Design and Implementation of an Android Host-based Intrusion Prevention System

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Introduction

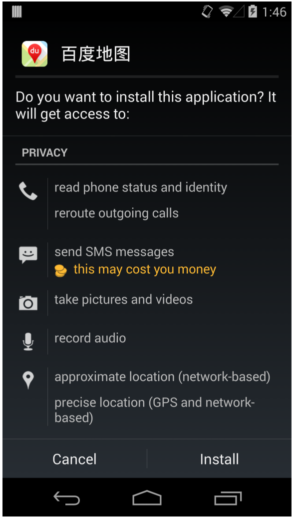
Android Security Status

- smartphone: home, company, car
- smartphone security: hackers' biggest target
- Android: 80% of all smartphone shipments
- 97% malware target Android
- 17,000 new Android malware found in the second quarter of 2013

Introduction

Protection

- permission mechanism
  - alert users about required permission of an installed application
  - plenty of Android permission abuses
- anti-virus software
  - static analysis & signature detection
  - malware transformation can bypass anti-virus software
  - ADAM, DroidChameleon
- dynamic analysis
  - run-time behaviors
  - TaintDroid, DroidScope, DroidBox for malware analysis
  - post-mortem analysis: the malware under investigation may have already infected many devices



Introduction

Host-based intrusion prevention system (HIPS)

- installed software on a mobile device
- monitor suspicious activities
- block and report malicious behaviors
- event at run-time
- dynamically intercept the applications
- notify users when the malware invoke dangerous APIs
- Jinshan Mobile Duba, LBE, 360 Mobile Safe, etc

Introduction

Current status of HIPS: three approaches

- system patching: modify Android OS with new permission management functions
- application repackaging
  - disassemble a mobile application
  - add new policy enforcement
- API hooking: intercept mobile application's API calls at run-time
- limitations and bring new vulnerabilities

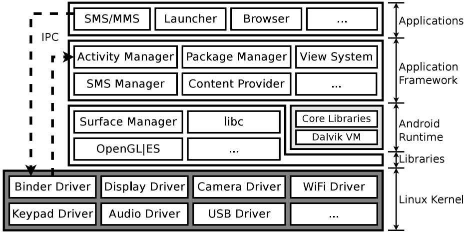
Introduction

Patronus

- enhanced HIPS
- performs a secure policy enforcement
- dynamically detects existing malware using run-time information
- does not require any modifications on the Android firmware
- system level inspection
- host-based run-time detection

Android Architecture

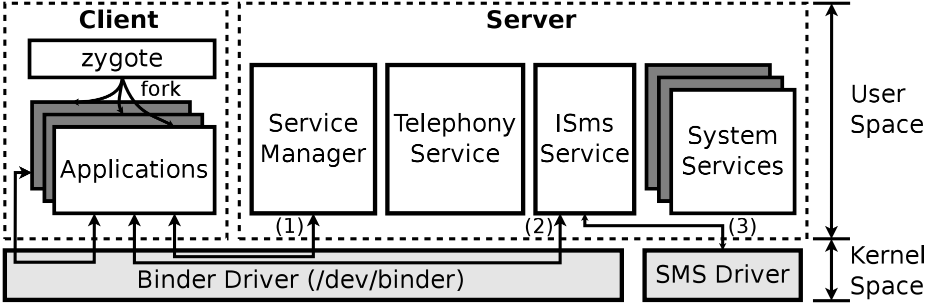
- five functional layers: kernel, libraries, runtime support, application framework and applications
- Java, Android SDK, Dalvik Virtual Machine
- Sandbox
- Inter-process communication



Background

Binder Mechanism

- inter-process communication mechanism
- IPC workflow
  1. contact `Service Manager`
  2. ask `ISms Service` to send message
  3. process the request and send through driver
- Binder transaction
- client-server communication model



HIPS

Systematical analysis on three popular HIPS frameworks

- system patching
- application repackaging
- API hooking

HIPS

System Patching

- third-party firmware
- patches from hackers, developers for policy enforcement
- hidden function (testing function) in latest Android system: `App Ops`

Limitations

- 10% of Android phones are powered by latest Android
- third-party firmware is not matched
- `App Ops` cannot prevent intrusion at run-time

HIPS

Application Repackaging: manifest file

- Android application file (`apk` file)
- `AndroidManifest.xml` file
- delete certain permission declarations in the `AndroidManifest.xml` file

Application Repackaging: reverse engineering

- Dalvik byte code is easy to reversed to readable codes
- several tools provide assembling and disassembling functions
- HIPS can insert stubs around sensitive Android APIs
- e.g., `requestLocationUpdates()` API

Application Repackaging: vulnerabilities

- incomplete security coverage
- policy enforcement on *all possible* APIs
- native code to bypass policy stubs
- bugs of disassembling tools

HIPS

Basic Flow of API Hooking (four steps)

1. gaining root or system privilege
   - root tools
   - third-party firmwares
   - root loopholes can be patched by existing system using hooking
2. injecting a shared library object file (`so` file)
   - ptrace() target process
   - inject shellcode
   - utlize `dlopen` and `dlsym` to inject an `so` file
3. carrying out hooking on target APIs
   - global object in DVM: `gDvm` in `libdvm.so`
   - pointers to the calling function
4. loading policy enforcement function: `jar` library file

HIPS

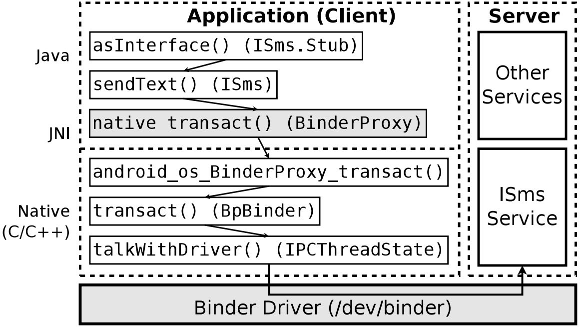
sending an SMS message

```
SmsManager smsManager = SmsManager.getDefault()
smsManager.sendTextMessage(
    ”phoneNumber”, null, ”message”, null, null
);
```

HIPS

hooking on the client side

- JNI method: `native transact()`
- corresponding native method: `android_os_BinderProxy_transact()`
- `zygote` process
- hook native transact method to intercept all method callings
- security problems?



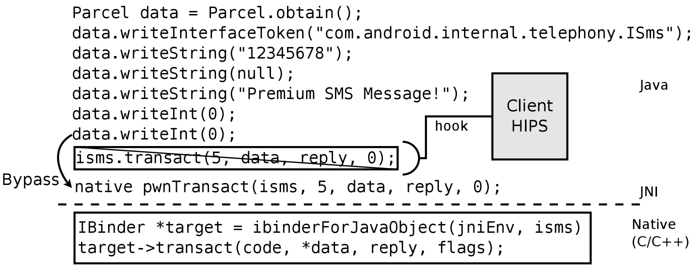
Vulnerability of Existing HIPS Products

- the hooking operations are done in the same sandbox of the application
- Client HIPS (LBE) has more than ten million users and pre-installed in a number of Android devices
- memory structure

```
# cat /proc/1459/maps                          <-- Memory structure of pid: 1459
...
6b811000-6b813000 r--s 00015000 b3:1d 927            <-- Mapped memory region
/data/data/com.lbe.security/app_hips/client.jar      <-- File path
6b831000-6b860000 r--p 00000000 b3:1d 1185
/data/dalvik-cache/data@data@com.lbe.security@app_hips@client.jar@classes.dex
6cc47000-6cc52000 r-xp 00000000 b3:1d 262788
/data/data/com.lbe.security/app_hips/libclient.so
...
```

Vulnerability of Existing HIPS Products (Proof of concept)

- modify method pointer to the original one
- create own transact implementation to bypass using native code
- hooking on the client side *cannot* prevent intrusion

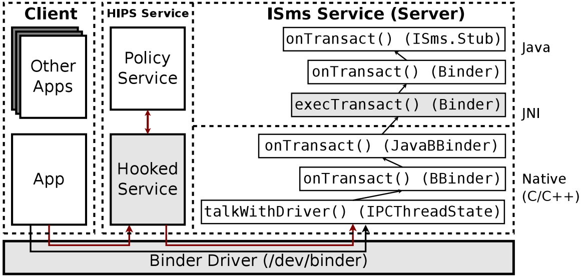


Patronus

- realize API hooking on *both* client side and server side

Hooking on the server side

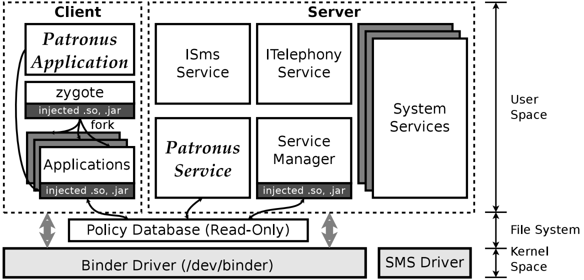
- two approaches to conduct API hooking on the server side
- Java API hooking
  - JNI method: `execTransact`
- hook the `Service Manager`



System Design of Patronus

Building Blocks

- Patronus Application
  - `ptrace()` injection
- Patronus Service
  - intercept all transactions
  - system protection
- Injected files
  - `injected .so, .jar`
  - applications
  - `Service Manager`
- Policy database
  - policy rules
  - sensitive transactions: `sendText`, `requestLocationUpdates`



Patronus

Table: Intrusive Transaction List

TD	TC	TC Name
com.android.internal .telephony.ISms	4	sendData
	5	sendText
	6	sendMultipartText
...	...	...
com.android.internal .telephony.ITelephony	1	dail
	2	call
	28	getCellLocation
...	...	...
android.location .ILocationManager	1	requestLocationUpdates
	5	getLastLocation
...	...	...

TD: Transaction Descriptor, TC: Transaction Code

Intrusion Prevention of Patronus

- client-side policy enforcement
- alert notification for users
- server-side policy enforcement
- not checked by client? suspicious transaction!

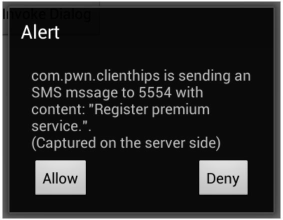


Figure: Alert of intrusive transaction (sendText).

Dynamic Detection: Malware Transaction Forensics

- malware triggering
  - record run-time transaction information
- malware transaction tagging
  - tagging malicious transaction
- transaction footprint

Dynamic Detection: Two-phase Dynamic Detection

- Phase one: correlation detection
  - $V_{runtime}$
  - $V_{malware}$
  - Pearson correlation
  - Correlation comparison

Definition

Define V as the transaction vector over a transaction footprint S where $V = [v_1, v_2, \ldots, v_n | v_i = N_i]$.

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}. \tag{1}$$

$$where\ X = V_{runtime},\ Y = V_{malware}$$

Dynamic Detection: Two-phase Dynamic Detection

- Phase two: transaction footprint comparison
  - r is higher than a pre-defined threshold
  - malicious transaction
  - decisive fields indicating the malicious behaviors
  - e.g., sendText transaction: destination address

Patronus

Dynamic Detection

- run-time information
- semantic information rather than system calls
- performance overhead compared to system-call-based system

Large Scale Evaluation

Intrusion Prevention & Dynamic Detection

- 500 legitimate applications
- 213 `BaseBridge`, 9 `FakeAV`, 15 `MobileTx`
- 49 intrusive transactions

Evaluation intrusive transaction

- 500 pseudo-random user events: clicks, touches, gestures, etc.

Table: Top 10 Intrusive Transactions

Transaction Name	Total #
CALL_TRANSACTION	3,508
REGISTER_RECEIVER_TRANSACTION	2,960
START_ACTIVITY_TRANSACTION	1,734
TRANSACTION_getDeviceId	1,732
GET_CONTENT_PROVIDER_TRANSACTION	1,400
QUERY_TRANSACTION	1,303
TRANSACTION_getSubscriberId	333
TRANSACTION_requestLocationUpdates	228
INSERT_TRANSACTION	139
TRANSACTION_getCallState	90

Large Scale Evaluation

Dynamic Detection

- true positive (TP), true negative (TN), false positive (FP), false nagative (FN), precision and F-score
- `MobileTX` crashed

Table: Detection Results

Malware	# of Samples	TP	TN	FP	FN	Precision	F-score
`BaseBridge`	213	186	495	5	27	0.87	0.92
`FakeAV`	9	9	500	0	0	1	1
`MobileTx`	15	11	494	6	4	0.65	0.69

Large Scale Evaluation

Benchmark Results

- Quadrant Standard Edition
- LG Nexus 5 (Qualcomm Snapdragon 800 2.26GHz CPU)
- Android 4.4.2
- Baseline v.s. Patronus

Table: Benchmark Results

Test	Baseline	Patronus	Overhead
Total	8,914	8,285	7.1%
CPU	20,383	20,205	0.9%
Memory	14,354	13,211	8.0%
I/O	7,274	6,482	10.9%
2D	333	330	0.1%
3D	2,230	2,195	1.6%

Large Scale Evaluation

Evaluation

- 1,000 `com.android.internal.telephony.IPhoneSubInfo` transaction
- 890 milliseconds
- 998 milliseconds (Patronus)
- 11.1 % performance overhead

Power consumption

- daily usage
- standby mode for 24 hours: 1% power consumption
- heavy user
- game playing: 3% power consumption

Conclusion

Summary

- systemectially analyze three popular HIPS frameworks
- design and implement a secure architecture HIPS: patronus
- two-phase detection algrithm based on run-time information
- large sacle evaluation on effectiveness and performance

Thank you!

Thank you very much! Questions?