FUSION:

A Unified Application Model for Virtual Mobile Infrastructure

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Outline

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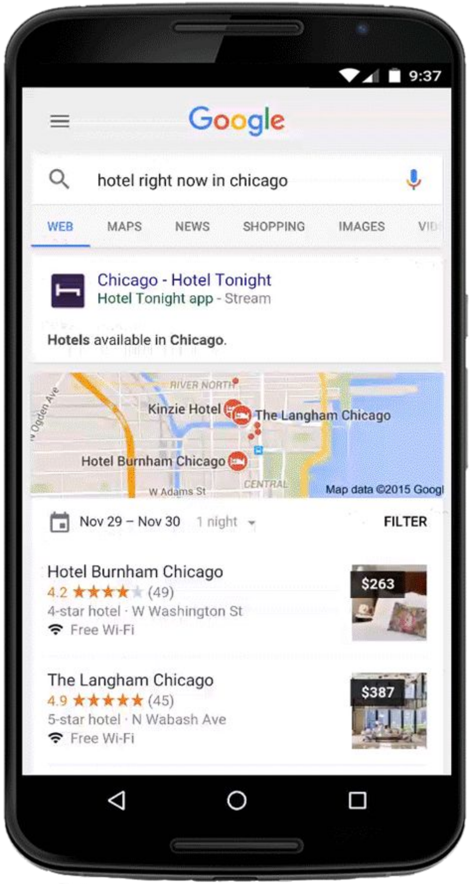
Introduction

- VMI and app streaming are becoming more popular today
  - Google acquired Agawi .Inc and had launched the app streaming test
  - VMFIVE launched AdPlay service



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Google

hotel right now in chicago

WEB MAPS NEWS SHOPPING IMAGES VID

Chicago - Hotel Tonight
Hotel Tonight app - Stream

Hotels available in **Chicago**.

Nov 29 – Nov 30 1 night FILTER

Hotel Burnham Chicago
4.2 ★★★★★ (49)
4-star hotel · W Washington St
Free Wi-Fi
$263

The Langham Chicago
4.9 ★★★★★ (45)
5-star hotel · N Wabash Ave
Free Wi-Fi
$387

Introduction

- VMI and app streaming environment are mostly isolated from the local phone environment
- FUSION is designed to enable the interactions between remote VMI environment and the local environment
- The remote VMI environment and the local device environment can be regarded as a unified environment

Background

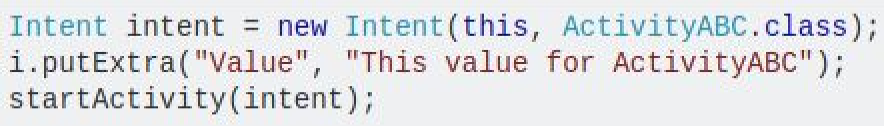
- Virtual mobile infrastructure(VMI) is a platform hosting virtual mobile operating system
  - The virtual machine’s screen content is passed to the user’s thin client
- Application streaming is a technique built on top of the VMI
  - Only passing specific apps’ screen content to the user’s thin client
  - Users feel the remote apps are just like regular apps installed on the local device
- Current solutions do not allow remote apps to interact with local apps
- FUSION bridges the gap between the VMI environment and the local device
  - Bi-directional IPCs
  - Loosely synchronized file system

Background: Android IPC events

- The most common and standard IPC event: Intent
    - Ask other apps to do some specific tasks for the users
- Intent structure
    - action -- The general action to be performed, such as ACTION_VIEW, ACTION_EDIT, ACTION_SEND, etc.
    - data -- The data to operate on, such as a file stored on the device, expressed as a Uri.
    - component -- Specifies an explicit name of a component class to use for the intent.

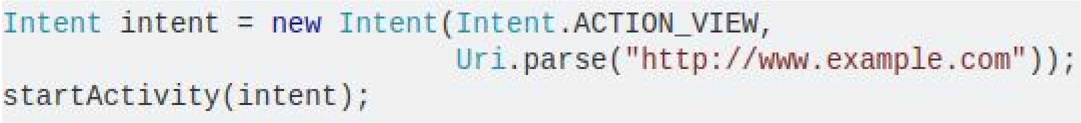
Background: Android IPC events

- Explicit Intent
  - A way for an application to launch various internal activities
  - Specify a component via *setComponent(ComponentName)* and *setClass(Context, Class)*



```
Intent intent = new Intent(this, ActivityABC.class);
i.putExtra("Value", "This value for ActivityABC");
startActivity(intent);
```

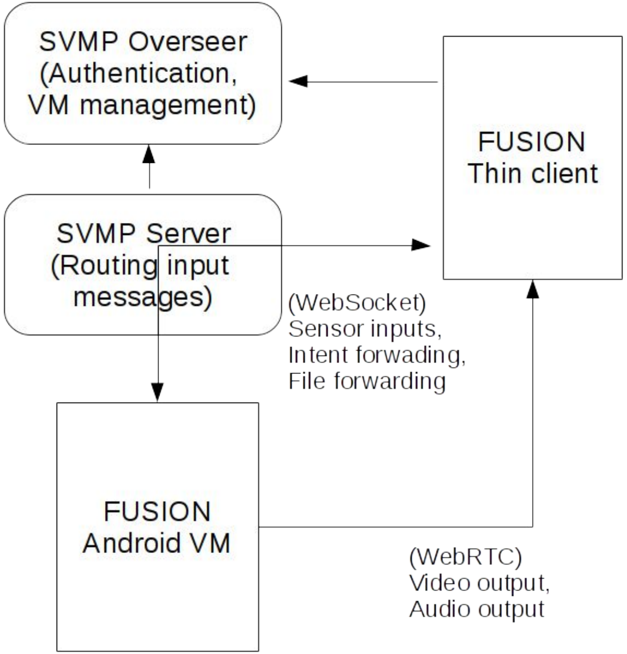
- Implicit Intent
  - Do not specify a component; Commonly used for communication between apps
  - Include enough information for the system to determine which component to run for the intent (via *setAction(String)*, *setData(Uri)*, *setType(String)* and *setDataAndType(Uri, String)*)



```
Intent intent = new Intent(Intent.ACTION_VIEW,
                           Uri.parse("http://www.example.com"));
startActivity(intent);
```

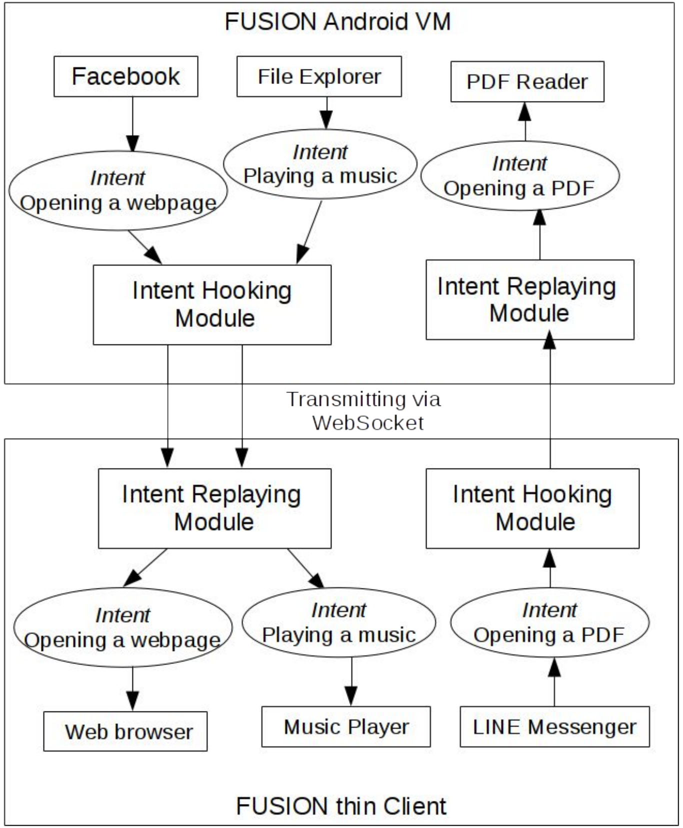
Design - FUSION Architecture

- FUSION implementation is based on SVMP project
  - SVMP project has been ceased since two years ago
- SVMP overseer
  - User login and authentication
- SVMP server
  - Routing input messages
- FUSION thin client
- FUSION Android virtual machine


SVMP Overseer (Authentication, VM management)
FUSION Thin client
SVMP Server (Routing input messages)
(WebSocket) Sensor inputs, Intent forwading, File forwarding
FUSION Android VM
(WebRTC) Video output, Audio output

Design - FUSION Architecture

- Intent hooking module and intent replaying module on both FUSION Android VM and FUSION thin client
- Intent hooking module
  - Intercept Android intent IPC events
  - Forward captured intents to the remote peer
- Intent replaying module
  - Replay intents

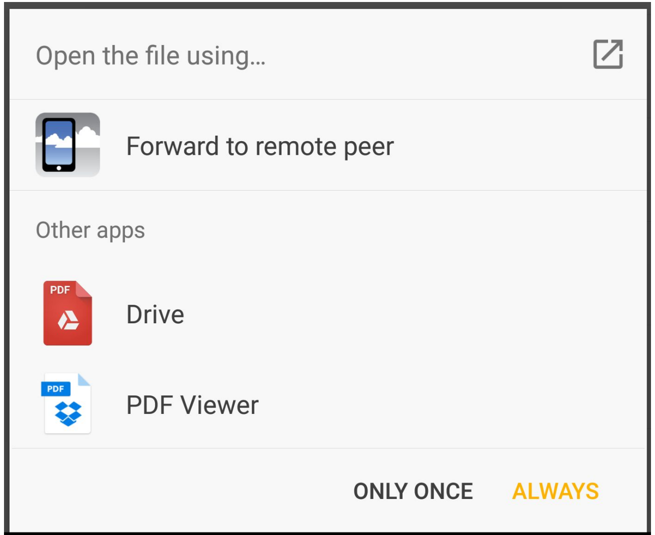


Design - FUSION Android VM

- SVMP Android VM is based on AOSP project
  - OpenGL does not work
  - Lacks GPU drivers for GPU passthrough
- FUSION Andorid VM is a port of SVMP from AOSP to Android x86
  - Using the drm_gralloc HAL implementation
  - Full support of GPU hardware that are compatible with standard x86 Linux
  - Newer Kernel support
- LOC changes
  - device_sense_svmp: 532 loc
  - android_external_svmp_eventserver: 494 loc
  - Other framework changes: 846 loc

Design - Intercepting IPC Events

- An intent hooking activity registering intent-filters that can intercept all intents
- ActivityManagerService will look for compatible activities installed on the system
- A prompt dialog when multiple matching activities are found



Open the file using...

Forward to remote peer

Other apps

Drive

PDF Viewer

Design - IPC Event Redirection

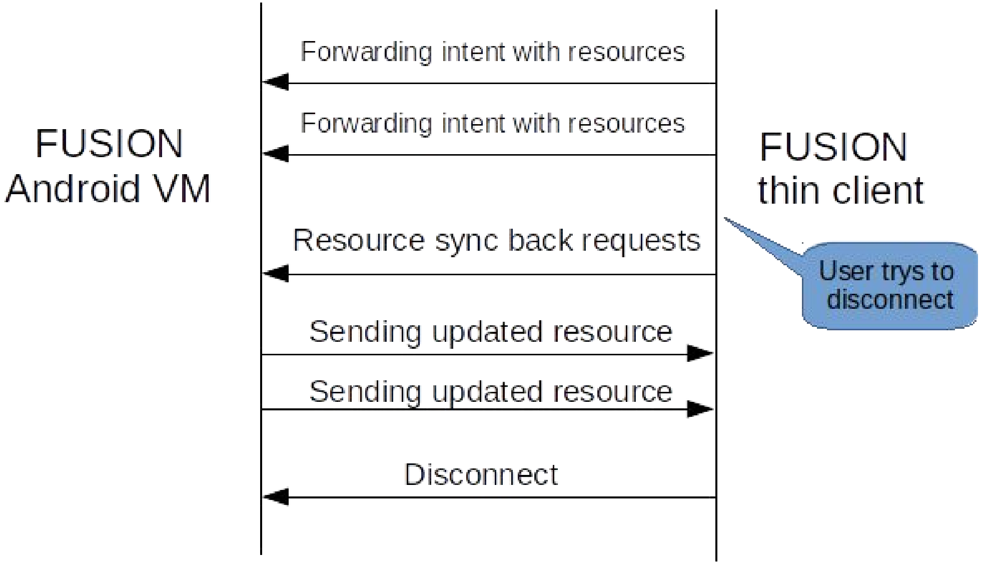
- Intent Hooking Module is responsible for hooking and forwarding intents
- Implicit Intent uses data field to specify resource used by Intent
  - Data is a Uri which conforms to RFC 2396
- FUSION classifies intents into two types by the uri scheme
  - Uri with remote resources (ex: http://senselab.tw)
  - Uri with local resources (ex: file:///sdcard/example.txt)

Design - IPC Event Redirection

- Uri scheme for remote resource: http, https and ftp...etc
  - Simply serializes and transmits the intents with all its fields
- Uri scheme for local resource: file
  - Serialize the local resource into a byte format
  - Pack the serialized resource into intent message
  - De-serialize the resource and store it into the remote environment
  - Modify uri path to match the file system structure of the remote environment
    - Some directory may not exist on the remote environment

Design - Resource Synchronization

- Ensure the resource modifications can be seen on both sides.
- FUSION records the resource meta data for every forwarded resource
- Synchronize resource back when user tries to disconnect



Implementation - Refactoring SVMP for Android x86

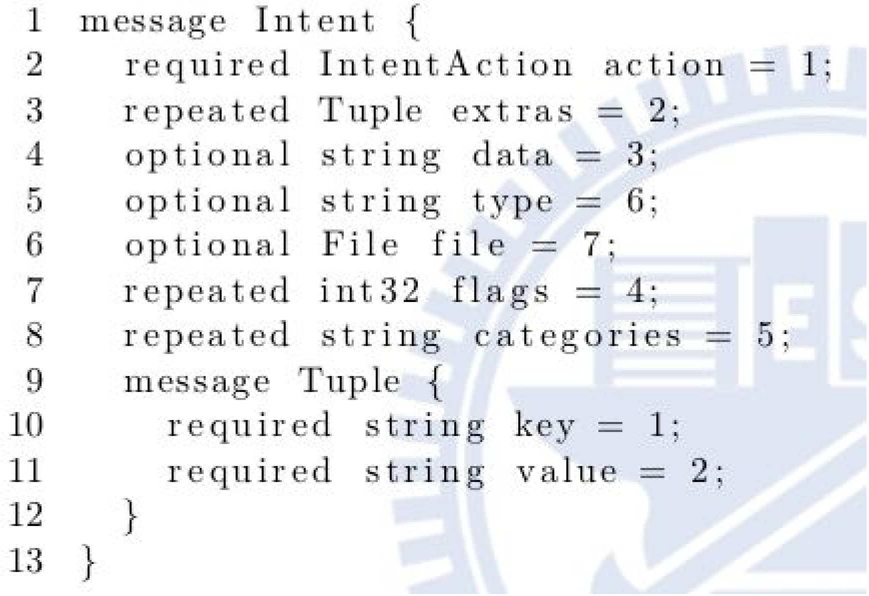
- Port the user-mode SVMP daemon to Android x86
  - Switch to Trebuchet for launcher setting
- Port SVMP’s AOSP framework changes to Android x86
  - Ex: Interception of notifications in NotificationManager
  - Android version from 4.4.4_r2 to 4.4.4_r2.0.1
- Port SVMP HAL libraries
  - libaudio and libsensor
  - Set ro.hardware.audio.primary and ro.hardware.board to corresponding value

Implementation - Communication links

- Screen content and audio output are transmitted via WebRTC
- Sensor data, location updates and intent/resource message are transmitted via WebSocket
  - Serialized to ProtocolBuffer format
  - Use AutoBahn websocket implementation
  - FUSION modifies AutoBahn WebSocket implementation to transmit big file over WebSocket
- NAT traversal
  - Bind the host machine with a public IP (Full Cone NAT for Android VM)
  - Use Google’s public STUN server

Implementation - Intent serialization

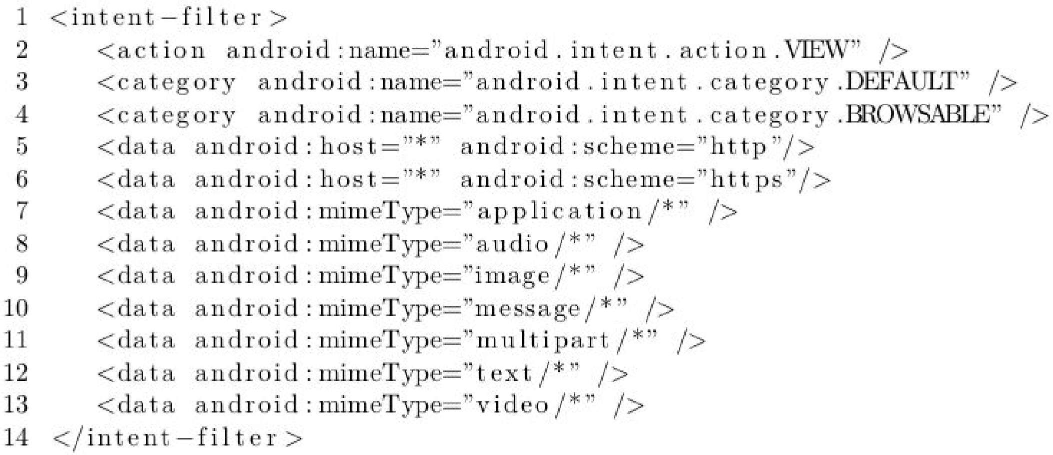
- Extend existing ProtocolBuffer interface
- Each field is one-to-one correspondent to the Android Intent class except the file field
- file field is used to store the serialized local resource



```
message Intent {
  required IntentAction action = 1;
  repeated Tuple extras = 2;
  optional string data = 3;
  optional string type = 6;
  optional File file = 7;
  repeated int32 flags = 4;
  repeated string categories = 5;
  message Tuple {
    required string key = 1;
    required string value = 2;
  }
}
```

Implementation - Intent Hooking

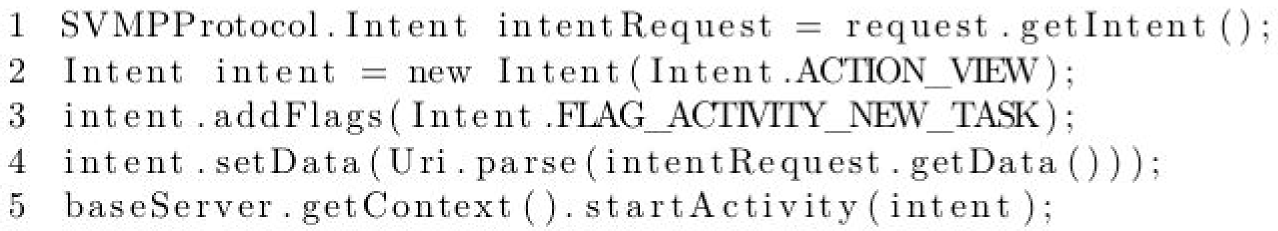
- Define multiple intent-filters to hook all kinds of intents
- There are many action type: ACTION_VIEW, ACTION_SEND, each has its own intent-filter
- Custom action type is not supported by FUSION



```
<intent-filter>
    <action android:name=”android.intent.action.VIEW” />
    <category android:name=”android.intent.category.DEFAULT” />
    <category android:name=”android.intent.category.BROWSABLE” />
    <data android:host=”*” android:scheme=”http”/>
    <data android:host=”*” android:scheme=”https”/>
    <data android:mimeType=”application/*” />
    <data android:mimeType=”audio/*” />
    <data android:mimeType=”image/*” />
    <data android:mimeType=”message/*” />
    <data android:mimeType=”multipart/*” />
    <data android:mimeType=”text/*” />
    <data android:mimeType=”video/*” />
</intent-filter>
```

Implementation - Intent Replaying

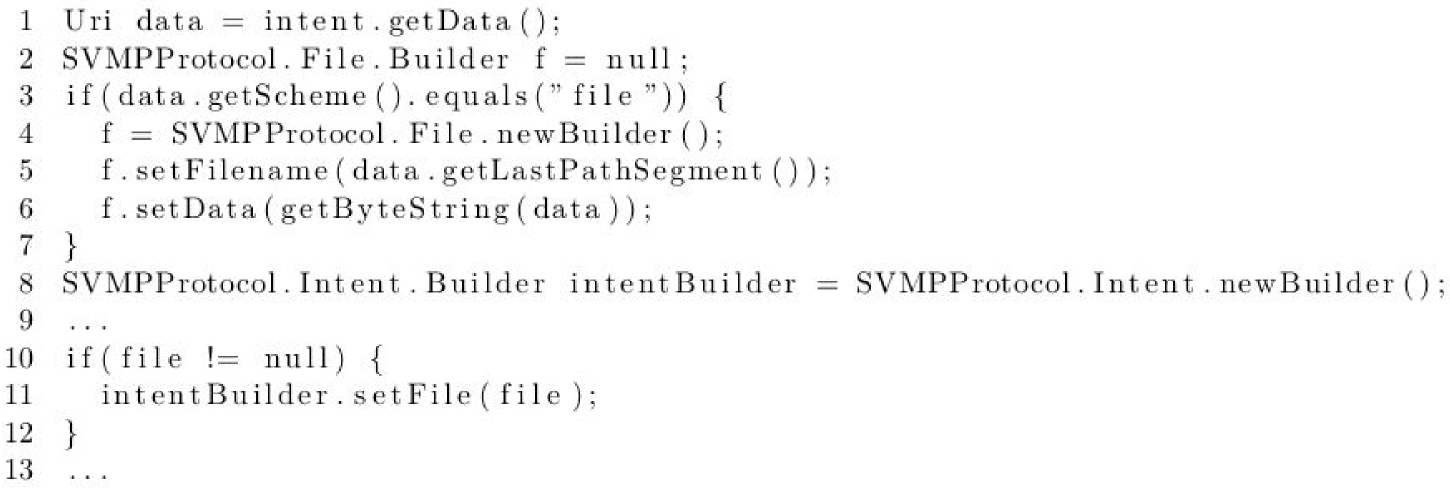
- Simply reconstruct intent with message received
- Adjust Uri path if needed
  - Ex: /sdcard/Documents/haha/pokemon.jpg
  - /sdcard/Documents/haha/ directory may not exist in the remote environment



```
SVMPProtocol.Intent intentRequest = request.getIntent();
Intent intent = new Intent(Intent.ACTION_VIEW);
intent.addFlags(Intent.FLAG_ACTIVITY_NEW_TASK);
intent.setData(Uri.parse(intentRequest.getData()));
baseServer.getContext().startActivity(intent);
```

Implementation - Processing URIs

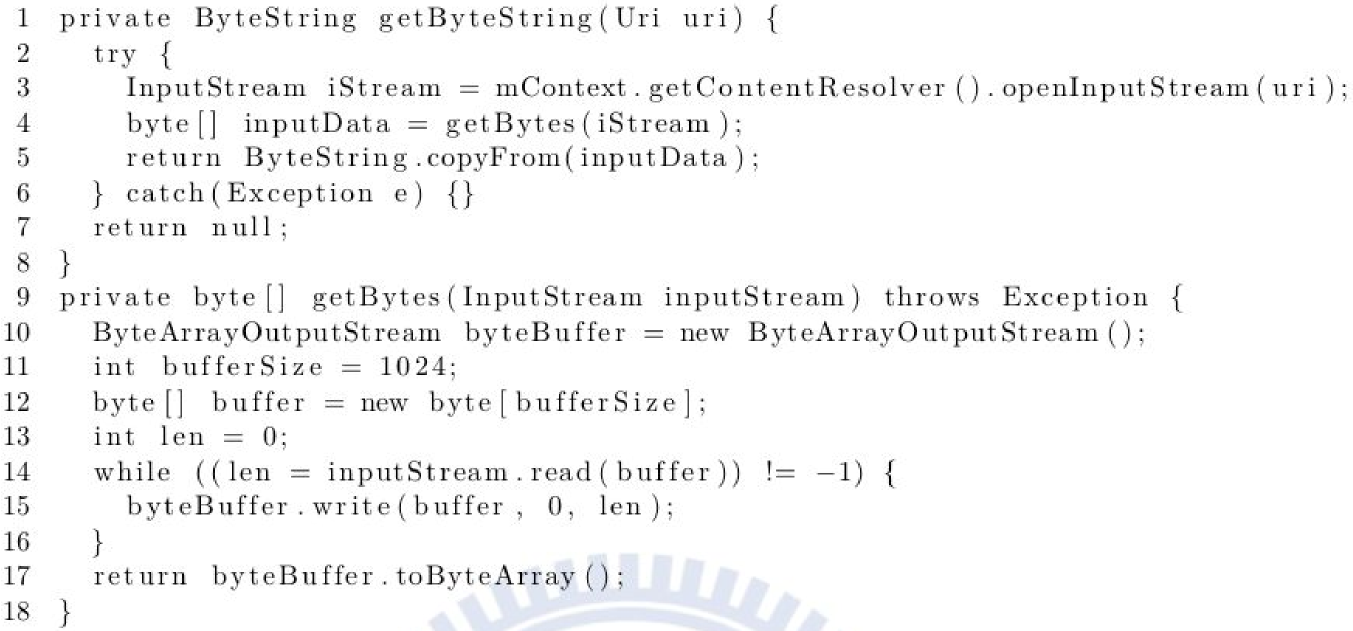
- Classify the type of intent by its scheme



```
Uri data = intent.getData();
SVMPProtocol.File.Builder f = null;
if(data.getScheme().equals(”file”)) {
  f = SVMPProtocol.File.newBuilder();
  f.setFilename(data.getLastPathSegment());
  f.setData(getByteString(data));
}
SVMPProtocol.Intent.Builder intentBuilder = SVMPProtocol.Intent.newBuilder();
...
if(file != null) {
  intentBuilder.setFile(file);
}
...
```

Implementation - Files Serialization

- Serialize to ProtocolBuffer’s ByteString type(Java binding for byte array)

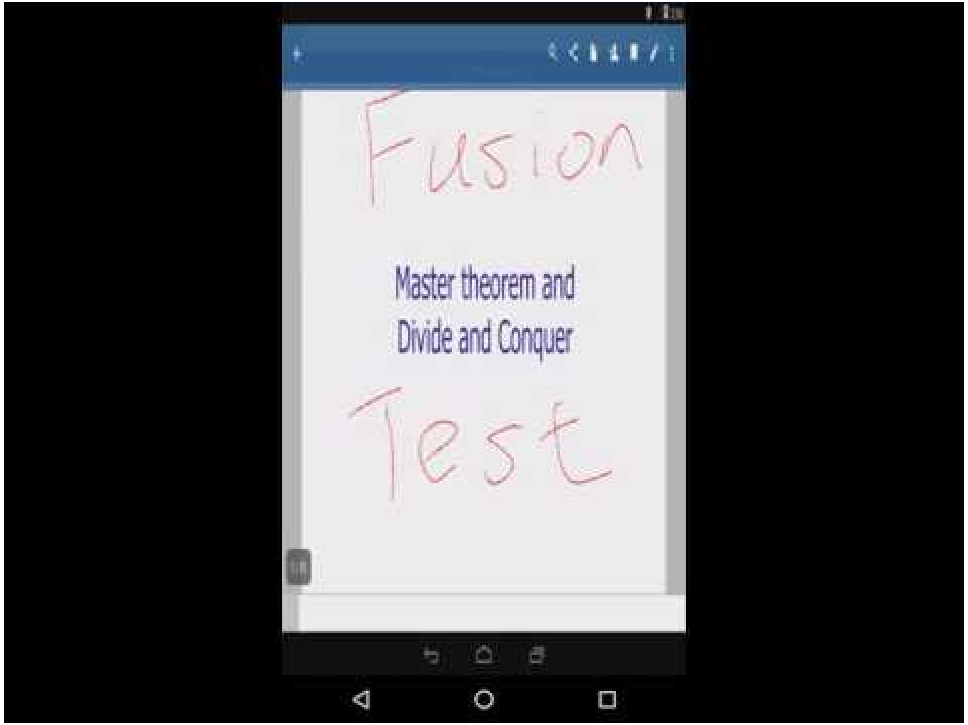


```java
private ByteString getByteString(Uri uri) {
  try {
    InputStream iStream = mContext.getContentResolver().openInputStream(uri);
    byte[] inputData = getBytes(iStream);
    return ByteString.copyFrom(inputData);
  } catch(Exception e) {}
  return null;
}
private byte[] getBytes(InputStream inputStream) throws Exception {
  ByteArrayOutputStream byteBuffer = new ByteArrayOutputStream();
  int bufferSize = 1024;
  byte[] buffer = new byte[bufferSize];
  int len = 0;
  while ((len = inputStream.read(buffer)) != -1) {
    byteBuffer.write(buffer, 0, len);
  }
  return byteBuffer.toByteArray();
}
```

Implementation - Resources Synchronization

- forwardedFiles and waitingFiles list in the Intent Hooking Module
  - forwardedFiles: record all resource which is forwarded to the remote peer
  - waitingFiles: record the resource that have not been synchronize back
- Maintain the two lists to handle resource forwarding and sync back simultaneously
- Resource synchronization stage will be triggered when the user tries to disconnect from the remote peer
  - Send file sync back requests for each resource in forwardedFiles list
  - Move all content from forwardedFiles into waitingFiles
  - waitingFiles list is a HashSet data structure in Java as the order of files may not be in the same order as we send the file sync back request

Evaluation - DEMO



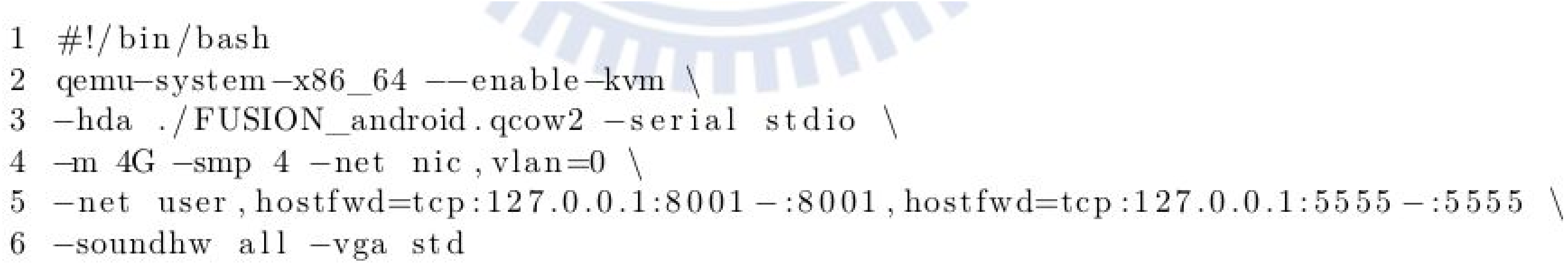
Fusion

Master theorem and
Divide and Conquer

Test

Evaluation

- Intel i7-4770 8-core processor, 32GB memory
- Each of the Android VMs is equipped with 4 VCPUs and 4G RAM
- Use QEMU/KVM to emulate peripheral devices and virtualize the CPU



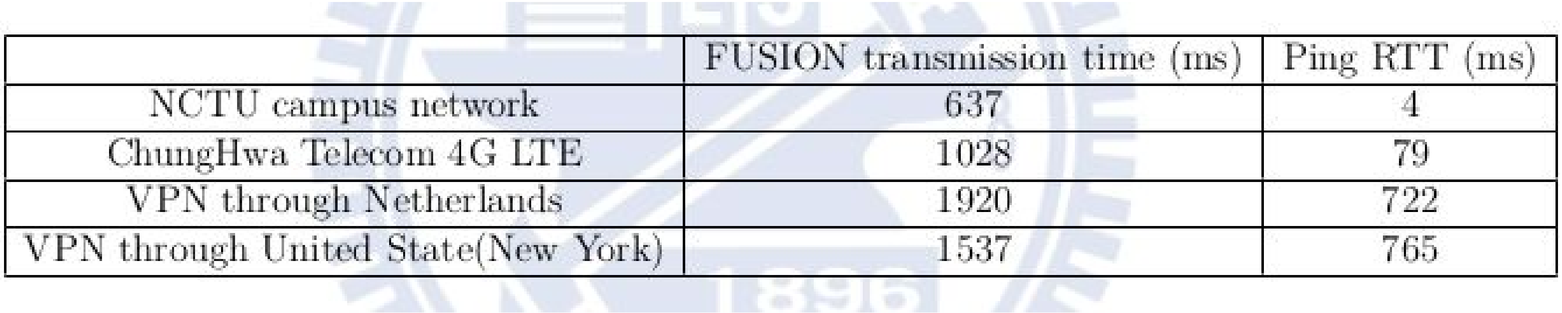
```
#!/bin/bash
qemu-system-x86_64 --enable-kvm \
-hda ./FUSION_android.qcow2 -serial stdio \
-m 4G -smp 4 -net nic,vlan=0 \
-net user,hostfwd=tcp:127.0.0.1:8001-:8001,hostfwd=tcp:127.0.0.1:5555-:5555 \
-soundhw all -vga std
```

Evaluation - Responsiveness

- Pure intent forwarding(no file forwarding involved)
- Intent forwarding with resources forwarding of different file size
- Log the timestamps at the hooking points in the intent hooking module and the receiving points in the intent replaying module
- Use PureVPN to emulate the deployment of FUSION on wide-area-network environment

Evaluation FUSION induced delay

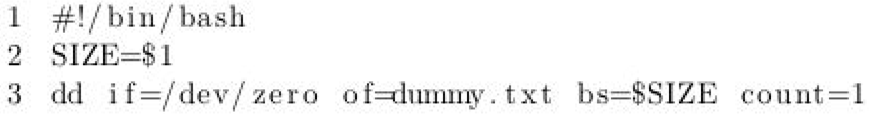
- Open a links in Facebook with remote browser
- Compare with RTT detected by ping tool



	FUSION transmission time (ms)	Ping RTT (ms)
NCTU campus network	637	4
ChungHwa Telecom 4G LTE	1028	79
VPN through Netherlands	1920	722
VPN through United State(New York)	1537	765

Evaluation - File synchronization delay

- Generate dummy files using dd

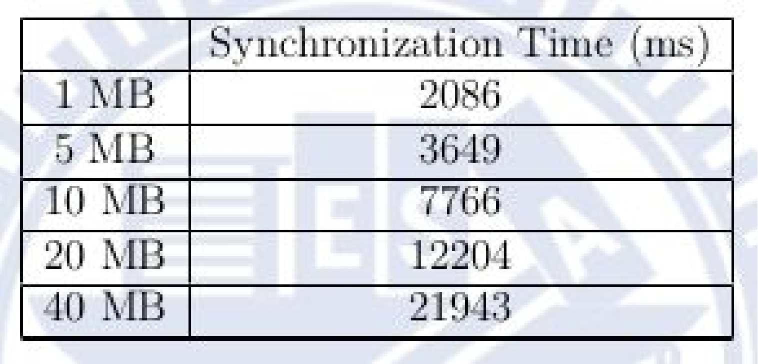


```
#!/bin/bash
SIZE=$1
dd if=/dev/zero of=dummy.txt bs=$SIZE count=1
```

- Evaluate using NCTU campus network(i.e the server and client is located in the same network)

Evaluation - File synchronization delay

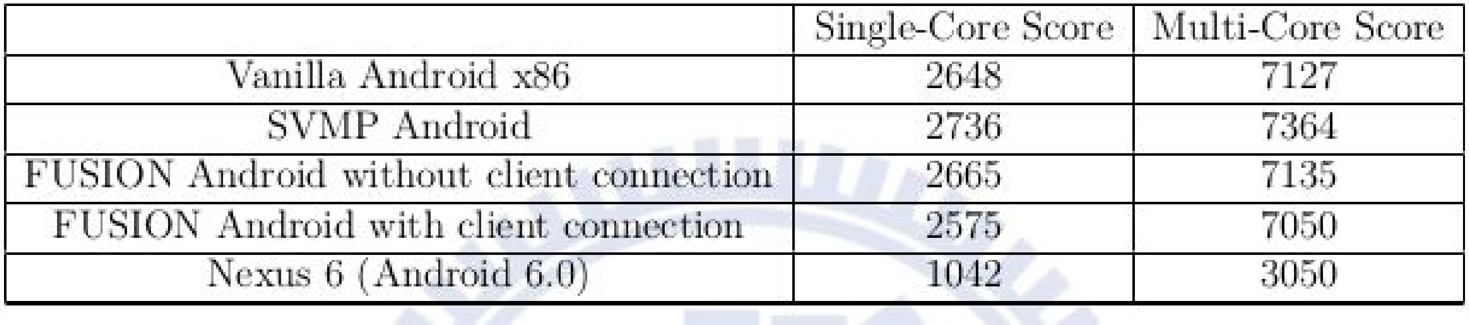
- WebSocket is not designed for transmitting large files
- Most files storing on mobile devices are not big
  - most mp3 music files or jpeg photo files are less than 5MB



	Synchronization Time (ms)
1 MB	2086
5 MB	3649
10 MB	7766
20 MB	12204
40 MB	21943

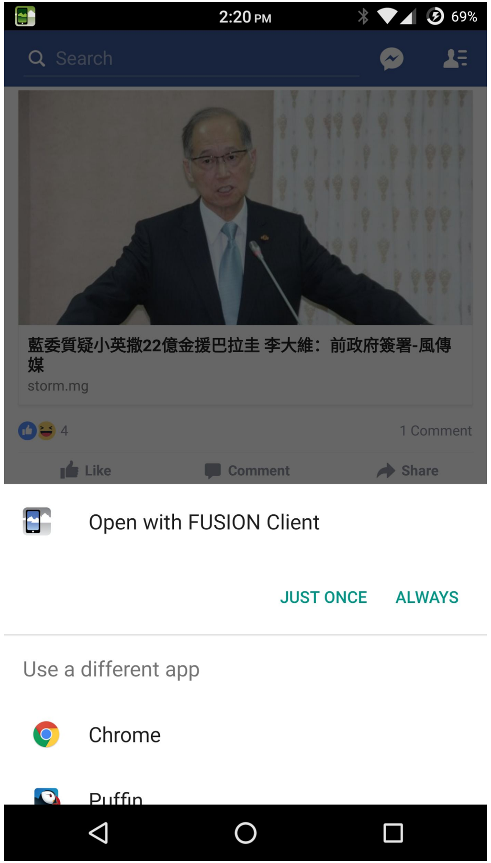
Evaluation - Performance Overhead

- Benchmark: Geekbench 3
- Performance overhead is less than 1%



	Single-Core Score	Multi-Core Score
Vanilla Android x86	2648	7127
SVMP Android	2736	7364
FUSION Android without client connection	2665	7135
FUSION Android with client connection	2575	7050
Nexus 6 (Android 6.0)	1042	3050

Evaluation - Case Studies: Opening link



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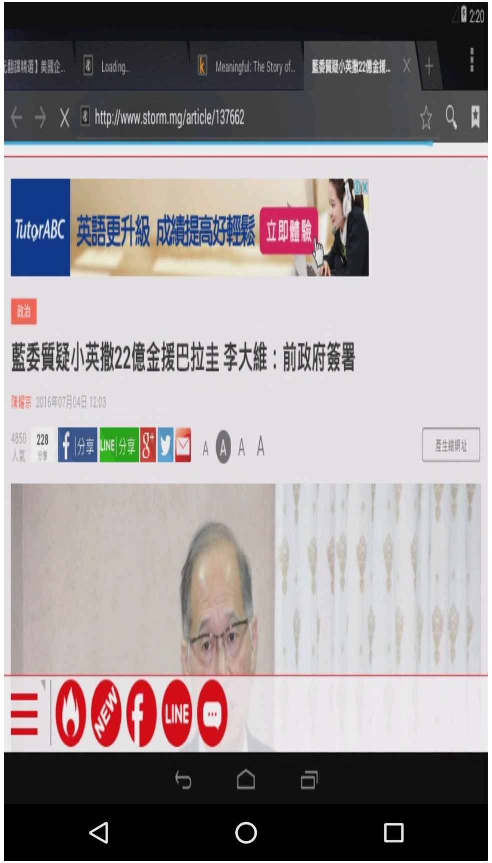
storm.mg

Open with FUSION Client

Use a different app



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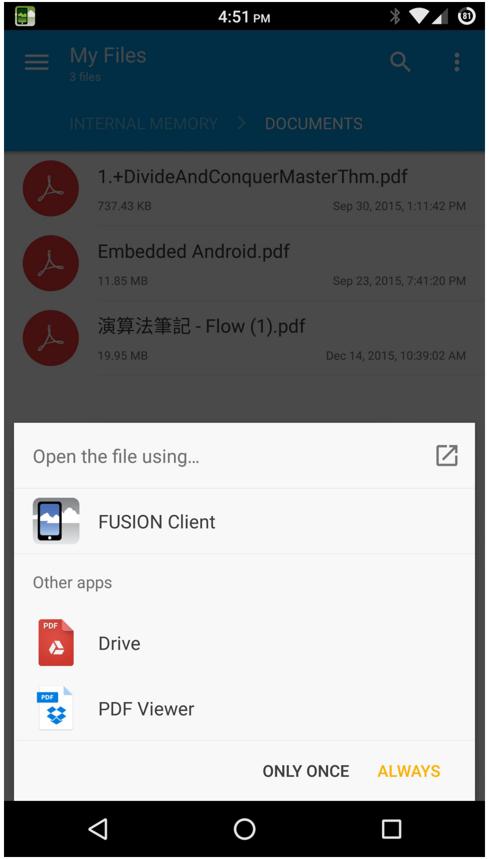
Evaluation - Case Studies: Viewing PDF



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My Files
3 files

INTERNAL MEMORY > DOCUMENTS

1.+DivideAndConquerMasterThm.pdf	
737.43 KB	Sep 30, 2015, 1:11:42 PM
Embedded Android.pdf	
11.85 MB	Sep 23, 2015, 7:41:20 PM
演算法筆記 - Flow (1).pdf	
19.95 MB	Dec 14, 2015, 10:39:02 AM

Open the file using...

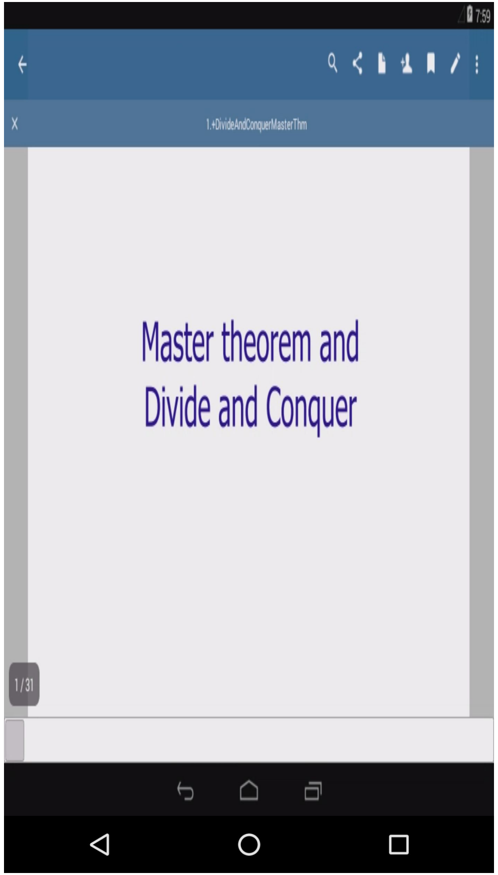
FUSION Client

Other apps

Drive

PDF Viewer

ONLY ONCE ALWAYS



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X 1.+DivideAndConquerMasterThm

Master theorem and
Divide and Conquer

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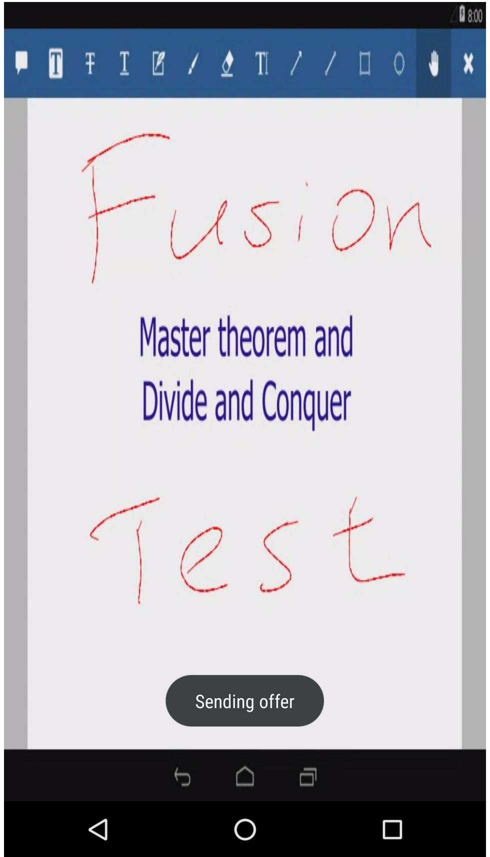
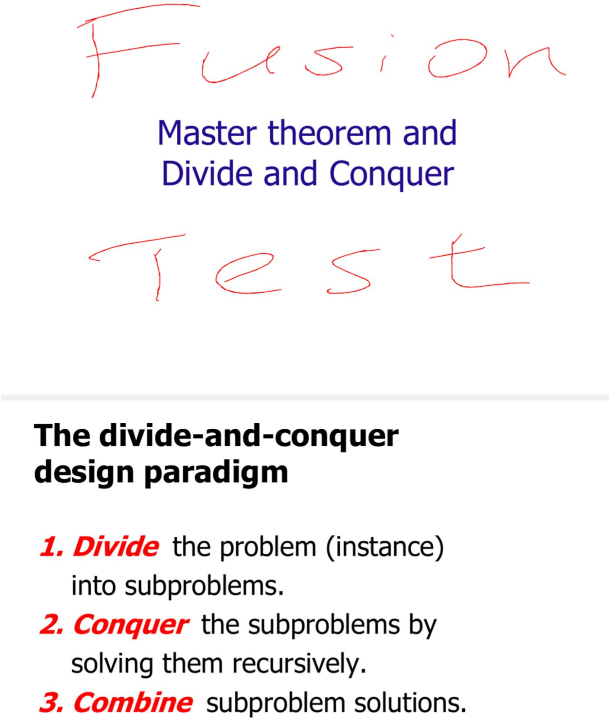
Evaluation - Case Studies: Viewing PDF



Fusion

Master theorem and
Divide and Conquer

Test



Fusion

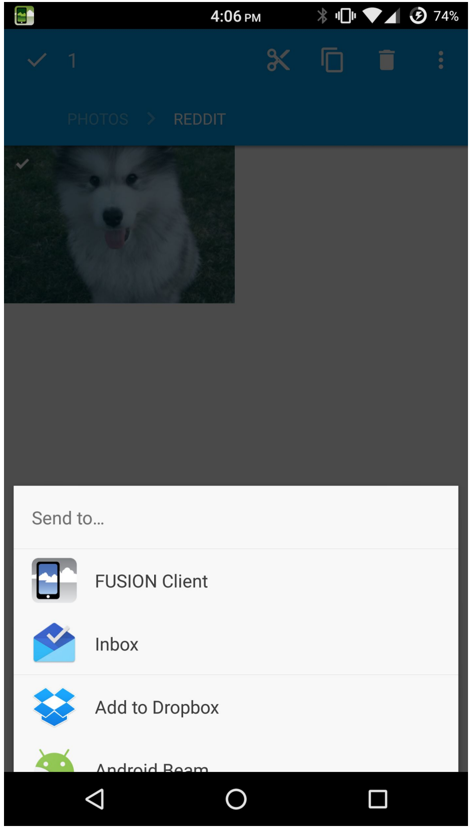
Master theorem and
Divide and Conquer

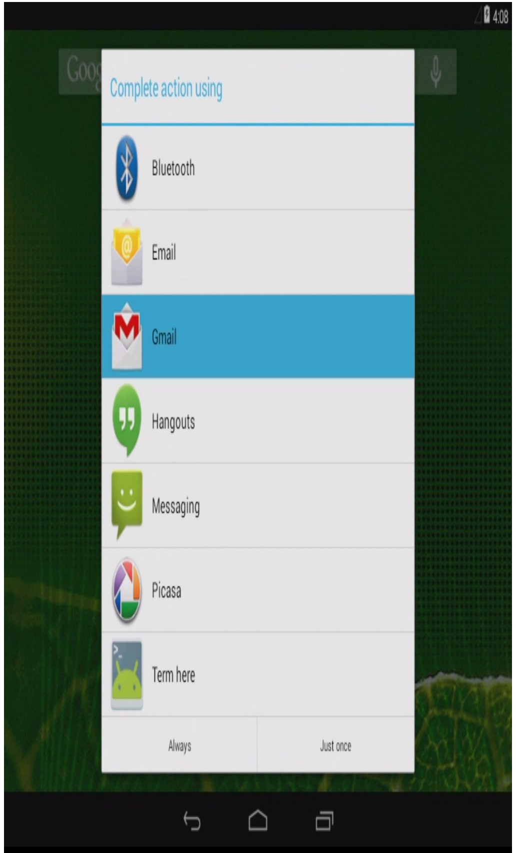
Test

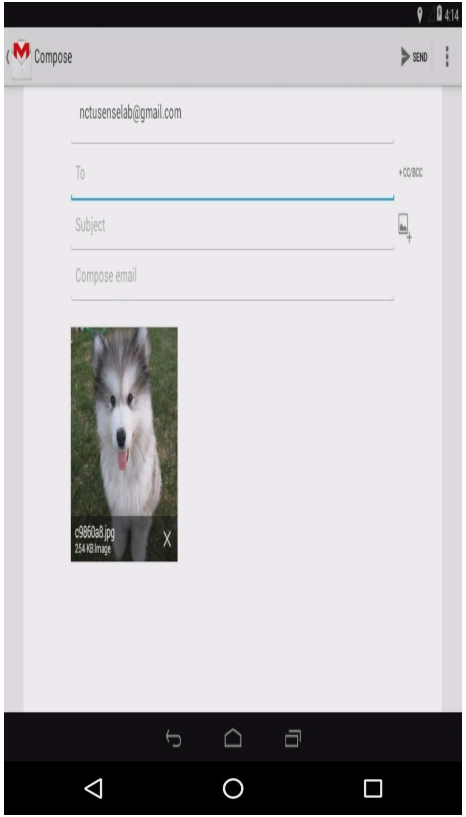
The divide-and-conquer design paradigm

1. ***Divide*** the problem (instance) into subproblems.
2. ***Conquer*** the subproblems by solving them recursively.
3. ***Combine*** subproblem solutions.

Evaluation - Case Studies: Sharing Files







nctusenselab@gmail.com

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254 KB Image

Evaluation - Limitations

- For app using startActivityForResult will not work
  - Require injecting the result into the ActivityManagerService
  - Framework modification is not allowed in VMI and app streaming scenario
- Custom action type defined by app is not supported by FUSION
  - Ex: Facebook and Facebook Messenger may use intents with custom action type

Related Work

- Remote desktop has been researched and developed for a long time
  - Micorsoft RDP, VNC, SPICE...etc
  - Provide simple integration: clipboard sharing and file sharing
- US patent ”method of providing a remote desktop session with the same look and feel as a local desktop”
  - Makes the remote app with the same look and feel as the windows of local app
  - Transferring the values of attributes of the local desktop to the server nodes
- US patent ”methods and systems for incorporating remote windows from disparate remote desktop environments into a local desktop environment”
  - makes the remote servers draw directly on the local windows
  - one channel conveys graphical data
  - another channel conveys window attribute data

Related Work

- All of the previous studies lack comprehensive system integration including bi-direction IPC event transmission and file system synchronization as provided by FUSION
- FUSION is novel because it makes applications in the two environments can communicate with each other directly

Conclusion

- VMI and app streaming provide a more convenient and scalable way for using mobile devices and apps
- Existing solutions do not provide interaction between remote VM and local device
- FUSION enables IPC interaction and bridges the remote VM and local device as an unified environment
- FUSION provides a loosely synchronized file system to bridge the two environments
- Intent and resource serialization and transmission are efficient
- The performance impact of FUSION on the VM is less than 1%

Q&A