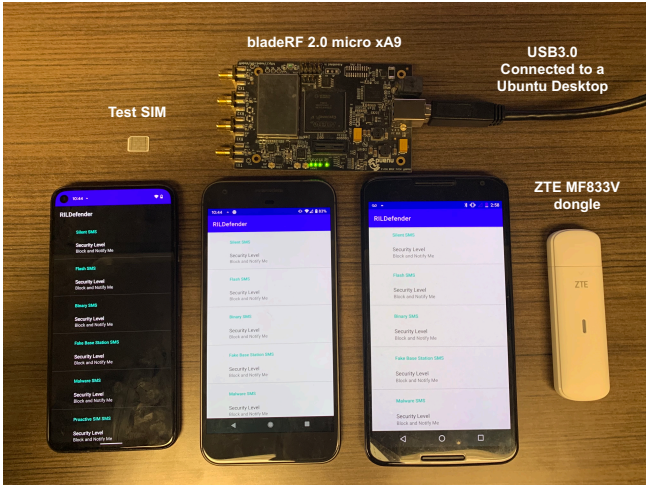

Effectiveness Evaluation

Attack	SMS Payload			Cellular Network Params.			D	B
	PID	DCS	Proactive CMD	TxPower	MNC	MCC		
Binary SMS (Interactive)	0x7F	0xF6	DISPLAY_TEXT	-	-	-	✓	✓
	0x7F	0xF6	SET_UP_CALL	-	-	-	✓	✓
	0x7F	0xF6	LAUNCH_BROWSER	-	-	-	✓	✓
	0x7F	0xF6	PLAY_TONE	-	-	-	✓	✓
	0x7F	0xF6	GET_INPUT	-	-	-	✓	✓
	0x7F	0xF6	SELECT_ITEM	-	-	-	✓	✓
	0x7F	0xF6	SET_UP_MENU	-	-	-	✓	✓
	0x7F	0xF6	GET_INKEY	-	-	-	✓	✓
Binary SMS (Non-interactive)	0x7F	0xF6	SEND_SMS	-	-	-	✓	✗
	0x7F	0xF6	RUN_AT_CMD	-	-	-	✓	✗
Silent SMS	0x40	0x00	-	-	-	-	✓	✓
Flash SMS	0x00	0x18	-	-	-	-	✓	✓
FBS SMS	0x00	0x00	-	>-40dBm	MNC	MCC	✓	✓
	0x00	0x00	-	<-40dBm	MNC*	MCC*	✓	✓
	0x00	0x00	-	>-40dBm	MNC*	MCC*	✓	✓
	0x40	0x00	-	>-40dBm	MNC*	MCC*	✓	✓
	0x00	0x18	-	>-40dBm	MNC*	MCC*	✓	✓
	0x7F	0xF6	DISPLAY_TEXT	>-40dBm	MNC*	MCC*	✓	✓
Proactive SIM SMS	0x00	0x00	-	-	-	-	✓	✓

SMS test cases (D: Detected, B: Blocked)

Effectiveness Evaluation

Attack	SMS Payload			Cellular Network Params.			D	B
	PID	DCS	Proactive CMD	TxPower	MNC	MCC		
Binary SMS (Interactive)	0x7F	0xF6	DISPLAY_TEXT	-	-	-	✓	✓
	0x7F	0xF6	SET_UP_CALL	-	-	-	✓	✓
	0x7F	0xF6	LAUNCH_BROWSER	-	-	-	✓	✓
	0x7F	0xF6	PLAY_TONE	-	-	-	✓	✓
	0x7F	0xF6	GET_INPUT	-	-	-	✓	✓
	0x7F	0xF6	SELECT_ITEM	-	-	-	✓	✓
	0x7F	0xF6	SET_UP_MENU	-	-	-	✓	✓
	0x7F	0xF6	GET_INKEY	-	-	-	✓	✓
Binary SMS (Non-interactive)	0x7F	0xF6	SEND_SMS	-	-	-	✓	✗
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	0x00	0x00	-	<-40dBm	MNC*	MCC*	✓	✓
	0x00	0x00	-	>-40dBm	MNC*	MCC*	✓	✓
	0x40	0x00	-	>-40dBm	MNC*	MCC*	✓	✓
	0x00	0x18	-	>-40dBm	MNC*	MCC*	✓	✓
	0x7F	0xF6	DISPLAY_TEXT	>-40dBm	MNC*	MCC*	✓	✓
Proactive SIM SMS	0x00	0x00	-	-	-	-	✓	✓

SMS test cases (D: Detected, B: Blocked)

Effectiveness Evaluation

Attack	SMS Payload		Malware Type	Malware Name	D	B
	PID	DCS				
Malware SMS	0x00	0x00	Open-source RAT	AndroRAT [and]	✓	✓
	0x00	0x00	Open-source RAT	AhMyth [and]	✓	✓
	0x00	0x00	Open-source RAT	BetterAndroidRAT [and]	✓	✓
	0x00	0x00	Open-source RAT	Android Trojan [and]	✓	✓
	0x00	0x00	Real-world malware	FakeSpy [fak]	✓	✓
	0x00	0x00	Real-world malware	Corona Updates [sms]	✓	✓
	0x00	0x00	Real-world malware	Anubis [sms]	✓	✓
	0x00	0x00	Real-world malware	Dendroid [sms]	✓	✓
	0x00	0x00	Real-world malware	Ginp [sms]	✓	✓
	0x00	0x00	Real-world malware	Golden Eagle [sms]	✓	✓
	0x00	0x00	Real-world malware	SilkBean [sms]	✓	✓
	0x00	0x00	Real-world malware	WolfRAT [sms]	✓	✓
	0x00	0x00	Real-world malware	BlackRock [sms]	✓	✓
	0x00	0x00	Real-world malware	Cerberus [sms]	✓	✓
	0x00	0x00	Real-world malware	Mandrake [sms]	✓	✓

Malware SMS test cases (D: Detected, B: Blocked)

Effectiveness Evaluation

Attack	SMS Payload		Malware Type	Malware Name	D	B
	PID	DCS				
Malware SMS	0x00	0x00	Open-source RAT	AndroRAT [and]	✓	✓
	0x00	0x00	Open-source RAT	AhMyth [and]	✓	✓
	0x00	0x00	Open-source RAT	BetterAndroidRAT [and]	✓	✓
	0x00	0x00	Open-source RAT	Android Trojan [and]	✓	✓
	0x00	0x00	Real-world malware	FakeSpy [fak]	✓	✓
	0x00	0x00	Real-world malware	Corona Updates [sms]	✓	✓
	0x00	0x00	Real-world malware	Anubis [sms]	✓	✓
	0x00	0x00	Real-world malware	Dendroid [sms]	✓	✓
	0x00	0x00	Real-world malware	Ginp [sms]	✓	✓
	0x00	0x00	Real-world malware	Golden Eagle [sms]	✓	✓
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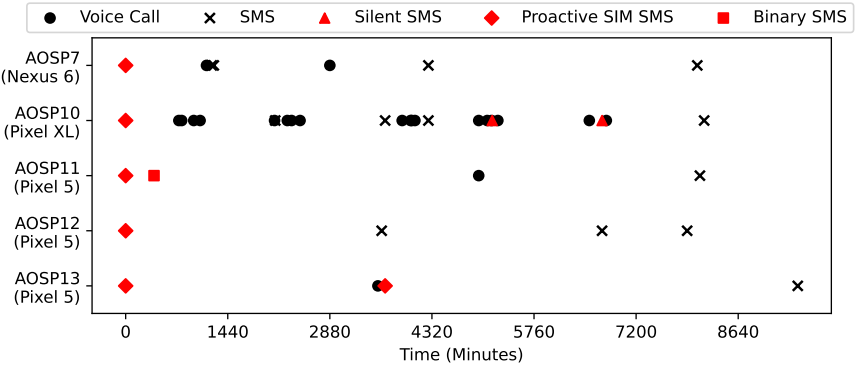
	0x00	0x00	Real-world malware	WolfRAT [sms]	✓	✓
	0x00	0x00	Real-world malware	BlackRock [sms]	✓	✓
	0x00	0x00	Real-world malware	Cerberus [sms]	✓	✓
	0x00	0x00	Real-world malware	Mandrake [sms]	✓	✓

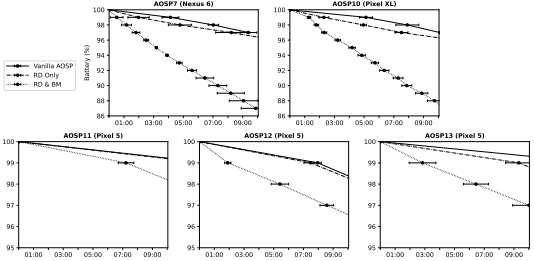
Malware SMS test cases (D: Detected, B: Blocked)

Effectiveness Evaluation

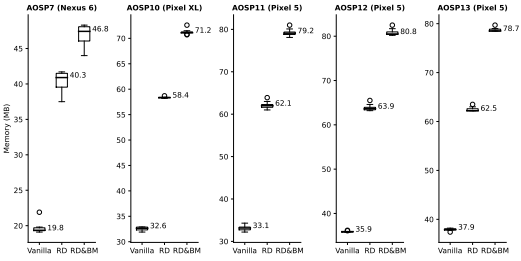


Real-world SMS events in 7 days collected by RILDefender on the five AOSP implementations

Overhead Evaluation



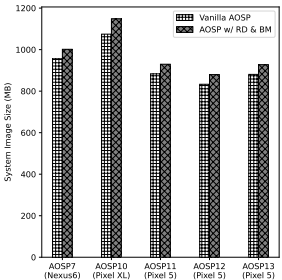
(a) Power.



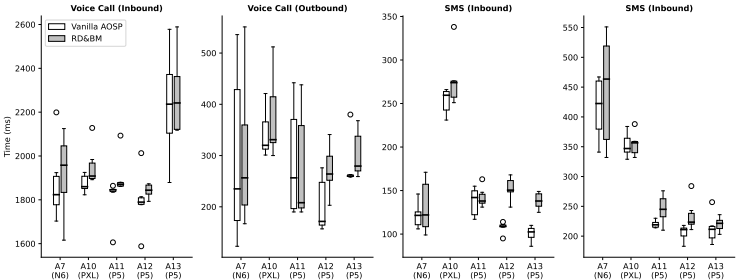
(b) Memory.

Overhead of RILDefender (A: AOSP, N6: Nexus 6, PXL: Pixel XL, P5: Pixel 5)

Overhead Evaluation



(a) Storage.



(b) Computation.

Overhead of RILDefender (A: AOSP, N6: Nexus 6, PXL: Pixel XL, P5: Pixel 5)

Future Work

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- Distinguish SMS attacks from benign use cases (law-enforcement tracking via silent SMS)

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- Distinguish SMS attacks from benign use cases (law-enforcement tracking via silent SMS)
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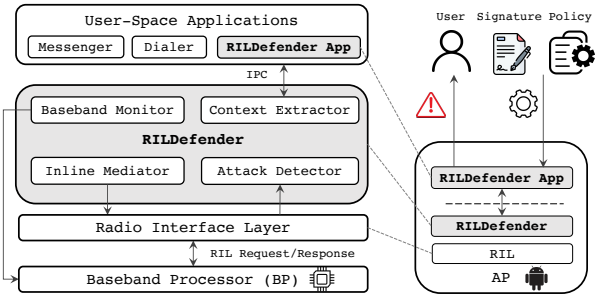
- Exploring vendor-specific RIL libraries and functions

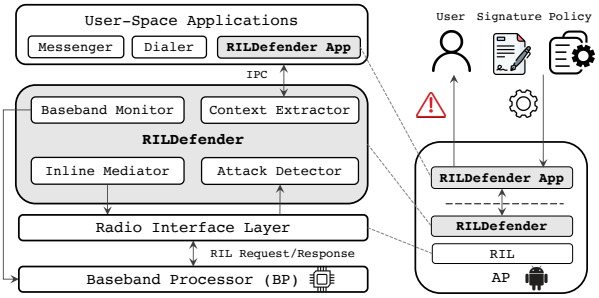
Takeaway



RILDefender

- We present RILDefender, the first RIL-based defense to automatically detect and mitigate SMS attacks.

Takeaway



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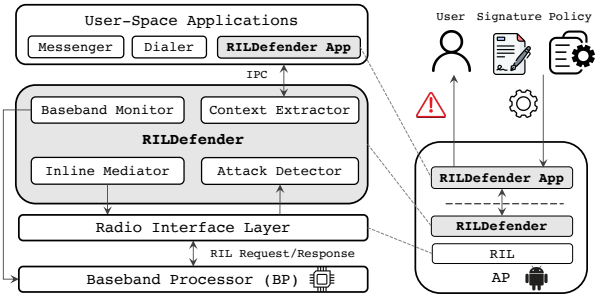

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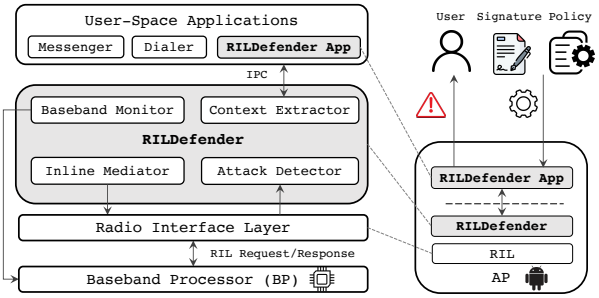

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The source code is available at https://github.com/OSUSecLab/RILDefender.

Thank You

Sec.Com

The Ohio State University

SRI International

RILDefender Source Code: *github.com/OSUSecLab/RILDefender*

RILDefender Video: *5GSec.com/distro/RILDefender.mp4*

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