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Comparison, Evolution and Challenges of Mobile Phone Batteries in iPhone and Android Devices: Forensic Study of Role of a Mobile Battery of an Android Xiaomi Phone

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ABSTRACT

This study examines recent advancements in mobile phone battery technology, exploring the evolution of battery types from nickel-cadmium to lithium-ion and lithium-polymer, and the integration of fast and wireless charging, as well as the potential of emerging technologies like solid-state and graphene batteries. These innovations have significantly improved energy density, efficiency, and charging speed, addressing the growing power demands of modern smart phones while enhancing user convenience, safety, and sustainability. The research highlights the parallel advancements in battery technology across iPhone and Android devices. Both platforms offer robust software features to optimize battery usage and extend battery life, leveraging machine learning and user data to manage power consumption effectively. However, mobile phone batteries still face challenges such as capacity limitations, degradation from fast charging, safety risks, and environmental concerns related to raw material sourcing and recycling. The study also delves into the forensic investigation of power events on Xiaomi phones, specifically the Poco F1 model running Android 10, by analyzing system logs that record charging events, power cycles, and device usage patterns. This forensic analysis aids in reconstructing timelines, detecting tampering, and understanding user activity, which is crucial in investigations. Overall, the study provides a comprehensive review of battery technology advancements, management features, challenges, and forensic applications in modern smart phones.

Key words: Mobile phone Forensics, Mobile phone Battery, Android phone battery, I phone battery, Mobile Device Power events

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I. Introduction

Mobile phones are indispensable in daily life due to their efficiency and portability, made possible by compact, powerful batteries. Recent developments have greatly increased battery life and efficiency as a result of the ongoing evolution of battery technology to fulfil consumer needs. The evolution of iPhone and Android mobile phone batteries has been significant since their inception. The batteries in early smartphones were sometimes not strong enough to keep up with the increasing power demands of the hardware and software. Battery technology has advanced over time, leading to significant improvements in energy density, efficiency, as well as lifespan. Examples of these developments include the switch from nickel-cadmium as well as nickel-metal hydride to the batteries of lithium-polymer along with lithium-ion. Additionally, innovations in fast charging technologies, wireless charging, and battery management systems have further improved user convenience and device performance. It is now possible for current smartphones to offer a wide range of functions while preserving longer battery life and faster charging times because of significant investments made by both iPhone and Android makers in research and development to push the boundaries of battery capabilities. The paper [1] reviews current recycling technologies for lithium-ion batteries, highlights challenges like economic viability and environmental impact, and suggests future directions for improving efficiency and sustainability. The article [6] discusses recent advancements in mobile phone battery technology, emphasizing improvements in energy density, charging speed, and overall performance to enhance user experience and device longevity. The paper [15] provides a comprehensive review of the advancements and challenges in solid-state battery technology over the past decade, highlighting its potential for superior performance and safety compared to traditional liquid electrolyte batteries. Advancements in battery technology are highlighted through research on high-energy-density and solid-state batteries, focusing on enhancements via nanotechnology, sustainable materials, and efficient thermal management. Additionally, the impact of fast charging on battery degradation and market trends in sodium-ion and lithium-ion batteries are explored [10-19]. Recent research going in this field highlights significant advancements in lithium-ion and solid-state battery technologies, focusing on high-efficiency electrode materials, environmental effects, and innovations in battery management and safety. Key developments include improvements in battery performance, charging speed, and lifespan, driven by novel materials, advanced safety features, and the integration of machine learning for life prediction [33-45].

II. History of iPhone and Android mobile battery

The history of iPhone batteries reflects a significant evolution in mobile technology, driven by advancements in battery chemistry, design, and integration. Since the launch of the first iPhone in 2007, Apple has prioritized battery performance as a critical component of user experience. The original iPhone introduced in 2007 featured a built-in rechargeable lithium-ion battery with a capacity of 1400 mAh, designed to support basic smart phone functionalities like calling, messaging, and web browsing. The iPhone 3G (2008) and iPhone 3GS (2009) saw incremental improvements in battery capacity and efficiency, with advancements in software optimization to enhance battery life. The iPhone 4 (2010) introduced a more compact design with a higher resolution Retina display and an improved 1420 mAh lithium-ion battery, focusing on balancing performance with battery life improvements. The iPhone 4S (2011) continued to refine battery management and introduced the A5 chip, enhancing overall efficiency while maintaining battery capacity. With the iPhone 5 (2012), Apple increased the battery capacity to 1440 mAh, supporting the larger 4-inch display and LTE connectivity, while also introducing improvements in power management through iOS updates. The iPhone 5S and iPhone 5C (2013) continued to iterate on battery technology, focusing on energy efficiency with the introduction of the A7 chip and M7 motion coprocessor. The iPhone 6 (2014) and iPhone 6 Plus (2014) marked a significant leap in battery capacity, with the iPhone6 featuring a 1810mAh battery along with the iPhone6 Plus a 2915mAh battery, catering to larger displays and improved performance demands. The iPhone6S and iPhone6S Plus (2015) introduced enhancements in battery efficiency with an A9 chip and improved power management, along with optimizations in iOS for longer battery life. In 2016, the iPhone 7 and iPhone 7 Plus maintained similar battery capacities but introduced optimizations such as the A10 Fusion chip and iOS improvements for increased efficiency and performance. Apple focused on balancing battery life with new features like stereo speakers and enhanced camera capabilities, supported by advancements in battery technology and software integration. The iPhone 8 (2017) and iPhone 8 Plus (2017) continued the trend of incremental improvements in battery life and efficiency, with the introduction of the A11 Bionic chip and iOS enhancements for better power management. These models also supported wireless charging, adding convenience while maintaining battery performance standards. The iPhone X (2017) introduced a new design with Face ID and OLED display, accompanied by advancements in battery technology to support these features. Subsequent models like the iPhoneXS, iPhoneXR, iPhone11, as well as iPhone12 series, have continued to refine battery life, efficiency, and charging capabilities, with improvements in battery capacity, fast charging, and power management through the integration of new processors and software updates. Throughout its history, Apple has prioritized battery longevity, safety, and performance, continuously refining iPhone battery technology to meet the increasing demands of users for longer-lasting, more efficient mobile experiences. Each generation has built upon the successes and challenges of its predecessors, contributing to the evolution of iPhone batteries into essential components of modern mobile technology [1-2] [6-13].

The history of Android mobile phone batteries parallels the rapid evolution of smart phone technology, as Android smart phones have evolved, so too has their battery technology. Since the initial implementation of lithium-ion batteries to the incorporation of fast charging technologies as well as AI-driven battery management systems, manufacturers have continually sought to enhance the user experience by extending battery life and optimizing power consumption. These advancements reflect a commitment to meeting the growing expectations of users for reliable performance and longevity in their mobile devices. The year 1983 marked a notable milestone with the launch of Motorola's DynaTac 8000X, a pioneering mobile phone that marked a milestone in telecommunications history. The device utilized a Ni-Cd (nickel-cadmium) battery with a conservative capacity of 500mAh, reflecting the early stages of mobile phone battery technology and the beginning of portable communication devices. Android smartphones in the early years (2008-2010) typically featured batteries based on Ni-MH (nickel-metal hydride) or Ni-Cd technologies. These batteries exhibited a moderate energy density and were progressively substituted by Li-Ion (lithium-ion) batteries due to their superior performance. Capacities ranged from around 1000mAh to 1500mAh, catering to smaller displays and basic functionalities like calling, texting, and basic web browsing. By the early 2010s, Android manufacturers began adopting lithium-ion (Li-Ion) batteries, providing longer lifespan along with higher density of energy in comparison to the older battery technologies. The capacities were expanded to handle larger displays and more complex functions that were introduced in smart phones, such as multitasking, HD movie playback, and gaming. During the period (2012-2015), Android smart phones saw significant improvements in battery capacity, often exceeding 2000 mAh and reaching up to 3000 mAh or more in flagship models. Manufacturers focused on optimizing battery life through hardware improvements such as more energy-efficient processors, AMOLED displays with lower power consumption, and software optimizations in Android OS versions. As smart phones became more powerful and capable during the period (2015-2017), fast charging technologies gained prominence in Android devices. Companies like Qualcomm introduced Quick Charge technology, allowing for rapid charging speeds and reducing downtime for users. This era also saw the introduction of features like USB-C connectors, which supported faster charging rates and improved power delivery efficiency. During the period 2017-2020, with advancements in artificial intelligence (AI), Android smart phones began employing AI-driven battery management systems. These systems learned user habits and adjusted power consumption to maximize battery life. Battery capacities continued to increase, with flagship devices pushing beyond 4000mAh to support larger screens, 5G connectivity, and effective applications such as VR (virtual reality) as well as AR (augmented reality). Today, Android smart phones continue to evolve with a focus on battery longevity, efficiency, and sustainability. Manufacturers are exploring technologies like graphene batteries and solid-state batteries to further improve energy density and charging speeds. Fast charging remains a key feature, with advancements in wireless charging and improved thermal management to enhance user convenience and device reliability. Throughout its history, the evolution of Android mobile phone batteries has been driven by technological innovation and consumer demand for longer battery life and faster charging capabilities. These advancements have not only improved the user experience but also enabled smart phones to support increasingly sophisticated features and applications in our daily lives [4-5] [10-20]

III. Different types of mobile battery used in iPhone and android devices

In iPhones, Apple has predominantly used lithium-polymer (Li-Po) as well as Li-Ion batteries throughout their history, with a focus on optimizing performance, efficiency, and user experience.

The batteries of Lithium-ion are extensively employed in iPhones due to their high density of energy, and reliability, along with the ability to hold charge effectively over many charge cycles. Similar to Li-Ion batteries, the batteries of Li-Po use a polymer electrolyte rather than a liquid one, offering flexibility in design and shape, which is advantageous for achieving thinner and more compact form factors. Apple has refined Li-Po technology to enhance charging speeds, optimize power consumption, and ensure safety standards. Solid state batteries represent the next step in battery technology, which includes possible benefits such as increased energy density, quicker charging abilities, enhanced safety, and longer life span in comparison to conventional lithium-based batteries. While not yet implemented in iPhones, Apple is actively researching and investing in solid-state battery technology.

Different types of batteries used in Android and feature phones have evolved significantly over time, catering to different needs and technological advancements.

Li-Ion batteries are extensively utilized in both Android smart phones as well as feature phones because of their exceptional energy density, lightweight construction, and capacity to retain a charge for prolonged durations. Li-Ion batteries have undergone continuous improvements in energy efficiency, safety features and charging speeds. Due to their optimal combination of performance as well as cost-effectiveness, they continue to be the preferred option for the majority of mobile devices. The batteries of Li-Po are a type of lithium-ion batteries that became popular in the mid-2000s due to their lightweight design and enhanced safety features in comparison to the cells of Li-Ion. They are commonly employed in slim-profile smartphones and feature phones where space and weight are critical considerations

Nickel-cadmium batteries were once prevalent in early mobile phones and feature phones. They are less commonly used today due to concerns over cadmium's environmental impact and lower energy density compared to newer technologies. Nickel-metal hydride batteries were an improvement over Ni-Cd batteries, offering higher energy density and reduced environmental concerns by eliminating cadmium. Ni-MH batteries provided a bridge between older Ni-Cd technology and modern lithium-based solutions. However, they have largely been replaced by Li-Ion batteries Because of their heavier weight as well as lower energy density.

The next generation of battery technology is represented by Solid-state batteries. While still in the research and development phase for mainstream mobile applications, solid-state batteries hold potential for future smart phones and feature phones. The development of mobile phone batteries has been driven by the need for longer battery life, faster charging capabilities, and improved environmental sustainability.

IV. Different Components of mobile batteries and how does it work

Mobile phone batteries are complex systems composed of several key components such as cathode, anode, electrolyte, separator, collectors, battery enclosure, Current Interrupt Device (CID) and thermistor. Individual components are essential in the process of storing as well as transmitting electrical energy to provide power for the device.

The cathode is a positive electrode within the battery cell. It is typically made of metal oxide and plays a critical role in the battery's energy storage capacity. During the process of discharge, ions, such as lithium ions in Li-Ion batteries, move from cathode to anode by passing through electrolyte. This movement of ions releases energy, which is then used to power the phone. The battery's negative electrode is known as the anode. It is usually made of carbon-based materials and serves as the site for ion absorption and release during charging as well as discharging cycles. As the battery builds up an electrical charge, ions travel from the cathode via the electrolyte to the anode, where they are stored. The electrolyte is a conductive solution or gel that facilitates the movement of ions between the cathode and anode during charge and discharge cycles. It allows for the flow of ions (eg: Li-ion) while insulating the electrodes to prevent short circuits and ensure safe battery operation. A porous membrane that physically separates the cathode and anode within the battery cell is known as a separator. It prevents direct contact between the electrodes, preventing short circuits while allowing ions to pass through during charging and discharging. Collectors are conductive materials that connect the electrodes to the external circuit, allowing for the flow of electrical current. They enable the movement of electrons between the electrodes as well as the devices, enabling battery to power the mobile phone and other electronics. The battery enclosure or casing provides physical protection for the internal components and isolates the battery from external elements. Current Interrupt Device (CID)is a safety feature designed to disconnect the battery in case of overcharging, over-discharging, or high temperature to prevent thermal runaway and potential hazards. It enhances the safety of the battery by protecting against conditions that could lead to overheating, fire, or explosion. The thermistor is a temperature-sensitive device that monitors the battery temperature. It provides feedback to the battery management system (BMS) to regulate charging rates and prevent overheating, optimizing battery performance and durability.

V. Key Trends in mobile Battery Evolution

Mobile phone battery capacities have increased significantly over the years to support more powerful processors, larger screens, and additional features. Advancements in chip technology, software optimizations, and more efficient displays have led to better battery life even as device capabilities have expanded. iPhone and Android devices have introduced fast charging and wireless charging to reduce charging times and add convenience. Modern smart phones include sophisticated power management systems that help extend battery life by optimizing resource usage.

VI. Software battery features available in iPhone& Android devices

In iPhones, battery management is largely handled by software features integrated into iOS, aimed at optimizing performance, extending battery life, and enhancing user experience. The following software features in iOS are designed to empower users with information and tools to manage battery usage effectively, prolonging battery lifespan and enhancing the overall performance of their iPhones.

Battery Health (iOS Settings)- iOS includes a "Battery Health" section under Settings > Battery, providing insights into the battery’s overall health. This functionality assists users monitor their battery’s condition over time and understanding if and when a battery replacement may be beneficial.

Battery Usage Statistics- iOS tracks battery usage for each app, showing the percentage of battery consumption attributed to different applications and services. This enables them to identify power-hungry apps and adjust usage patterns accordingly.

Low Power Mode- This is a feature that reduces battery consumption by limiting background app refreshes, automatic downloads, and visual effects. When enabled (typically below 20% battery remaining), it extends battery life by temporarily reducing performance and background activity until the device can be charged.

Optimized Battery Charging- This uses machine learning to understand users' charging habits and reduce battery ageing. It slows down the charging process in certain situations, such as when the device is plugged in overnight, to avoid prolonged periods of being fully charged, which can stress the battery

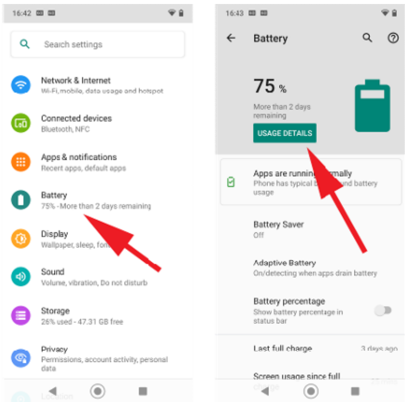
Battery Usage Suggestions- iOS provides personalized suggestions to improve battery life based on usage patterns and settings. These suggestions may include adjusting display brightness, managing background app refresh, and reviewing location service usage to optimize power consumption.

Background App Refresh Management- Users can manage which apps can refresh content in the background, helping to conserve battery by preventing unnecessary updates when the app is not actively in use.

Low Battery Notifications- iOS alerts users when their battery reaches a low level, prompting them to enable Low Power Mode or find a nearby charger to ensure uninterrupted usage.

Android phones also offer several software features and tools to manage battery usage efficiently and enhance user experience. The following software features in Android phones empower users with tools to monitor, manage, and optimize battery usage, enhancing the longevity of the battery and optimizing the overall functionality of their mobile devices.

Battery Settings and Usage Details- Android provides detailed battery usage statistics under Settings > Battery. Users have the ability to view the apps and services that are utilizing the most amount of battery power across different time intervals. This feature helps users identify and manage power-hungry apps, adjust settings, and optimize battery usage based on usage patterns



Battery Saver Mode- Similar to iOS's Low Power Mode, Android devices include Battery Saver mode. Battery Saver mode is typically enabled when the battery reaches a predetermined percentage, such as 15% or 20%. It helps conserve battery power by restricting background activity, decreasing performance, along removing features like vibration. Users have the option to manually enable Battery Saver mode or configure it to automatically activate when the battery reaches a predetermined level.

Adaptive Battery- It uses machine learning to allocate battery power to apps and services that are often utilized. It restricts battery usage for less frequently used apps, optimizing power consumption and extending battery life without compromising user experience.

Battery Optimization- Android devices allow users to optimize battery usage for individual apps. Under Settings > Apps & notifications, users can select specific apps and enable Battery Optimization. This feature reduces background activity for selected apps, limiting their impact on battery life while still allowing them to function normally when actively used.

Battery Health Information- Some Android devices provide battery health information similar to iOS's Battery Health feature. This includes details on the battery's capacity relative to when it was new and suggestions for improving battery longevity. Users can access this information under Settings > Battery or similar menu options depending on the device manufacturer.

Power Usage Alerts and Notifications- Android devices may notify users of power-hungry apps or services consuming significant battery resources. These alerts prompt users to take action, for example closing background apps or adjusting settings to save battery life.

Doze Mode- Doze Mode is a feature that improves battery life by reducing background activity when the device is not in use and stationary. It automatically activates to conserve battery power, ensuring minimal power consumption during periods of inactivity.

Fast Charging and Charging Optimization- Fast charging technologies for example USB Power Delivery as well as Qualcomm Quick Charge are frequently supported by Android devices. Some Android devices also include features to optimize charging cycles, similar to iOS's Optimized Battery Charging.

VII. Advancements in Mobile Phone Battery Technology

Solid State Batteries-The technology of Battery has advanced significantly with the introduction of solid-state batteries. These batteries have a solid electrolyte instead of the liquid or gel electrolyte which exists in traditional batteries, resulting in increased safety, longer lifespans, as well as higher energy density.

Graphene Batteries- Graphene batteries incorporate graphene, a highly conductive material with excellent thermal properties. These batteries promise higher conductivity, faster charging, increased capacity, and better thermal management compared to traditional batteries.

Silicon Anode Batteries- Silicon anode batteries replace the graphite anodes in lithium-ion batteries with silicon, significantly increasing energy density. This innovation allows for higher capacity, faster charging, and longer battery life.

Fast Charging Technologies-Rapid charging methods have fundamentally transformed the manner in which we supply energy to our electronic devices. Innovations in charging protocols and materials have led to ultra-fast charging, capable of charging at speeds exceeding 100W.

Battery Management Systems (BMS)-Advanced battery management systems are essential for maximizing battery efficiency and durability. Modern BMS uses software as well as hardware to monitor and manage battery health, implementing features like adaptive charging and predictive maintenance.

Battery Recycling and Sustainability- With growing environmental concerns, battery recycling and sustainability have become crucial areas of focus. Companies have introduced comprehensive recycling programs to recover valuable materials from used batteries.

Alternative Battery Technologies- Exploration of alternative battery chemistries, for example batteries of sodium-ion, magnesium-ion, as well as lithium-sulfur, is underway. These options have the potential to provide greater energy density, reduced costs, and enhanced safety.

Enhanced Safety Features- Safety is a paramount concern in battery technology. Recent advancements focus on improving thermal management and incorporating advanced safety mechanisms. These include pressure relief valves and sophisticated BMS that detect and mitigate potential issues before they become hazardous, ensuring increased user safety and device reliability.

VIII. Challenges in Mobile Battery Evolution

Mobile phone batteries face several challenges, which can affect their performance, longevity, and user experience. Mobile phone batteries have limited capacity relative to the power consumption of modern smart phones with high-resolution displays, powerful processors, and multiple sensors. Fast charging of mobile phones generates excessive heat, which may degrade the battery over time. Batteries degrade with each charge cycle, gradually losing capacity and efficiency. Extreme temperatures, whether they are high or low, can expedite the deterioration of batteries. Batteries can overheat due to manufacturing defects, improper charging, or physical damage, leading to risks of swelling, leakage, or even explosion. Ensuring safety standards and regulations adds complexity to battery design and manufacturing. Balancing battery size with the slim, lightweight design of modern smart phones is challenging. Larger batteries provide more capacity but can increase the device's size and weight. Sourcing raw materials like lithium, cobalt, and nickel sustainably and ethically is a significant challenge with concerns over environmental impact and labour practices. Efficiently recycling old batteries to reclaim valuable materials and reduce electronic waste is technically and logistically challenging.

IX. Forensic investigation of power events of a Xiaomi phone-role of the mobile battery

Forensic investigation of power events on a Xiaomi phone involves examining various system logs and files that record the device's power-related activities. Xiaomi devices, running on MIUI (a custom Android-based operating system), have unique artifacts and logs that can be crucial for forensic analysis. In this study the phone is a Xiaomi make, Poco F1 model android mobile phone (Android 10). The acquisition of the mobile phone was done using the Universal Forensic mobile extraction Device UFED 4PC v7.53.0.24, by advanced logical & physical qualcomm live methods. The UFED Physical Analyzer was used for decrypting and analysis. Power events or device events artifacts are logs and data files that record various activities related to the power state and overall status of a mobile device. These artifacts provide detailed insights into actions such as powering on and off, rebooting, battery charging, and system crashes. In forensic investigations, these artifacts can help reconstruct timelines, understand user behaviour, and identify anomalies. Digital Wellbeing provided a new artifact that explicitly tracked and displayed powering events on Android devices. While other artifacts were available for monitoring these events, Digital Wellbeing offered a more straightforward and explicit view, giving forensic examiners better insights into device usage patterns. This tool aided investigations by providing clear and detailed logs of when the device was powered on or off. It's integrated into Android devices and provides tools to monitor and control device usage [3]. The key artifacts studied in this paper include

i. charge_logger.csv:
   a. Location: Typically found in the /data/system/ directory.
   b. Contains logs of charging events, including timestamps for when charging starts and stops, battery levels, and charger types.

ii. Battery and Power Logs:
   a. Logs related to battery usage and power events can be found in system directories such as /data/system/batterystats.bin.
   b. These logs provide insights into power cycles, battery usage, and charging history.

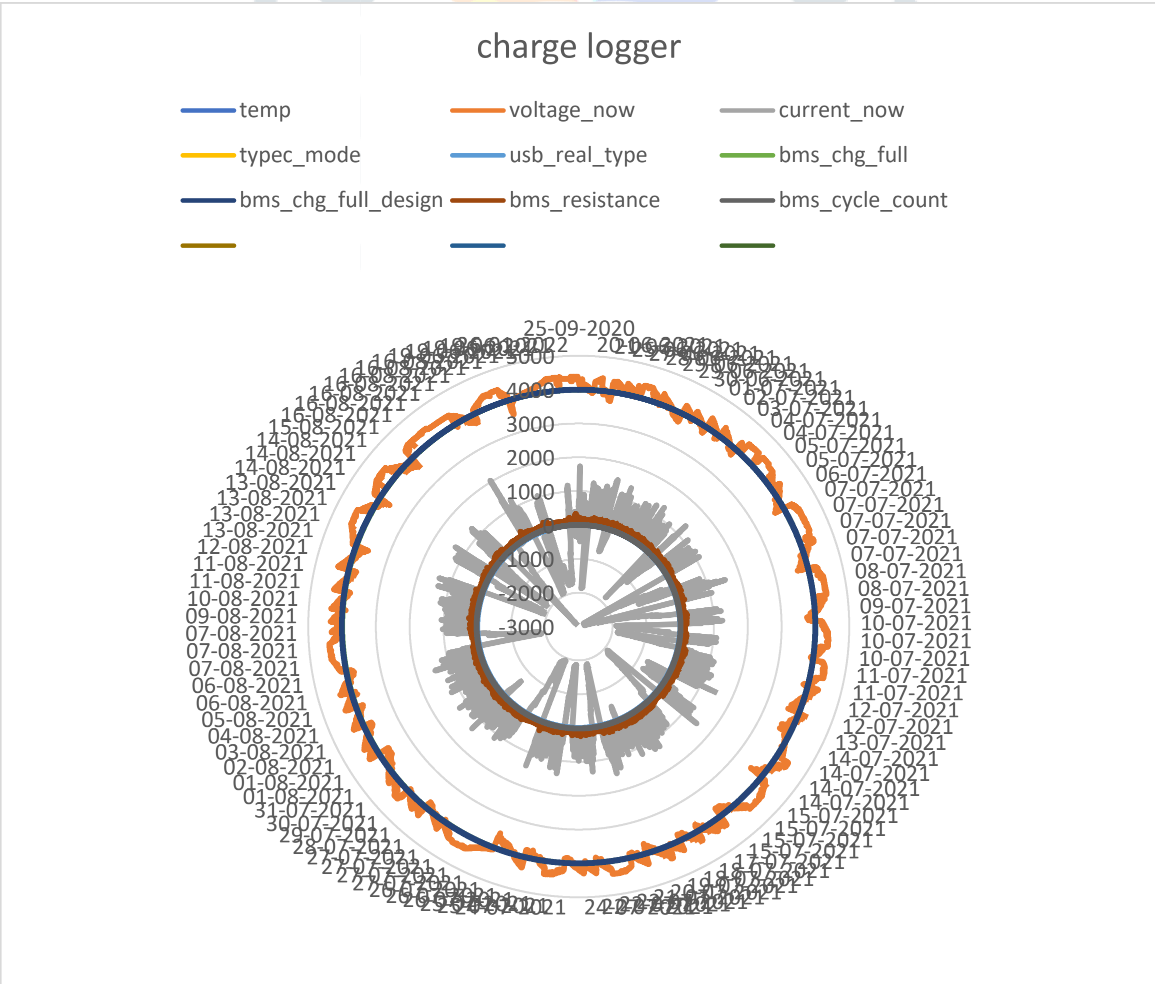
iii. eRR.p File:
   a. As mentioned earlier, this file, associated with Digital Wellbeing, contains data about usage statistics and power events.
   b. Location: Typically found in /data/data/com.google.android.apps.wellbeing/files/.

iv. Event Logs and System Logs:
   a. Android's event logs (/data/logs/eventlog, /data/logs/systemlog, /data/logs/radio/) may contain records of power-related events, such as shutdowns, reboots, and crashes.
   b. These logs can provide timestamps and reasons for power events.

The charge_logger.csv file found inside a mobile device typically logs details about the device's charging history. This file can contain valuable forensic data related to the charging events of the device such as when the device starts and stops charging, providing timestamps for each event. This helps in constructing a timeline of the device's charging history. It records battery levels at the start and end of each charging session. This information can assist in determining the duration of device charging as well as the frequency of charging. May include details about the type of charger used (e.g., USB, wireless, fast charging). This can offer insights into the charging behaviour and preferences of the user. Information about the power source (e.g., wall outlet, computer USB port) may also be logged, further detailing the charging context. In forensic investigations, charge_logger.csv can be useful for:

- Timeline Reconstruction: Establishing a detailed timeline of charging events, which can help corroborate other evidence or refute claims about the device's usage.
- User Behavior Analysis: Understanding the user's habits and routines related to charging, which can provide context for other activities.
- Event Correlation: Correlating charging events with other activities, such as app usage or communication patterns, to build a comprehensive picture of the device's use.

The specific content and format of charge_logger.csv can vary between device models and manufacturers, but the general principles of logging charging events and related details remain consistent. Here in the Xiaomi phone the file of interest charge_logger was present in userdata(ExtX)/Root/vendor/charge_logger/charge_logger_a.csv and is plotted in a radar chart as below.



Forensic Analysis of Power Events or Device Event artifacts help to correlate power events with other activities such as app usage, network connections, and user interactions. It also helps to cross-reference power event logs with other forensic artifacts (e.g., messages, call logs, location data) to build a comprehensive understanding of the device's usage and the user's behaviour.

The device events of the Xiaomi phone were studied in detail. The main events that occurred were power on, power off and device lock status. The precise timestamps of when the device was powered on can help establish a timeline of activities. This is useful for verifying or refuting alibis and claims about the device usage. Frequent power on events may indicate regular use, while sporadic power on events may suggest infrequent usage or attempts to minimize tracking. Unusual power on events at odd times may indicate tampering or unauthorized access. Forensic investigators can look for patterns that deviate from the user's normal behaviour. Power off events can be crucial for understanding the sequence of events leading up to or following a significant incident (e.g., a crime or suspicious activity). Frequent power off events may indicate attempts to cover tracks or avoid being tracked. This can be particularly relevant in cases involving illegal activities. Lock status records provide information about when the device was locked or unlocked. This helps in determining if and when unauthorized access might have occurred. Multiple failed unlock attempts can indicate attempts to access the device without authorization. Frequent lock and unlock events indicate active user interaction with the device. This helps in understanding the user's engagement and patterns of usage. The battery-usage-db-v4 file logs battery levels, charging events, and app power usage, providing a comprehensive view of the device's power consumption and charging habits. This data is essential for understanding the device's power cycles, which can correlate with user activities or uncover unusual patterns indicative of tampering or unauthorized access. The eRR.p file records when the device is powered on and off, including precise timestamps. This information is crucial for establishing a timeline of the device's activity. In the Xiaomi phone the power events source file is located in userdata (ExtX)/ Root/ data/ com. google. android.apps. wellbeing/ database/app_usage. Device events retrieved from the phone memory of the questioned mobile phone are shown below.

Device event

#	Start time	Event type	Value	Source	Source Extraction	Source file information
1	18-06-2021	Power event	Power on		Physical	
2	18-06-2021	Power event	Power on		Physical	
3	18-06-2021	Power event	Power on		Physical	
4	18-06-2021	Power event	Power on		Physical	

5	18-06-2021	Power event	Power on		Physical	
6	18-06-2021	Power event	Power on		Physical	
7	19-06-2021	Power event	Power on		Physical	
8	30-06-2021	Power event	Power on		Physical	
9	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x1860D (Table: events; Size: 5562368 bytes)
10	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x18F6A (Table: events; Size: 5562368 bytes)
11	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x18F10 (Table: events; Size: 5562368 bytes)
12	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x18AD4 (Table: events; Size: 5562368 bytes)
13	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x1927B (Table: events; Size: 5562368 bytes)
14	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x19E24 (Table: events; Size: 5562368 bytes)
15	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usag

						e : 0x19BEC (Table: events; Size: 5562368 bytes)
16	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x19909 (Table: events; Size: 5562368 bytes)
17	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x197D0 (Table: events; Size: 5562368 bytes)
18	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x39E8DD (Table: events; Size: 5562368 bytes)
19	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x39E621 (Table: events; Size: 5562368 bytes)
20	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x39E4B9 (Table: events; Size: 5562368 bytes)
21	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x39E273 (Table: events; Size: 5562368 bytes)
22	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x3A3BFA (Table: events; Size: 5562368 bytes)
23	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usag

						e : 0x3A360A (Table: events; Size: 5562368 bytes)
24	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x3A359D (Table: events; Size: 5562368 bytes)
25	15-07-2021	Device Lock Status	Unlocked	Digital Wellbeing	Physical	userdata (ExtX)/Root/data/com.google.android.apps.wellbeing/databases/app_usage : 0x3A33AA (Table: events; Size: 5562368 bytes)

X. Conclusion

In conclusion, the evolution of mobile phone batteries in Android and iPhone devices has been marked by significant advancements and persistent challenges. Both platforms have strived to enhance energy density, extend battery lifespan, and improve safety features amidst the demands for faster charging and compatibility with emerging technologies. However, challenges such as managing heat during rapid charging, ensuring long-term durability, and addressing environmental impacts remain critical areas of focus. As manufacturers continue to innovate in battery chemistry, thermal management, and regulatory compliance, the goal persists: to deliver longer-lasting, safer, and more sustainable battery solutions that support the increasing complexity and functionality of modern smart phones.

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