CS 528 Mobile and Ubiquitous Computing
Lecture 12: Mobile Measurements and Wireless Networks

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Mobile Measurements: Android Users in China

Introduction

- Understanding user behaviors while using mobile apps is critical. Why?
  - App stores can build better recommender systems
  - Developers can better understand why users like certain apps
- This paper presents results of a comprehensive measurement study to investigate smartphone user patterns
- Sample questions addressed:
  - Characterize app popularity among millions of users?
  - Understand how mobile users choose and manage apps?
  - Type and amount of network traffic generated by various apps
  - Investigate economic factors affect app selection and network behavior?

Dataset

- Gathered from Wandoujia, leading Android App Store in China

- Wandoujia:
    - Over 250 million users as of 2015
    - All apps are free

- 1 month of data gathering
    - Over 260,172 unique apps in dataset
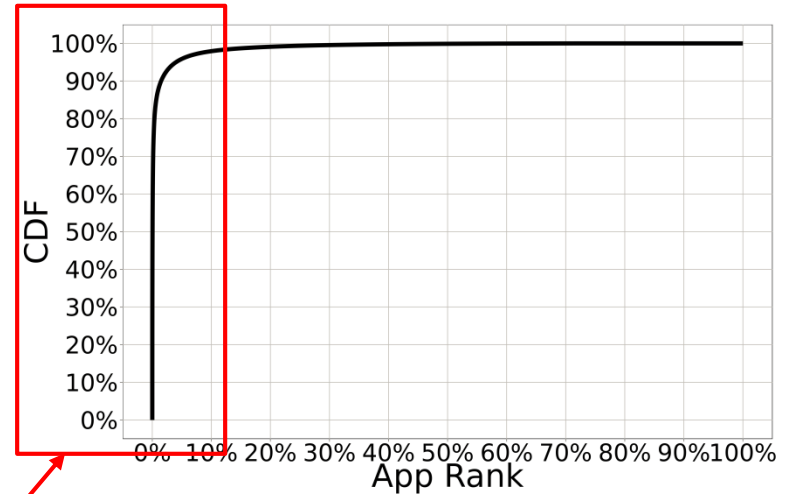   - Over 8 million unique users

App Popularity Metrics

- Number of downloads of the app

- Number of unique devices that download the app;

- Total data traffic generated by the app;

- Total access time users spend interacting with the app.

App Popularity: Downloads & Unique Subscribers
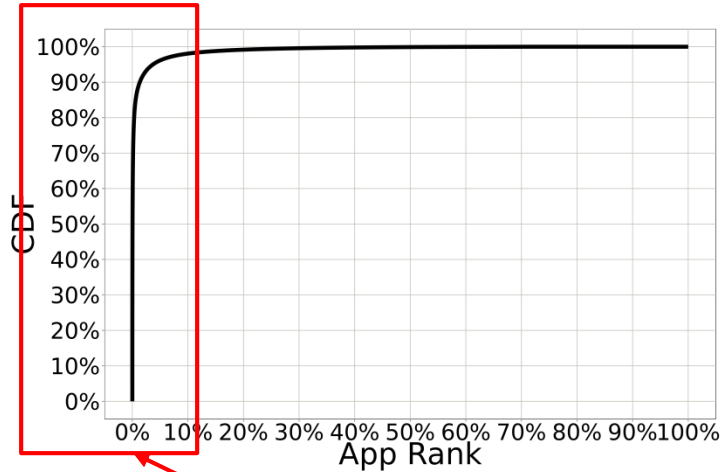
Percentage of Downloads against App Rank

Percentage of Unique Subscribers against App Rank

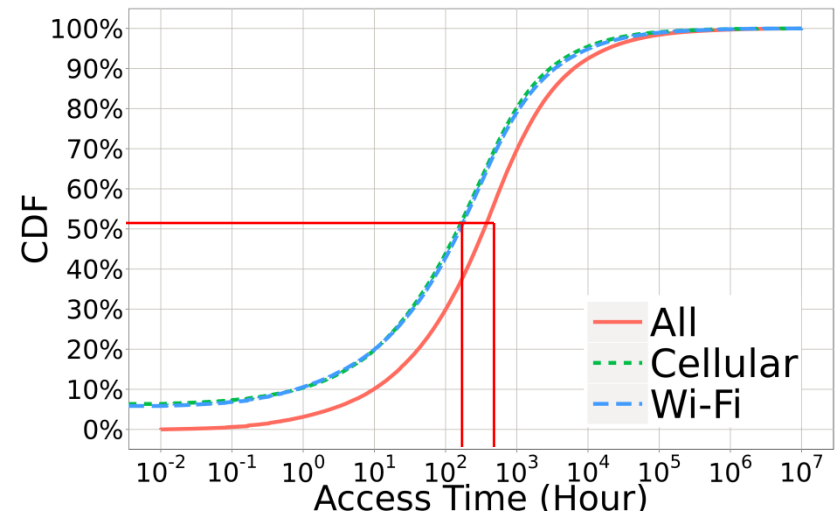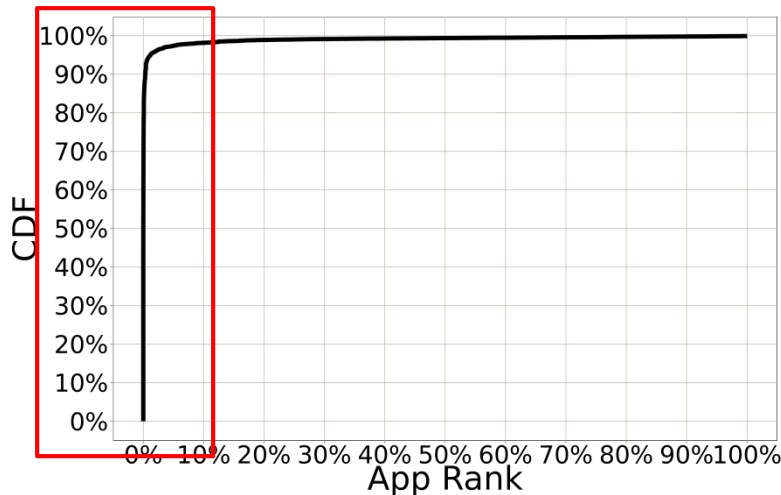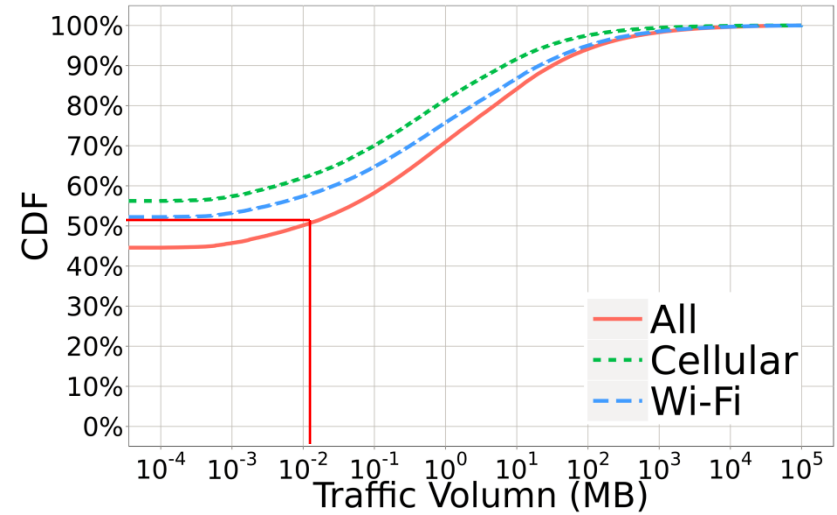Top 10% of apps get over 99% of the downloads and Unique subscribers

App Popularity: Network Traffic

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

97% apps consume < 100 MB traffic in 1 month
95% of apps are used less than 100 hours/mo
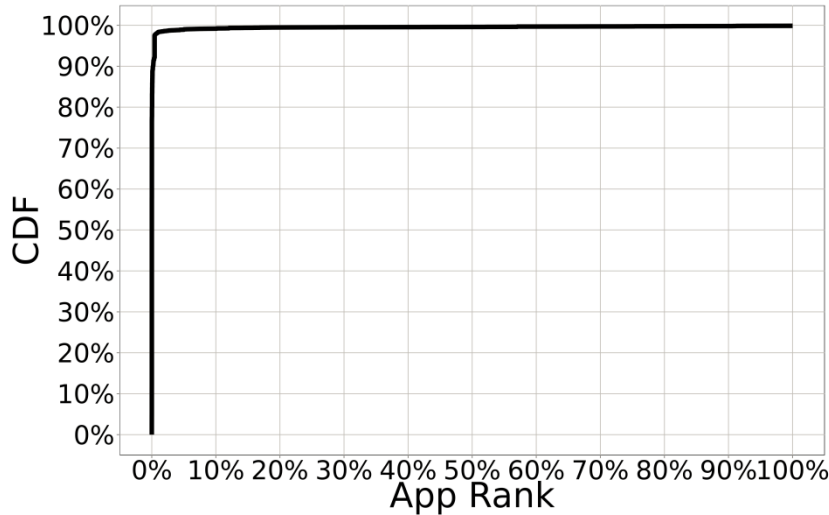
App Management & Installation Patterns

- About 32% of app downloading and updating activities performed between 7:00 pm to 11:00 pm (at night)
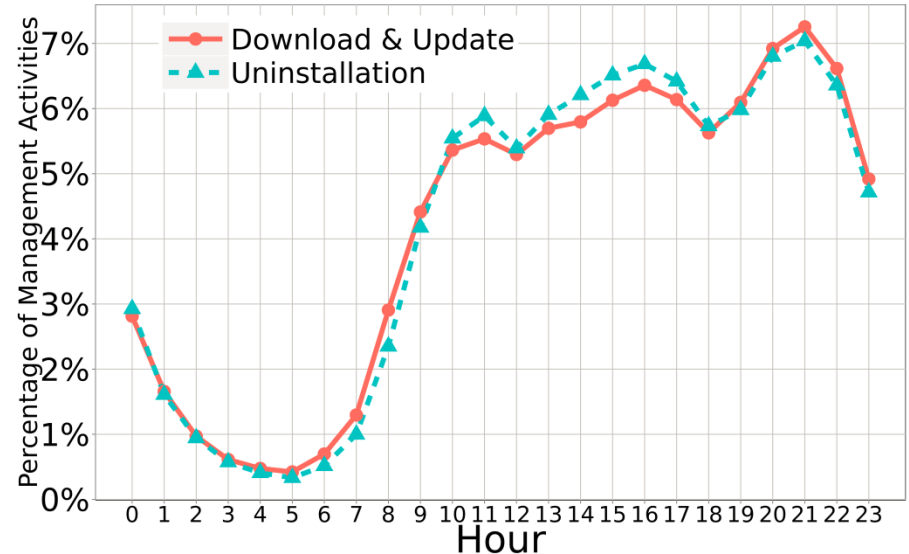
App Co-Occurrence of App Categories

- Gives sense of apps users like to use together
- E.g. Many users like to share video = high co-occurrence of video + communication apps
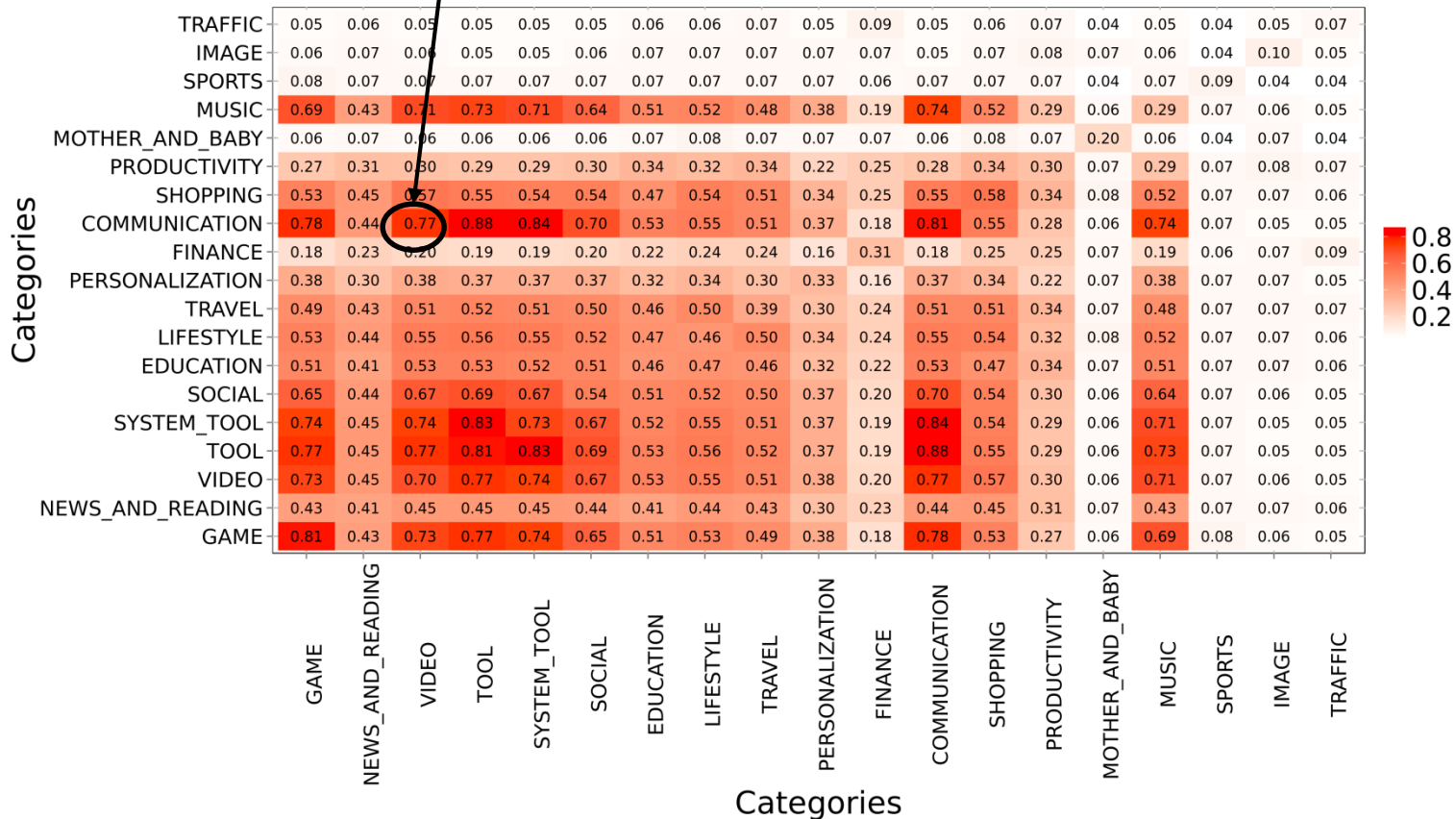
App Uninstallation Patterns

- **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
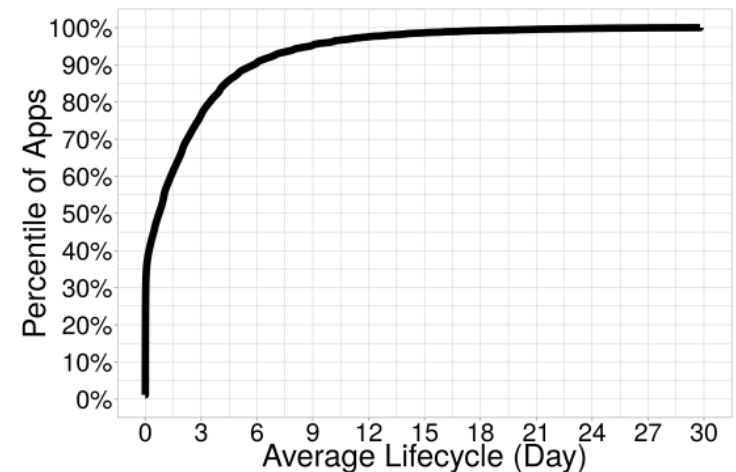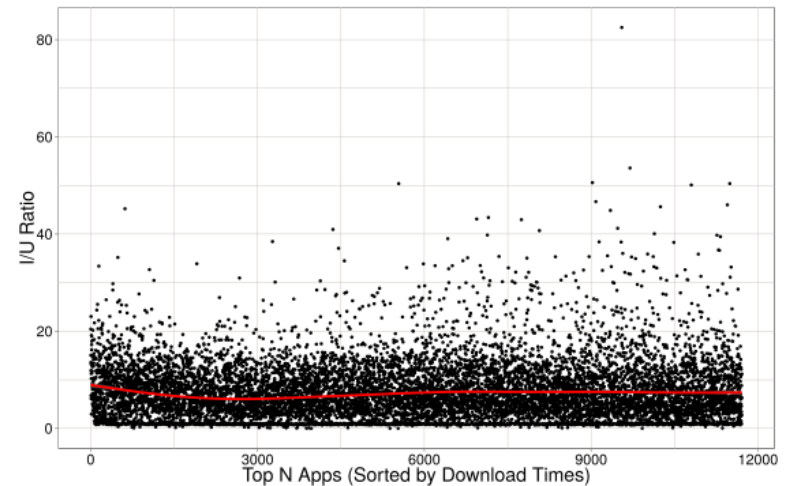
Data Traffic Patterns

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

Table 1: Chosen Top Apps by Category.

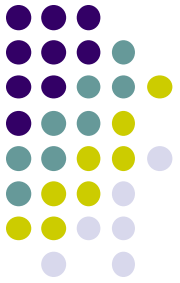| App Category	Apps	Users (10^6 devices)	Downloads (10^6 times)	Traffic (GB)	Access-Time (10^7 hours)	C-Traffic	C-Time	W-Traffic	W-Time
GAME	1,227	3.87	15.15	13,669.71	0.38	2.98%	5.19%	0.76%	6.39%
NEWS_AND_READING	274	1.17	1.97	13,143.17	0.23	3.11%	2.91%	0.72%	3.95%
VIDEO	238	2.86	6.52	1,196,978.79	0.38	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. 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.

Device Model Clustering

- 96% device models have less than 500 users
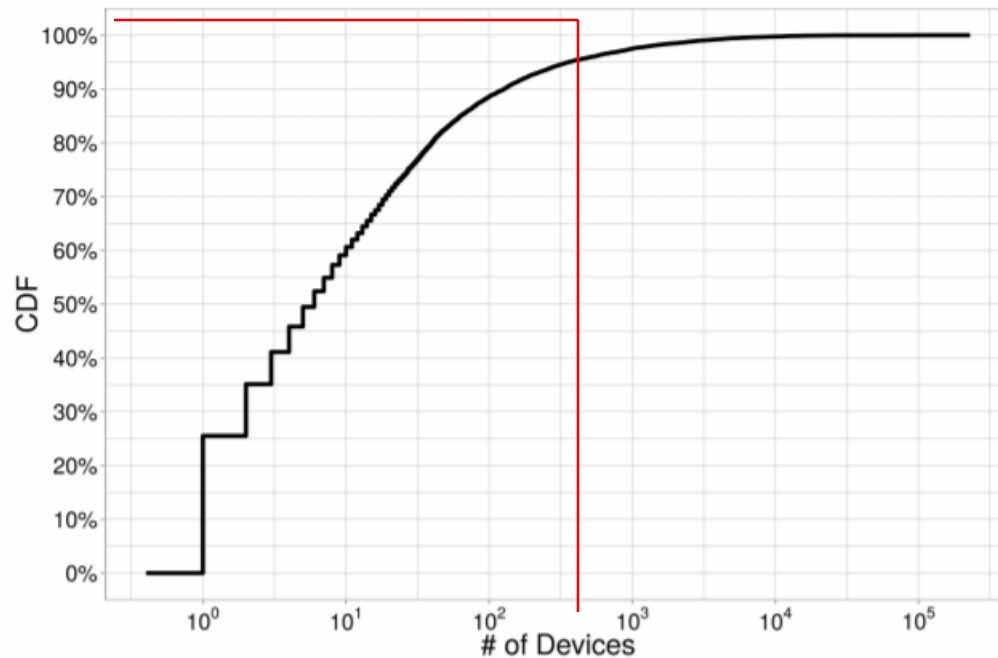- Device model refers to e.g. Moto G5, Samsung galaxy 6, etc

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 who pre-install apps (bloatware)
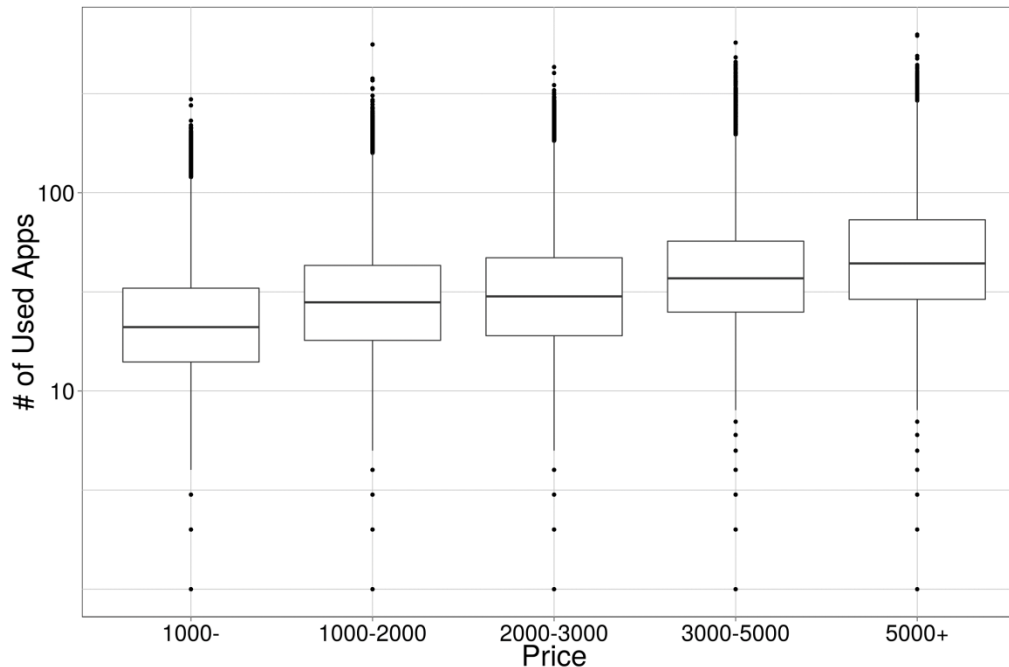
Network Activity & App Preference Among Device Groups

- Wi-Fi usage correlated with device model prices
  - i.e. higher priced devices consume more Wi-Fi traffic

Figure 12: Network Activity Distribution among User Groups

- Also, different groups of devices (based on price) had different app preferences (e.g. browser, eBook, etc)

Study Limitations

Limitations:

- Dataset was from 1 app marketplace in China
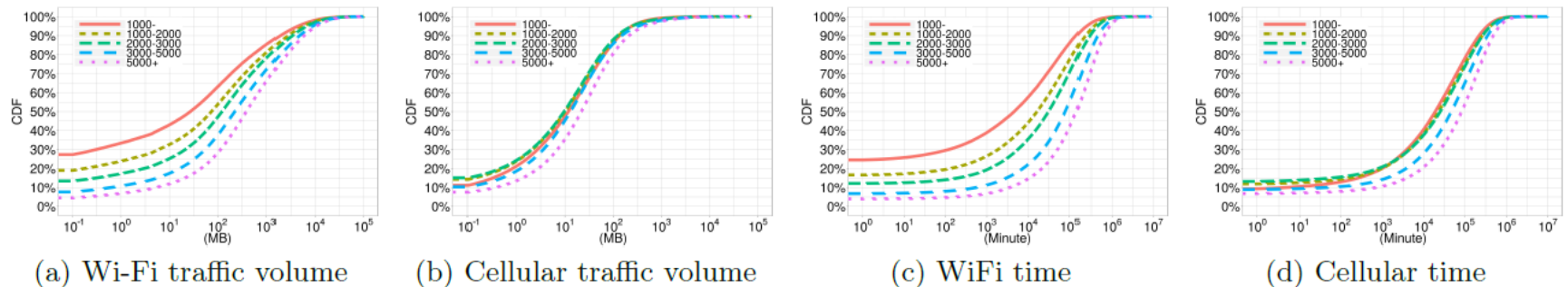- Users are mostly Chinese. Other regions may be different
- Study and analysis was on 1 month of usage data

Measurements: Angry Birds

Motivation

Bohmer, M., Hecht, B., Schoning, J., Kruger, A., & Bauer, G. Falling Asleep with Angry Birds, Facebook and Kindle – A Large Scale Study on Mobile Application Usage. MobileHCI 2011

- Older study, but answered important questions, insightful
  - How long does each interaction with an app last?
    - Does this vary by application category?
      - If so, which categories inspire the longest interactions with their users?
  - How does the user's context (e.g. location, time) affect her app choices?
  - Does the opening of one application predict the opening of another?
  - In such chains, what type of app is opened first?

Methodology

- AppSensor collected app usage statistics as "events"
- App was advertised on app market as recommendation service
  - Unclear whether users were aware data was being used for studies
- Events recorded
  - Installing apps
  - Updating apps
  - Uninstalling apps
  - Opening/Closing apps
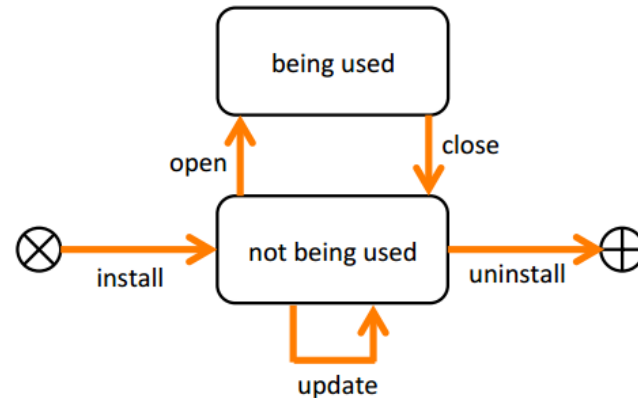
Demographics of Study Participants

- 4125 users between August 2010 and January 2011
  - Mostly in the US & Europe
- 22,626 different app usage events collected
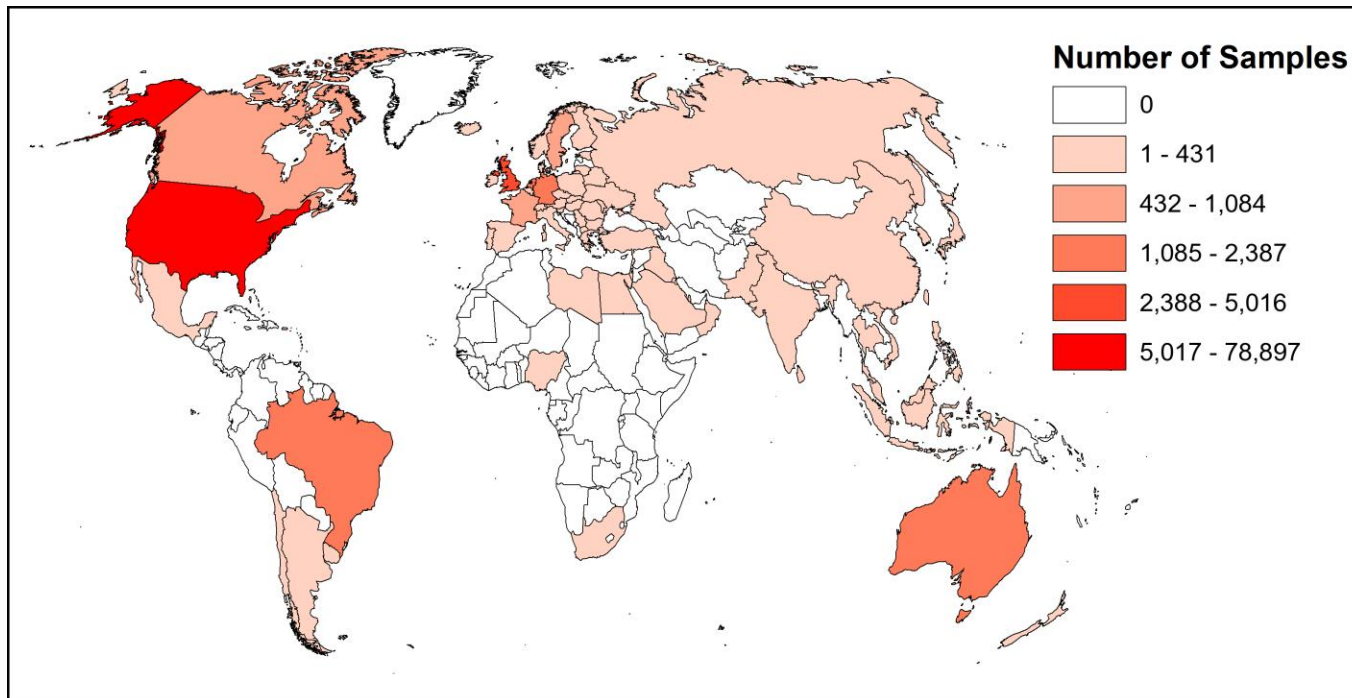
Results: Average App Usage Time

- Users used their phones an average of 59.23 minutes/day

- Average app session: 71.56 secs

- App usage time also varied based on category

- These numbers were in 2011

Category	Apps	Avg. usage	Examplary Apps
unknown	4,823	36.37 sec	-
Finance	307	37.01 sec	Mint.com Personal Finance, Bank of America, Google Finance, iStockManager
Travel	782	44.72 sec	Google Maps, Yelp, Waze
Communication	881	46.92 sec	Google Mail, Handcent SMS, K-9 Mail
Productivity	1,062	61.49 sec	Calendar, Evernote, GTasks
Shopping	326	61.71 sec	Market, Barcode Scanner, Craigslist
Social	538	62.69 sec	Facebook for Android, Twitter, TweetDeck
Sports	385	65.98 sec	Yahoo! Fantasy Football '10, ESPN ScoreCenter, NFL Mobile
News	784	68.11 sec	NewsRob, reddit is fun, BBC News
Settings	1	68.71 sec	Default Settings App
Browser	10	74.01 sec	Default Browser, Skyfire Browser, Dolphin Browser
Entertainment	84	76.90 sec	IMDb Movies & TV, TV Guide Mobile, PhotoFunia
Multimedia	130	82.79 sec	Pandora Radio, Music, Camera
Comics	3,242	91.33 sec	DailyStrip, XkcdViewer, Dilbert Mobile
Games	2,828	114.25 sec	Angry Birds, Wordfeud FREE, Solitaire
Health	424	153.80 sec	CardioTrainer, Sleep Bot Tracker Log, Baby ESP
Lifestyle	956	167.77 sec	DailyHoroscope, Gentle Alarm, Epicurious Recipe
Reference	764	176.28 sec	Kindle for Android, Aldiko Book Reader, Audible
Tools	3,004	206.26 sec	AppBrain App Market, Apps Organizer, Google Goggles
Themes	1,061	258.28 sec	Zune Home, Fingerprint Screensaver, HomeChange
Libraries & Demos	240	274.23 sec	Google Services Framework, default Updater, Motorola Updater, Bubbles Demo, Ride Logger Demo, ES Task Manager

Table 2. Number of apps investigated in our study and average usage time of every categories' apps from opening to closing.

App Launches: Times and Session Lengths

- App launches:
  - Lowest at 5am
  - Increased linearly through the day
  - Peaked at 6pm
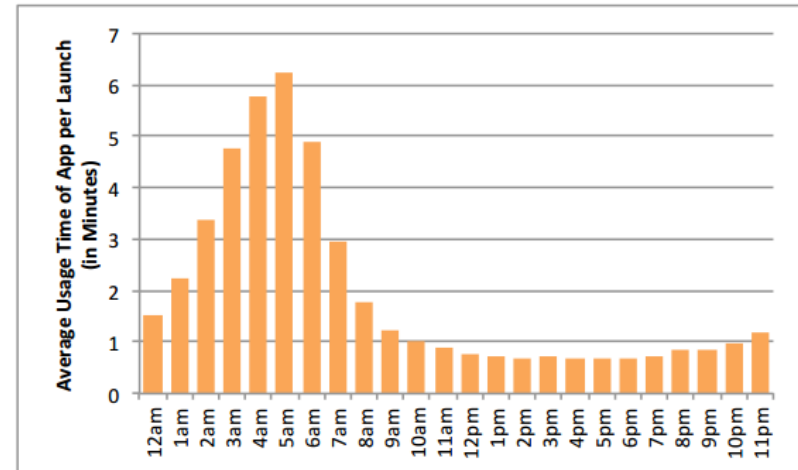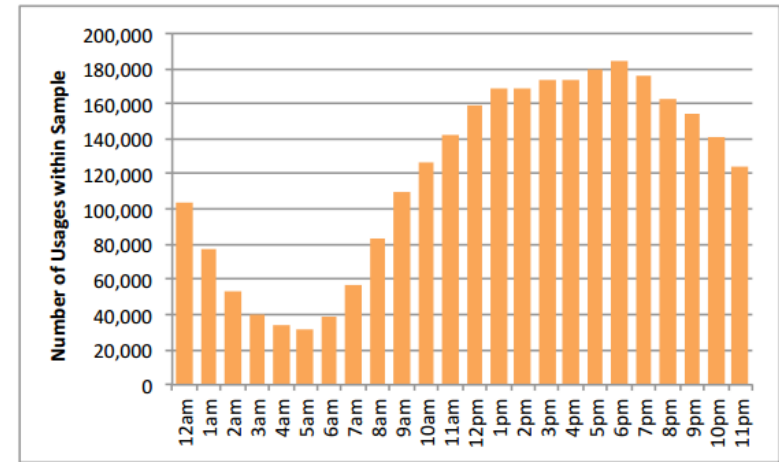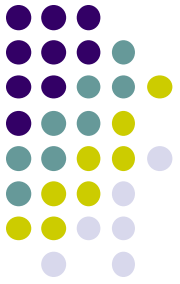
- App session length: Longest sessions at 5am!

Figure 4. Daily average usage duration of opened apps per launch in minutes.

App Usage by hour of the day

Overnight usage, mostly browsing, multimedia, comics, games
- Fewer productivity apps (Calendar, Google Tasks, etc)

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	% of Total Launches	Users	Apps
Browser	7.9%	7.7%	7.8%	7.6%	7.3%	7.4%	7.0%	7.9%	8.1%	8.0%	7.7%	7.3%	7.0%	6.9%	6.8%	6.4%	6.6%	6.6%	6.4%	6.6%	7.0%	7.4%	7.5%	7.4%	6.83%	2,398	9
Comics	4.5%	5.2%	5.4%	5.8%	5.8%	5.6%	5.5%	5.2%	5.4%	5.1%	4.7%	4.3%	4.3%	4.2%	4.2%	4.3%	4.4%	4.0%	4.4%	4.2%	4.1%	4.1%	4.1%	4.4%	4.31%	2,151	1,810
Communication	44.9%	41.1%	38.3%	35.4%	31.6%	31.8%	32.7%	34.7%	39.4%	44.8%	49.0%	52.6%	54.8%	55.2%	55.2%	56.1%	55.7%	56.8%	57.1%	56.1%	54.8%	53.3%	52.0%	49.0%	49.50%	2,769	550
Entertainment	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.02%	126	43
Finance	0.2%	0.3%	0.3%	0.2%	0.1%	0.1%	0.1%	0.2%	0.3%	0.3%	0.4%	0.5%	0.3%	0.3%	0.4%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.25%	604	164
Games	3.2%	3.0%	3.0%	2.7%	2.5%	2.3%	2.2%	1.7%	1.9%	1.9%	2.0%	2.1%	2.2%	2.2%	2.2%	2.3%	2.3%	2.2%	2.2%	2.4%	2.7%	3.0%	3.0%	3.2%	2.30%	1,716	1,702
Health	0.3%	0.4%	0.4%	0.4%	0.6%	0.6%	0.7%	0.6%	0.4%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.2%	0.3%	0.2%	0.3%	0.26%	540	227
Libraries & Demo	0.4%	0.5%	0.6%	0.7%	0.9%	0.8%	0.7%	0.6%	0.5%	0.4%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%	0.3%	0.30%	1,267	117
Lifestyle	0.8%	0.9%	1.0%	1.4%	1.3%	1.5%	1.4%	1.4%	1.1%	0.9%	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	0.6%	0.5%	0.3%	0.4%	0.4%	0.5%	0.5%	0.5%	0.60%	2,132	451
Multimedia	2.1%	2.1%	2.4%	2.4%	2.7%	2.4%	1.8%	1.8%	1.9%	1.7%	1.8%	2.0%	2.0%	2.0%	2.2%	2.1%	2.2%	2.4%	2.3%	2.3%	2.2%	2.1%	1.9%	2.0%	2.03%	1,713	76
News	2.6%	2.5%	2.6%	2.5%	2.5%	2.7%	3.3%	3.7%	4.1%	3.6%	3.0%	2.6%	2.5%	2.7%	2.5%	2.4%	2.2%	2.1%	2.3%	2.2%	2.3%	2.2%	2.3%	2.3%	2.46%	1,777	440
Productivity	3.6%	5.0%	5.0%	5.8%	6.3%	6.5%	6.0%	5.4%	4.8%	5.1%	4.9%	4.3%	4.2%	4.0%	4.0%	3.7%	3.4%	3.4%	3.0%	3.1%	3.1%	3.0%	2.9%	3.2%	3.76%	2,190	648
Reference	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.7%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.3%	0.4%	0.4%	0.4%	0.5%	0.5%	0.5%	0.6%	0.47%	903	346
Settings	1.3%	1.6%	1.5%	1.3%	1.6%	1.2%	1.2%	1.1%	1.3%	1.4%	1.4%	1.4%	1.2%	1.3%	1.2%	1.2%	1.3%	1.1%	1.1%	1.2%	1.2%	1.3%	1.3%	1.4%	1.23%	2,178	1
Shopping	3.9%	4.5%	3.7%	3.4%	3.2%	3.2%	3.1%	3.0%	3.1%	3.3%	3.2%	3.2%	3.2%	2.8%	2.9%	2.9%	2.7%	2.7%	2.7%	2.7%	2.8%	3.1%	3.6%	3.5%	2.96%	2,556	198
Social	5.7%	5.0%	4.9%	4.3%	4.2%	4.0%	4.4%	5.1%	5.3%	5.4%	5.2%	5.0%	4.7%	4.8%	4.9%	4.5%	4.5%	4.6%	4.6%	4.9%	5.2%	5.4%	5.8%	5.7%	4.77%	1,902	342
Sports	0.5%	0.3%	0.3%	0.2%	0.3%	0.3%	0.2%	0.3%	0.3%	0.3%	0.3%	0.4%	0.4%	0.6%	0.7%	0.8%	0.9%	0.8%	0.6%	0.6%	0.7%	0.8%	0.7%	0.7%	0.56%	571	215
Themes	0.2%	0.1%	0.2%	0.3%	0.4%	0.4%	0.4%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.2%	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.1%	0.14%	249	231
Tools	10.9%	12.2%	14.6%	17.6%	20.3%	21.5%	21.4%	18.6%	14.7%	10.4%	8.4%	6.8%	6.1%	5.9%	5.9%	6.0%	6.1%	5.8%	6.0%	6.3%	6.8%	7.4%	9.1%		7.89%	2,512	1,688
Travel	1.4%	1.6%	2.1%	2.2%	2.4%	2.6%	2.2%	1.9%	2.0%	2.1%	2.0%	1.8%	1.9%	1.9%	1.9%	1.8%	2.0%	1.9%	2.2%	2.2%	1.9%	1.7%	1.6%	1.4%	1.86%	1,752	407
Unknown	4.7%	5.3%	5.1%	5.0%	5.3%	4.4%	5.0%	5.9%	4.6%	4.4%	4.1%	3.8%	3.5%	3.8%	3.7%	3.7%	4.0%	3.6%	3.7%	3.7%	3.7%	3.9%	4.1%	4.5%	3.88%	2,284	1,796
Total Launches per Hour	103,604	77,053	53,633	40,332	33,438	30,949	38,161	56,895	83,488	109,550	127,069	142,642	158,876	168,082	169,018	172,935	173,963	179,801	184,012	176,050	163,080	153,835	141,303	123,639			

Figure 5. Hourly relative app usage by category in terms of launches. Each cell value refers to the percentage of app launches done by our users within each hour for each category. Colors are normalized by row, with green indicating each category's maximum percentage of application time, and white indicating each category's minimum. For example, games reach their peak in the evening (green) and trough in the morning (white).

App Chains: Transitioning between apps

- Found interesting app chains (used one after the other):
  - E.g. Grocery app -> GrubHub Food Delivery -> Recipe App (Hungry?)
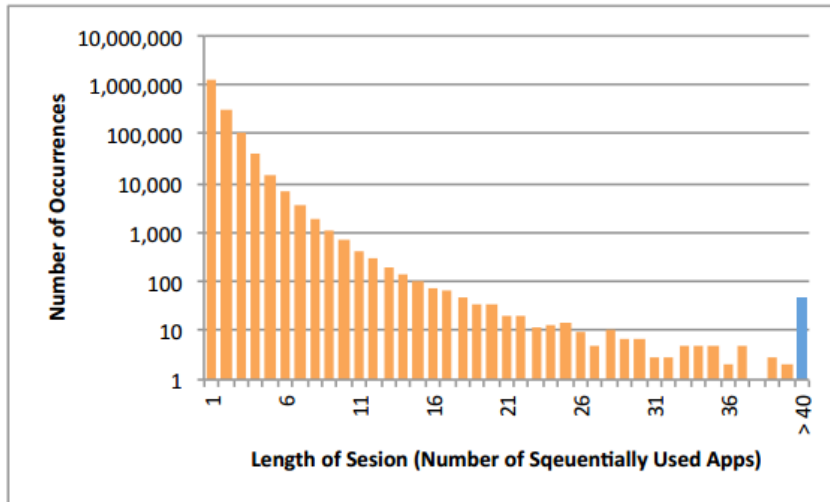- Most sessions (68%) had only 1 app in chain

Figure 6. Number of apps used in a session. We aggregated sessions longer than 40 apps since the graph flattens out and scarcity increases. Maximum length is 237.
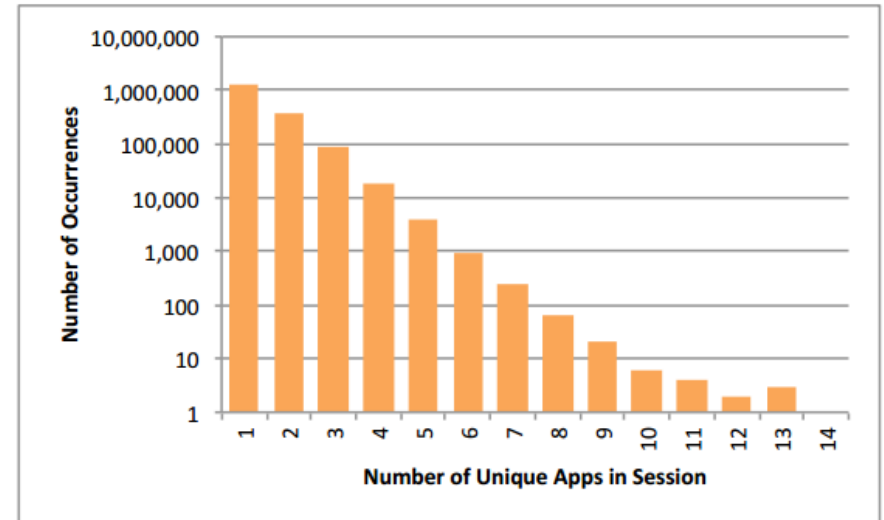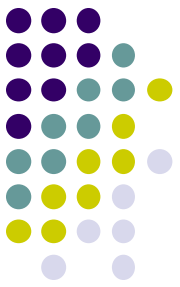

Figure 7. Occurrences of sessions according to number of unique apps used within a session.

Chains of App Usage

- Most app chains (49%) started with communications apps
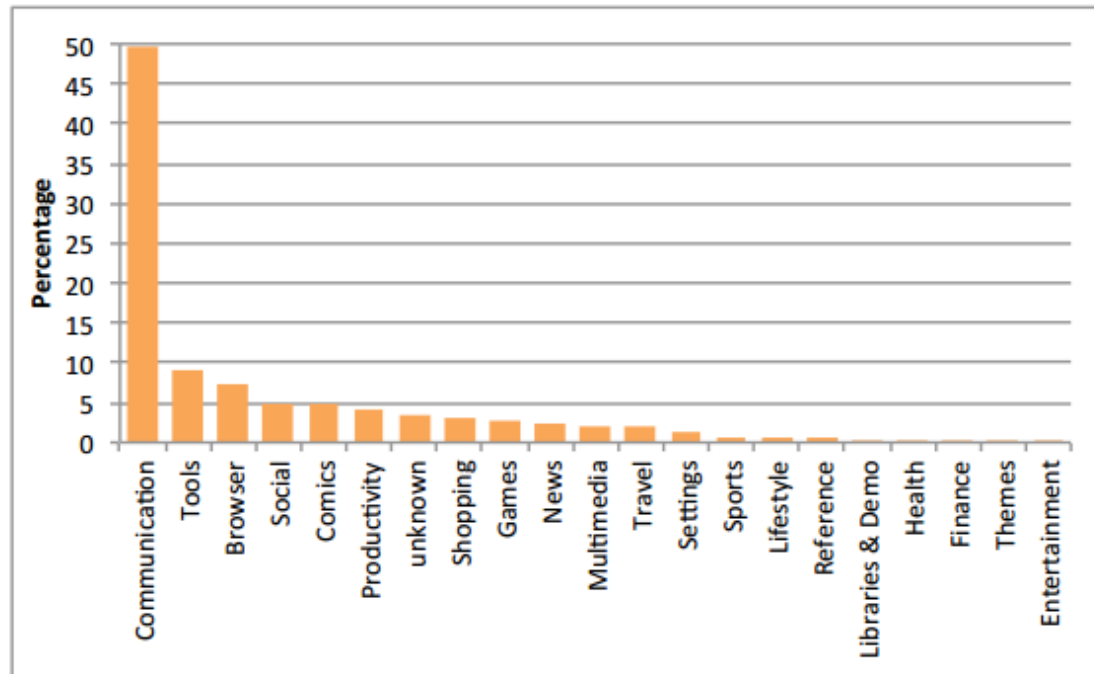 - SMS (15%), Browser (6%), phone (9%), mail (6%)

Figure 8. Categories of first used app within a session.

Application Usage by Location

When In an airport, users were:

- 2.78 times more likely to be using a browser
  - Maybe not enough native travel-related apps in 2011

When moving > 25 kph (e.g. driving in a car), users were:

- 2.26 times more likely to be using multimedia app (e.g. listening to music)

General Conclusions

- Mobile phones are still used mostly for communication (phone calls, SMS, instant messaging VoIP, etc)

- Overnight users use non-communication apps

- Users spend
  - \> 1 hour/day using apps
  - < 72 seconds with an app every time they launch it

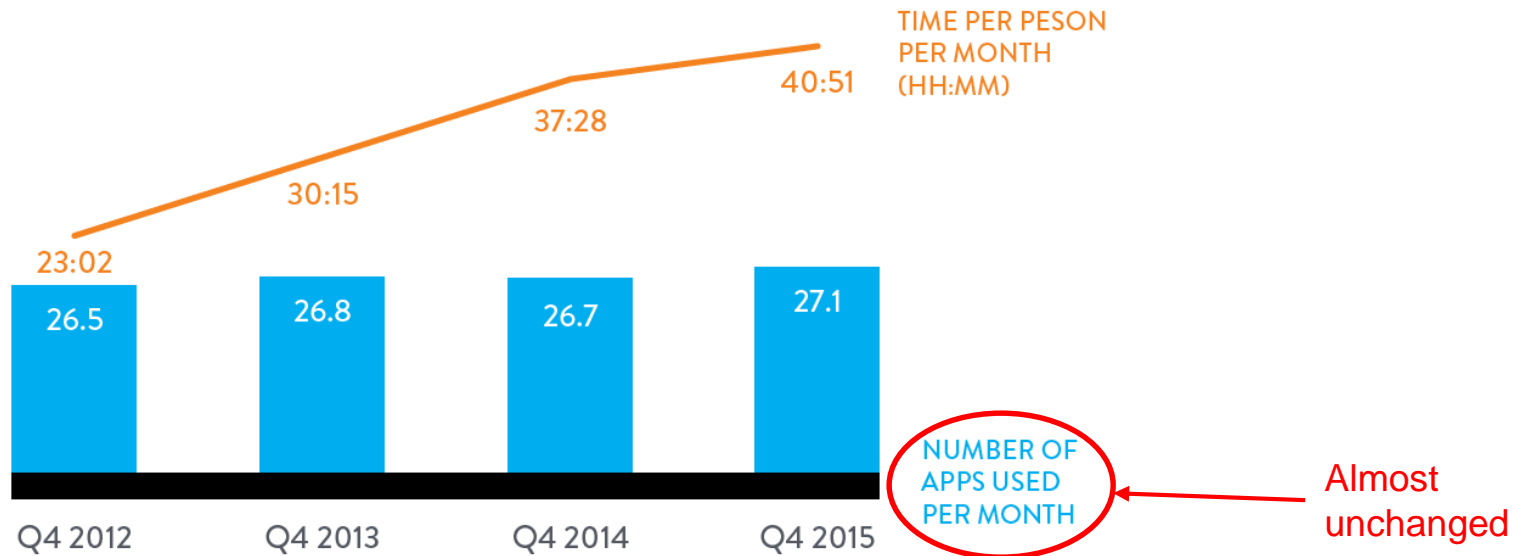- Users frequently switching between apps vs spending long time in a single app

Amount of Time Spent in Apps Increasing

THE AMOUNT OF TIME SPENT ON APPS CONTINUES TO INCREASE

Average number of apps used and time per person per month

TIME PER PESON PER MONTH (HH:MM)

40:51

37:28

30:15

23:02

26.5 — Q4 2012
26.8 — Q4 2013
26.7 — Q4 2014
27.1 — Q4 2015

NUMBER OF APPS USED PER MONTH

Almost unchanged

Read as: In Q4 2015, smartphone users accessed 27.1 apps per month on average, and spent 40 hours and 51 minutes per month on apps.
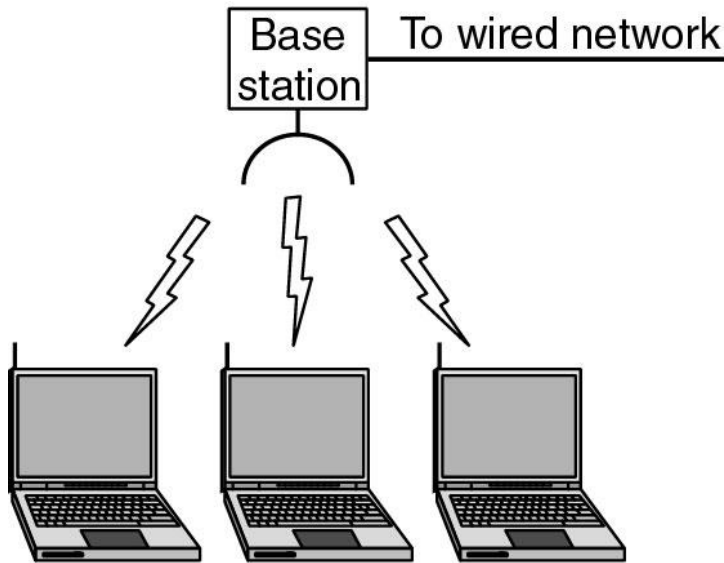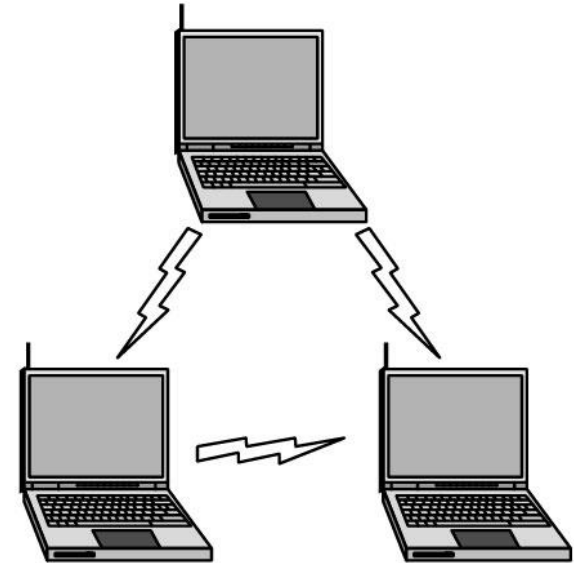Source: Nielsen Electronic Mobile Measurement, U.S. Android and iPhone, 18+

Wireless Networks
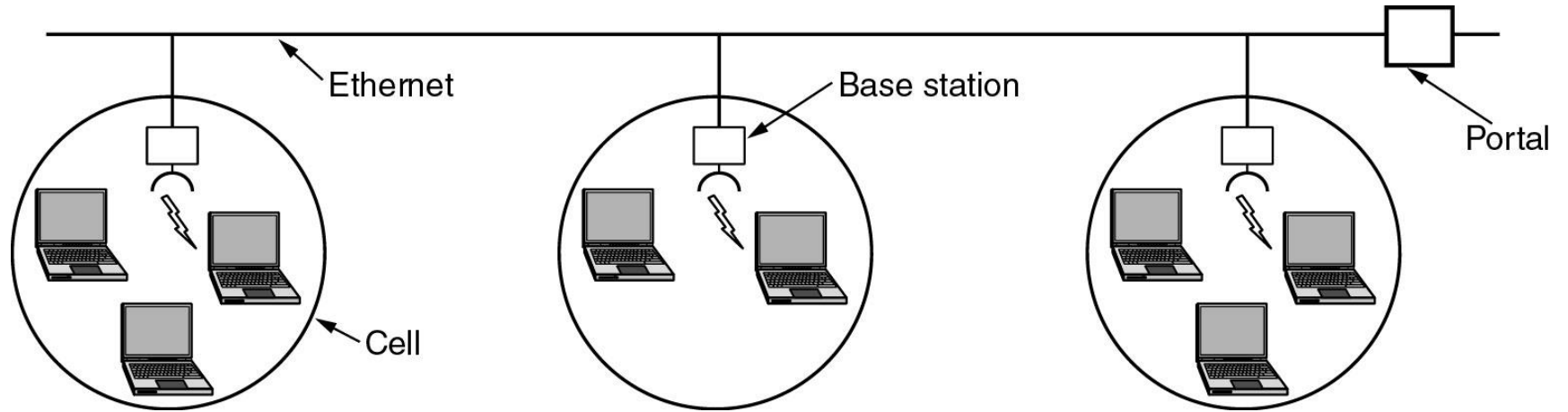
IEEE 802.11 Wireless LAN Types

(a)

(b)

a) Wireless networking with a base station.
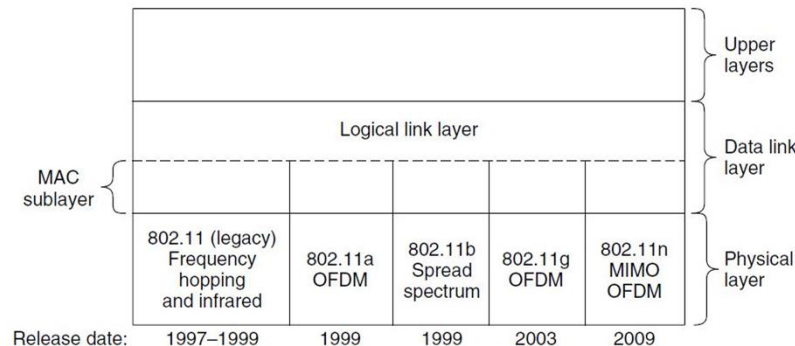b) Ad hoc networking.

Wireless LANs

- *Infrastructure:* A multicell 802.11 network

Wireless LANs: Physical Layer

- Transmission in 0.9, 2.4, 3.6, 5, and 60 GHz frequency bands
- Also called the Industrial, Scientific and Medical (ISM) bands
  - Shared frequencies with unlicensed devices (e.g. garage door openers)
  - Physical layer, MAC protocol has to avoid collisions with other devices
- Different physical layers supported by each standard (a, b, g, etc):
  - Frequency hopping
  - OFDM
  - Spread spectrum
  - MIMO-OFDM
- Much of 802.11 speedup is due to advances in physical layer encoding

						Upper layers
	Logical link layer					Data link layer
MAC sublayer						
	802.11 (legacy) Frequency hopping and infrared	802.11a OFDM	802.11b Spread spectrum	802.11g OFDM	802.11n MIMO OFDM	Physical layer
Release date:	1997–1999	1999	1999	2003	2009	

Part of the 802.11 protocol stack.

Bluetooth: Background

- **Goal:** Connect short range, low-power wireless devices (phones, headsets, printers, keyboards, mice, smartwatches)

- Basic idea: Replace wires for short range connections. Versions:

- 1.0: 1999

- 2.0: 2004 (higher data rate)

- 3.0: 2009 (higher data rate)

- 4.0: 2011 (Low power)

- 5.0: Connects IoT devices

- **Pairing:** Bluetooth allows devices find and connect to each other

Bluetooth Architecture: PicoNets

- Bluetooth Devices organized into piconets, 10 meters max range
- Each device can be either a master or slave
- 1 Master, many (up to 7) slaves per piconet
- 2 piconets can be connected to form a scatternet
- **Power savings:** Nodes can also switch to "parked mode", only respond to messages from the master

Piconet 1   Piconet 2

Active slave

Bridge slave

Parked slave
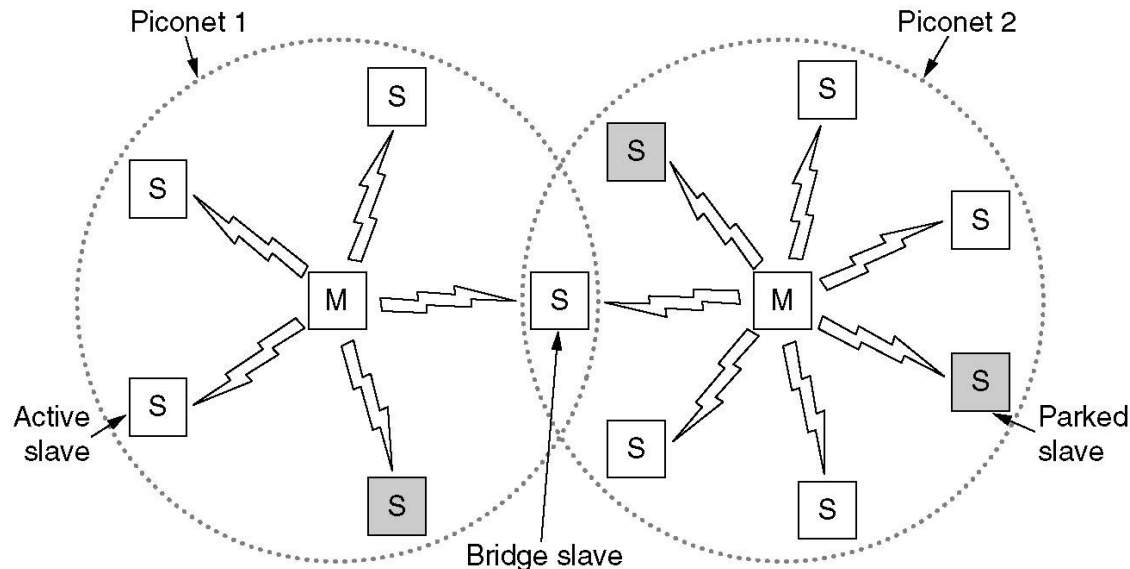
Cellular Networks
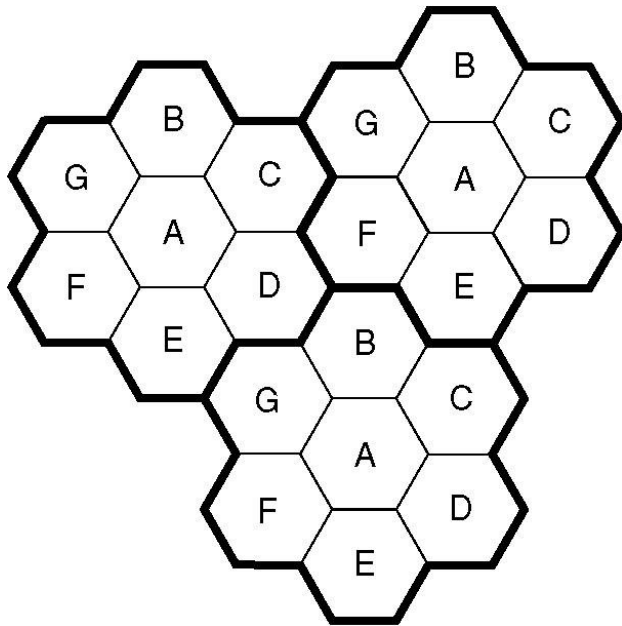
(a)
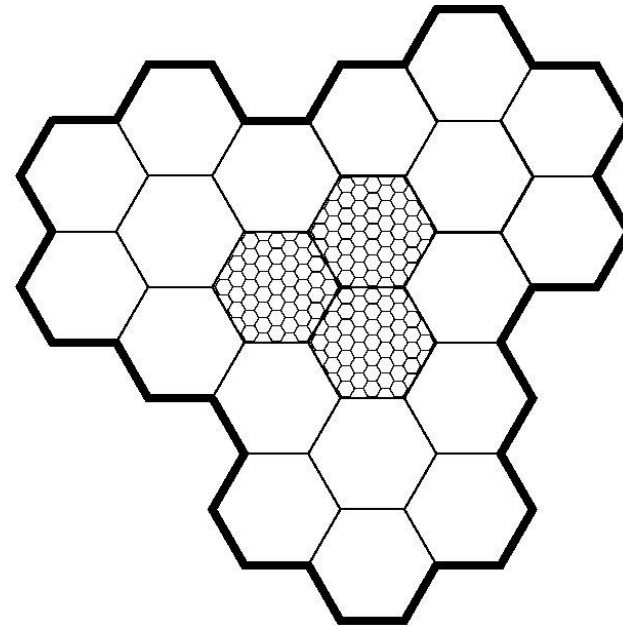
(b)

a) Frequencies are not reused in adjacent cells.

b) To add more users, smaller cells can be used.

● Now 4G LTE speed: 50 Mbps, 5G coming: 1-10GB expected