MagThief: Stealing Private App Usage Data on Mobile Devices via Built-in Magnetometer

Hao Pan[†], Lanqing Yang[†], Honglu Li[†], Chuang-Wen You[‡], Xiaoyu Ji[§], Yi-Chao Chen[†], Zhenxian Hu[†], Guangtao Xue[†]

[†]Shanghai Jiao Tong University

[‡]National Tsing Hua University

[§]Zhejiang University

Outline

Background and Motivation

Related Works and Limitations

Preliminary Analysis

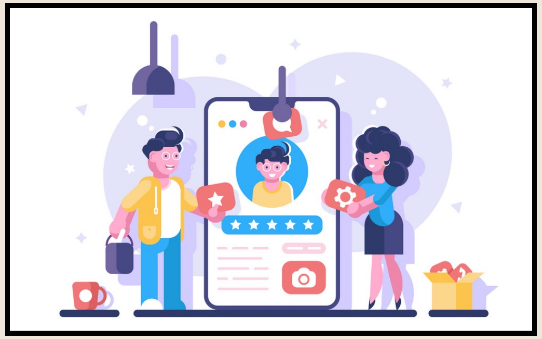
System Design

Evaluation

Conclusion

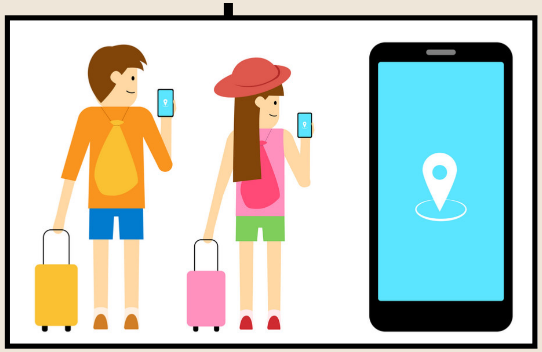
Mobile apps are so popular!

Social Network



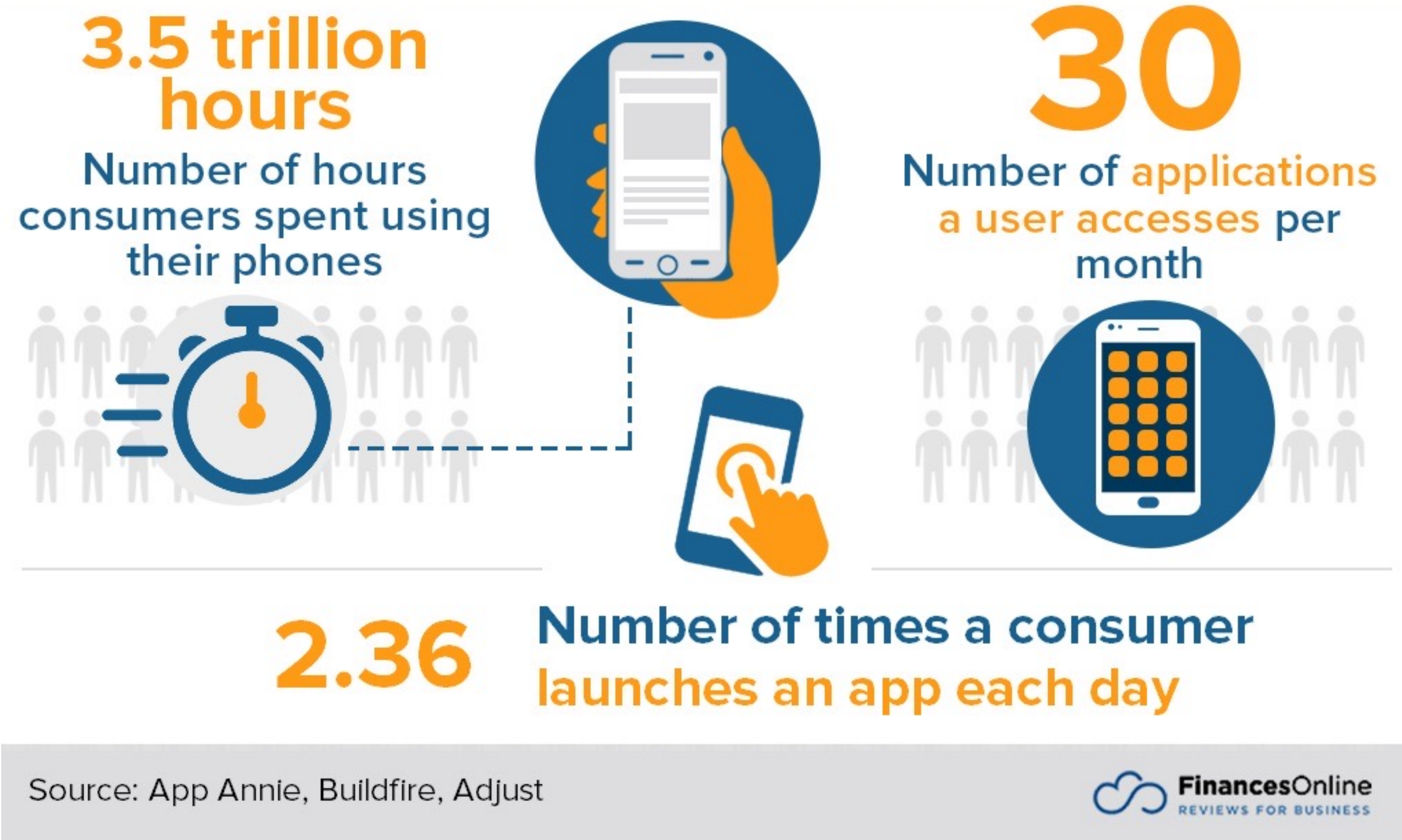
Online

Navigation/Trav



Business/Workin

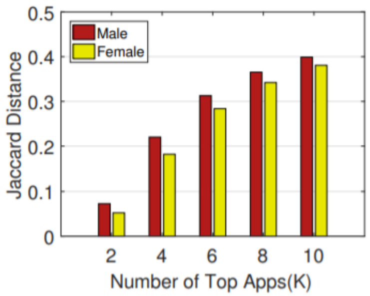
Mobile app usage by the numbers



Mobile apps may also give you away...

Discover Different Types of Mobile User

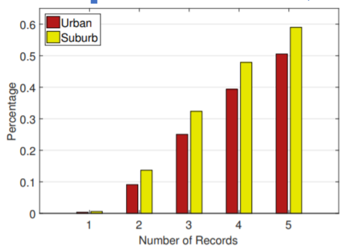
➤ Age, Gender, Income

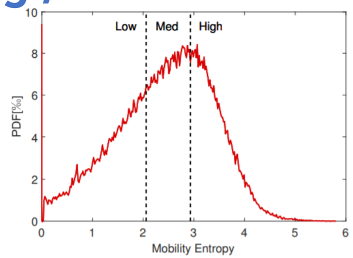


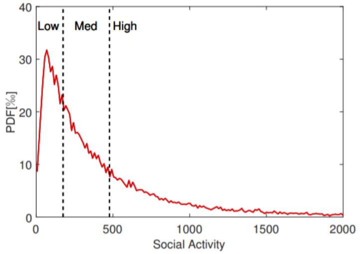
➤ Personal Interests

APPs	Attributes	Installation package
QQ电影票	Movie_fan	com.tencent.movieticket
号百彩票	Lottery	buke.besttone.caipiao.plugin
股票财经	Stocks	com.besttone.FortuneStreet.plugin
艺龙旅行	Travel	com.dp.android.elong
搜房网	Housing	com.soufun.app
高德导航	Driving	com.autonavi.xmgd.navigator
超级课程表	Student syllabus	com.xtuone.android.syllabus
美团	Group_buying	com.sankuai.meituan
美丽购	Beauty shopping	com.geili.gou
粉粉日记	Pinknote	pinkdiary.xiaoxiaotu.com

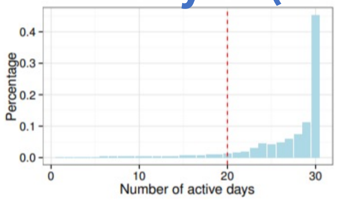
➤ Spatial Info (e.g., urban or suburb)

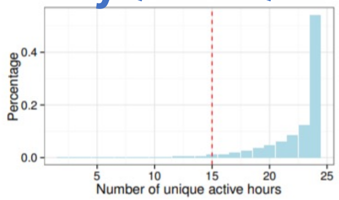


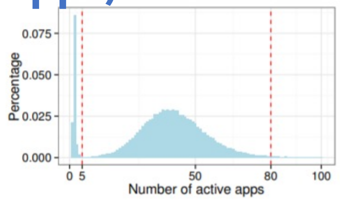




➤ Lifestyles (active days/hours/# of apps)



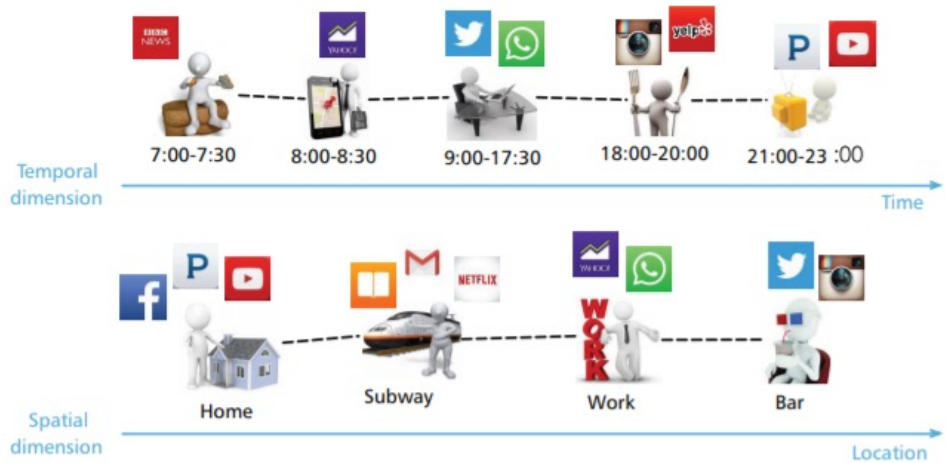


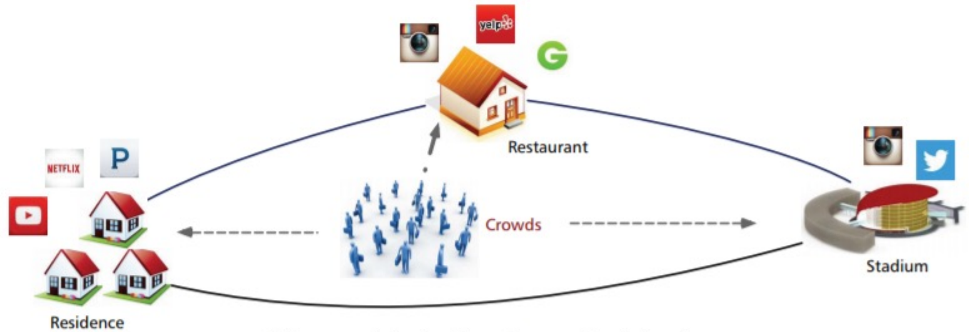


ACM UbiComp/IMWUT 2016/2018/2019

IEEE System Journal 2017

Understand Human Mobility





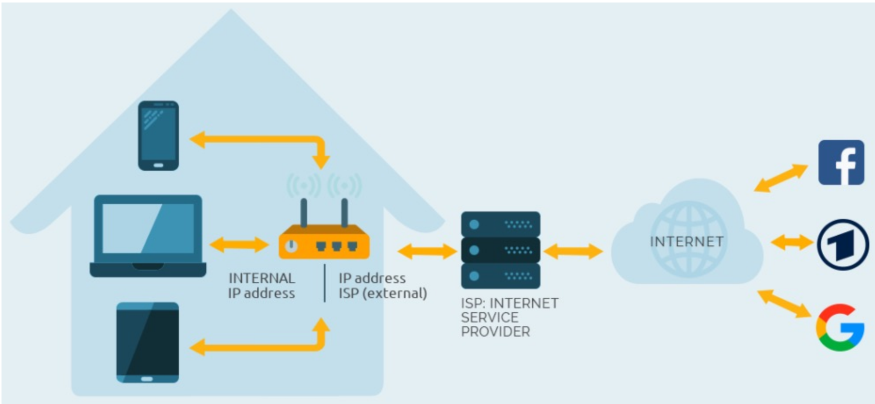
(b) App usage behavior of crowds at crowd gathering places.

IEEE Networks 2016

How to collect mobile app usage behaviors secretly?

Internet Service Provider (ISP) Datasets

- Cellular network traffic
- Extract app usage from HTTP headers

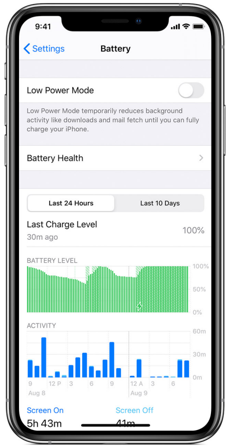


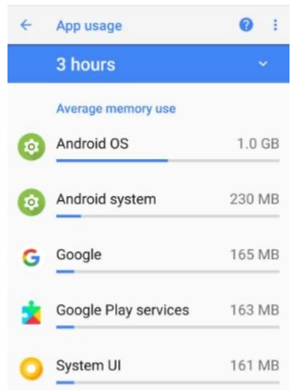
User ID	Date	Hours	Used apps	Weight
0000751aecb005a2	2015-09-01	09-10	com.miui.home	0.85
0000751aecb005a2	2015-09-01	09-10	com.android.incallui	0.85
0000751aecb005a2	2015-09-01	10-11	com.miui.home	0.15
0000751aecb005a2	2015-09-01	10-11	com.android.incallui	0.15

Privacy-related regulations limit third-party access to data ☹

Pertain from the mobile devices directly

- App usage function
- System-kernel information
  - proc filesystem
  - memory
  - internet traffic data
  - battery and CPU





Operating systems have prompted the third-party apps to curtail access to these data ☹

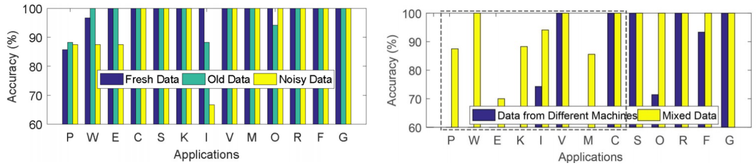
Outline

Related Work: *Application launching process* identification with EM side-channel signals

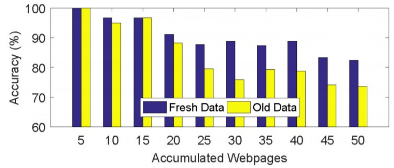
Use smartphone to sense victim's app usage on surrounding laptops

Sniff app usage on the smartphone with built-in magnetometer

Applications classification:

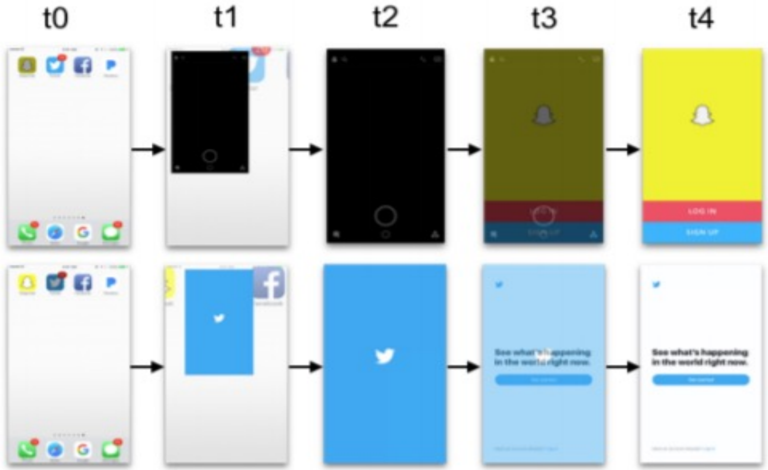


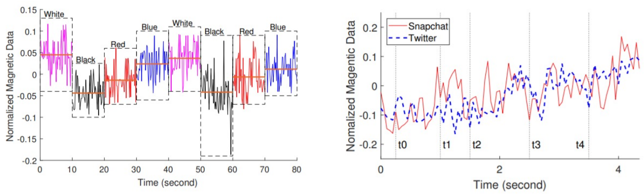
Websites classification:



MagAttack (ACM AsiaCCS 2019)
Magneticspy (ACM WPES 2019)

Infer app usage with magnetometer readings by training CNN model





Distance to Refrigerator (cm)	25	50	100
Magnetic Model (Cross Model Mix) + Motion	0.9721	0.9817	0.9769
Orientation Model (Cross Model Mix) + Motion	0.9768	0.9761	0.9782

DeepMag (IEEE PerCom 2018)

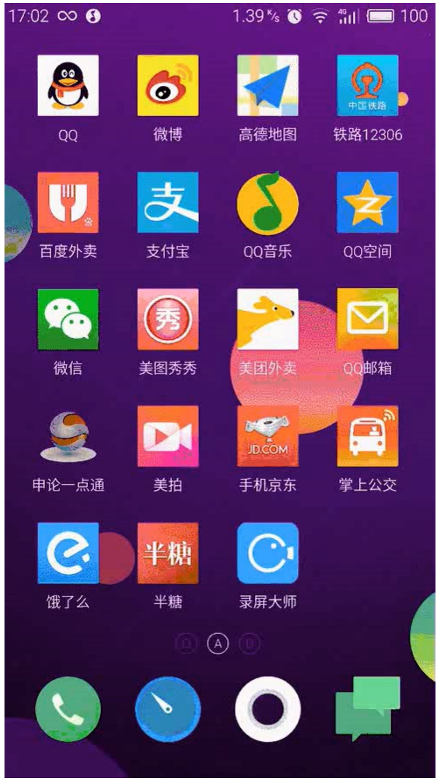
Different manners of launching an app

Cold Start (from scratch)

***Cold* start has four tasks:**

1. Loading and launching of the app
2. Displaying a theme starting window
3. Creating the application process
4. Inflating & rendering of layouts

Warm Start (from memory)



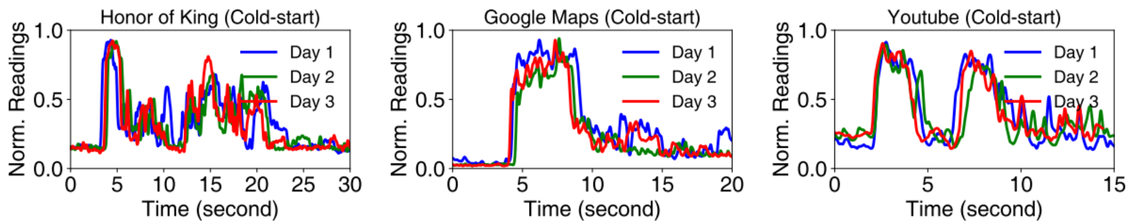
***Warm* starts has one tasks:**

1. Switching back to the app from "warming" memory.

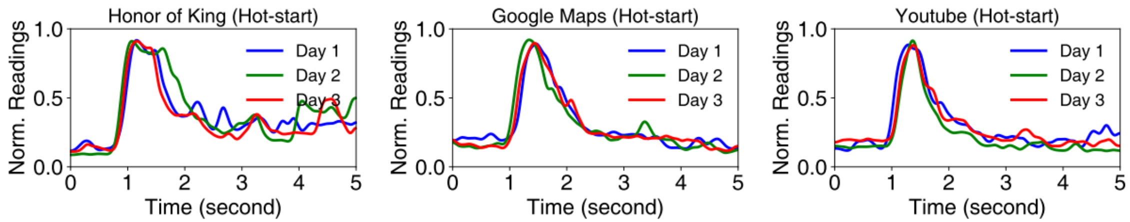
A high-frequency method used to launch apps for the mobile users ☺

Problems of app launching identification

EM signals of app launching via Cold Start



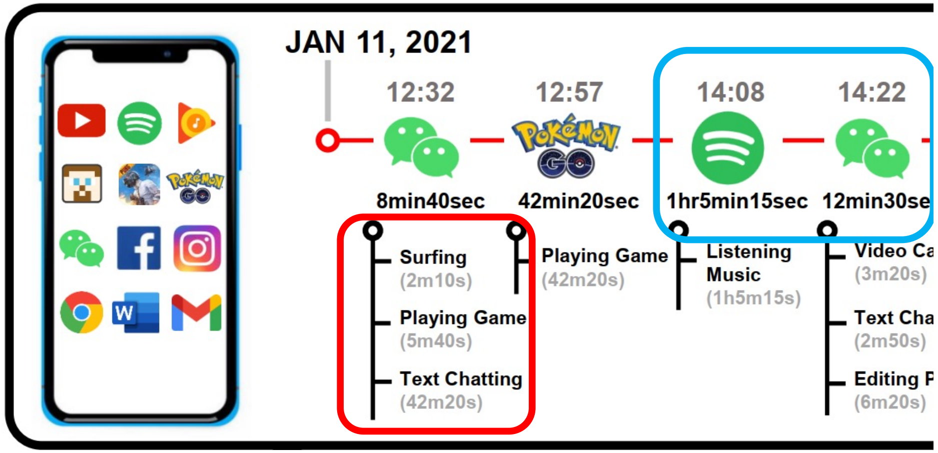
EM signals of app launching via Cold Start



Classification results of EM signals generated by app launching

	kNN	LDA	SVM	RF	MLP
Cold	89.7%	93.5%	93.7%	94.9%	95.6%
Hot	11.67%	12.92%	13.37%	15.72%	16.14%

PROBLEM 1: warm start of app launching is HARD to identification.



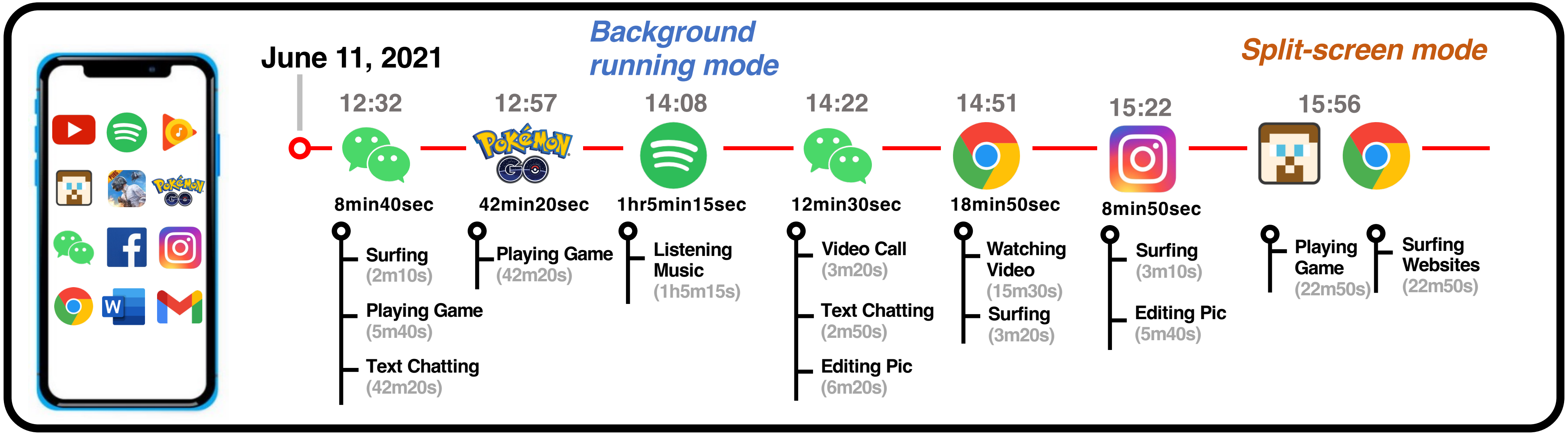
Complete app usage behaviors contains:

1. Start/Switch/Close timestamp
2. In-app service when using an app
3. Simultaneous usages of multiple apps

(in split-screen mode/background running)

PROBLEM 2:
App's launching information
≠
Complete app usage behaviors

Our Target



Tracking the complete app usage behaviors in real time :

- **Multi-label problem:**
  - **Identify the *app & in-app services* types**
- **Multi-target problem:**
  - **Identify multiple running apps, including *background running* and *split-screen modes***

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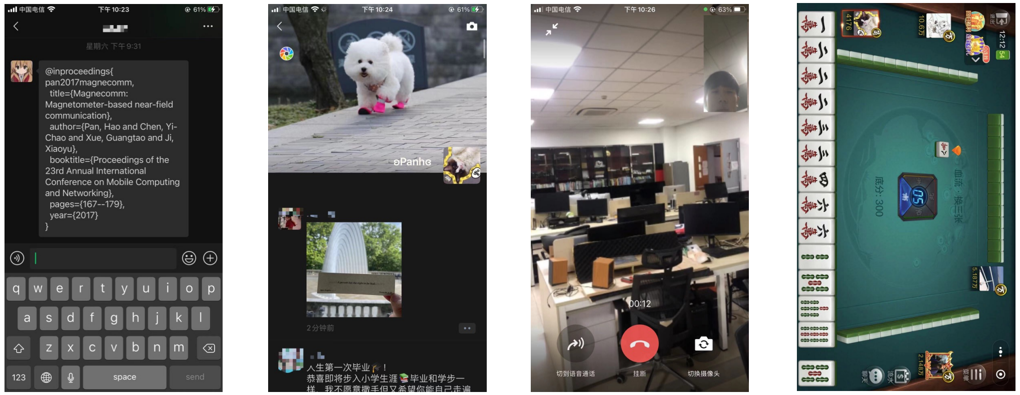
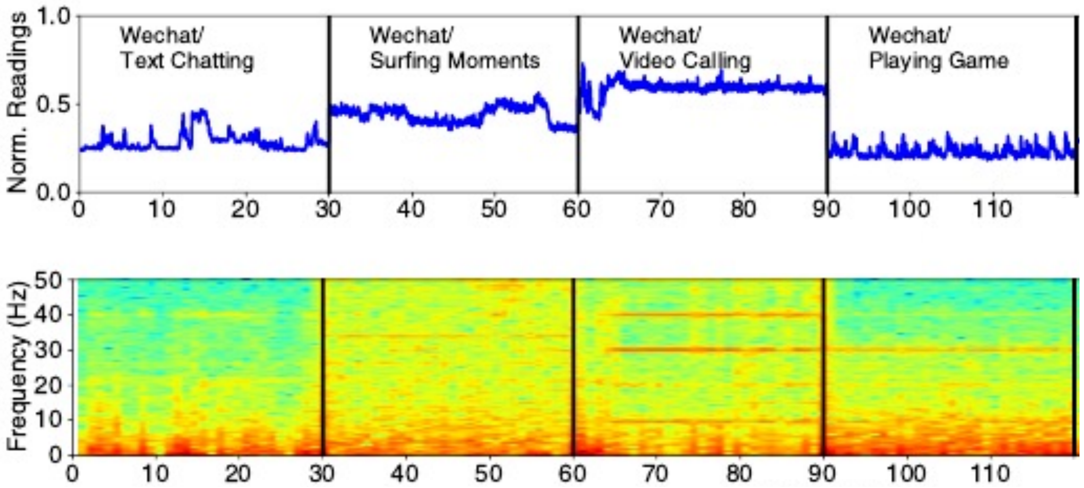
Preliminary experiment I – app & in-app service

App 1: Wechat

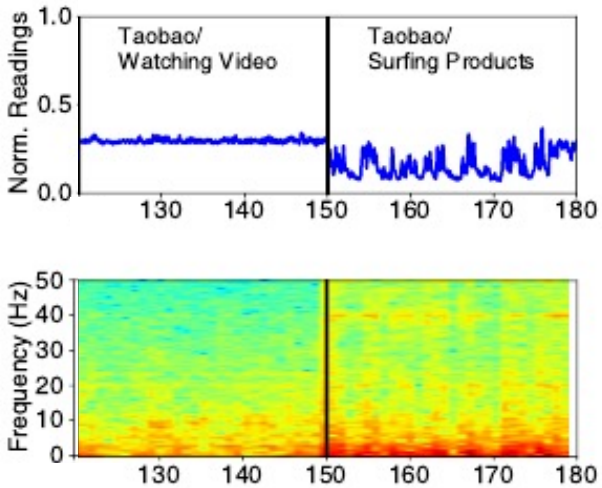
Text chatting | *Surfing moments* | *Video calling* | *Playing games*



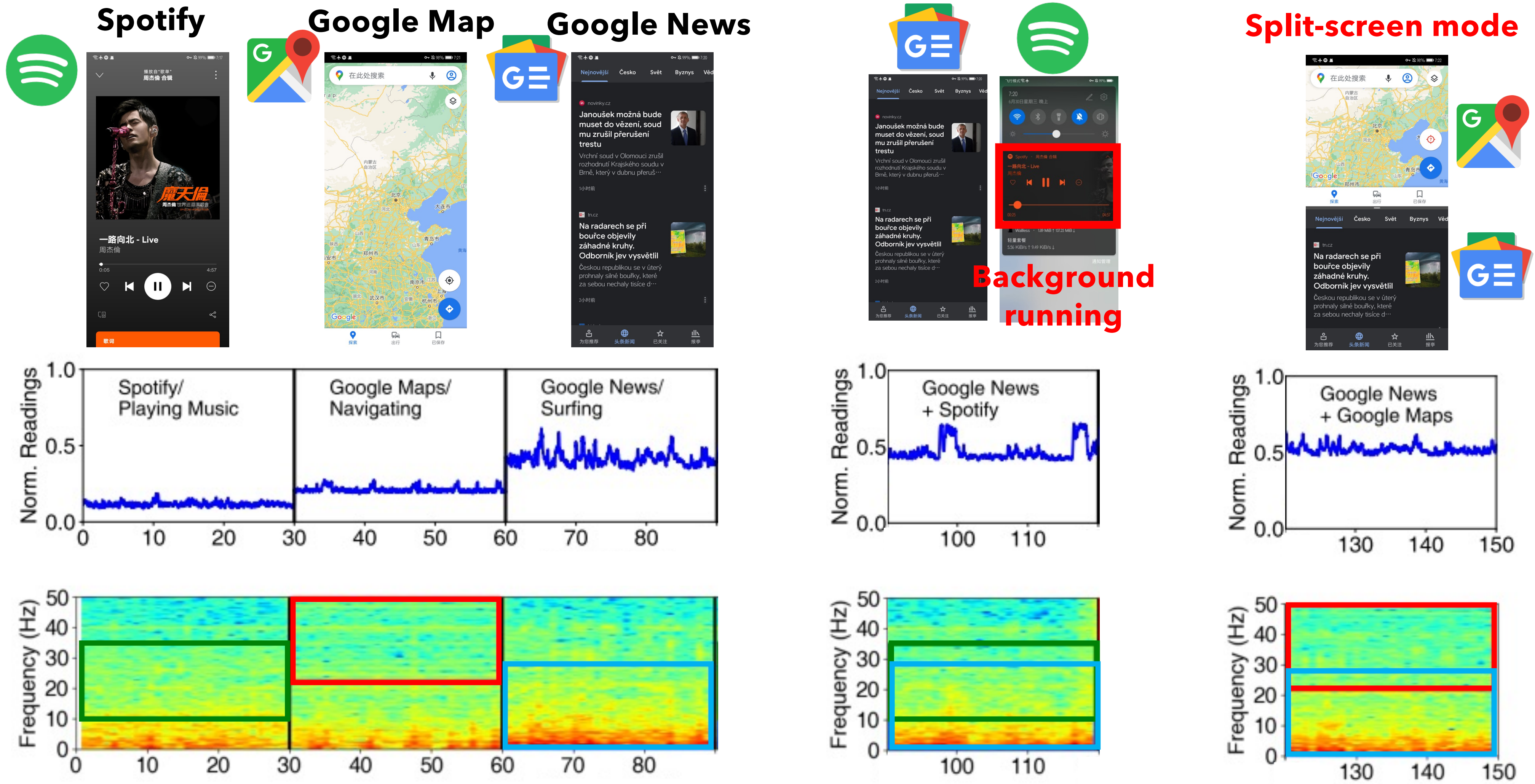


App 2: Taobao

Watching video | *Surfing products*



Preliminary experiment II – multiple running apps



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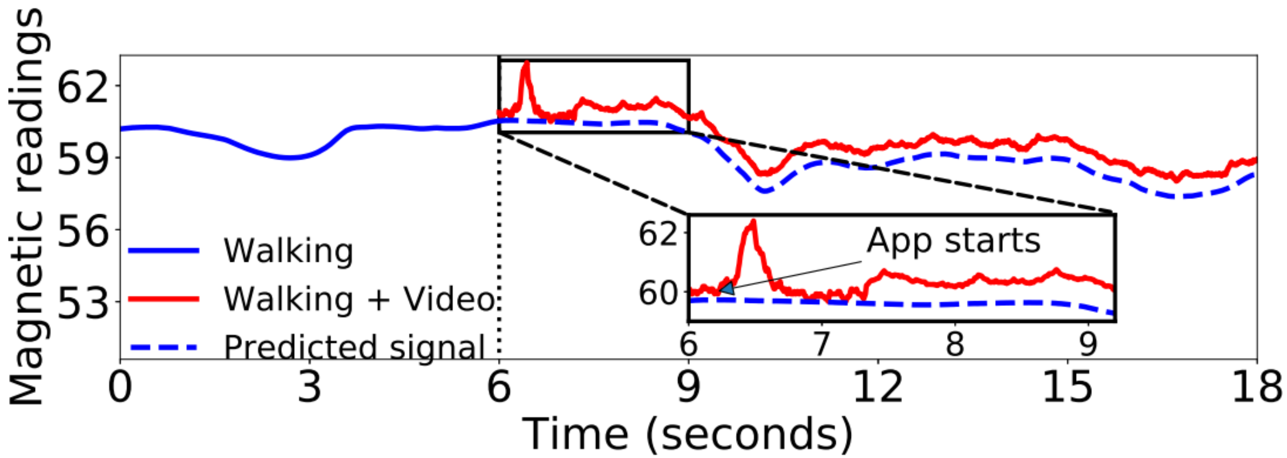
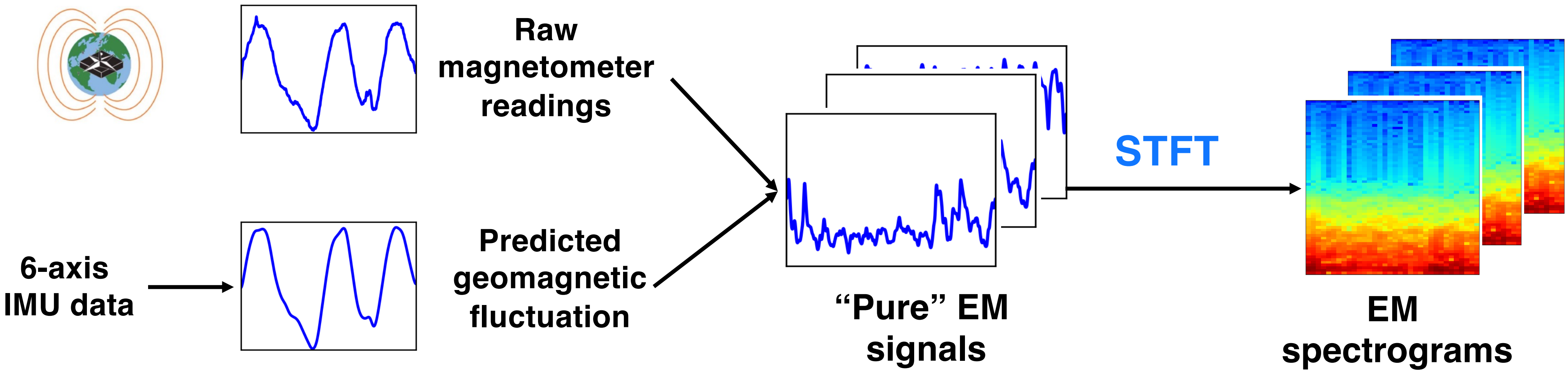
Cancel out the geomagnetic filed signals

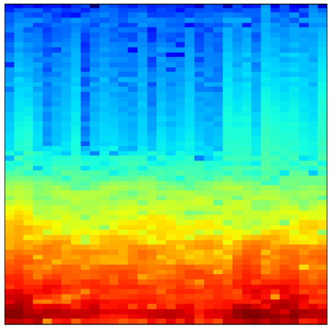
Using phones when walking

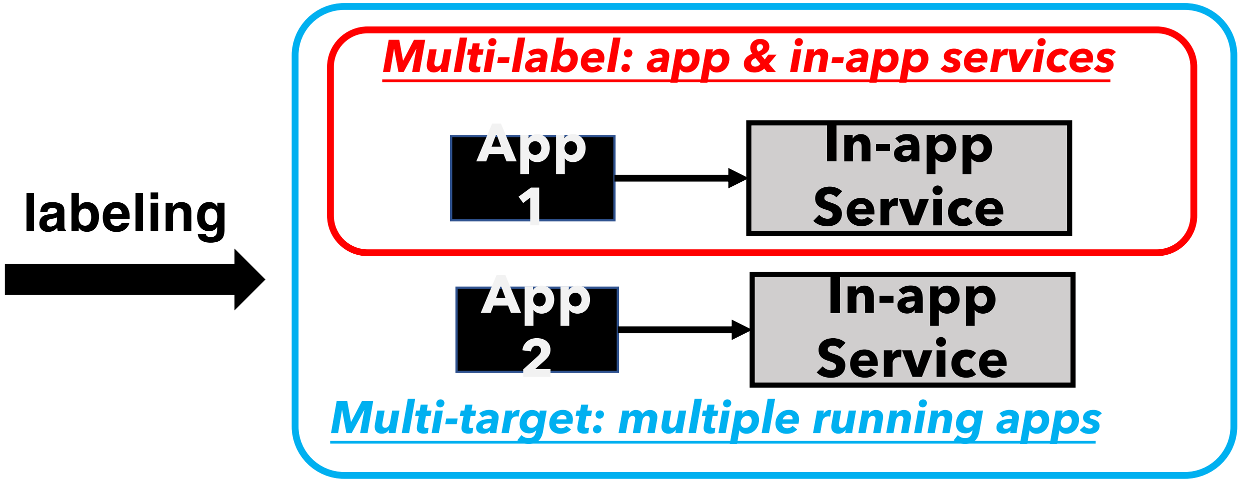




Dataset collection

EM spectrograms

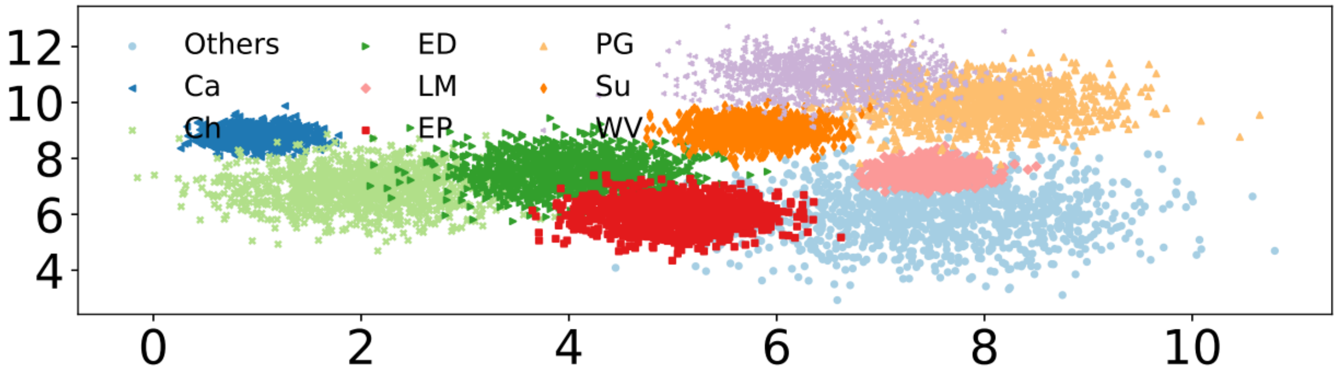




App types are known!

How about labels of in-app services?

EM signal clusters related to nine types of in-app services



In-app service labels:

- ✓ Ca: video/voice calls
- ✓ Ch: text chatting/typing
- ✓ ED: editing documents
- ✓ LM: listening to music
- ✓ EP: editing photos
- ✓ PG: playing games
- ✓ SU: surfing/reading
- ✓ WV: watching videos
- ✓ Others

How to define the region of each running app?

Our idea:
Region Proposal Network

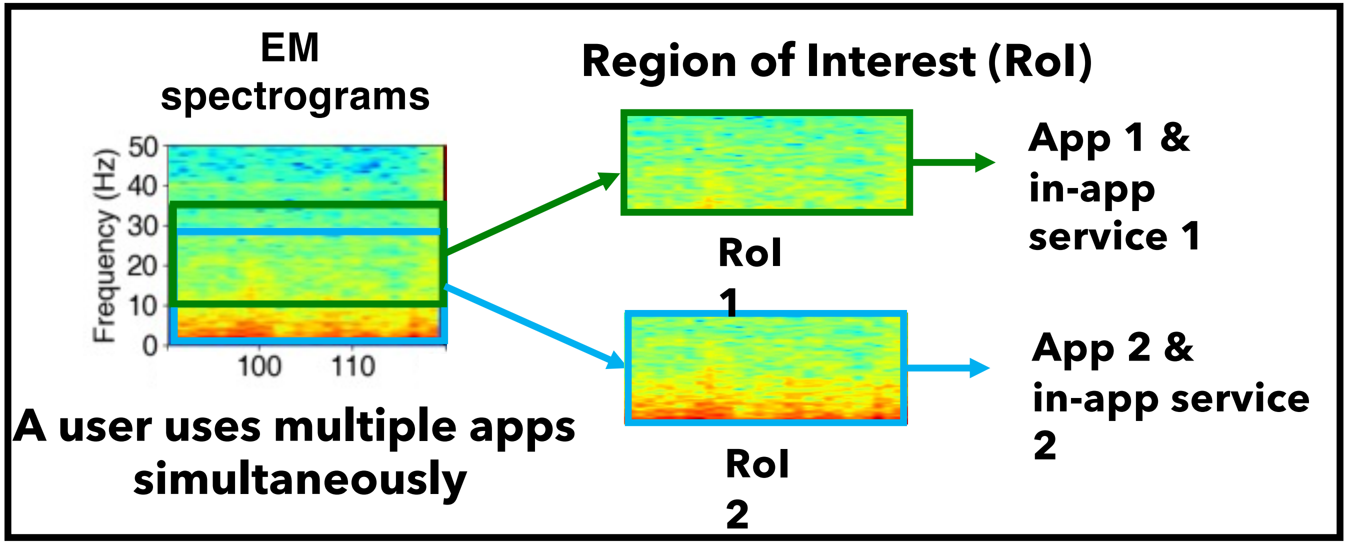
Ground truth of bounding box (manual labeling)

w: *Box width*

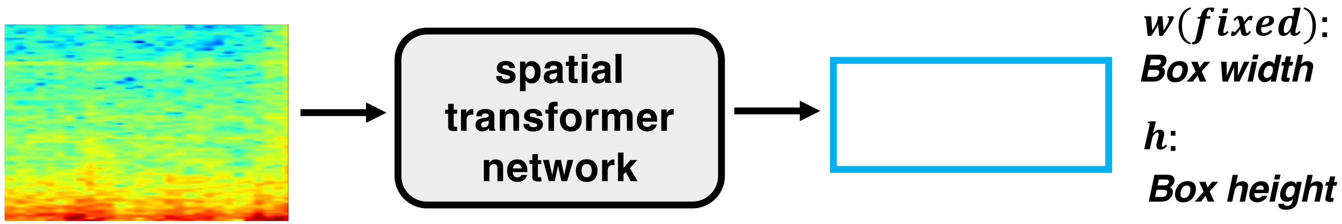
h: *Box height*

x, y: *Box center*

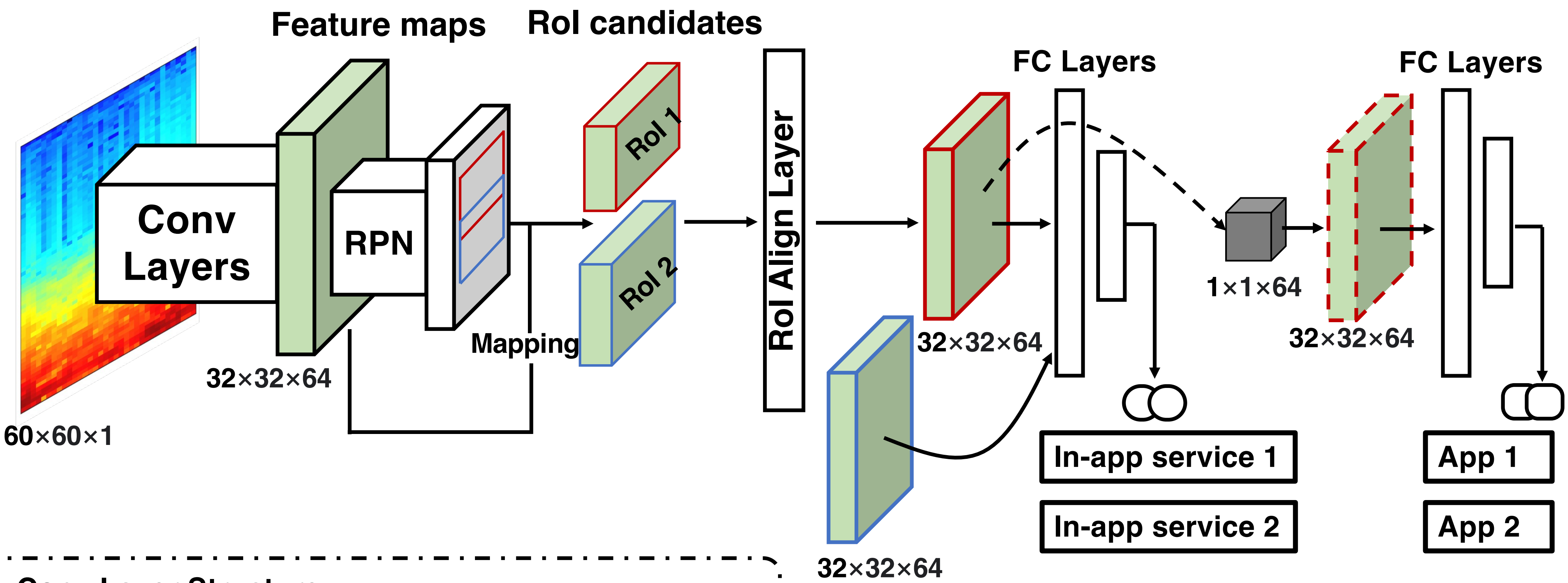
Design the app/in-app classification model:



Determine the bounding box of each single running app with STN



DRCNN: multiple apps/in-app services classification



Conv Layer Structure:
Conv2D(32) – BN – ReLU – Conv2D(64) – BN – ReLU

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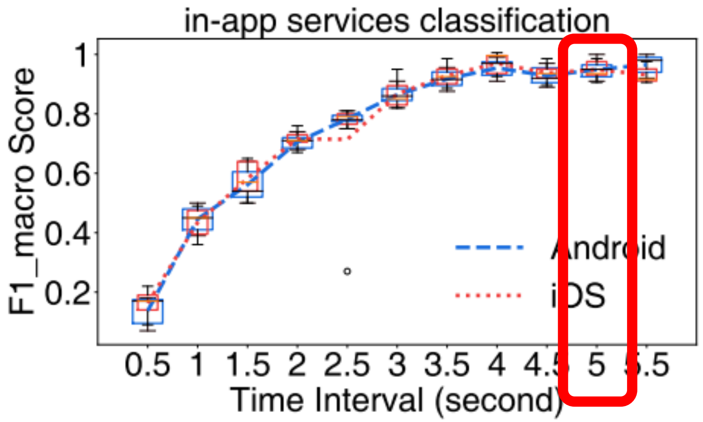
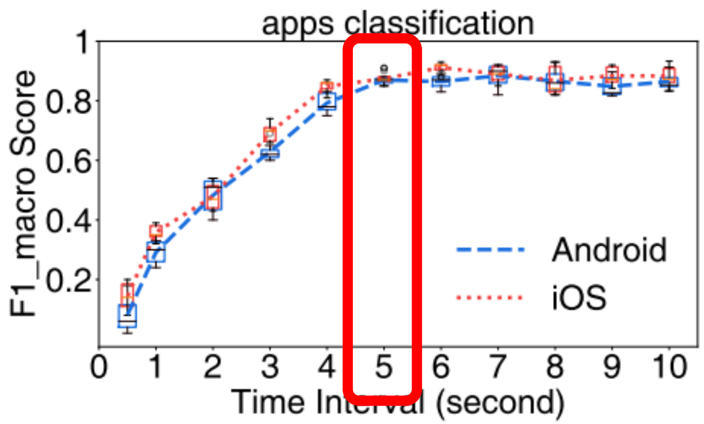
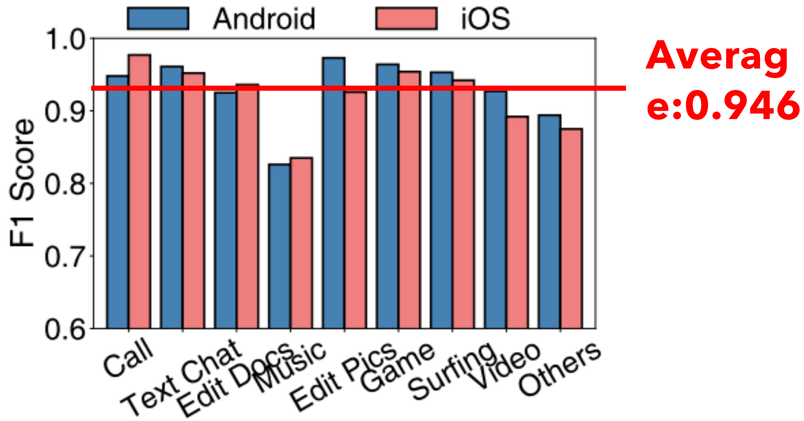
Experiment Results

Determine the time interval length of EM signals:





Multiple in-app service classification:

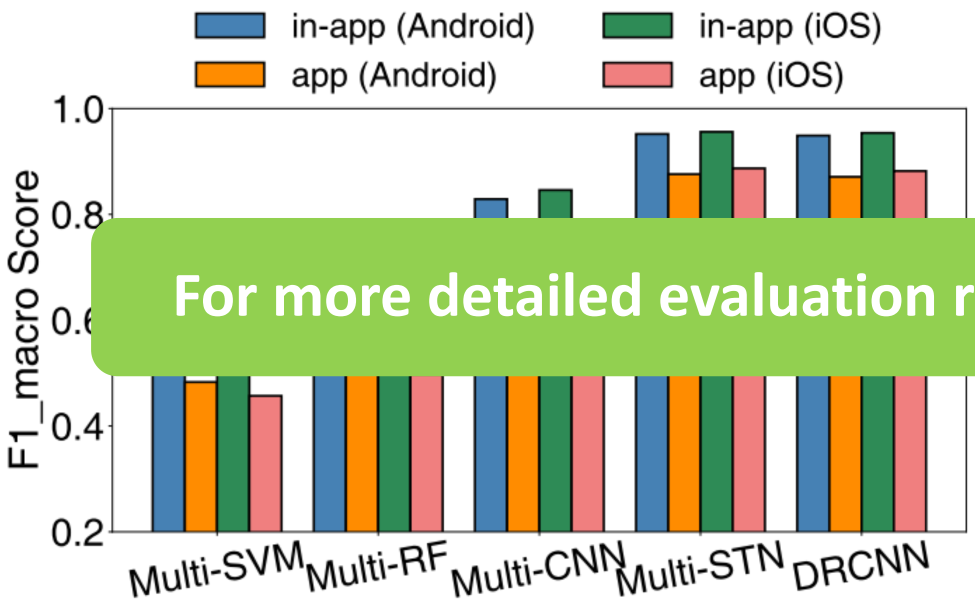


Multiple app classification:

Partly:
Social network

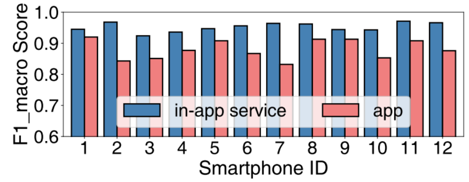
Experiment Results

Comparison of multi-label classification models



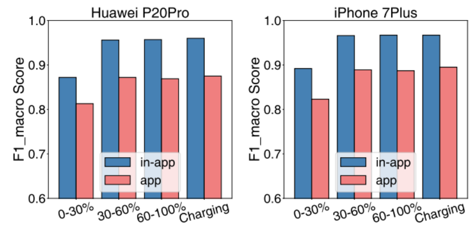
For more detailed evaluation results, please read our paper ☺

Performance on different smartphones:



Against different environments:

Smartphone settings (e.g., battery):



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- **MagThief** can steal fine-grained sensitive app usage info with the built-in magnetometer readings:

  ✓ We developed a Deep Region CNN (DRCNN) to facilitate the ***multi-target*** and ***multi-label*** classification of multiple running **apps** as well as corresponding **in-app services**.

  ✓ Extensive experiments demonstrated the efficacy of the MagThief, and it achieves high average macro F1 scores of 0.87/0.95 when identifying multiple apps/in-app services respectively.