Diversity in Locked and Unlocked Mobile Device Usage

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Abstract
We analyze locked and unlocked mobile device usage of 1 960 Android smartphones. Based on approximately 10 TB of mobile device data logs collected by the Device Analyzer project, we derive 6.9 million usage sessions using a screen power state machine based approach. From these session we examine the number of interactions per day, the average interaction duration as well as the total daily device usage time. Findings indicate that on average users interact with their devices 117 minutes a day, separated over 57 interactions – while unlocking their device only 43% of the time (e. g. to check for notifications).

Author Keywords
Mobile device usage, device unlocking, session duration

ACM Classification Keywords
K.6.2 [Installation Management]: Performance and usage measurement; D.4.6 [Security and Protection]: Authentication.

Introduction
With the number of smart mobile devices like smartphones and tablets being expected to exceed the world's population by the end of 2014 [1], understanding how users interact with their devices becomes increasingly important for many research areas. Consequently, a

number of handset-based studies have been conducted recently to investigate metrics of mobile device interaction, such as frequency and duration [2, 3, 5, 8]. A common assumption in most such studies is that interacting with mobile devices requires unlocking them first (in case a locking mechanism is used, e. g. entering a PIN or drawing a pattern). However, even without unlocking such devices allow limited interaction, such as checking for new messages. As by today, little is known about how users interact with their devices when not unlocking them – although understanding device usage in relation to unlocking habits impacts for example the development of new authentication methods [7], energy saving strategies [3], and innovative applications [6]. In this work we therefore analyze mobile device usage in both locked and unlocked state based on usage data collected from a total of 17 103 Android mobile devices by the Device Analyzer project [8]. We throughly filter devices suitable for analysis, then determine the distribution of locked, unlocked as well as overall device usage with: *a)* number of interactions per day, *b)* usage session duration, and *c)* usage time per day. At first we give an overview of mobile device usage studies. Next we describe the data used within our analysis, how device usage sessions can be derived from raw system events and the major challenges in doing so. We then state the statistical analysis in detail and elucidate our results in comparison to previous studies.

Related Work

Different aspects of mobile device usage have been studied previously: Falaki et al. [2] analyzed user interaction on 255 Android and Windows Mobile smartphones. They found immense diversity in smartphone usage, e.g. the number of sessions per day varying from 10 to 200 on average. Oliver [3] surveyed usage traces recorded on 17 300 BlackBerry devices, drawing by far the largest sample of smartphone users. They observed an average interaction time of 101 minutes per day with 80% of the usage sessions lasting less than 90 seconds, but did not distinguish between locked and unlocked usage. Oulasvirta et al. [4] explain this observation with the emergence of *checking habits*, repetitive access of dynamic content providing an informational "reward" such as email or Facebook. Soikkeli et al. [5] derived context locations from Wifi scan data and GSM cell IDs of 140 smartphones, concluding that sessions in home-context are on average 37% longer while 36% less frequent than in office-context. Wagner et al. [8], who originally collected the Device Analyzer dataset we use within this paper, observed that a number of interactions happen without unlocking the device. Work closely related to our research has recently been published by Truong et al. [6]. They conducted a two-week study with 10 participants to analyze how often users unlock their devices to motivate *Slide to X*, an alternative lock screen utilizing microtasks. Their work emphasizes the need for understanding mobile device unlocking habits, and we propose that – given diversity in mobile device usage reported consistently by previous studies – a larger user study is desirable to gain more insight in mobile device unlocking habits.

Methodology and Data

Our analysis is based on mobile device usage data from the Device Analyzer project,[1] which contains mobile device logs collected from 17 103 Android devices world-wide [8].The complete dataset we were granted online access to by the University of Cambridge Computer Laboratory[2] consists of chronological log files per device, containing

[1] https://deviceanalyzer.cl.cam.ac.uk/

[2] The University of Cambridge Computer Laboratory and Data Funder do not bear any responsibility for our analysis or interpretation of the Device Analyzer Dataset or data thereof.

263 different key/value pairs along with timestamps, recorded either periodically or event based. Processing the complete dataset can be challenging due to it's total size of approximately 10 TB. Due to our lack of local storage capacity we accessed the dataset using a custom download client. The client downloads chunks of the dataset, extracts 31 key/value pairs relevant for our particular research question and discards all other data. This way we were able to reduce the dataset size by more than 99% to 55 GB, enabling us to store and process it using commodity hardware.

Usage Session Extraction

Mobile device usage sessions are generally considered to be consecutive periods of time in which a user interacts with the device. To derive usage sessions from chronological mobile device system event logs, two approaches have been used in previous research. The first is to define a usage session as the period a certain application is running in the foreground [5]. This approach is not capable of catching interactions with the device while the device is still locked (e.g. users checking time/notifications) on Android devices, as there is no application running in the foreground capable of tracking interactions. The more frequently stressed approach is to define a usage session as the period the device screen is on [2, 3, 6, 4], because mobile device displays are commonly switched on when usage starts and switched off soon after usage (either manually or after a short idle timeout). While using this screen power state allows for a fairly close approximation of actual device interaction, some pitfalls with the potential to distort the extracted device usage exist. For instance an incoming call will activate the display even if the phone is unattended thus leaving the call unanswered. The corresponding events could falsely be interpreted as a session of user interaction. If a call is made or answered, modern mobile phones will utilize a proximity sensor to switch off the display when the phone is held close to the user's head in order to prevent accidental touch events, e.g. by the ear. Relying only on the display power state would in this case result in mistakenly assuming multiple short usage sessions instead of a consecutive session. We observed that overall 12.7% of the changes in power state are actually related to calls and do not mark the boundaries of genuine user interaction sessions. Consequently, phone calls adversely affect the accuracy of solely display power state based usage session extraction approaches. We therefore developed a more sophisticated model of usage session extraction in the form of a finite state machine (see Fig. 1).

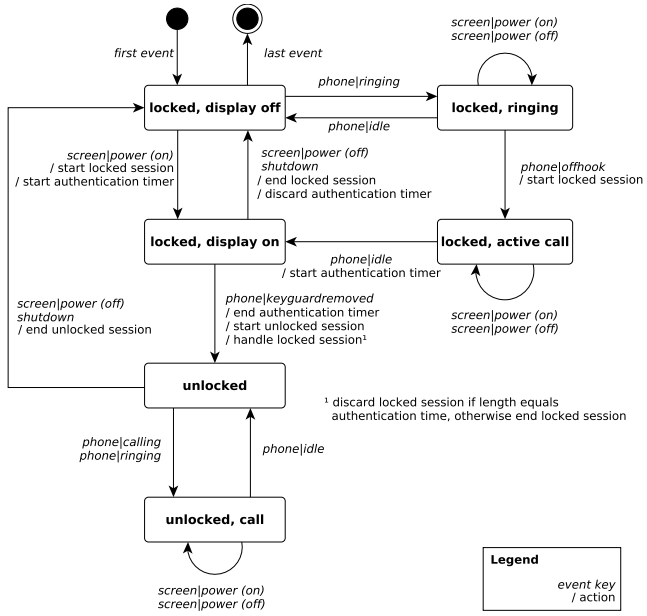


Figure 1: State machine for usage session detection

Utilizing events like incoming calls, outgoing calls, and answering calls allows us to discard changes in display power state caused by the phone application and not related user interaction. Unlike previous studies we distinguish two types of usage sessions: *Locked usage sessions* occur when device interaction takes place while the device remains locked by a keyguard (such as PIN, password, pattern, face unlock, fingerprint, or swipe to unlock). Typical use cases which do not require unlocking are checking time, battery state, network connectivity, notifications, appointments, or even taking a picture. Accordingly, *unlocked usage sessions* happen after unlocking the device, e.g. by entering a PIN.

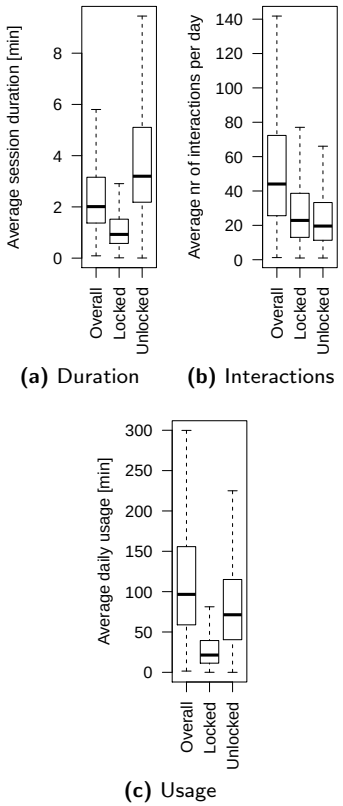
Data Revision

To ensure the quality of the usage sessions derived from the Device Analyzer dataset, the raw data was cautiously revised in several aspects. Device logs recorded with early versions of the Device Analyzer application do not include all keys crucial to our session model. Therefore we restrict our study to logs recorded with Device Analyzer version 1.1.5 or higher. Devices featuring no keyguard (not even slide-to-unlock) were removed as they do not allow us to distinguish between locked and unlocked state. Since parts of our analysis feature per-day statistics, only days that have been captured entirely were taken into account. Thus days only partially recorded were disregarded. Examples for events causing partially recorded days are: the recording application got installed/uninstalled, crashed, was paused on user request for privacy reasons or paused itself to throttle local storage consumption. Because the usage session model relies on display idle timeouts, devices which were configured at least once during the observation period to keep the display on while charging or had been used in a dock,[3] which also prevents display timeout, were discarded as well. To ensure devices to be representative, only devices providing usage sessions for seven or more valid days were considered. The original dataset contains recordings of tablets along with those of mobile phones – which we expect to show different usage behavior (e. g. longer but less frequent sessions). In order to achieve results comparable to previous studies we only considered mobile phone in our analysis. Consequently, we discarded devices not conducting or answering a single call during the observation period. Due to this strict selection, in total 88.5% of the devices from the original Device Analyzer dataset were disregarded. The remaining 1 960 devices used in the analysis provide usage data from 7 to 533 days, with a mean observation period of 63 days, from which 6.9 million total usage sessions were derived. While there will still be factors left causing falsely detections of usage sessions, we argue that – in comparison to previous studies – our state based session model captures device interaction at a higher degree of consistence. The main reasons thereto are: *a)* a representative amount of devices providing data, *b)* reducing falsely detected sessions by tracking the user's interaction state (e. g. currently telephoning) *c)* thoroughly filtering devices and sessions to reduce usage of incomplete data and not falsify results.

Statistical Analysis

Assuming that a device has only one primary user, the extracted usage sessions are examined for certain usage characteristics. For each locked, unlocked and overall usage sessions we computed mean interactions and mean usage time on a per-day basis. This was done by first calculating the mean for each observed day and then the mean for each device across the means of all observed days. The mean locked, unlocked and overall session duration was calculated per device across the entire observation period.

[3] Dock status information has not been available for all the devices.



(a) Duration **(b)** Interactions

(c) Usage

Figure 2: Average session duration, average daily number of interactions and daily usage

Results and Discussion

Our results confirm the immense diversity in any mobile device usage characteristic on both session level and user level that has consistently reported by previous studies [2, 5].

Daily interactions

We found that Android users interact with their devices on average 33 times per day without unlocking it with a median of 22 interactions (see Fig. 2 (b)). On average unlocked usage happens 25 times per day with a median of 20 – which indicates that users unlock their devices for about 43% of all interactions. As with locked usage, the unlocked mean value is biased by a small number of users unlocking their devices up to 212 times per day on average. Since locked usage allows only for a limited set of actions of which most relate to checking information, this can be explained by users' *checking habits* as described by Oulasvirta et al. [4]. Overall, the daily number of interactions is 57 times with a median of 44.

Session duration

Regarding session durations, we found the mean locked usage session duration being 88 seconds with a median of 56 seconds (see Fig. 2 (a)), which we find surprisingly high. Spot tests suggest a distortion by display timeouts counted towards usage time for users seldom switching off their devices screen after usage. Fig. 3 (a) illustrates this problem by a locked session duration histogram from a user showing this behavior. Apparently, some users regularly switch off the screen of their devices after usage (see Fig. 3 (b)) while others almost never do so (see Fig. 3 (c)). Unlocked session duration results suffer from the same problems. However, since unlocked sessions are longer in general, the distorting affect of display timeouts is smaller in comparison. The mean unlocked session duration is 285 seconds or 4.7 minutes with a median of 192 seconds. As for locked sessions, the mean value for unlocked sessions is biased by a small number of hour-long sessions.

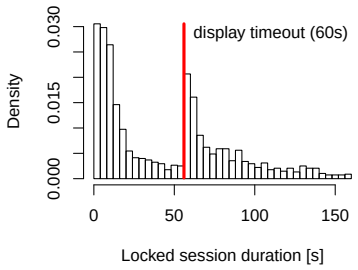
Daily usage

Overall, we found that users interact on average 117 minutes with their devices per day with an median daily usage time of 97 minutes (see Fig. 2 (c)). With locked sessions, the daily usage time is 33 minutes on average with a median of 21 minutes while with unlocked sessions, the usage time is 87 minutes on average with a median of 71 minutes per day.

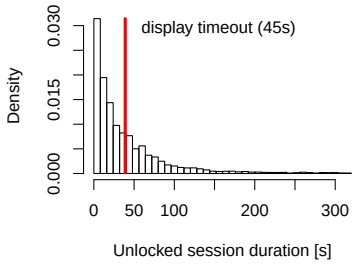
Comparison with previous mobile device usage studies

The mean number of interactions per day across the number of mean interactions per user we found are well in line with the results of [8] and [5]. Studies conducted by [2] and [6] do not outline the mean number of interactions across users, so we can not directly compare our findings to their results. A notably higher mean number of interactions (87 vs 57) than we observed was reported in [3]. One possible explanation could be a higher percentage of enterprise users among BlackBerry user panel in [3], considering the observation by [5] that in office context sessions occur 56% more frequently compared to home context. For the mean unlocked session length, our results again confirm the findings by [5] (285 s vs 263 s). However, the overall mean session length we observe (177 s) is higher than the numbers by [8] (116 s) and [3] (68 s), which we assume to be at least partly caused by the distorting effect of user sessions terminated by display timeouts. The mean daily usage time we found, however, is again in line with results by [8, 3, 5].

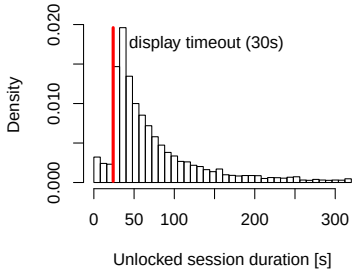
See tab. 1 for a summary of our findings as well as a comparison with results from previous mobile device usage studies.



(a) Sample user 1 - Locked



(b) Sample user 2 - Unlocked



(c) Sample user 3 - Unlocked

Figure 3: Sample user session duration histograms indicating device locking habits.

	Devices	Mean daily interactions			Mean session length [sec]			Mean daily usage [min]		
		overall	locked	unlocked	overall	locked	unlocked	overall	locked	unlocked
Falaki et al. [2]	255	10 - 250	-	-	10 - 250	-	-	30 - 500	-	-
Oliver [3]	17 300	87	-	-	68	-	-	101	-	-
Soikkeli et al. [5]	140	-	-	20	-	-	263	-	-	73
Truong et al. [6]	10	-	-	5 - 105	-	-	-	-	-	-
Wagner et al. [8]	16 000	57	-	-	116	-	-	123	-	-
Our study	1 969	57	33	25	177	88	285	117	33	87

Table 1: Usage session characteristics in different mobile device usage studies

Conclusion

This work studied locked and unlocked mobile device usage sessions. Our results extend previous studies by showing that while Android users interact with their devices on average 57 times per day, adding up to almost two hours per day, they only unlock their devices 43% of the time on average. Additionally, our findings indicate that a noteworthy amount of users do not lock their devices themselves after usage. This increases the possibility of malicious interaction with the device when considering unlocked usage, as devices stay unlocked for a short period afterwards. Since display timeouts generally blur screen power based usage monitoring, we encourage further research to compensate this problem as well as to analyze differences in tablet and mobile phone usage habits.

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