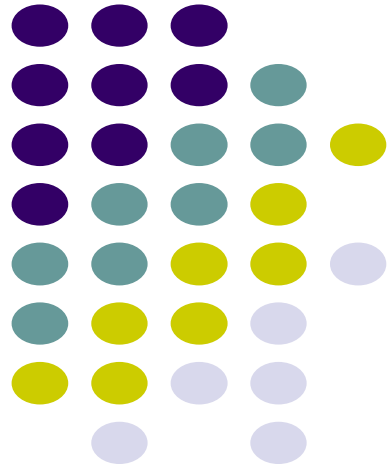
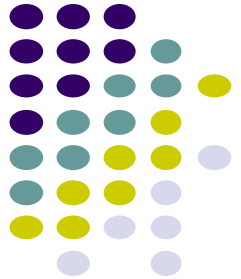
CS 528: Mobile and Ubiquitous Computing

Lecture 10a: App Usage Characterization

Emmanuel Agu



Announcement

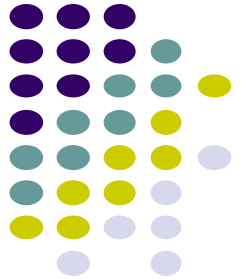


- Next class:
  - Final project presentations
  - Quiz
- Quiz covers everything after last quiz
  - 6 papers presented by student groups
  - Today's class

Mobile Measurements: Android Users in China

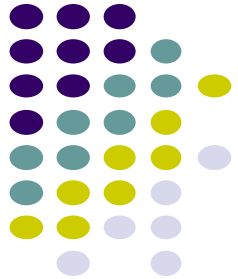
Introduction

Huoran Li et al., "Characterizing Smartphone Usage Patterns from Millions of Android Users" Internet Measurement Conference (IMC) 2015



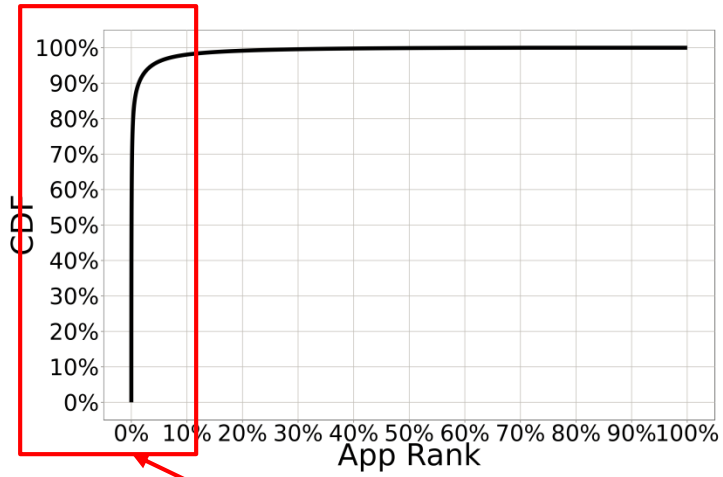
- Comprehensive measurement study to investigate smartphone user patterns
- Sample questions addressed:
  - Popularity of various apps among millions of users?
  - Understand how mobile users select, install and manage apps?
  - Type and amount of network traffic generated by various apps
  - Investigate economic factors affecting app selection and network behavior?

Dataset

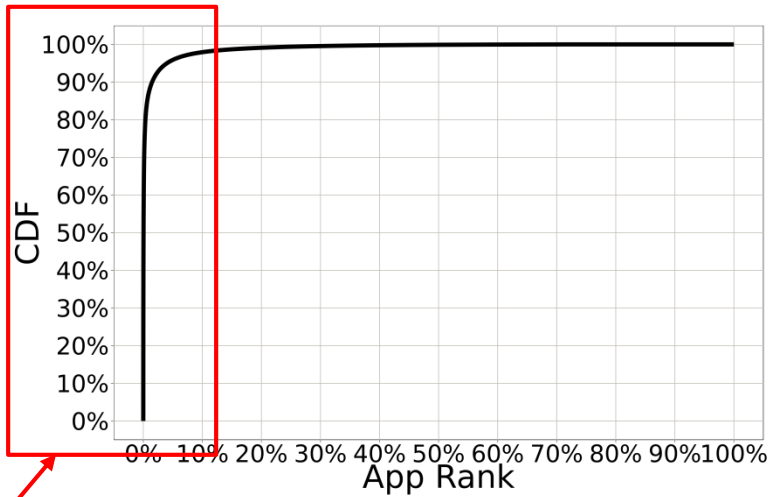


- Gathered from Wandoujia, leading Android App Store in China
  - Acquired by Alibaba in 2016
- Wandoujia:
  - Over 250 million users in 2015
  - All apps are free
- Data gathered for 1 month, from:
  - 8 million unique users
  - 260,172 unique apps in dataset

App Popularity: Downloads & Unique Subscribers



Percentage of Downloads against App Rank



Percentage of Unique Subscribers against App Rank

Top 10% of apps get over 99% of:

- Downloads
- Unique subscribers

→

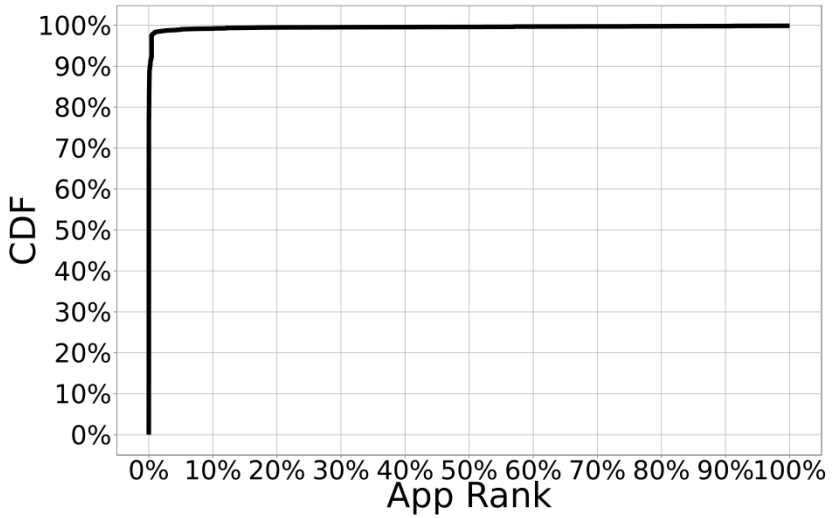
Bottom 90% of apps share 1% of:

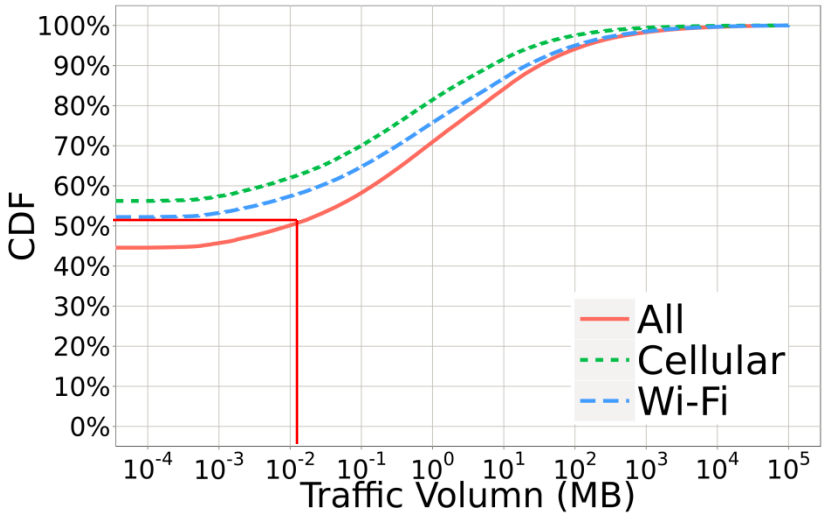
- Downloads
- Unique subscribers

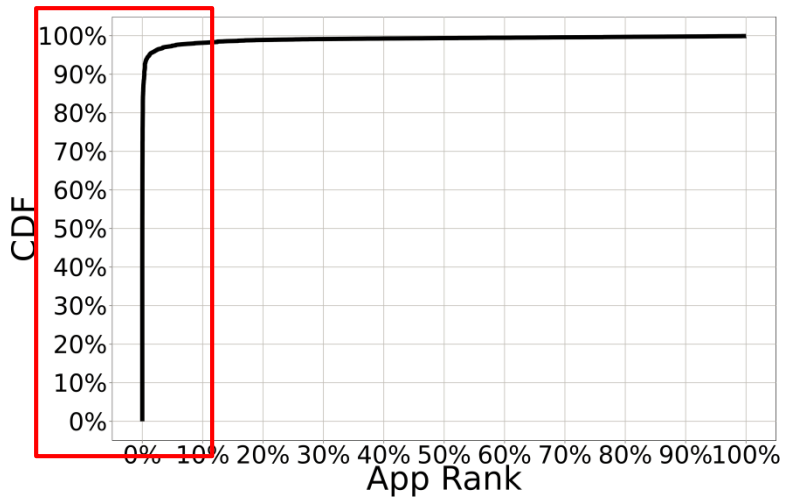
App Popularity: Network Traffic

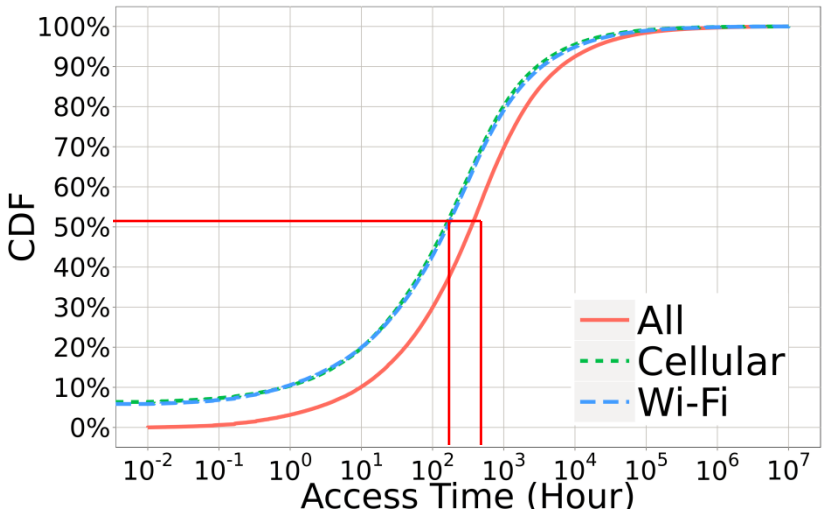
Top-ranked 10% of apps generates over 99% of network traffic

97% apps consume < 100 MB traffic per 1 month
95% of apps are used less than 100 hours/mo



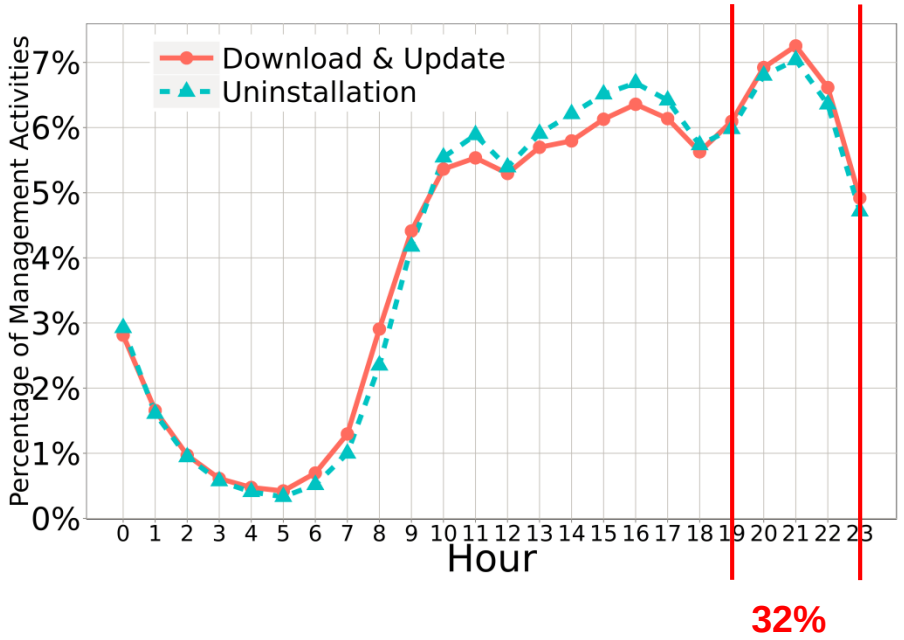






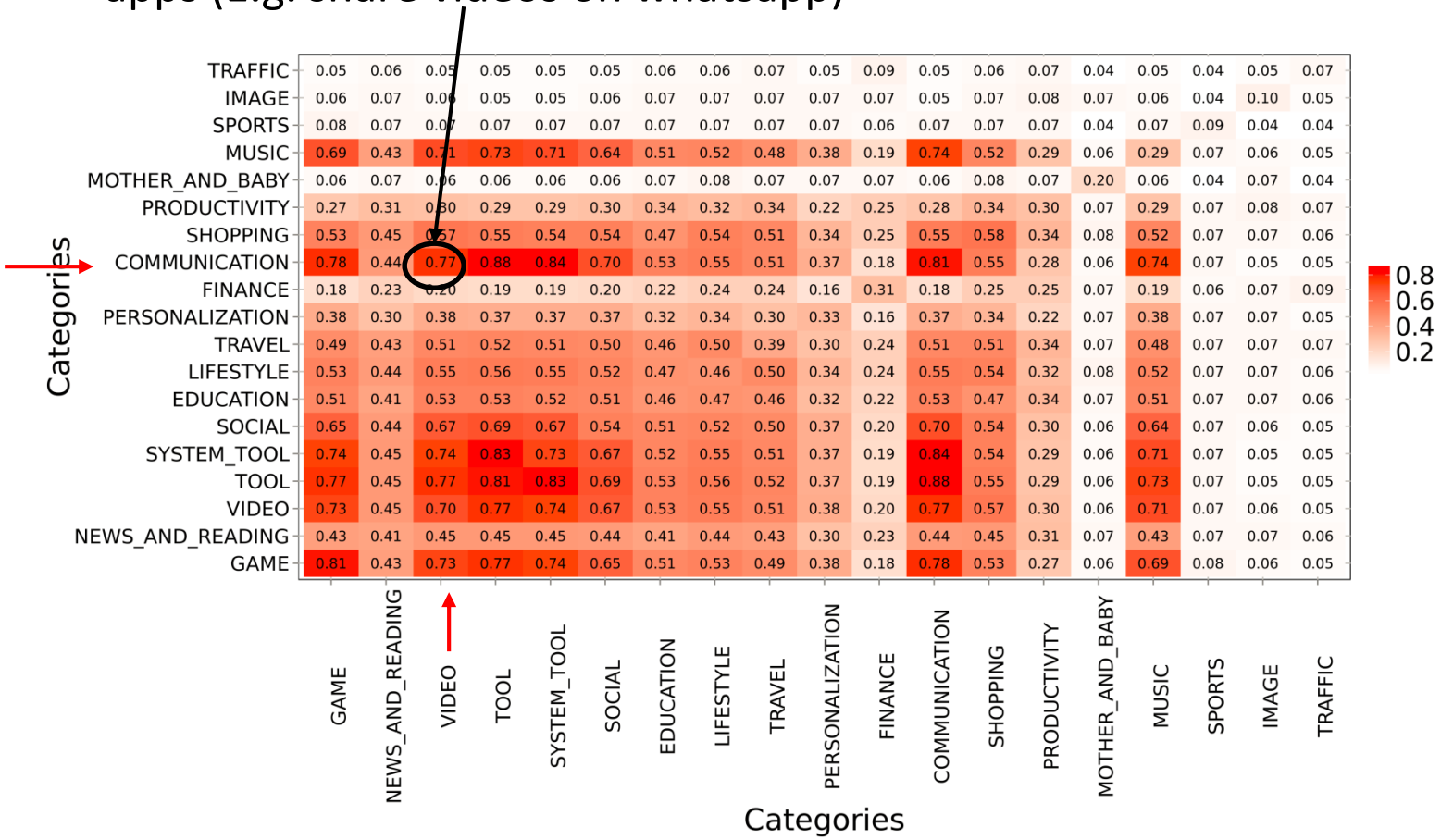
App Management & Installation Patterns

- About 32% of app downloads and updates performed at night (7:00 pm to 11:00 pm)



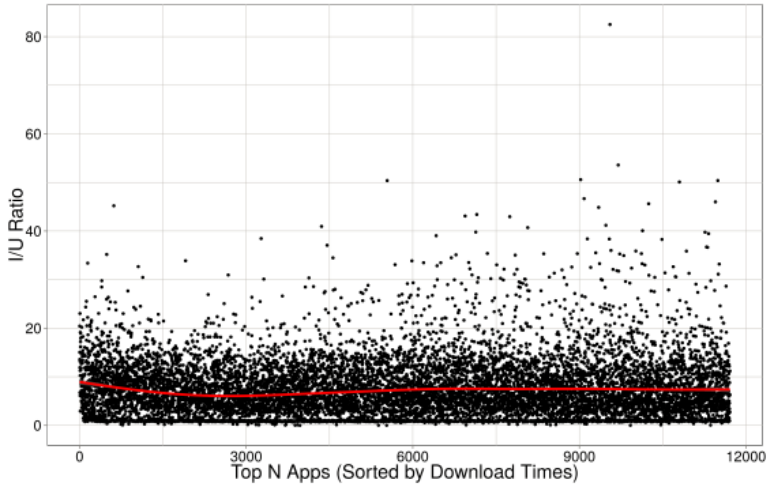
App Co-Occurrence of App Categories

- Examine which apps users like to use together
- E.g. Many users like to share video => high co-occurrence of video + communication apps (E.g. share videos on whatsapp)

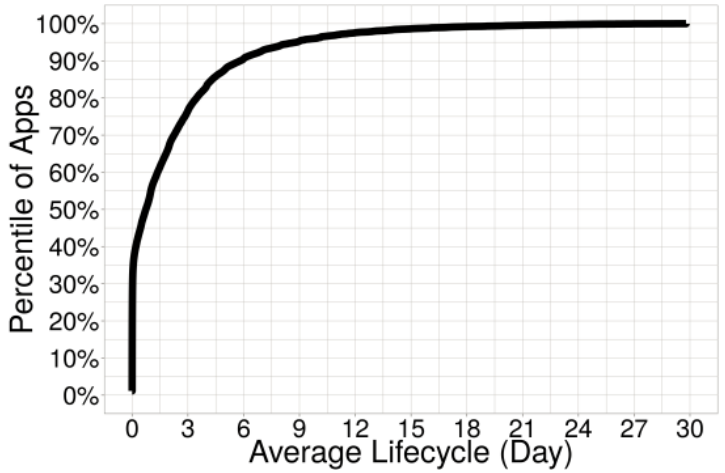


App Uninstallation Patterns

- **I/U ratio:** No. of Installations/No. Uninstallation
  - E.g. I/U = 8 => 1 out of 8 users who download the app uninstall it



- Users react quickly to disliked apps
- Of all apps that are uninstalled
  - 40% are uninstalled within 1 day
  - 93% are uninstalled within 1 week



Data Traffic Patterns

- Users are more likely to lauch video apps on WiFi
- Video apps consume over 81% of Wi-Fi traffic and 28% of cellular traffic

Table 1: Chosen Top Apps by Category.

App Category	Apps	Users (10^6 devices)	Downloads (10^6 times)	Traffic (GB)	Access-Time (10^7 hours)	*C*-Traffic	*C*-Time	*W*-Traffic	*W*-Time
GAME	1,227	3.87	15.15	13,669.71	0.38	2.98%	5.19%	0.76%	6.39%
NEWS_AND_READING	274	1.17	1.97	13,143.17	0.23	3.11%	2.91%	0.72%	3.95%
VIDEO	238	2.86	6.52	1,196,978.79	0.38	28.41%	1.42%	81.08%	10.54%
TOOL	227	3.84	9.43	77,329.87	0.68	15.63%	10.79%	4.40%	9.46%
SYSTEM_TOOL	217	3.37	7.54	34,012.16	0.25	3.05%	3.37%	2.17%	4.24%
SOCIAL	188	2.18	4.01	35,926.76	0.35	8.96%	4.77%	1.94%	5.66%
EDUCATION	172	1.68	2.98	13,893.55	0.34	1.46%	5.35%	0.87%	4.71%
LIFESTYLE	156	1.68	2.85	2,388.59	0.07	0.72%	1.00%	0.12%	1.06%
TRAVEL	111	1.62	2.75	8,182.24	0.03	0.78%	0.53%	0.52%	0.25%
PERSONALIZATION	104	1.49	3.68	7,426.38	0.86	0.85%	12.03%	0.46%	13.67%
FINANCE	99	0.32	0.50	382.60	0.02	0.13%	0.24%	0.02%	0.26%
COMMUNICATION	85	4.09	8.45	54,394.71	2.85	24.74%	49.01%	2.26%	35.26%
SHOPPING	78	1.57	3.00	21,808.51	0.07	3.16%	0.65%	1.32%	1.60%
PRODUCTIVITY	75	0.76	1.17	2,712.50	0.01	0.18%	0.17%	0.18%	0.26%
MOTHER_AND_BABY	48	0.10	0.15	525.72	0.01	0.07%	0.04%	0.03%	0.12%
MUSIC	43	2.33	3.39	49,540.12	0.17	5.66%	2.47%	3.08%	2.49%
SPORTS	27	0.31	0.36	61.40	0.00	0.02%	0.05%	0.00%	0.04%
IMAGE	23	0.14	0.17	801.64	0.00	0.06%	0.01%	0.05%	0.03%
TRAFFIC	14	0.10	0.12	78.10	0.00	0.02%	0.03%	0.00%	0.01%

The users, downloads, traffic, and access time are all computed by aggregating the data of each app in the category
The percentile of *W*-Traffic (*C*-Traffic) and *W*-Time (*C*-Time) refer to the data traffic and foreground access time over Wi-Fi (W) and cellular (C) network, respectively.

Data Traffic of Foreground and Background

- App categories with high traffic:
  - VIDEO: prefetching of videos
  - SYSTEM_TOOL: Anti-virus updating
  - GAMES: Embedded ads
- < 2% of network access time in foreground, 98% in background
  - Many apps keep long-lived background TCP/IP connections. Secret downloads. Hmm…

Table 2: Network Summary by App Category

App Category	C-Traffic (B)	W-Traffic (B)	C-Traffic (F)	W-Traffic (F)	C-Time (B)	W-Time (B)	C-Time (F)	W-Time (F)
VIDEO	0.81%	45.13%	1.28%	52.78%	42.62%	56.66%	0.10%	0.63%
TOOL	8.16%	39.13%	9.56%	43.14%	48.57%	50.42%	0.57%	0.43%
COMMUNICATION	12.42%	15.90%	27.48%	44.20%	48.01%	46.85%	3.15%	1.99%
MUSIC	4.35%	35.19%	5.67%	54.80%	49.23%	50.09%	0.36%	0.32%
SOCIAL	7.26%	20.65%	14.63%	57.47%	48.43%	50.41%	0.57%	0.59%
SYSTEM_TOOL	5.07%	51.57%	2.80%	40.55%	50.02%	49.48%	0.23%	0.26%
SHOPPING	3.29%	17.09%	9.42%	70.21%	43.34%	56.42%	0.08%	0.17%
EDUCATION	3.76%	39.38%	5.46%	51.40%	45.57%	52.83%	0.90%	0.69%
GAME	10.34%	43.11%	8.80%	37.74%	48.13%	51.34%	0.26%	0.28%
NEWS_AND_READING	5.91%	24.64%	14.83%	54.62%	43.43%	55.25%	0.60%	0.71%

W and C refer to Wi-Fi and Cellular, respectively.
B refers to background and F refers to foreground.

Add these 2 columns
Cellular background time + Wi-Fi background time > 98%

Device Model Clustering

- 12,091 device models in existence
- Device model are Moto G5, Samsung galaxy 6, etc
- 96% device models have less than 500 users

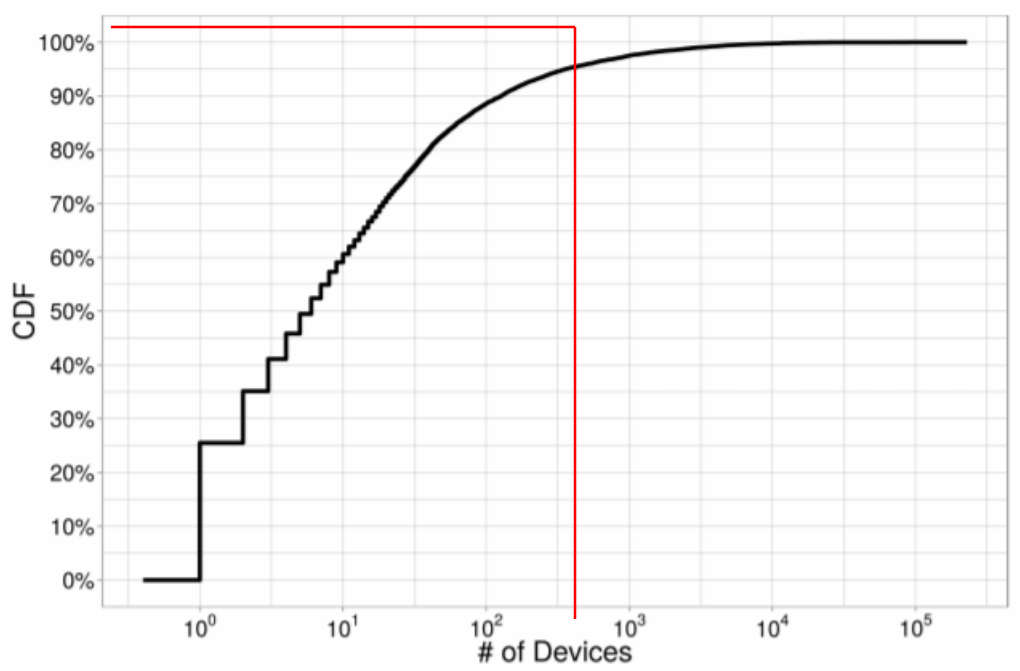
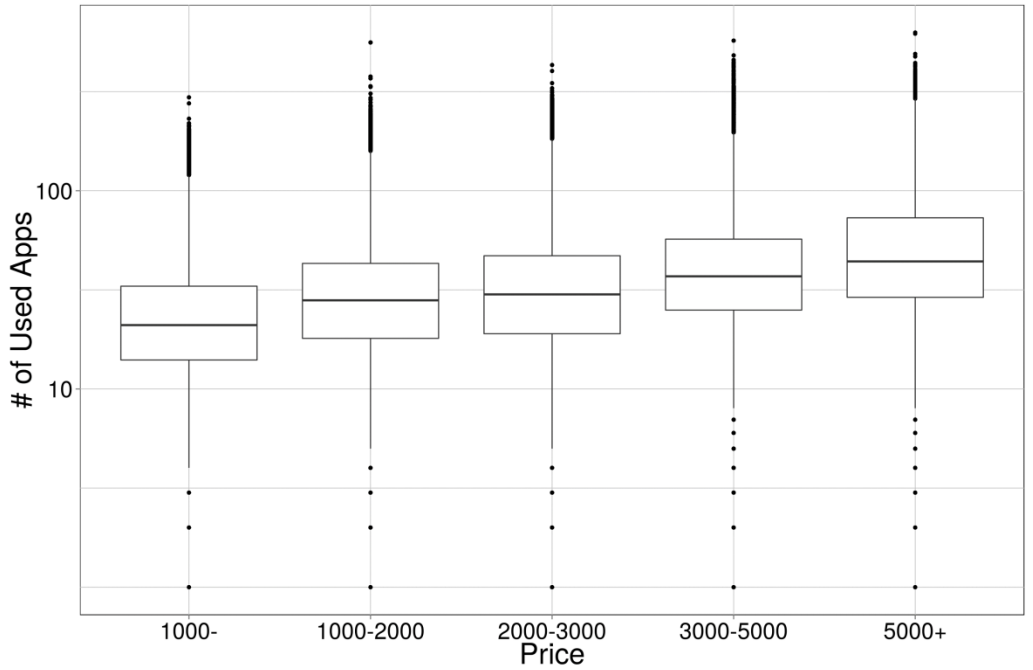


Figure 10: CDF for Number of Users of Device Models

Apps Installed on Various Device Groups

- Higher priced devices have more apps installed, maybe because
  a) More RAM, better CPU, hardware, etc
  b) Bigger manufacturers (E.g. Samsung?) who pre-install apps (bloatware)



Study Limitations

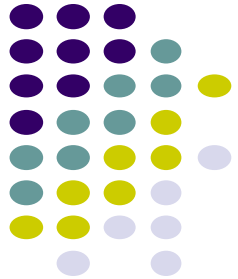
Limitations:

- Dataset was from 1 app marketplace in China
- Users are mostly Chinese.
- Other regions may be different
- Need to look at other groups to get complete picture
- Study and analysis was on 1 month of usage data

App Usage Survey

App Usage Analysis

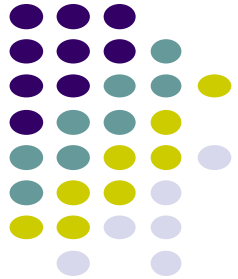
Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.



- More recent survey, summarizes main findings of many studies
- Understanding app usage can improve app design, supporting infrastructure
- Methods for collecting data about app usage:
  - **Survey user (e.g. in-app survey):** Coarse information such as no. or apps downloaded per month, app stores used
  - **Monitoring app:** installed on users' phones, snoops on volunteers, records app launches, notification, clicks, emails
  - **Network operators:** collect network packets, inspect app packets, may use apps like AppScanner
  - **App stores:** retrieve information about app downloads, installs, updates, user preferences

App Usage Contextual Patterns

Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

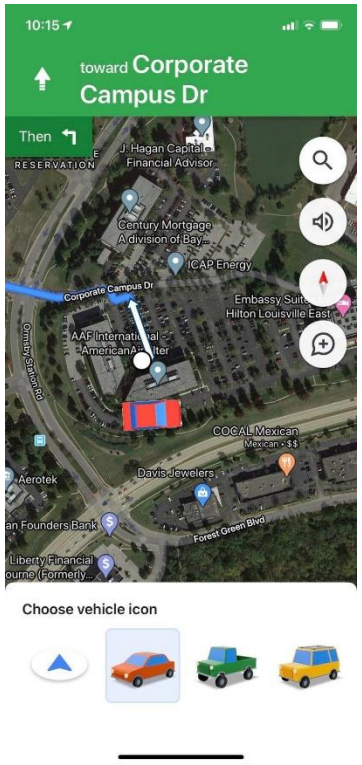


- App usage varies with user context (situation), depends on:
  - **Sensor:** Time, location, battery levels, activity/movement status
  - **Usage context:** Prior and posterior apps (before and after)
  - **Social context:** Who with? Friends, family, co-workers

App Usage Contextual Patterns: Location

Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

- **Location affects receptiveness to app notifications**
  - Students more attentive to app notifications at college, libraries, in residential areas
  - Users less attentive at religious institutions (e.g. church)
- While waiting for, during drips, users prefer to surf web, use multimedia apps



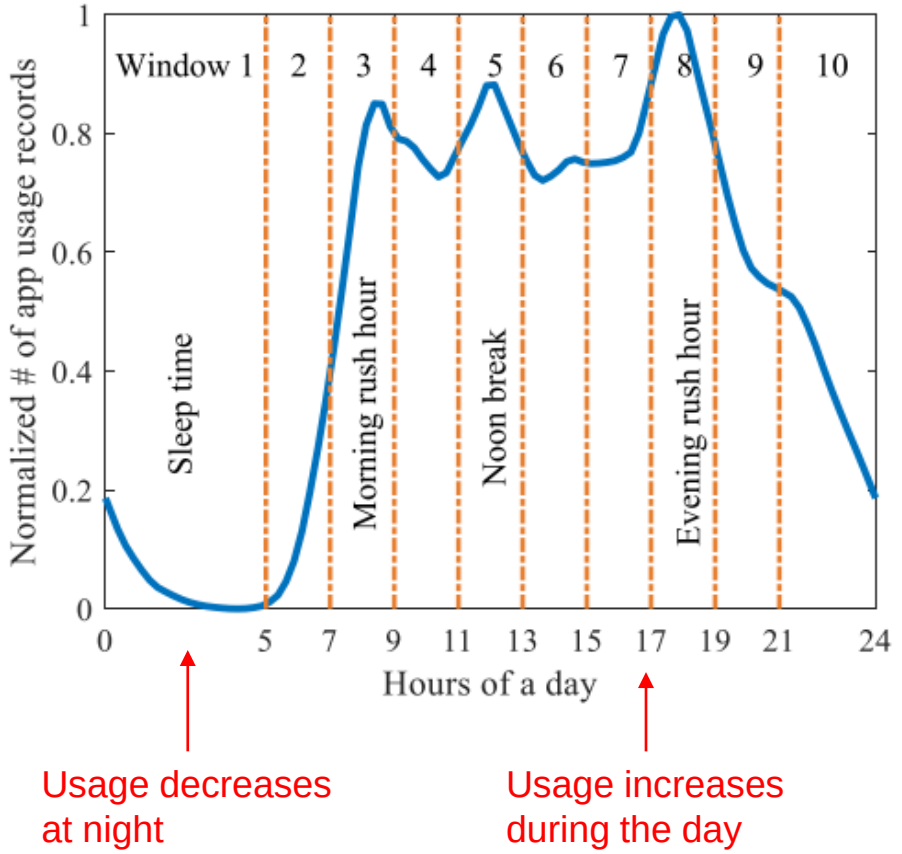
Less attentive to notifications

Likely to surf web, use multimedia apps (e.g. YouTube)

App Usage Contextual Patterns: Time of Day

Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

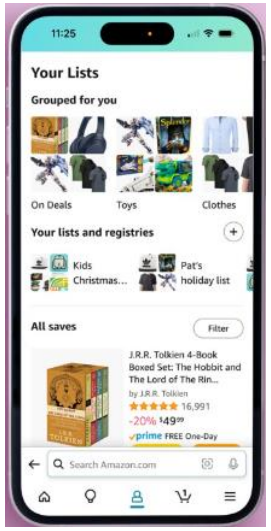
- Diurnal patterns (app usage daily cycles) exist for app usage
  - Increased usage during day
  - Decrease at night
- Time influences app usage
  - News apps most popular in morning
  - Game apps most popular at night
  - Regular app patterns disrupted during major events (e.g. New years' day, world cup, Covid)



App Usage Contextual Patterns: Co-Occurrence

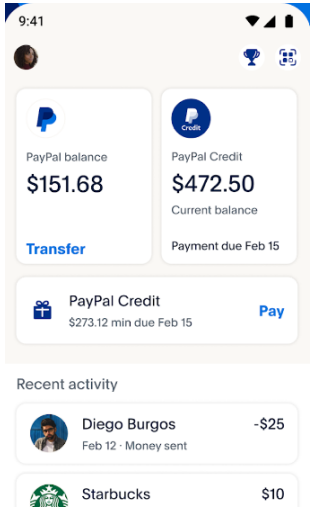
Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

- Certain apps frequently used either
  - Concurrently (together): E.g. Online shopping/e-commerce apps often used with payment apps
  - Before or after certain app (chain off app usage): E.g. album app after camera app



Online shopping app

Used Together



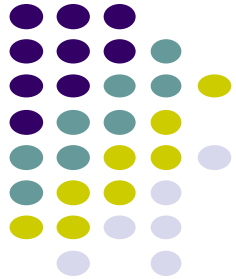
Payment app

Camera app

Gallery app

App Usage Contextual Patterns: User Profiling

Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

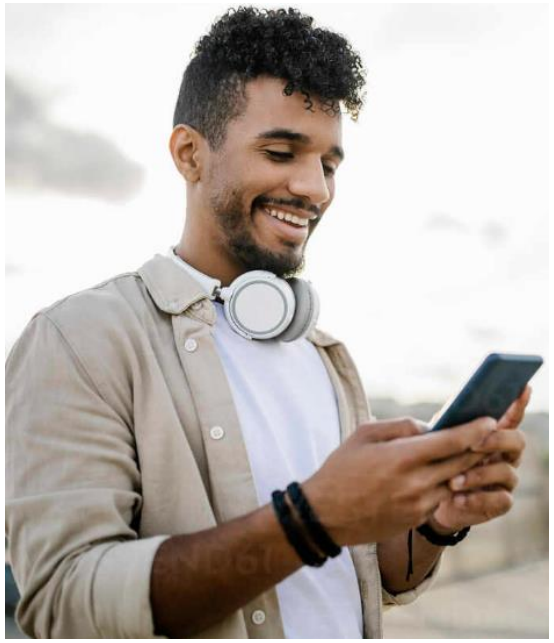


- **User Profiling:** Categorize users based on app usage to facilitate personalized recommendations and advertisements
  - **Demographics:** Gender, age, income level, occupation, nationality, etc
  - **Personality traits:** Extrovert, agreeableness, conscientiousness, openness to experiences
  - **Psychological status:** stress levels, well-being, emotion, etc
  - **Personal interests:** sports, music, cooking, reading, etc
  - **Life events:** life stage, social status

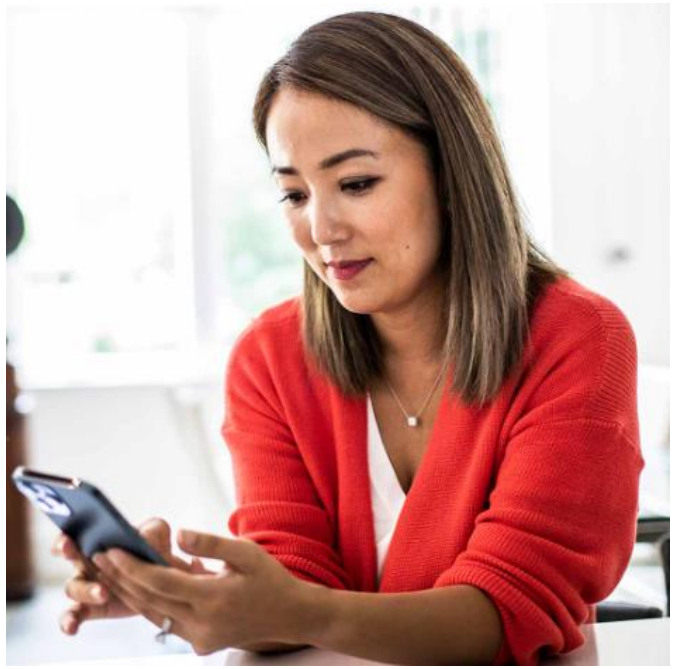
App Usage Contextual Patterns: Demographic Differences

Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

- Gender:
  - Females spent more time on communication and social apps
  - Males spent more time playing games



More time playing games



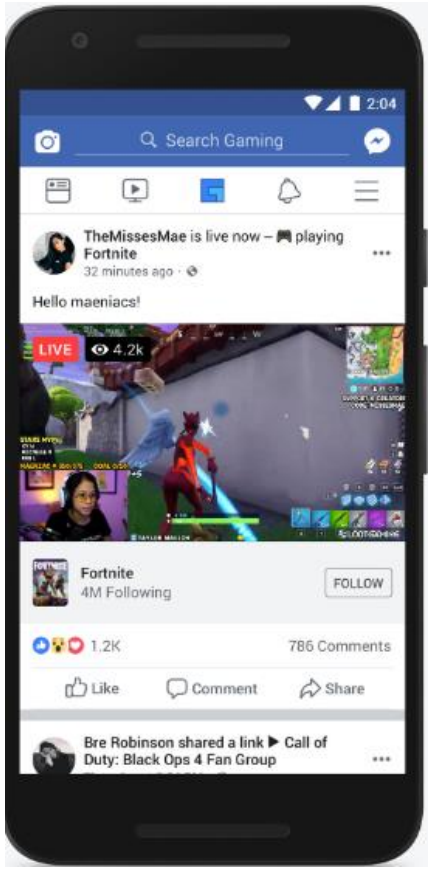
More time on communication and social apps

App Usage Contextual Patterns: Demographic Differences

Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

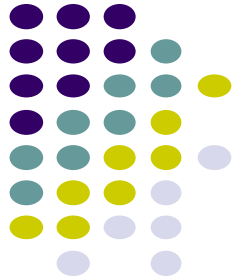
- Age:
  - Teenagers (12 to 17): more time on communication, social media and gaming apps (40 mins/day)
  - Adults (over 30): spend less time on these apps (< 10 minutes per day)

- Income level:
  - High income: shopping , finance, travel, business apps
  - Low income: gaming and video apps



App Usage Contextual Patterns: Demographic Differences

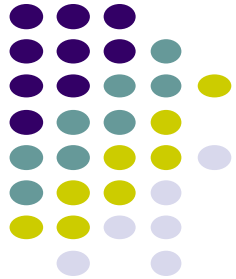
Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.



- Education level
  - PhD holders: More communication apps, fewer sports apps
- Country-related differences: Across 15 countries studied,
  - 3 clusters of countries that were similar: European, English-speaking, mixed
  - US users more likely to download medical apps
- Personality traits
  - Extraverts use more photography and video editing apps
  - More agreeable people use less health and lifestyle apps
  - Conscientous people avoid e-commerce apps

App Usage Contextual Patterns: Demographic Differences

Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

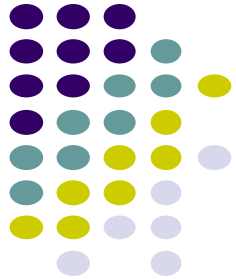


- Psychological Status
  - Lonely people or with anxiety: less incoming calls, use health apps more
  - Higher social anxiety: fewer messages, less use of camera apps
  - Late night usage linked with lower psychological well-being
  - Happy users: more usage of social media apps

- Life stage
  - When user becomes parent, travel and entertainment app usage drops
  - People in downtown areas walk more than sub-urban users

App Usage Contextual Patterns: User Profiling

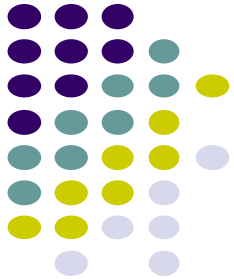
Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.



- Some work tried to predict demographics, personal interests, etc from app usage
  - **Demographics:** Gender, age, income level, occupation, nationality, etc
  - **Personality traits:** Extrovert, agreeableness, conscientiousness, openness to experiences
  - **Psychological status:** stress levels, well-being, emotion, etc
  - **Personal interests:** sports, music, cooking, reading, etc
  - **Life events:** life stage, social status

App Usage Contextual Patterns: User Profiling

Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.

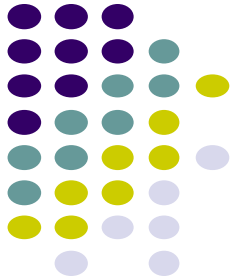


- Gender:
  - List of apps installed can predict user's gender with 75%-82% accuracy
  - Wealth can be predicted with 60% accuracy from apps used

- Psychological status:
  - Big 5 personality traits can be predicted with 86-96% accuracy
  - Graph representation of order of app usage can also predict stress levels with 54% accuracy

App Usage Contextual Patterns: Energy Drain

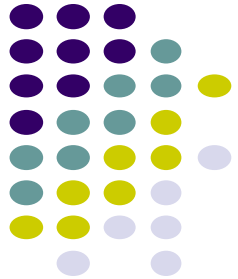
Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.



- Energy hogs:
  - Apps that utilize more energy than other apps
  - Typical hogs: Pandora radio, Skype, Live Wallpapers
- Some apps use Internet/network more, which increases energy consumption
  - Kindle: to synchronize notes and bookmarks, download books
  - Facebook: Retrieve updates
  - YouTube: Download videos
- Background apps consume a lot of energy: 16% of energy when screen is off
  - Can save energy by killing/sleep background apps when screen is off
  - But some apps prevent user from putting them to sleep

App Usage Contextual Patterns: App Traffic Patterns

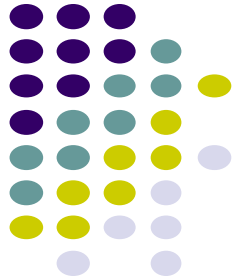
Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.



- Smartphone network traffic:
  - 73% of all network traffic in 2018
  - Predicted to rise to 89% by 2023

- Network traffic depends on app category
  - **High traffic volume:** entertainment and social media apps
  - **Low traffic:** education, weather apps

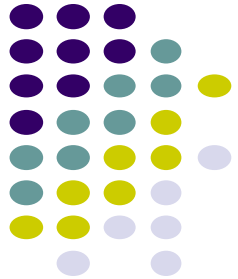
- High traffic app category based on time of day
  - Morning: music, shopping apps
  - Lunchtime: e-mail, game apps



Android Power Management

Android Power Management

https://developer.android.com/training/monitoring-device-state/doze-standby

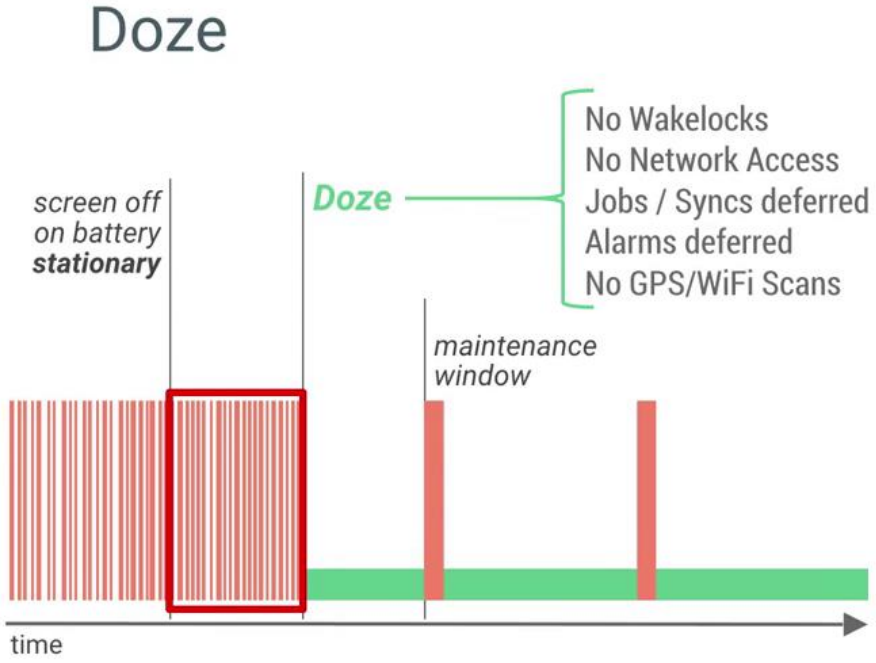


- **Power management goal:** Manage how apps behave when mobile device is running on battery power
- Android (6.0 or higher) has 2 power saving features that extend battery life
  - Doze
  - App standby

Android Power Management: Doze

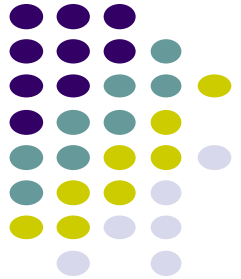
https://developer.android.com/training/monitoring-device-state/doze-standby

- Device enters Doze mode if mobile device:
  - Unplugged
  - Stationary for a while
  - Screen off
- In doze mode, system conserves battery energy by:
  - Restricting network access, WiFi scans + CPU intensive services
  - Deferring jobs, syncs and alarms
- App periodically wakes up to complete deferred jobs, syncs, alarms, network access
- User can make app exit doze state by:
  - Plugging in cord
  - Moving device, or
  - Turning on screen



Android Power Management: App Standby

https://developer.android.com/training/monitoring-device-state/doze-standby



- If app in standby mode, system defers all background network access
- System determines that app is idle (in Standby mode) when user does not touch app for a period of time, and none of the following conditions applies:
  - User explicitly launches the app
  - App has a process in foreground (activity or foreground service), or in use by another activity of foreground service
  - App generates notification seen on lock screen or notification tray
- App exits standby state when user plugs device into main power supply
- If app in Standby for several days, system allows idle apps access network about once a day

References

- Li, T., Xia, T., Wang, H., Tu, Z., Tarkoma, S., Han, Z. and Hui, P., 2022. Smartphone app usage analysis: Datasets, methods, and applications. *IEEE Communications Surveys & Tutorials*, *24*(2), pp.937-966.