Sara Artang

E-Waste Tracker: A Solution to Monitor E-Waste Recyling Process

Master’s thesis in Simulation and Visualization
Supervisor: Ibrahim A. Hameed
July 2023

Master’s thesis

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Abstract

Electronic waste (e-waste) production is increasing at a pace that is unprecedented due to factors such as rapid technological advancements, changing consumer preferences, product obsolescence, and the growing number of non-repairable parts. They also pose significant environmental and health risks due to improper disposal and management. However, current e-waste management practices are insufficient, frequently providing incomplete coverage of a product's end-of-life (EOL) cycle, restricted access control, weak tracing mechanisms for missing items, and a lack of experimental validation. As a result, the ability to effectively track e-waste is essential for facilitating its long-term sustainable management. This thesis dives into the development and implementation of a novel end-to-end e-waste tracking platform aimed at addressing current e-waste management challenges and improving the existing e-waste management paradigm.

This thesis proposes a tracking platform that uses QR code technology to uniquely identify each piece of e-waste, enabling real-time tracking by GPS technology across the entire waste management chain. The platform developed makes use of both web and cloud computing. It also offers a complete end-of-life (EOL) tracking solution for electronic products. The ability of the platform to track e-waste is just one of many features designed to increase accountability and trust among the numerous parties involved in the e-waste management chain. Other features include an easy-to-use interface, strong and secure data storage solutions, and user authentication systems to ensure security and privacy, all of which improve accountability and trust among the various stakeholders involved in the e-waste management chain. Furthermore, the platform emphasizes transparency by giving all relevant parties, including manufacturers, waste collectors, recyclers, and regulators, real-time access to data about the status and location of e-waste at every stage of the process, including collection, recycling, and disposal.

The research also considers future challenges and developments, such as the potential integration of emerging technologies such as artificial intelligence, machine learning, and blockchain, to improve the platform's functionality and efficiency. As an example, incorporating blockchain technology improves the security and transparency of the tracking process by providing a tamper-proof and immutable record of all transactions associated with each device. This feature boosts stakeholder trust and confidence in the system and prevents illegal e-waste disposal.

The dissertation includes a proof-of-concept platform implementation on the Azure cloud using cutting-edge web technologies. This demonstration highlights the system's feasibility and effectiveness in terms of high availability, user experience simplicity, and added security advantages in the field of e-waste management. The proposed platform represents a significant advancement in e-waste management, promising a more sustainable and responsible future in dealing with the growing e-waste problem. As we move forward, continual refinement and enhancement of the platform are necessary to align with evolving technological advancements and environmental needs. The study's findings and implications provide an insightful perspective for researchers, policymakers, and practitioners interested in e-waste management and contribute to the future achievement of a more sustainable and responsible approach to e-waste management.

Sammendrag

Produksjonen av elektronisk avfall (e-avfall) øker i en hastighet som er uten sidestykke på grunn av faktorer som raske teknologiske fremskritt, endrede forbrukerpreferanser, produktets levetid og det økende antallet ikke-reparerbare deler. De utgjør også betydelige miljø- og helsefarer på grunn av feilaktig håndtering og styring. Imidlertid er dagens praksis for håndtering av e-avfall utilstrekkelig, og gir ofte ufullstendig dekning av et produkts livssyklus (EOL), begrenset tilgangskontroll, svake spormekanismer for manglende elementer, og mangel på eksperimentell validering. Som et resultat er evnen til å spore e-avfall effektivt avgjørende for å lette langvarig bærekraftig styring. Denne avhandlingen dykker inn i utviklingen og implementeringen av en ny ende-til-ende plattform for sporing av e-avfall, rettet mot å takle nåværende utfordringer med håndtering av e-avfall og forbedre det eksisterende paradigmet for håndtering av e-avfall.

Denne avhandlingen foreslår en sporeplattform som bruker QR-kode-teknologi for å unikt identifisere hver del av e-avfallet, noe som gjør det mulig med sanntidssporing med GPS-teknologi over hele avfallshåndteringskjeden. Den utviklede plattformen gjør bruk av både web og sky-databehandling. Det gir også en komplett løsning for sporing av elektroniske produkters livssyklus (EOL). Plattformens evne til å spore e-avfall er bare en av mange funksjoner designet for å øke ansvarlighet og tillit blant de mange partene som er involvert i kjeden for håndtering av e-avfall. Andre funksjoner inkluderer et brukervennlig grensesnitt, sterke og sikre datalagringsløsninger og brukerautentiseringssystemer for å sikre sikkerhet og personvern, noe som alle forbedrer ansvarlighet og tillit blant de forskjellige interessentene som er involvert i kjeden for håndtering av e-avfall. Videre legger plattformen vekt på gjennomsiktighet ved å gi alle relevante parter, inkludert produsenter, avfallsinnsamlere, gjenvinnere og regulatorer, sanntids tilgang til data om status og plassering av e-avfall i hver fase av prosessen, inkludert innsamling, gjenvinning og avhending.

Forskningen vurderer også fremtidige utfordringer og utviklinger, som potensiell integrering av nye teknologier som kunstig intelligens, maskinlæring og blokkjede, for å forbedre plattformens funksjonalitet og effektivitet. For eksempel forbedrer integrering av blokkjedeteknologi sikkerheten og gjennomsiktigheten i sporeprosessen ved å gi en ugjennomtrengelig og uforanderlig post over alle transaksjoner knyttet til hver enhet. Denne funksjonen styrker interessenters tillit og tillit til systemet og forhindrer ulovlig avhending av e-avfall.

Avhandlingen inkluderer en bevis-på-konsept-implementering av plattformen på Azure-skyen ved hjelp av banebrytende webteknologier. Denne demonstrasjonen fremhever systemets gjennomførbarhet og effektivitet når det gjelder høy tilgjengelighet, brukeropplevelse enkelhet og ekstra sikkerhetsfordeler innenfor feltet e-avfallshåndtering. Den foreslåtte plattformen representerer en betydelig fremgang innen e-avfallshåndtering, og lover en mer bærekraftig og ansvarlig fremtid i å håndtere det voksende problemet med e-avfall. Som vi går videre, er kontinuerlig raffinering og forbedring av plattformen nødvendig for å justere med utviklende teknologiske fremskritt og miljøbehov. Studiens funn og implikasjoner gir et innsiktsfullt perspektiv for forskere, beslutningstakere og utøvere som er interessert i e-avfallshåndtering og bidrar til fremtidig prestasjon av en mer bærekraftig og ansvarlig tilnærming til e-avfallshåndtering.

Preface

This master's thesis is the last project of the Simulation and Visualization master's program at the Department of ICT and Engineering at the Norwegian University of Science and Technology (NTNU) in Alesund. The research presented in this thesis has been completed during the spring semester of 2023. The thesis is about tracking e-waste throughout its life cycle. The motivation for selecting this thesis originates from a personal interest in nature and concern for the future of our planet.

I have been able to complete my dissertation because of the encouragement and support I have received. It is my pleasure to express my gratitude to my supervisor, Prof. Ibrahim A. Hameed, for guiding me along the right path throughout this journey. In addition, I would like to appreciate my industrial expert supervisor, Afshin Ghasemian, the Cloud Architect and Full Stack.NET Developer of the Cryon company, who enabled me to develop the proposed platform for my master's thesis and supported my research in finding the best solution and enhancing the proposal. As a result of his guidance, I was able to choose the right path and successfully complete my master's thesis.

Finally, I would like to express my heartfelt thanks to my friends Amin Mohimanianpour, Amirashkan Haghshenas, and Mohammad Hosseini for supporting me in every aspect of this journey. I am especially grateful for the constant encouragement and tender care I have received throughout my life from my wonderful family, who are always supportive of me and my endeavors. Last but not least, I would like to express my appreciation to the rest of my friends and classmates for their emotional and motivational support throughout my years of study. Without you, this journey would be much more challenging.

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List of Abbreviations (or Symbols)

E-waste	Electronic waste
Mt	Million tons
QR	Quick Response
EEE	Electrical and Electronic Equipment
WEEE	Waste Electrical and Electronic Equipment
PCBs	Polychlorinated Biphenyls
ITU	International Telecommunications Union
Kt	kilotons
Millions €	Millions of Euros
BAN	Basel Action Network
SVTC	Silicon Valley Toxics Coalition
EPR	Extended producer responsibility
RFID	Radio-Frequency IDentification
GPS	Global Positioning System
SaaS	Software as a service
PaaS	Platform as a service
IaaS	Infrastructure as a service
SMEs	Small and Medium-sized Enterprises
Latitude	Lat
Longitude	Long
IP addresses	Internet Protocol addresses
ISP	Internet Service Provider
RoSH	Restriction of Hazardous Substances Directive
StEP	Solving the E-waste Problem
3Rs	Reduce, Reuse, Recycle
ETBC	Electronics Take-Back Coalition
NSES	National Strategy for Electronics Stewardship
IETC	International Environmental Technology Centre
GeSI	Global e-Sustainability Initiative
UN	United Nations
ICT	Information and Communication Technology
IDS	Intrusion Detection Systems
CCPA	California Consumer Privacy Act
GDPR	General Data Protection Regulation
EOL	End-Of-Life
NTNU	Norwegian University of Science and Technology
NFC	Near-field communication

1 Introduction

Electronic waste, or e-waste, represents one of the most rapidly growing waste streams worldwide. The global generation of e-waste has been dramatically increasing due to technological advancement and the decreasing lifespan of electronic devices (Forti et al., 2020). While e-waste poses significant environmental and health risks, it also presents opportunities for resource recovery and the transition to a circular economy (Kumar et al., 2017). However, realizing these opportunities depends on effective e-waste management, which includes the proper collection, transportation, sorting, dismantling, and material recovery of discarded electronics.

Globally, 53.6 million tons (Mt) of e-waste were generated in 2019, exceeding previously predicted figures. According to Forti et al., the volume of e-waste generated globally will exceed 74 million tons (Mt) by 2030 (Forti et al., 2020).

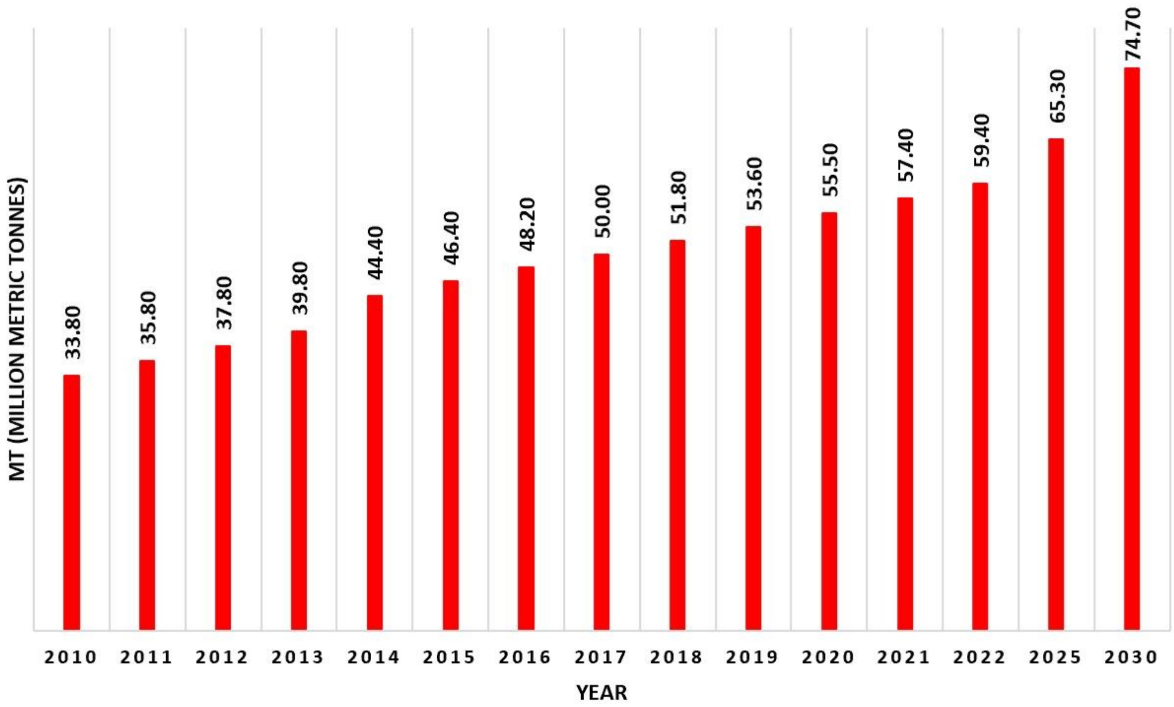


Figure 1-1: Global trend of producing e-waste.

However, the rate of recycling is not keeping up with the rate of e-waste production. Furthermore, the rate of e-waste generation is increasing, with a current rate of 3-5%. The amount of e-waste produced globally increased three times faster than the global population (Andeobu et al., 2021).

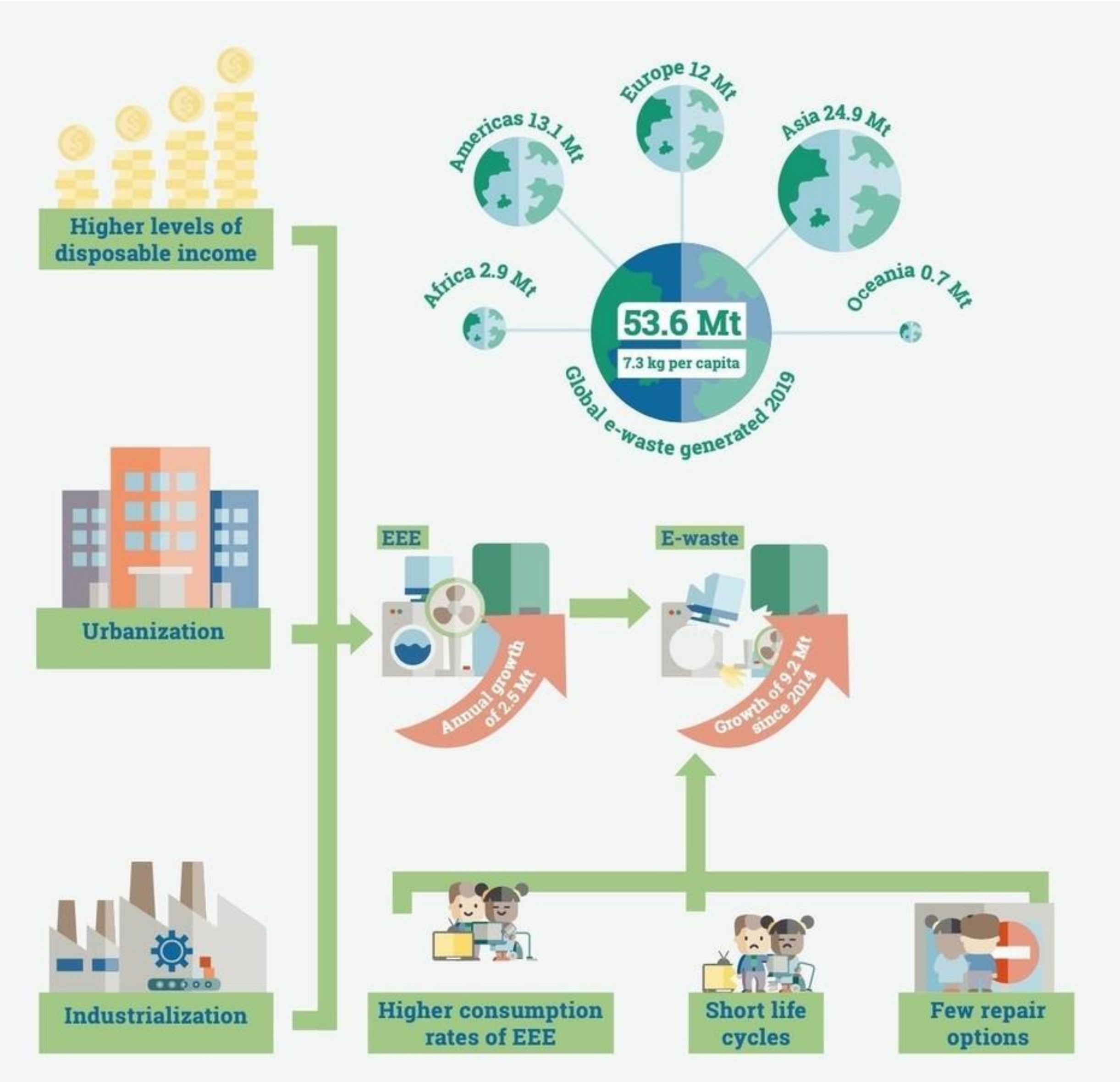


Figure 1-2: Global e-waste generated in 2019/per capita.

(Forti et al., 2020)

This is where this research as an e-waste tracking platform comes into play. E-Waste Tracker is a novel solution designed to monitor e-waste from collection to recycling. The platform aims to improve the traceability and transparency of e-waste management by leveraging advanced technologies such as QR codes, cloud computing, and geolocation. This study explores the development and implementation of the E-Waste Tracker, demonstrating its potential to improve waste management efficiency and contribute to sustainable development and long-term growth.

1.1 Background and motivation

The term "electronic waste" or "e-waste" refers to discarded electronic components and devices like computers, smartphones, televisions, and other consumer electronics (Baldé et al., 2017). In recent years, the production of electronic waste has increased at an unprecedented rate due to several factors, such as technological advancements, a sharp rise in the use of electronic devices, and shorter device lifespans (Forti et al., 2020).

E-waste contains toxic substances such as heavy metals, and incorrect disposal of electronic waste poses risks to ecosystems and human health. The risks posed by heavy metals and other hazardous chemicals leaking into the water and soil supply are highly dangerous to both human health and the environment (Lundgren, 2012).

In addition, informal waste workers who process and disassemble e-waste are frequently exposed to dangerous substances in the absence of adequate safety measures, increasing the risk to their health (Grant et al., 2013).

Given these worries, it is crucial to create efficient e-waste tracking and management systems to reduce the harmful effects of e-waste and enhance recycling and disposal procedures (Kiddee et al., 2013). By accurately tracking e-waste, stakeholders can make sure that discarded electronics are handled responsibly and in accordance with applicable regulations (Parajuly et al., 2019).

The current project is an extension assignment from the previous semester's specialization course to develop a tracking platform, which is an effort to research and present the most cutting-edge technologies, as well as to develop a digital infrastructure for tracking systems. It will enable the government to collect, visualize, and analyze data from the platform, which will be combined with authentication and artificial intelligence methodologies to improve user assurance, facilitate decision-making, alleviate potential concerns, improve reliability and availability, and reduce annual illegal e-waste exports and misappropriation of valuable materials and information.

1.2 Problem and scope

Proper e-waste management and tracking have become increasingly important because of the rapid growth of electronic devices, their disposal, and the environmental and health risks associated with improper handling (Baldé et al., 2017; Bhutta et al., 2011; Kiddee et al., 2013).

Although various e-waste tracking methods and technologies have been developed (Ongondo et al., 2011; Tiwari et al., 2018), many of them require specialized equipment, infrastructure, and technical knowledge. The complexity of current technologies, high implementation costs, and the need for extensive structure and infrastructure frequently make managing and tracking e-waste more difficult (Omondi et al., 2022; Shevchenko et al., 2019). These challenges can make it difficult for smaller waste management organizations and recyclers to implement e-waste tracking systems due to a lack of resources and expertise (Nowakowski et al., 2021).

Another problem is the sensitive information kept on electronic devices, which can make users hesitant to dispose of their devices, resulting in an increase in e-waste rate (Abbas et al., 2021; Aziz et al., 2022). Stakeholders can encourage responsible e-waste disposal by developing a robust e-waste tracking system that ensures data security during the recycling and disposal processes (Khan & Ahmad, 2022).

1.3 Research goals and question

The main goal of this study is to develop and test an e-waste tracking platform that is easy to use, user-friendly, and cost-effective, especially for ordinary users, recyclers, and smaller-scale waste management organizations. This platform should be able to track e-waste from collection to recycling or disposal and provide transparency and traceability to all stakeholders in order to improve the accuracy and efficiency of e-waste management.

The research questions for this study are:

1. What are the essential features and functionalities needed for an efficient e-waste tracking platform, and how can they be implemented using readily available technologies like smartphones and QR codes?
2. How do the efficacy, transparency, and traceability of e-waste management procedures change after the implementation of the proposed e-waste tracking platform?
3. How can an e-waste tracking platform be developed to be a user-friendly, widely available, and cost-effective solution for e-waste management?
4. What are the potential challenges and limitations of using the proposed e-waste tracking platform, and how can they be addressed?

This research aims to contribute to the development of more efficient and sustainable e-waste management practices by focusing on the platform's simplicity and accessibility.

In order to answer this question, the research project will:

- evaluate the drawbacks of current e-waste tracking methods as well as the potential benefits of cloud-based e-waste tracking systems and the simplicity of using QR codes for this purpose.
- Create a platform for producing QR codes that are linked to e-waste location data and scanning them to update location data.
- Examine the platform's accuracy and effectiveness in tracking e-waste.

1.4 Thesis structure

This research addresses the specific problem of a lack of efficient and accurate e-waste tracking systems. Existing tracking methods have flaws such as inadequate data quality, a lack of transparency, and vulnerability to fraud (Wang et al., 2013). Furthermore, because of the presence of valuable materials such as gold, silver, and copper, e-waste is frequently illegally exported to developing countries, posing additional environmental and health risks (Borthakur & Govind, 2017; Lepawsky, 2018). Finally, a cloud-based e-waste tracking platform can address these issues by providing an accessible, user-friendly solution that requires minimal investment in equipment and infrastructure (Conti & Orcioni, 2019; Das et al., 2020; Shevchenko et al., 2021). The platform can be easily implemented and adopted by various stakeholders involved in the e-waste management process by leveraging widely available technologies such as smartphones and QR codes (Fernandes et al., 2023; Rosário & Dias, 2023)

The structure of this thesis is as follows:

- Chapter 1- Introduction: Provides an overview of the research topic, background, motivation, problem and scope, research goals and questions, and thesis structure.

- Chapter 2- Related Work: Reviews existing e-waste tracking methods and relevant technologies, highlighting gaps that this research aims to address.

- Chapter 3- Theory Background: Provides an overview of the key concepts and technologies related to the e-waste tracking platform, including generating unique QR codes, tracking definition in programming, cloud-based technologies, geolocation technologies, relevant regulations and standards, data security and privacy, and existing e-waste tracking methods and technologies.

- Chapter 4- Methodology: Describes the development of the e-waste tracking platform, including the generation of QR codes and the scanning process, data storage technologies and methods, user authentications and authorities, and cloud-based technologies.
- Chapter 5- Results: Presents the results of the platform's development, testing, and evaluation, including challenges encountered and user feedback.
- Chapter 6- Discussion: Analyzes the implications of the findings for e-waste management, compares the platform to existing methods, and addresses future challenges and developments.
- Chapter 7- Conclusion: Summarizes the research findings, their implications for e-waste tracking, and potential future research directions.

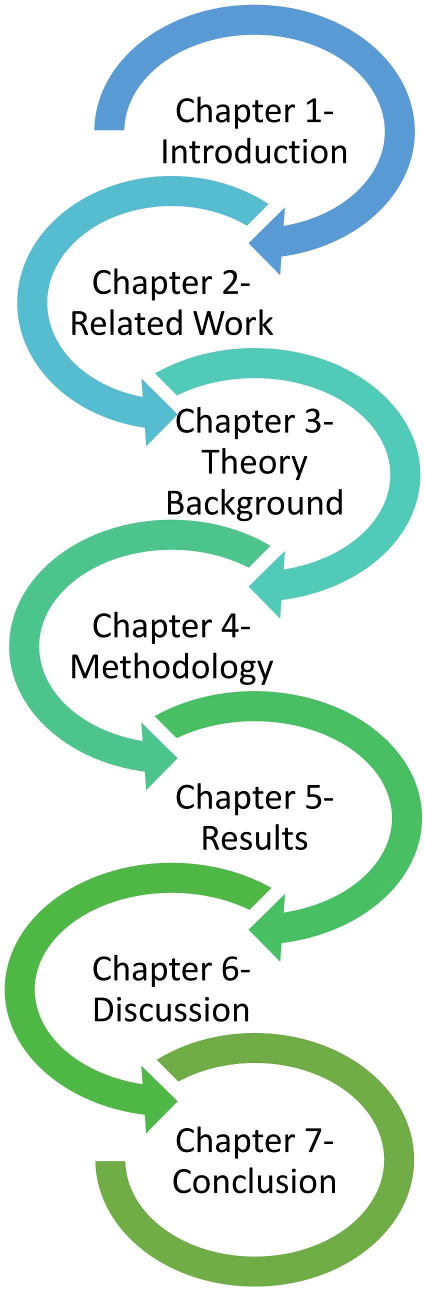


Figure 1-3: The structure of thesis

2 Related work

This chapter provides a general overview of the published literature on e-waste tracking techniques, relevant technologies, e-waste management challenges, as well as applications, and existing solutions. This research aims to identify gaps in knowledge and practice that this research seeks to address.

2.1 What is the e-waste?

The word "electronic waste" (e-waste) is used when electrical and electronic equipment (EEE) reaches the end of its useful lifetime. In different parts of the world, e-waste is also referred to as WEEE (Waste Electrical and Electronic Equipment), electronic waste, or e-scrap. The term "WEEE" refers to any electrical and electronic equipment (EEE) and its associated components that has been discarded or is intended for such disposal without the owner's intention of reuse (European Union, 2012).There are a total of 54 different product types that fall under the classification of e-waste, but they are categorized into six categories: large equipment, small equipment, temperature exchange equipment, screens and monitors, small information exchange equipment, and lamps (Forti et al., 2020). When users discard these items for disposal or recycling, they become 'waste' (Baldé et al., 2015).

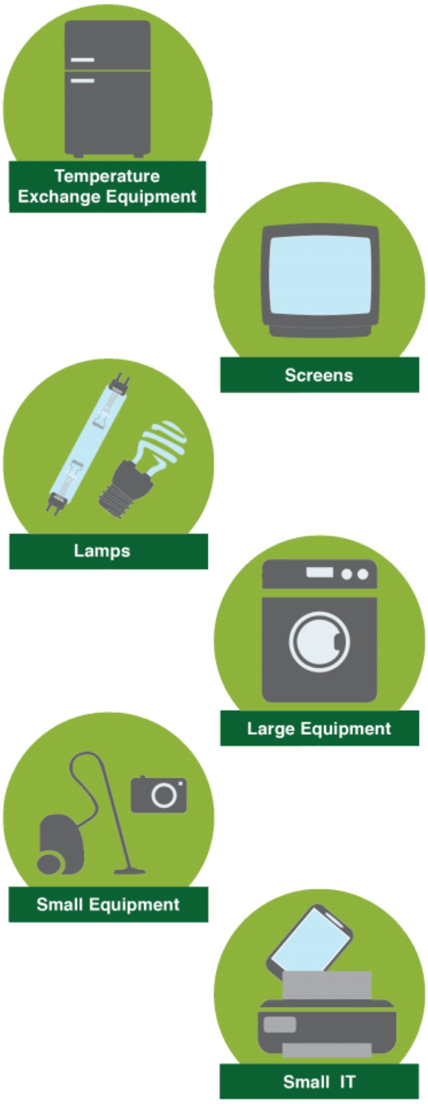


Figure 2-1: The e-waste categories

(Baldé et al., 2017)

E-waste is categorized by the diversity of its constituent materials and the presence of both hazardous and valuable substances. On the one hand, e-waste frequently includes heavy metals like lead, mercury, and cadmium, and also organic pollutants such as polychlorinated biphenyls (PCBs), both of which pose serious environmental and health risks (Widmer et al., 2005). On the other hand, electronic waste includes precious metals like gold, silver, and palladium, and also base metals such as copper, aluminum, and iron, all of which can be recovered and reutilized (Tansel, 2017).

Rapid advances in technology and diffusion, paired with a shorter lifespan of products, have resulted in an exponential increase in e-waste generation. The world generated approximately 53.6 million metric tonnes of e-waste in 2019, with this figure expected to increase to 74.7 million tonnes by 2030 (Forti et al., 2020). As a result, effective and efficient e-waste management is critical for both mitigating negative impacts and utilizing e-waste's valuable resources.

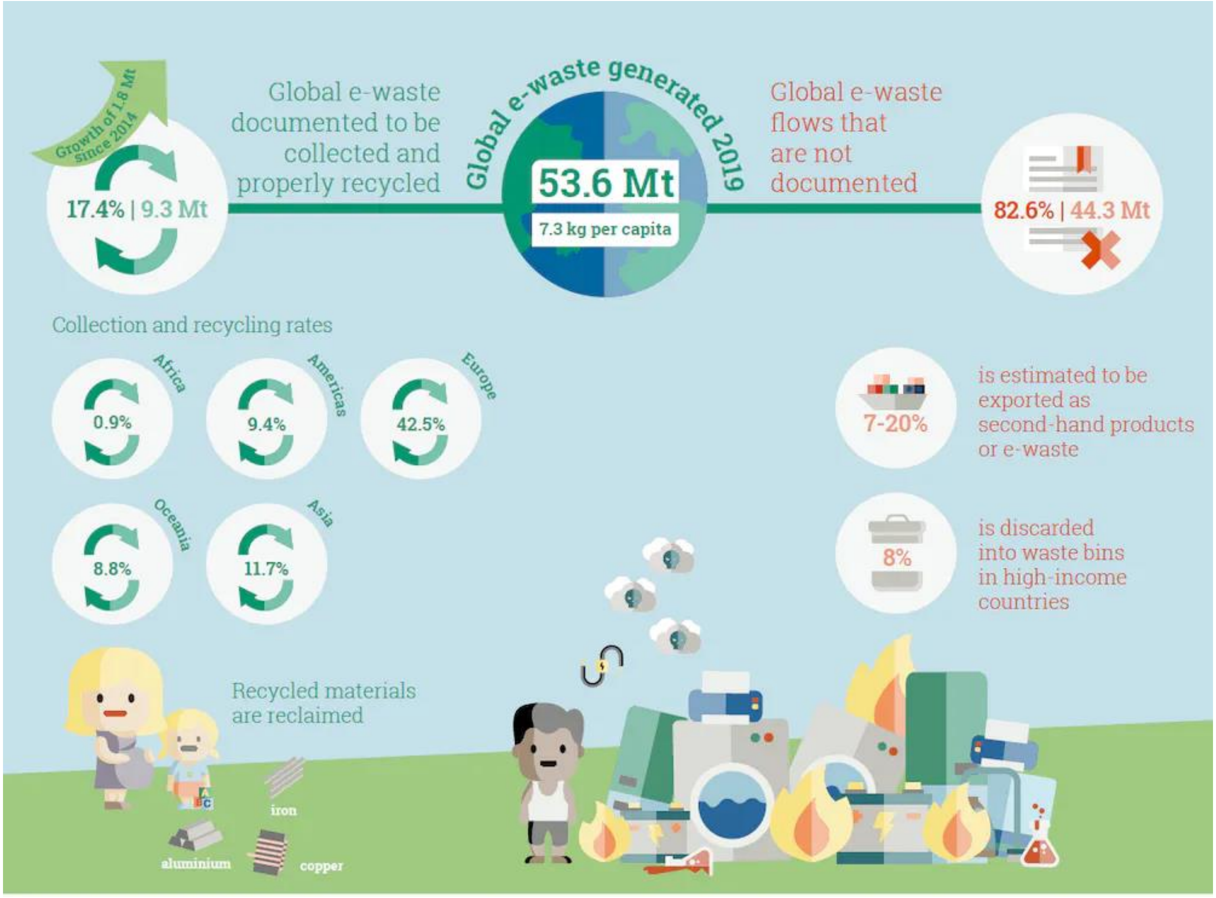


Figure 2-2: How the world managed e-waste in 2019.

Illustration: © Global E-waste Monitor 2020 / UNU, UNITAR, SCYCLE / Nienke Haccoû (Forti et al., 2020)

2.2 E-waste management and recycling processes

There are several steps involved in the management of electronic waste, including collection, transportation, sorting, dismantling, and material recovery (Bakhiyi et al., 2018; Forti et al., 2020). Recycling e-waste is essential for minimizing environmental and health risks, conserving natural resources, and promoting a circular economy (Forti et al., 2020; Tansel, 2017). Only 17.4% of global e-waste was properly recycled in 2019 (Forti et al., 2020; Van Yken et al., 2021), showing that recycling rates are still quite low globally. Measures implemented to improve global e-waste recycling (Ilankoon et al., 2018) have not been able to compete with the increased generation rate, as evidenced by the fact that the recycling rate has only slightly increased since the rate calculated in 2014 (17%) (Andeobu et al., 2021). The remaining 82.6% are either not recycled or are not formally tracked, leading to their sale on black markets and ultimate disposal in landfills (Forti et al., 2020; Li et al., 2013). Figure 2-3 presents the 2016 European countries' recycling rankings for electronic waste.

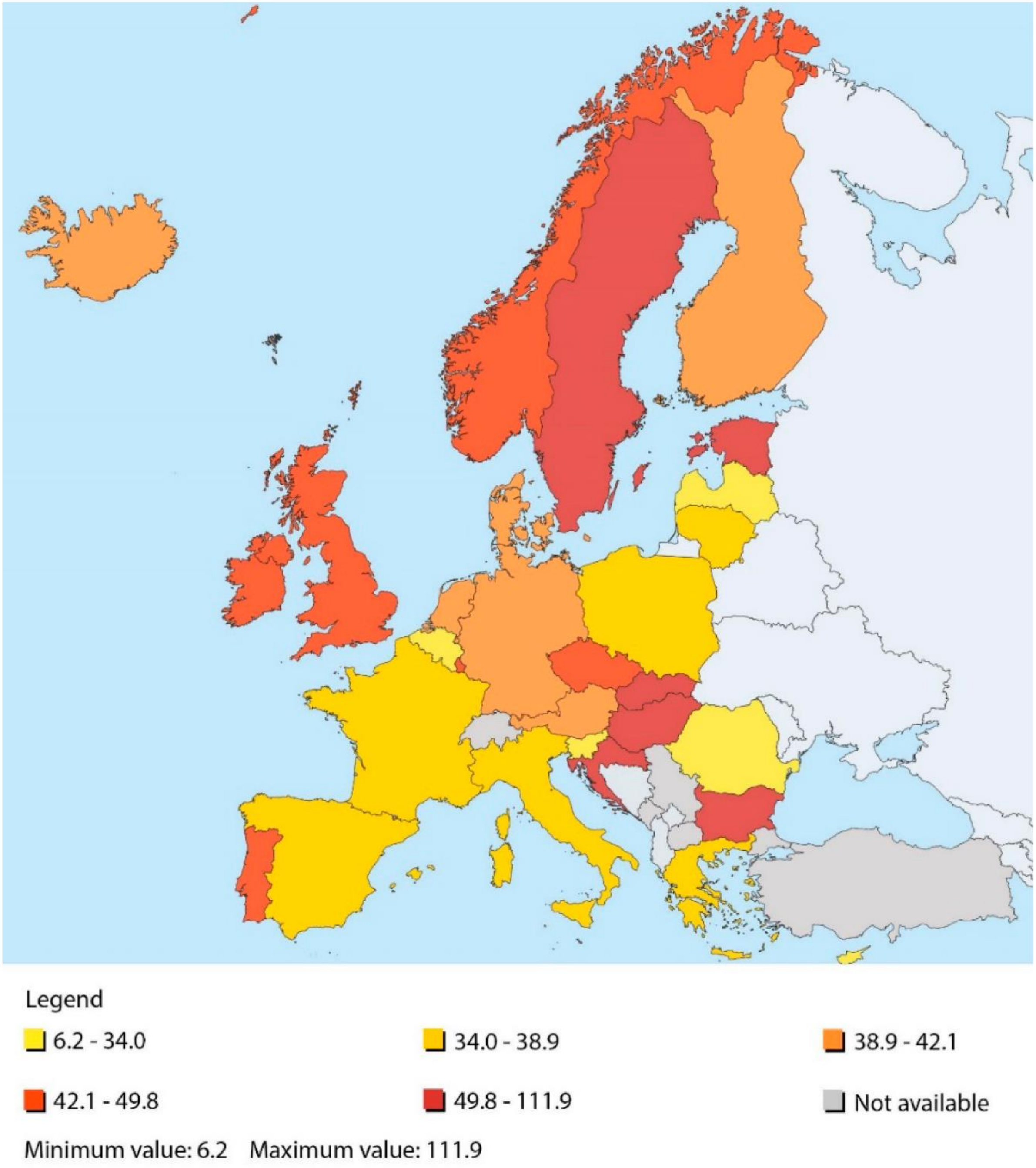


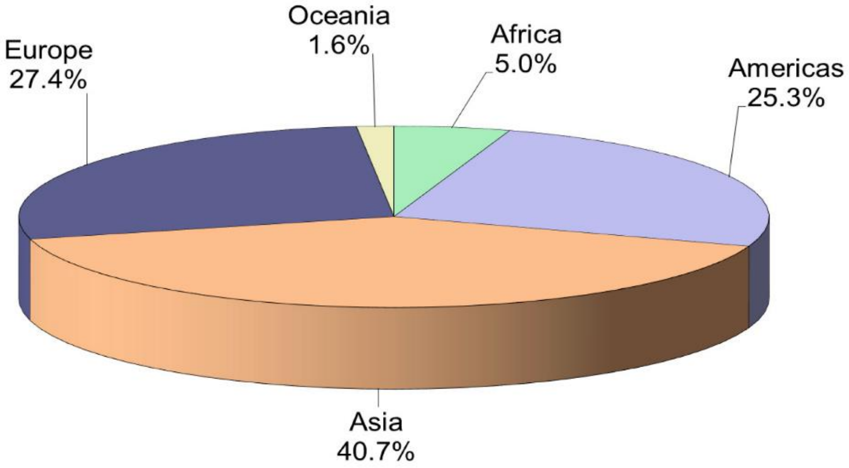
Figure 2-3: E-waste recycling percentage for the 28 EU countries in 2016

(Shevchenko et al., 2019)

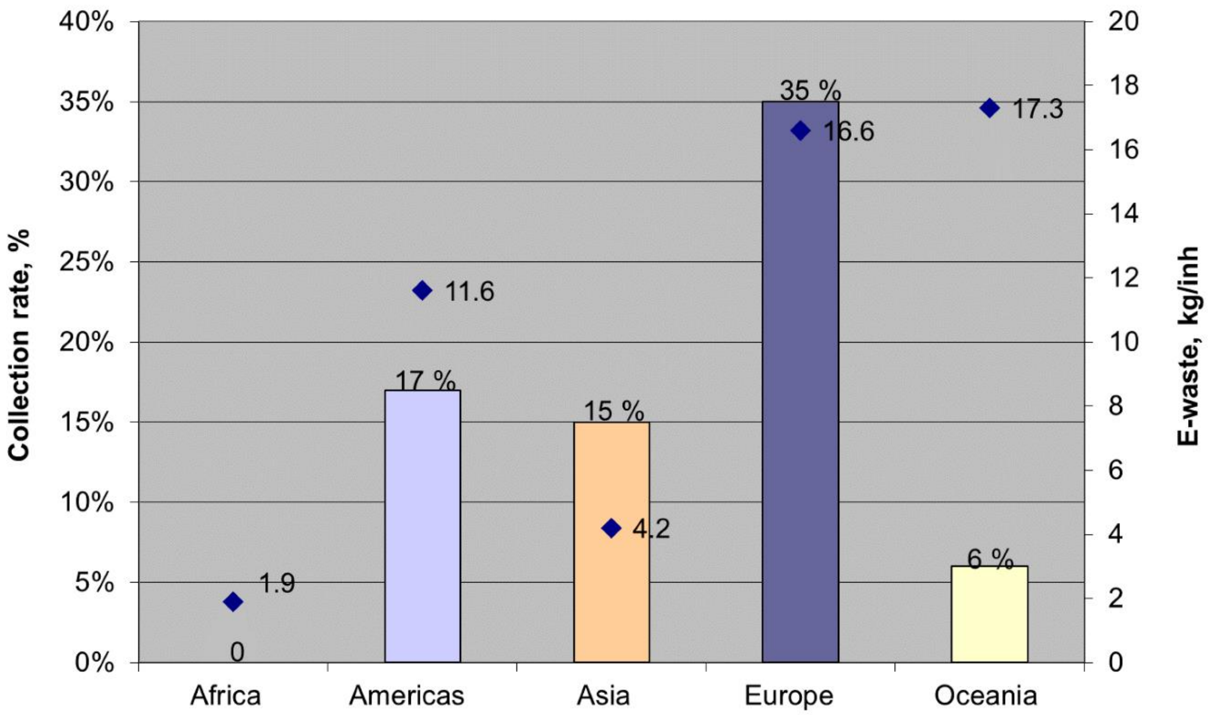
A lack of consumer awareness, inadequate recycling infrastructure, and complex legislation all play a role in the low recycling rates (Golev et al., 2016; Ongondo et al., 2011).

2.2.1 Collection

The first step in recycling is called e-waste collection, which entails gathering electronic devices and components from a variety of locations, including homes, businesses, and collection points (Awasthi & Li, 2017; Grant et al., 2013). E-waste must be collected properly to ensure safe handling and to keep it out of the general waste stream (Kiddee et al., 2013). Figure 2-4 displays the continental distribution of e-waste generation and collection rates around the world in 2017.



(a)



(b)

Figure 2-4: E-waste generation structure and collection rates by continents.

(a) E-waste generation global structure; (b) E-waste generation per inhabitant and collection rates by continents. (Shevchenko et al., 2019)

2.2.2 Transportation

Transportation of the collected e-waste to processing facilities is the next step (Kumar et al., 2017). The safe and effective transport of hazardous materials requires meticulous management of this process based on Basel Action Network (BAN) and Silicon Valley Toxics Coalition (SVTC) in 2002 (Jim Puckett & Asma Hussain, 2002).

2.2.3 Sorting

Sorting e-waste entails categorizing electronic devices and components according to their type, materials, and recycling potential (Cucchiella et al., 2015). This procedure can be carried out manually or by automated systems such as sensor-based sorting technologies (Kaya & Kaya, 2019).

2.2.4 Dismantling

The term "dismantling" refers to the process of taking apart an electronic device by hand or using a machine in order to reuse valuable components like metals, plastics, and glass (Khaliq et al., 2014). This procedure calls for specialized knowledge and equipment in order to minimize the possibility of exposure to dangerous substances (Kaya, 2016).

2.2.5 Material recovery

Material recovery is the final step in the e-waste recycling process, which involves extracting valuable materials from e-waste using various techniques such as pyrometallurgical, hydrometallurgical, or bioleaching methods (Tezyapar Kara et al., 2023; Xavier et al., 2023; Zeng et al., 2018). Material recovery is critical to advancing the circular economy because it reintroduces valuable materials into the manufacturing process (Parajuly et al., 2019).

According to the International Telecommunications Union (ITU), the total value of e-waste worldwide could be around 55 billion euros in 2016. Some sixty of the elements in the periodic table, including silver, palladium, and copper, can be recovered from electronic waste (Loesche, 2017). Figure 2-5 illustrates the global volume (in kilotons) and monetary value (in Millions of Euros) of electronic waste in 2016.

	Silver (Ag)	Paladdium (Pd)	Iron (Fe)	Aluminum (Al)	Copper (Cu)	Plastics	Gold(Au)
kilotons (kt)	1.60	0.20	16,283.00	2,472.00	2,164.00	12,230.00	0.50
Million €	884	3,369	3,582	3,585	9,524	15,043	18,840

Figure 2-5: Potential value and volume of raw materials in e-waste worldwide 2016

2.3 Existing e-waste tracking methods and technologies

The flow of e-waste has also been the subject of various studies. Some studies have attempted to quantify the transboundary movement of e-waste, (Breivik et al., 2014; Lee et al., 2018; Lepawsky, 2015; Lepawsky & McNabb, 2010; Shinkuma & Huong, 2009; Q. Song et al., 2017; X. Song et al., 2017; Tong et al., 2018) while others have focused on the domestic flow of e-waste through tracking and tracing the flow of e-waste (Dwivedy & Mittal, 2012; Kahhat & Williams, 2012; Miller et al., 2016; Mishima et al., 2016; Veenstra et al., 2010; Yoshida et al., 2009).

To effectively manage e-waste, it is necessary to embrace appropriate technological solutions that address the following aspects:

- Transparency in the electronic waste movement
- Extended producer responsibility (EPR) implementation
- Traceability of e-products across their entire life cycle, from manufacturing to e-waste conversion to recycling back into raw materials.
- Constructing appropriate channels for reaching out to e-waste
- A sufficient number of recycling facilities and their connectivity to a technology-driven e-waste management system (Sahoo et al., 2021)

According to the literature, it is clear that there is a gap in the field of electrical and electronic waste collection, particularly in regard to the use of track-and-trace technologies and smart collection systems (Alvarez et al., 2008; Kazancoglu et al., 2021; Martin & Leurent, 2017; Rada et al., 2013).

E-waste tracking is critical for proper management and recycling processes. To track and monitor e-waste flows, various methods and technologies have been developed, including the use of electronic tracking systems, barcodes, radio frequency identification (RFID) (Dwivedy & Mittal, 2010), and blockchain technology (Kazancoglu et al., 2021). Despite advancements in e-waste tracking technologies, challenges such as data privacy and data security concerns, the need for standardization, and the integration of various tracking methods continue to exist (Alghazo et al., 2018; Kapoor et al., 2021; Khan & Ahmad, 2022).

2.3.1 Electronic tracking systems

Electronic tracking systems are widely used to manage e-waste logistics, such as waste collection, sorting, and transportation. These systems typically make use of computer hardware and software components to manage and monitor e-waste flows throughout the recycling process. By doing so, they can help to streamline the recycling process and improve supply chain transparency (Grant et al., 2013; Khetriwal et al., 2009; McNeill et al., 2021; Ruponen, 2017).

2.3.2 Barcodes and RFID technology

In tracking systems, barcodes and RFID tags are commonly used to provide unique identifiers for individual electronic devices, allowing for efficient and accurate data collection. RFID technology has advantages over traditional barcodes, such as the ability to store more information and to be read from a distance without direct line of sight. RFID tags can be integrated into electronic products during the manufacturing process, allowing devices to be tracked throughout their life cycles. However, the high cost of tags and the requirement for specialized equipment can stymie RFID technology implementation (Condemi et al., 2019; Dwivedy & Mittal, 2010; Fernando & Jorge Jr, 2015; Namen et al., 2014; Ruponen, 2017).

2.3.3 Blockchain technology

Blockchain technology, which is a decentralized and distributed digital ledger system, has emerged as a game changer in a variety of industries, including e-waste management. By providing a decentralized, tamper-proof, and transparent platform for recording and sharing data, blockchain technology has emerged as a promising solution for improving e-waste tracking systems. In e-waste management, blockchain-based systems can improve traceability, security, and data integrity. Several studies, including pilot projects and proof-of-concept implementations, have proposed the use of blockchain technology for tracking e-waste (Abalansa et al., 2021; Dasaklis et al., 2020; Dua et al., 2020; Khan & Ahmad, 2022; Sahoo et al., 2021).

The term "blockchain" is shorthand for a digital ledger consisting of linked "blocks" that record transactions. Because each block is connected to the ones that came before and after it, the order of the blocks and the transactions they record cannot be altered. Importantly, because of its decentralized nature, blockchain technology is impervious to tampering, making it a reliable tracking tool (Tapscott & Tapscott, 2016).

Blockchain technology can be used in the context of e-waste tracking to create a transparent and verifiable record of each piece of electronic waste, from its creation to its disposal or recycling. This is accomplished by assigning a unique identifier to each e-waste item, which is then stored in the blockchain. Each transaction (e.g., collection, transportation, and recycling) of this piece of e-waste is recorded on the blockchain as it moves through its lifecycle (Kshetri, 2018).

The increased transparency offered by blockchain technology is one of the primary benefits when applied to e-waste tracking. Manufacturers, waste collectors, recyclers, and regulators are just a few of the parties involved in managing e-waste who have access to the same verifiable data about the lifecycle of an item. This openness can discourage improper handling, illegal dumping, or mismanagement of e-waste while encouraging responsible recycling methods. Traceability is another noteworthy benefit that blockchain offers. The relevant parties can use the blockchain to track the lifecycle of an e-waste item in the event of a dispute or regulatory investigation, providing a transparent and impenetrable evidence trail (Caro et al., 2018; Chaudhary et al., 2021; Khan & Ahmad, 2022; Sahoo & Halder, 2020; Sahoo et al., 2021).

However, incorporating blockchain technology into e-waste tracking is not without difficulties. Among the obstacles that must be overcome are technical barriers, high setup costs, and a lack of understanding of the technology. Furthermore, for blockchain-based tracking to be effective, it must be widely adopted by all stakeholders involved in e-waste management, which has not yet occurred (Mougayar, 2016).

While blockchain technology offers exciting possibilities for e-waste tracking, more research and collaboration among various stakeholders is required to fully realize its potential and overcome the current challenges.

2.4 Challenges in e-waste management

In order to ensure effective and environmentally responsible disposal and recycling practices, there are a number of significant challenges associated with managing e-waste that must be addressed. Some of the main challenges are:

2.4.1 Volume and Complexity of e-waste

The sheer volume of e-waste generated worldwide poses a significant challenge. As of 2021, the world produces approximately 50 million tonnes of e-waste per year, a figure that is expected to rise due to rapid technological advancements and increased consumer demand for electronic devices (Forti et al., 2020). Aside from the volume, the complexity of e-waste presents an additional challenge due to the mixture of valuable materials like gold and copper, as well as hazardous substances like mercury and lead, which necessitate specialized processing techniques (Borthakur & Govind, 2017; Lepawsky, 2018; Parajuly et al., 2019).

2.4.2 Complex technologies and Infrastructure Requirements

The technological complexity of e-waste tracking systems may limit their adoption, particularly by smaller-scale waste management organizations that find it difficult to implement and maintain these systems. Regular customers may be put off by how difficult they are to use. Developing and maintaining a dependable and efficient tracking system necessitates a level of technical expertise that not all stakeholders have (Ismail & Hanafiah, 2020; Khetriwal et al., 2009; Ongondo et al., 2011).

Infrastructure requirements further complicate e-waste management efforts. Traditional e-waste management systems often require extensive infrastructure to support them, including collection and classification centers, transportation networks, waste processing facilities, and data management systems (Ongondo et al., 2011). The logistical and financial implications of such requirements can be particularly challenging for organizations, particularly in regions with underdeveloped infrastructure or limited access to resources or in developing countries that may already struggle with waste management issues (Sahoo & Halder, 2020).

2.4.3 High implementation costs

The financial challenges associated with the development and deployment of e-waste tracking systems can be expensive and act as a barrier for organizations with limited resources. The costs linked to purchasing equipment, training personnel, and ensuring compliance with regulations can be prohibitive, especially for smaller companies or those operating in developing countries with limited funding (Khetriwal et al., 2009; Wang et al., 2013). For example, the cost of GPS (Global Positioning System) tracking devices for monitoring e-waste has been a concern for both recyclers and regulators (Breivik et al., 2014).

2.4.4 Regulatory and Compliance Issues

Many nations have taken steps to curb the growth of electronic waste and profit from the advantages of this potentially valuable secondary resource. More than 2000 sections of legislation from more than 90 jurisdictions are currently in force worldwide to regulate the negative effects of WEEEs (Ilankoon et al., 2018).

E-waste management is governed by a patchwork of international, national, and regional laws and regulations, making compliance a challenging issue. Even though the Basel Convention regulates the international transboundary transportation and disposal of hazardous wastes, e-waste illegal trafficking continues to be a major problem (Forti et al., 2020). It can be difficult to ensure that electronic waste is processed in accordance with these regulations, especially in countries with less strict environmental regulations (Lundgren, 2012).

2.4.5 Environmental and health risks

The environmental and health risks related to improper handling of e-waste are remarkable concerns in e-waste management. Environmental pollution is one of the side effects of not properly managing e-waste for disposal. It can lead to hazardous substances such as heavy metals and toxic chemicals leaching into the soil and water systems. Furthermore, individuals involved in informal recycling processes may face serious health risks as a result of exposure to these harmful substances (Baldé et al., 2017; Kiddee et al., 2013). Valuable materials are also lost due to informal recycling because individuals who recycle lack the technology to effectively recover these materials (Parajuly et al., 2019).

Another issue is the storage of waste from electrical and electronic equipment (WEEE) by residents, which may pose risks if not appropriately removed from households (Nowakowski et al., 2021).

2.4.6 Data Security

Electronic waste, or e-waste, can be dangerous because of the private or confidential data of people or corporate it may contain. According to Abbas et al. (2021), a significant barrier to the safe disposal and destruction of data is the possibility that sensitive information could be compromised as a result of improper handling of electronic waste (Abbas et al., 2021).

2.4.7 Lack of Awareness

Despite the risks associated with improper e-waste disposal, consumers are not sufficiently aware of the value of good e-waste management. E-waste frequently gets mixed up with regular household trash due to this ignorance, entering the general waste stream without being properly treated (Ongondo et al., 2011).

Addressing these challenges is crucial for creating more effective and sustainable e-waste management systems.

3 Background theory

3.1 Generating Unique QR Codes

A Quick Response (QR) code is in the category of a two-dimensional barcode. Denso Wave, a Toyota subsidiary, invented the first practical QR code in Japan in 1994 for the automotive industry (Wave, 2010). QR codes have a significant advantage over traditional barcodes in that they can store much more data, such as URL links, geo coordinates, and text (Petrova et al., 2016). These characteristics have increased their popularity in a variety of fields, including waste and e-waste tracking (Aparna et al., 2021).

Figure 3-1: A sample of QR code

To produce a unique QR code, a piece of data (also known as a data string) must first be generated. This data string usually includes a unique identifier or information regarding the object to which the QR code is attached. QR codes can be generated using various software and hardware tools, and they can be customized to include specific information, such as the manufacturer, model, and serial number of the device (Dutson, 2013).

Then they can be widely used in e-waste tracking systems to create a unique identifier for each electronic device, which allows the device to be tracked throughout the recycling process. In the case of e-waste tracking, for example, the data string could consist of information about the type of e-waste, its brands, its weight, and its origin. Once the data string has been generated, it is converted into a QR code using a QR code-generating algorithm. There are several open-source libraries available that can be used to generate and decode QR codes, including ZBar and ZXing (Jang, 2012; Widaningsih & Suheri, 2021).

The resulting QR code is a square black-and-white matrix that can be read by a QR code reader, typically found on smartphones, to reveal the data stored within. E-waste can be tracked from the time it is collected until it is disposed of or recycled by using QR codes in this; (Xu et al., 2021).

The generated codes can then be printed onto labels, stickers, or other materials and attached to the corresponding item or location. By scanning the QR code, the item or location can be easily identified and tracked.

The Python code below generates a unique QR code for each device in an inventory. The code generates a QR code with a unique ID and device information. It is important to note that the data structure (e.g., device_id, device_type) can be modified to meet the needs of the inventory and tracking system. This code makes use of a hypothetical list of device data and a simple data structure. This information would be retrieved from actual inventory or asset management systems in real-world applications.

```
import qrcode

# List of devices in the inventory (for demonstration purposes)
devices = [
    {'device_id': '123', 'device_type': 'PC'},
    {'device_id': '456', 'device_type': 'Laptop'},
    {'device_id': '789', 'device_type': 'Monitor'},
    # add more devices as needed...
]
def create_qr(data):
    # Create QR code instance
    qr = qrcode.QRCode(
        version=1,
        error_correction=qrcode.constants.ERROR_CORRECT_H,
        box_size=10,
        border=4,
    )
    # Add data to the QR code
    qr.add_data(data)
    qr.make(fit=True)

    # Create an image from the QR Code instance
    img = qr.make_image(fill='black', back_color='white')

    return img

# Generate a QR code for each device
for device in devices:
    data = f"ID: {device['device_id']}, Type: {device['device_type']}"
    img = create_qr(data)
    # Save the QR code as an image file

   img.save(f"QR_{device['device_id']}.png")
```

This script develops a unique QR code for each device and saves it as a.png image. To keep track of the generated QR codes, the image's filename corresponds to the device_id. The code on this platform follows a similar pattern, utilizing the.NET framework.

3.2 Tracking Definition in Programming

Tracking is a term used in programming and computer science to describe the action of continuously following or monitoring a subject or object. Depending on the circumstances, this can be accomplished in a variety of methods. Tracking, for example, is frequently used in web development to refer to the practice of monitoring a user's interactions with a website, often for analytics or personalization purposes (Spiekermann et al., 2001; Uchida et al., 2011).

Tracking in programming refers to the process of monitoring the location and status of objects throughout the entire process. Tracking can be accomplished via the use of different technologies such as GPS, RFID, and barcode scanning (Chanda, 2019; Dash, 2012; Li et al., 2015). Tracking can also be integrated with other systems, such as inventory management systems, to provide real-time data on device location and status (Mourtzis et al., 2016; Ning et al., 2016).

Tracking in the context of an e-waste tracking system consists of logging and updating the location and status of e-waste items as they move through the waste management process. A combination of hardware (such as sensors or scanners), software (to process and store tracking data), and network infrastructure (to transmit data between devices and servers) is typically used.

Tracking in programming frequently involves a variety of algorithms and data structures, depending on the system's requirements. Tracking systems, for example, may use databases to store tracking data, with database operations carried out using SQL (structured query language) or similar technologies. Furthermore, tracking systems may use graph theory or spatial data processing algorithms to calculate optimal transportation routes or to perform other location-based calculations (Reddy, 2018).

A basic tracking system may include functions for adding, viewing, and updating item status. For illustrative purposes, you can see a simplified example using C# and a basic Console Application. Please keep in mind that a real-world system would be much more complex, with databases, user interfaces, error handling, security measures, and so on, all of which have been considered in the proposed platform. The proposed e-waste tracking platform's tracking functionality has been implemented in this thesis using QR codes, geolocation technologies, and cloud-based technologies. The platform provides users with real-time tracking data, improving transparency and accountability in e-waste management.

```
using System;
using System.Collections.Generic;
class Program
{
    static void Main(string[] args)
    {
        EWasteTracker tracker = new EWasteTracker();
        tracker.AddNewItem("Device 1", "Location 1");
        tracker.UpdateItem("Device 1", "Location 2");
        foreach (var item in tracker.GetItems())
        {
            Console.WriteLine($"Device ID: {item.Id}, Location:
{item.Location}");
        }
    }
}
class EWasteItem
{
    public string Id { get; set; }
    public string Location { get; set; }
}
class EWasteTracker
{
    private List<EWasteItem> items;
    public EWasteTracker()
    {
        items = new List<EWasteItem> ();
    }
    public void AddNewItem(string id, string initialLocation)
    {
```

```
        EWasteItem item = new EWasteItem { Id = id, Location =
initialLocation };
        items.Add(item);
    }
    public void UpdateItem(string id, string newLocation)
    {
        EWasteItem item = items.Find(i => i.Id == id);

        if (item != null)
        {
            item.Location = newLocation;
        }
    }
    public List<EWasteItem> GetItems()
    {
        return items;
    }
}
```

In this example, we have an "EWasteTracker" class that manages a collection of "EWasteItem" objects. Each "EWasteItem" represents a tracked e-waste item and has a unique "ID" and "Location".

"EWasteTracker" presents methods for adding new items (AddNewItem), updating existing item locations (UpdateItem), and viewing all items (GetItems). The "Main" function in the "Program" class shows how to use these methods to track e-waste items.

It's important to keep in mind that this is an extremely simplified example. A real-world system would be much more complex, addressing issues such as concurrency, data persistence, error handling, security, and more.

3.3 Cloud-Based Technologies

Researchers and developers in the software industry have both taken notice of the cloud computing trend because of its potential. Cloud computing is a low-cost, scalable, and adaptable computing environment that enables remote access to shared resources. The term "cloud computing" refers to a computing model that delivers this service as a commodity to satisfy the regular requirements of businesses. Delivering software, hardware, and data storage over the Internet is what's known as "cloud computing" (Buyya et al., 2013). "Software as a service (SaaS), platform as a service (PaaS), and infrastructure as a service (IaaS) are the three delivery model categories for cloud computing services. Cloud service models can be seen in Fig. 2 "(Abd Elmonem et al., 2016).

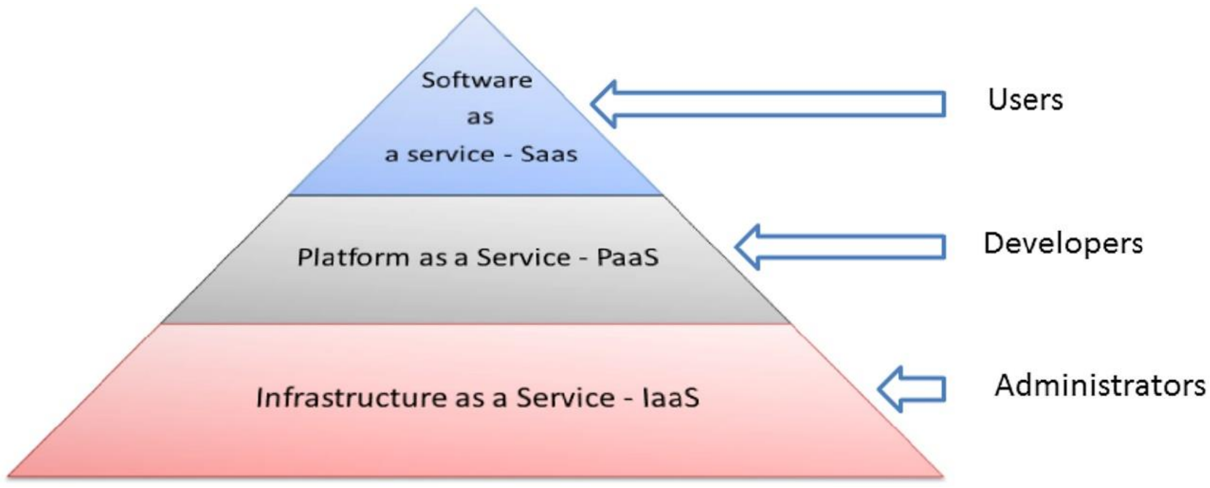


Figure 3-2: Cloud service models

(Abd Elmonem et al., 2016)

SaaS (Software as a Service) is aimed at the end-user or business. It is concerned with the distribution of software applications to multiple users via the Internet. Platform as a Service (PaaS) is the delivery of middleware that includes tools, services, and platforms aimed at software developers in order for them to create SaaS applications. Infrastructure as a Service (IaaS) is the delivery of computing power to administrators via hardware and software. The company pays for what it needs and expands its usage as its business grows.(Abd Elmonem et al., 2016)

Instead of keeping information on a computer or server at home, cloud-based technologies keep everything online. In the context of e-waste tracking systems, this technology offers many benefits, including accessibility, scalability, cost-effectiveness, and real-time data sharing (Mell & Grance, 2011).

Tracking systems have also made use of cloud-based technologies in many different industries. The use of cloud computing, for instance, has enhanced logistics management and enabled real-time tracking of goods in supply chain management (Gammelgaard & Nowicka, 2023; Yenugula et al., 2023) . In a similar vein, cloud-based systems have been adopted by the healthcare industry for patient monitoring and data management (Iranpak et al., 2021; Xu et al., 2017); Transport monitoring has used this tracking method in various aspects (Arthurs et al., 2021; Priyanka et al., 2021).

Cloud-based technologies, as previously stated, are internet-based computing systems that enable users to store and access data remotely. In e-waste tracking systems, cloud-based technologies can provide a platform for storing and managing data related to the recycling process, such as the location of electronic devices, the status of the recycling process, and the amount of e-waste generated. Cloud-based technologies can also provide real-time data on the location and status of devices, which can improve the recycling process's efficiency and transparency (Kang et al., 2020; Vincent Wang et al., 2015; Zhang et al., 2010).

Cloud-based technologies can be used in the context of e-waste tracking to store, process, and share data on e-waste collection, transportation, recycling, and disposal. These technologies can improve transparency and accountability in e-waste management by providing real-time access to this data (Rong et al., 2013).

Cloud-based technology, like all technologies, has advantages and disadvantages. The most significant opportunity provided by cloud computing is the ease of access to advanced computing resources without the need for upfront infrastructure investment. When compared to setting up and maintaining their own computing infrastructure, SMEs (Small and medium-sized enterprises) can benefit greatly from cloud computing (Mell & Grance, 2011). Furthermore, cloud computing allows organizations to easily adjust their computing needs in response to changing requirements. In the rapidly changing field of e-waste management, this adaptability is of the utmost significance (Kumar & Vidhyalakshmi, 2012). Finally, using cloud computing in e-waste tracking platforms can improve data sharing and collaboration among various stakeholders. The ability to access and update data in real-time from any location can significantly improve e-waste management processes' efficiency and transparency (Dey et al., 2022; Gopalakrishnan et al., 2020).

Despite its numerous advantages, cloud computing does pose some challenges. One of the primary concerns when using cloud services is data security. As sensitive data is moved to the cloud, ensuring its security against unauthorized access and breaches becomes increasingly important (Ren et al., 2015). Another issue is data privacy. When storing and processing data in the cloud, organizations must ensure that they comply with all relevant privacy regulations, which can be especially difficult when operating across multiple jurisdictions (Svantesson & Clarke, 2016). Finally, when data is stored on cloud servers in different countries, the issue of data sovereignty can arise, raising concerns about jurisdiction and control over the data. When selecting cloud service providers, businesses must be aware of these legal implications (Janssen & van den Hoven, 2015).

3.4 Geolocation Technologies

The process of determining or approximating the geographic location of an object is called geo-positioning, geo-tracking, geo-localization, geolocating, geolocation, or geo-position fixing. Positions can be expressed in terms of bearing and range from a reference point in addition to geographic coordinates (such as latitude and longitude) in a specified map datum produced by geo-positioning. In this way, a street address or other meaningful location can be determined from a set of coordinates. Some uses of geolocation technology include internet geolocation (the process of determining the physical location of an internet-connected device), mobile phone tracking, and animal geo-tracking (the inference of the location of animals) (Gentile et al., 2012).

Due to the widespread incorporation of digital location or "geolocation", as it is more commonly known, with web content, services, and interfaces, has become an integral part of the design, logistics, and organization of digital platform interfaces, utilities, and affordances. Users add location data to their social media posts in a variety of ways, including using geocoding for tweets and Snapchat's Geo-filters. Digital map data and geo-logistics are the backbone of ride-hailing platforms like Uber and Lyft, powering everything from in-route navigation to real-time driver tracking to the identification of riders' pick-up and drop-off locations. Tinder is a dating app that lets users narrow their search for a romantic interest to a specific radius. The short-term rental listings on Airbnb (an online marketplace) are presented in a map-based interface. An entire subset of the data broker industry has emerged to scrape, mine, repackage, analyze, and sell digital location data, particularly that collected from mobile devices (Leszczynski, 2019).

Geolocation technologies, such as GPS and RFID, can be used to track the location of electronic devices during the recycling process. GPS can provide real-time data on the location of devices, while RFID can be used to identify and track devices as they move through the recycling process. Geolocation technologies can help to improve the accuracy and efficiency of e-waste tracking systems, which can lead to more effective e-waste management. Latitude and longitude (lat/long) coordinates are used in geolocation, which is the process of gathering this information.

Technologies based on geolocation are essential for real-time monitoring. Many sectors, ranging from navigation and surveying to monitoring and surveillance, rely heavily on geolocation technologies. They make it possible to track the location of a specific device, object, or person. They provide the ability to determine the exact location of a tracked object using information about the device's geographic location, such as a smartphone. The Global Positioning System (GPS), Internet Protocol (IP) addresses, and radio frequency identification (RFID) will be discussed in detail below.

3.4.1 Global Positioning System (GPS)

Whenever there is a need for accurate time and location data anywhere on or near Earth, regardless of atmospheric conditions, the Global Positioning System (GPS), which is a space-based and/or satellite-based navigation system, can be used. Because it functions autonomously and does not require the user to transmit any data, GPS is a trustworthy and independent system for determining locations. There are approximately thirty satellites in the system, and they orbit the Earth at a distance of about 20,000 kilometers (Milner, 2016). These satellites broadcast microwave signals that are decoded by GPS receivers on the Earth's surface and give accurate and reliable time, velocity, and geographical coordinates.

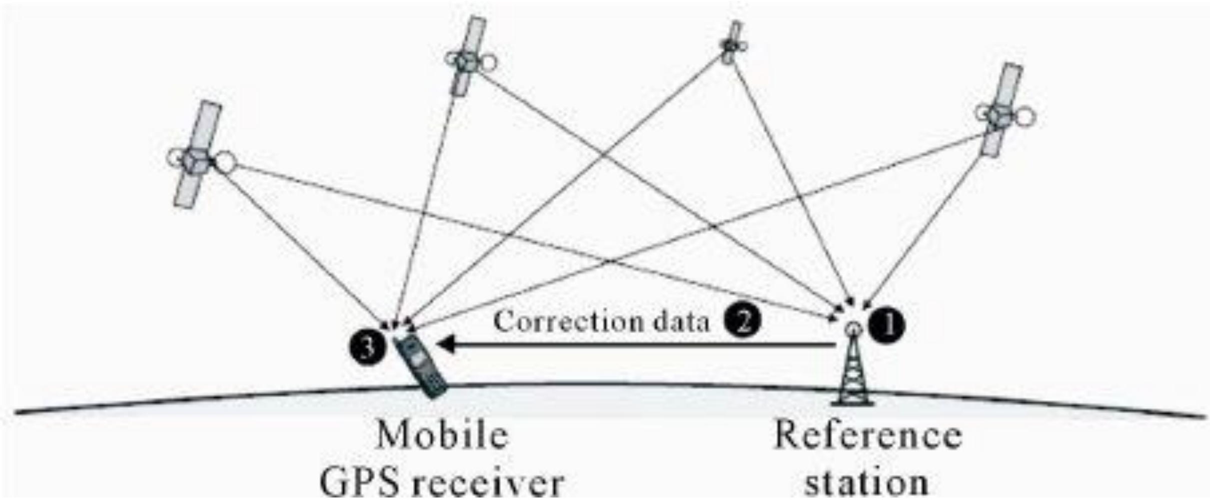


Figure 3-3: Simple GPS overview (Appendix 1)

In the context of e-waste tracking, as e-waste travels through the disposal process, GPS may supply accurate location data. This information can be used to track the movement of electronic waste and guarantee its proper handling and recycling (Bajaj et al., 2002; Lee et al., 2018).

3.4.2 Internet Protocol addresses (IP Address)

Each electronic device that uses the Internet Protocol (IP) on a network is defined by a unique numeric label that serves as its identifier. Internet Protocol (IP) addresses are given to devices by the Internet Service Provider (ISP) when they connect to the web. While IP addresses can be used to approximate a device's location, they are typically less accurate than GPS because they can only provide an estimate of the region based on how the network is configured and set up (Stone, 2000).

In the context of e-waste tracking, when GPS data is unavailable, IP address-based geolocation can be used as a fallback mechanism for the e-waste tracking platform. Even if GPS data cannot be obtained, this approach can help maintain a continuous record of the e-waste's journey (Fathi et al., 2022).

3.4.3 Radio-Frequency Identification (RFID)

RFID (Radio-Frequency Identification) tags attached to objects are automatically identified and tracked using electromagnetic fields. An RFID system is made up of two fundamental components: a tag and a reader. The tag, which can be attached to an object, contains information that has been electronically stored. The tags store information electronically, which can include location data. In contrast, the reader emits radio waves that cause the tag to respond with the information encoded in it (Xiao et al., 2007).

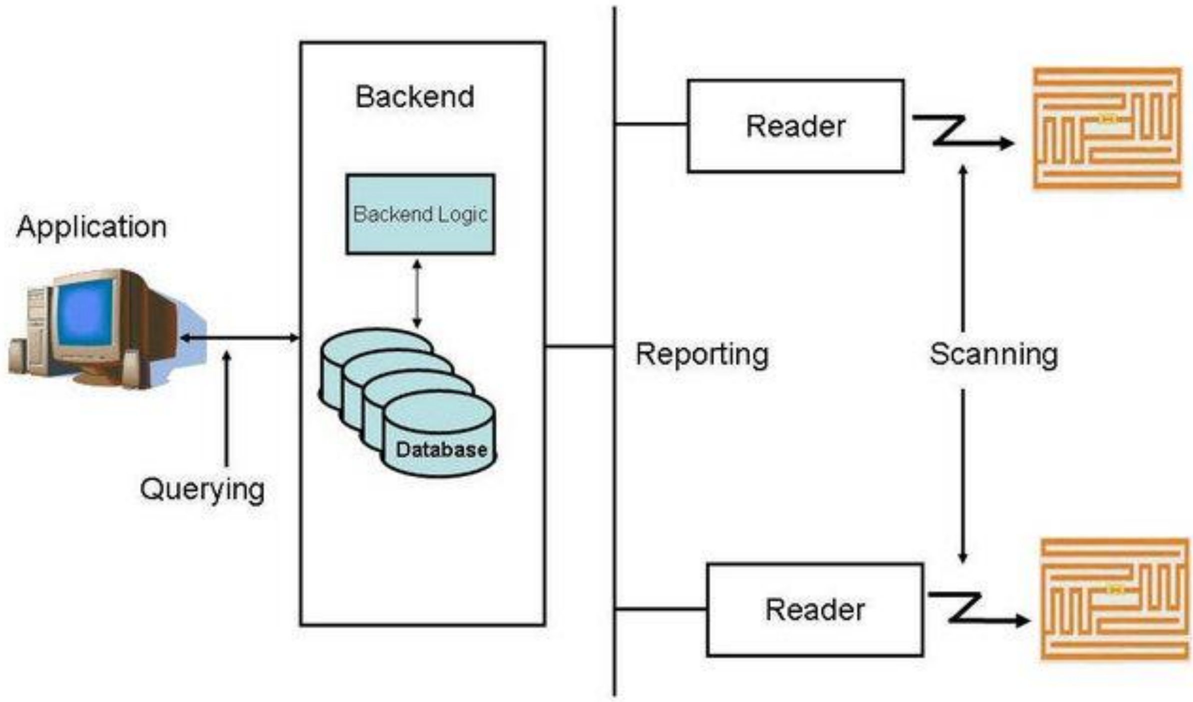


Figure 3-4: A simplified RFID system

(Jechlitschek, 2006)

RFID stands among the most significant identification technologies. Its technology is based on wireless communication, specifically radiofrequency waves, between an object-attached tag and an interrogator. This system makes product identification easier than with other methods, such as barcodes. RFID tags, for instance, can be inserted into boxes or containers, injected into animals, or embedded in any object, like passports, because they don't require visual contact.

Although barcodes have limited capabilities when compared to RFID, they remain on the market at the expense of RFID due to their current cost. Despite this, RFID systems are becoming increasingly popular in a wide range of industries. Over 3000 known use cases exist, ranging from logistics and identification to toll roads and pharmacy to item, pallet, and animal tracking (Bibi et al., 2017).

RFID technology provides an additional or alternative tracking mechanism for the proposed e-waste tracking platform. RFID tags can be attached to e-waste to track it even when it is not in range of GPS satellites or an IP-enabled network (Li et al., 2017).

3.5 Relevant Regulations and Standards

Many nations have taken steps to curb the growth of electronic waste and profit from the advantages of this potentially valuable secondary resource. More than 2000 sections of legislation from more than 90 jurisdictions are currently in force worldwide to regulate the negative effects of WEEEs (Ilankoon et al., 2018). In the past, environmental protection was the driving force behind most regulations and strategies, but nowadays, human health concerns are at the forefront of most management strategies (Thakur & Kumar, 2022). Table 1 lists some of the international groups and initiatives that have advanced the cause of proper monitoring and recycling. Each of these groups is working together to inform consumers and investigate potential e-waste management solutions (Patil & Ramakrishna, 2020; Thakur & Kumar, 2022).

Initiatives	Key features
Basal convention	Endorsed in 1992 to avoid exportation of hazardous waste from producer countries. 172 nations stand by the agreement but US does not ratify the treaty
Bamako Convention	Aimed to restrain the import of e-waste more stringently than Basel Convention. Applied in African Union nations from 1998
EU WEEE Directive	In 2007 all the EU members adopted the system with initiation of takeback approach for 10 groups of electrical things
Restriction of Hazardous Substances Directive (RoSH)	Enforced along with EU WEEE, particularly aimed to restrain the use of hazardous substances. also validated by various nations, counting China and India as well
Solving the E-waste Problem (StEP)	Initiated in 2007 by UN agencies to promote reusability of the recycled components to limits the waste generation
3Rs (Reduce, Reuse, Recycle)	Initiated by Japan. Work to prevent e-waste generation. Allows exportation to other countries for remanufacture and recycling. Convicting the goal of Basel Convention treaty
US State laws and the Responsible Electronic Recycling Act (HR2284)	25 states of US, imposed with the law. HR2284 is anticipated to control e-waste exportation. This law enforcers assembly and reprocessing of e-waste via stipulating deposits from consumers
US NGOs—Basel Action Network (BAN), Silicon Valley Toxic Coalition (SVTC), Electronics Take-Back Coalition (ETBC)	These three acts work to promote the “Basel Ban” amendment for restrictive transborder exportation. Enhance general e-waste assortment and reusing programs

National Strategy for Electronics Stewardship (NSES), US	Focus to limits the use of harmful substance Improve the handling and management strategies of e-waste in the US or reduce their harmful impact in other nations
International Environmental Technology Centre (IETC) 7– UNEP	Strengthen utilization of environmentally suitable technologies in developing nations on waste management
Global e-Sustainability Initiative (GeSI)	Focus to engage Information and Communication Technology (ICT) companies, industries and organizations to concern e-waste management

Table 3-1: Initiatives for e-waste regulation and legislation

(Thakur & Kumar, 2022)

3.6 Data Security and Privacy

Data security and privacy are two fundamental aspects of the digital world, ensuring that individuals' and entities' information is protected from unauthorized access, disclosure, alteration, or destruction. With an increasing amount of data being stored and processed electronically, maintaining data security and privacy has become paramount. This section delves into the theoretical background of these concepts.

3.6.1 Data Security

The measures, protocols, and strategies put in place to prevent modification, destruction, or unauthorized access to data are referred to as data security. It covers a wide range of technologies, devices, and practices aimed at protecting data from breaches, leaks, or hacks (Anderson, 2020). Data security techniques include encryption, which involves converting plaintext data into unreadable ciphertext using a key; access controls, which limit who can access certain data; and authentication, which verifies a user's identity before providing data access. Firewalls are used alongside intrusion detection systems (IDS) to monitor and restrict network traffic (incoming and outgoing data) based on established security policies (Stallings & Brown, 2018).

3.6.2 and Privacy

Data security deals with keeping data safe from intruders and external threats, while data privacy is related to the lawful and fair treatment of data, especially personal data. Information security includes all phases of data lifecycle management, from collection to disposal. To protect individuals' privacy, it mandates that organizations treat sensitive data with care (Petrescu & Krishen, 2018).

Legislation such as the California Consumer Privacy Act (CCPA) of the United States and the General Data Protection Regulation (GDPR) of the European Union protect individuals' right to privacy in their personal and private data. Consent must be obtained prior to data collection, individuals must be informed of how their data will be used, and individuals must be given the means to access, modify, or delete their data (Schwartz & Solove, 2011).

4 Methodology

The purpose of this dissertation study is to develop a robust and reliable e-waste tracking platform that can address the current challenges in the e-waste management sector. A qualitative review of the literature on e-waste, its tracking system, and the theoretical background of each component of the system had been completed prior to this chapter. In-depth research was conducted on use cases for tracking system implementations. The research methodology can be seen in figure 4-1.

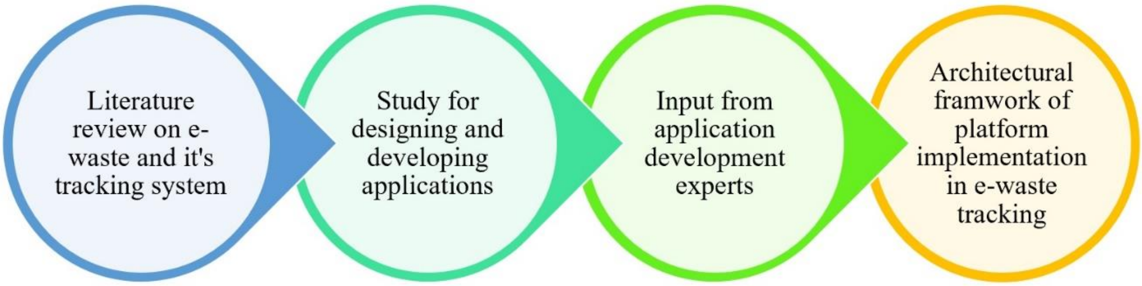


Figure 4-1: The research methodology

The updated figure 4-1 in this chapter depicts the research methodology, which represents the steps taken in the development of the e-waste tracking platform. The figure serves as a visual roadmap, highlighting the key stages and providing the reader with an immediate understanding of the processes involved in the development of this complex system. The role of expert consultation is also illustrated, emphasizing their significant contribution to developing the architectural framework of the e-waste management tracking system. Overall, the revised figure (Figure 4-2) serves as a comprehensive visual guide that describes the detailed journey of the e-waste tracking platform's development.

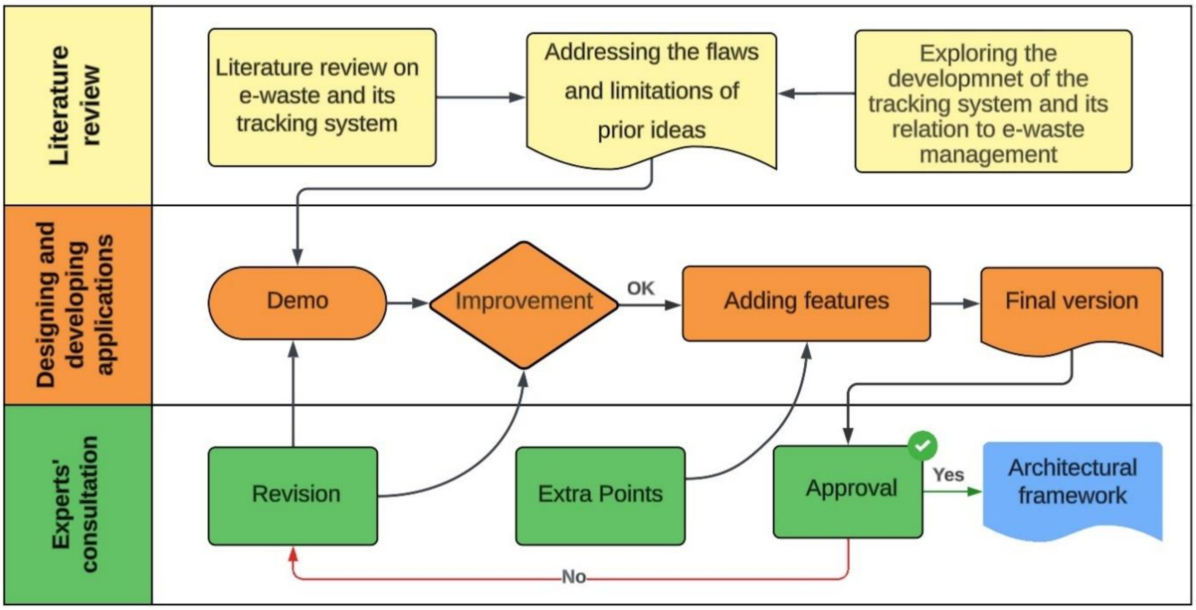


Figure 4-2: The revised project methodology

This chapter describes the methodology used to develop this platform, from the initial stages of QR code generation and scanning to advanced aspects such as data storage methods, user authentication, and cloud-based technology implementation. Every step is described in detail. Furthermore, the framework emphasizes the iterative and cyclical nature of the process, focusing on the system's continuous refinement and improvement. Experts' ideas and consultation were considered in developing the architectural framework for tracking e-waste management implementation. The architectural framework for tracking implementation is shown in figure 4-3.

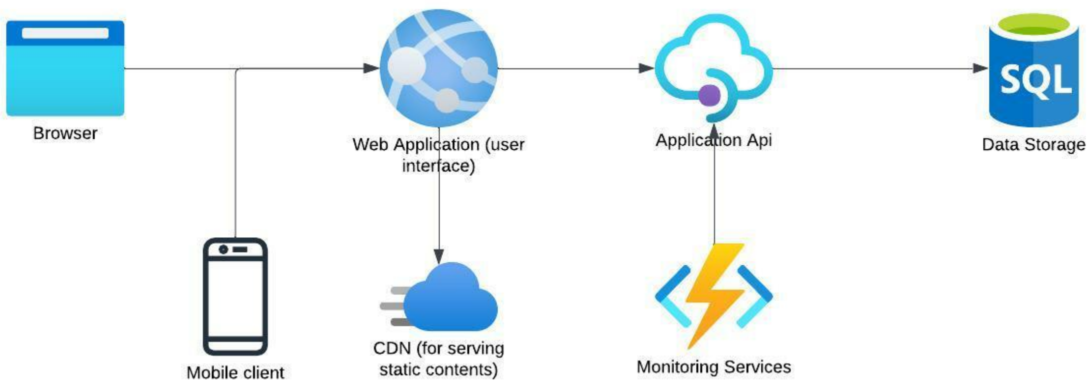


Figure 4-3: The architectural framework for tracking implementation

4.1 QR Code Generation and Scanning Process

Each device is assigned a unique QR code in order to effectively track individual pieces of e-waste. The QR codes are created with an algorithm that ensures each code is unique, allowing each piece of e-waste to be tracked separately. After that, the QR codes are printed and physically attached to the e-waste. The QR code can contain data such as the type of e-waste, its origin, and the date it was deposited in the waste management system.

This platform saves identifier of the device in the unique QR code and after scanning user is redirected to the tracking page on the platform.

The QR codes are read using a smartphone or a dedicated scanning device during the scanning process. When the device undergoes scanning, it connects to the tracking platform, retrieves the e-waste's information from the platform, and displays it to the user.

4.2 Data Storage Methods and Technologies

Given the large volume of e-waste handled on a daily basis, it's critical to use a data storage method that can handle such large volumes of data. To ensure that the platform can handle the expected data loads, we use a combination of database technologies, including SQL for structured data and NoSQL for unstructured data.

4.3 Authentication and Authorization of Users

We use a multi-tiered user authentication system to ensure that only authorized personnel can access and change the data on the e-waste tracking platform. Access levels are assigned to users based on their role in the e-waste management process. A waste collector, for example, may only have access to the scanning function, whereas a regulator may be able to view and download the entire e-waste data set.

Task/Role	Anonymous	Scanner	Administrator	Super-Admin
Track a device	x	x	x	x
Register a device	-	x	x	x
Scan new location	-	x	x	x
View all devices	-	-	x	x
Manage users	-	-	-	x

Table 4-1: Roles and their associated permissions in the e-waste tracking platform

Table 4-1 shows the various roles and their associated permissions in the e-waste tracking platform. Anonymous users, scanners, administrators, and Super-Admin are among the roles available. Here's a more in-depth explanation of the table:

4.3.1 Anonymous

This role represents an ordinary user who has not logged into the system or has no account. This user can only perform the "track device" operation, which allows them to see a device's current location and status by using its unique identifier. They are unable to register a device, search for a device in a new location, view all devices in the system, or manage users.

4.3.2 Scanner

The scanner role most likely represents employees or workers who are in charge of scanning devices as part of the e-waste tracking process. They can also "register device," which means adding new devices to the system, and "scan new location," which updates the system when a device's location changes. They are unable to see all devices in the system or manage users.

4.3.3 Administrator

In comparison to the anonymous user and the scanner, the administrator has more privileges. The administrator can "view all devices" in addition to tracking, registering, and updating the location of devices, giving them a broader overview of the system. However, they cannot manage users.

4.3.4 Super-Admin

The Super-Admin has the highest level of system privileges. They can track devices, register devices, scan for new locations, view all devices, and manage users. They can use the "manage users" operation to add, remove, or change the roles of users in the system.

This permissions system is used in both the platform's authentication and authorization processes. Authentication verifies a user's identity, while authorization controls which operations a user can perform based on their role.

4.4 Cloud-based Technologies

The use of cloud-based technologies is critical to ensuring that the e-waste tracking platform is scalable and accessible from any location. A cloud server hosts the entire platform, including the database and user interface. This configuration allows for easy access to the platform regardless of the user's location. Furthermore, cloud hosting provides the benefit of easy scaling, which means that the platform can handle an increase in data volume or user load with little disruption to its performance.

This e-waste tracking platform was created through a rigorous process that included careful consideration of various technologies and methods. We hope to significantly improve e-waste management practices with this platform by increasing transparency, efficiency, and accountability.

4.5 Platform description

The process for developing an e-waste tracking platform includes five steps, including Registration, Tracking, Visualization, Administration, and Storing data. These steps have been shown in figure 4-4.

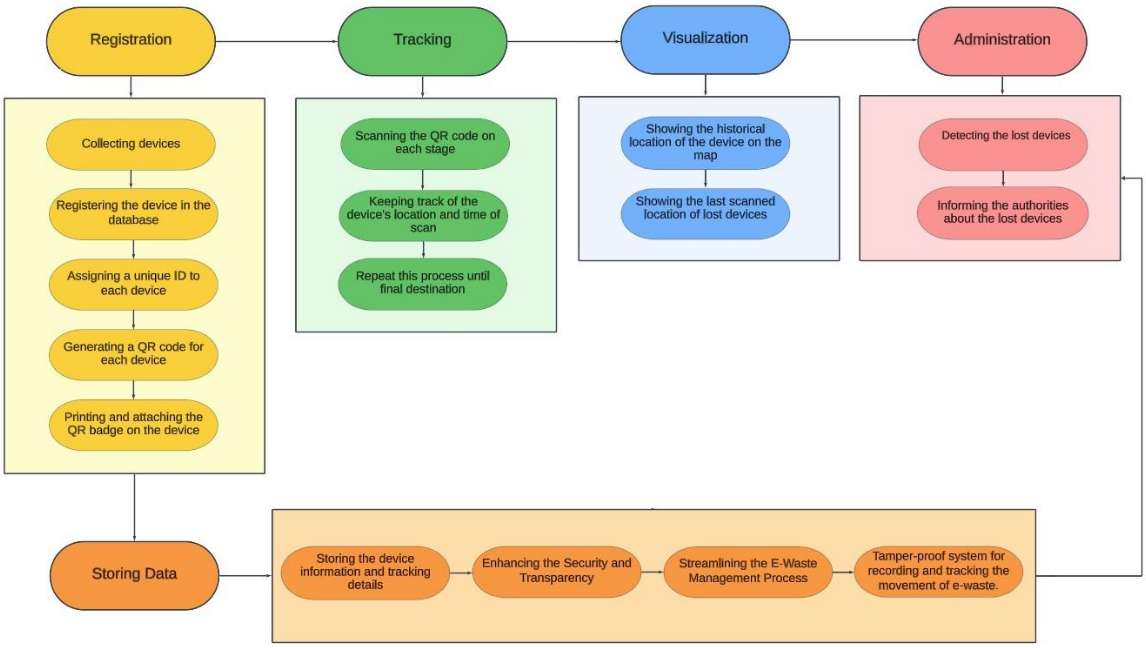


Figure 4-4: The process for developing an e-waste tracking platform.

4.5.1 Registration

During this stage, devices that have reached their end-of-life (EOL) period are collected and identified as e-waste. Each device's specifications, such as model, manufacturer, year of production, etc., are recorded in the system database. The system gives each device a unique ID after it has been successfully registered (Figure 4-5).

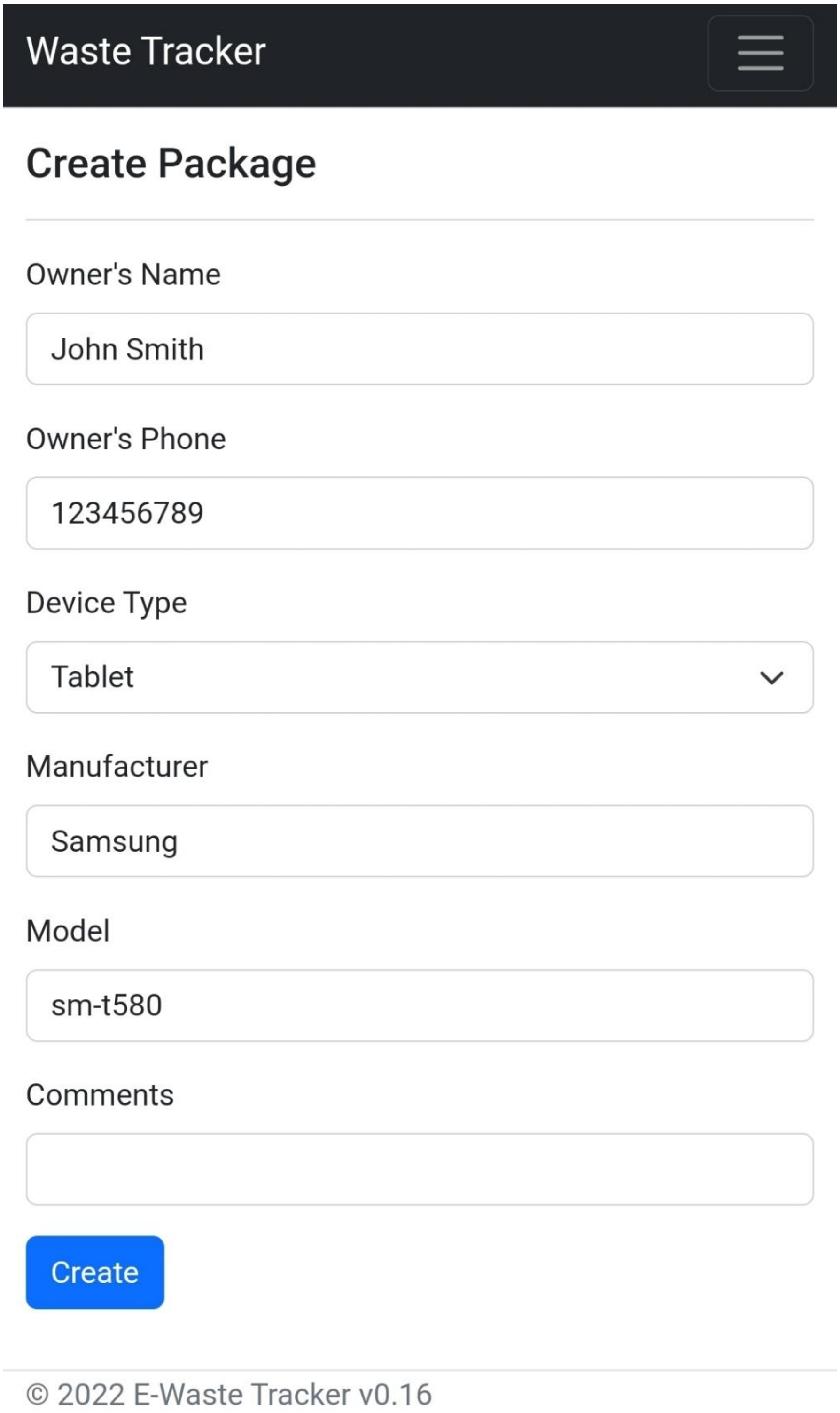


Figure 4-5: Device registration on the platform

Now is the time to generate a QR code (Figure 4-6). This unique ID is used to generate a QR code that is specific to each device.

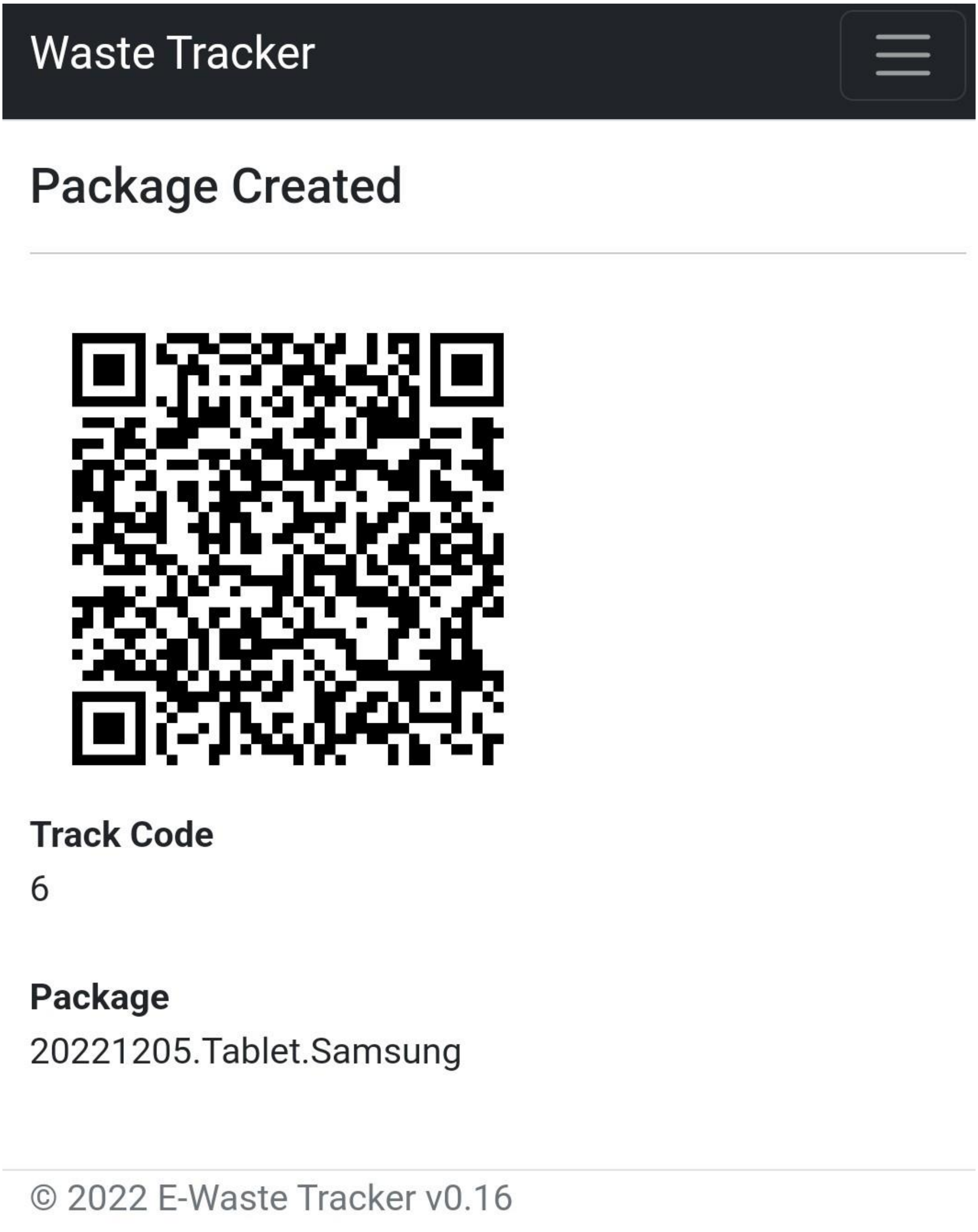


Figure 4-6: Generate a QR code for the device.

This QR code can be printed out and attached to each device as a badge (Figures 4-7, 4-8).

Figure 4-7: Printing the QR code.

Figure 4-8: Attaching the QR code.

Although a machine-learning or deep-learning approach can frequently perform e-waste recognition, this platform instead uses manual data entry to keep the procedure simple and straightforward.

4.5.2 Tracking

The tracking process begins when the QR code is scanned with a mobile device, which is usually at the first point of collection. This is the starting point for the tracking procedure. The tracked e-waste is then linked to the GPS location of the device that scanned the QR code at each destination.

The system then logs the exact date and time of this action, appending a timestamp to the location data. This procedure is repeated at each stage of the e-waste's journey until it reaches its final destination. This is noteworthy that this destination can be specified, which means that the exact location can be pre-designated.

All tracking data, including the location, and timestamp, is immediately updated in the database after each scan. Users can enter the tracking code assigned to the device in the registration section at any time to view the current location and movement history of each device. (Figures 4-9).

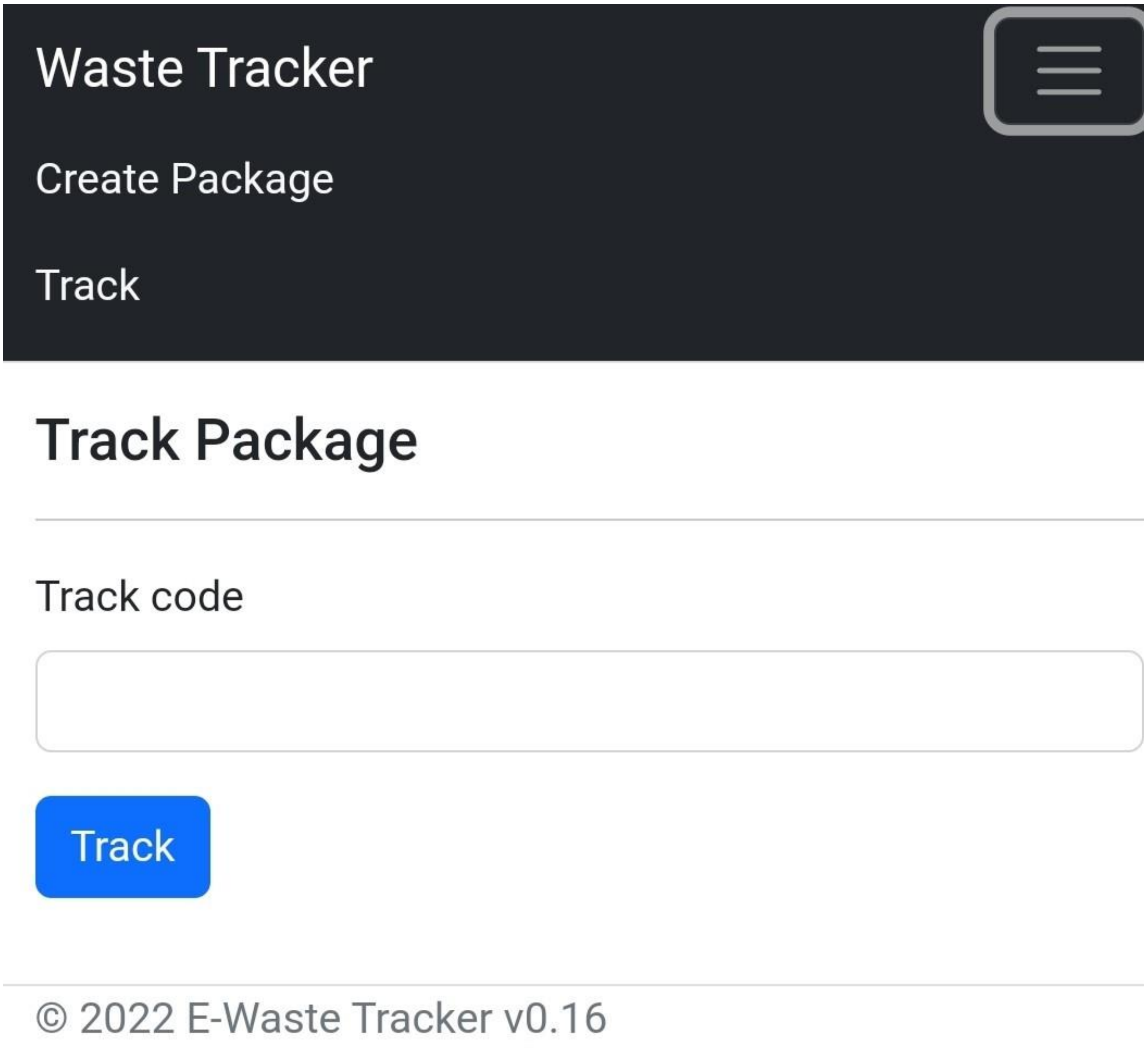


Figure 4-9: Monitoring the tracking code assigned to the device.

4.5.3 Visualization

When the e-waste movement has been tracked, Platform can visualize the trend in location based on time logs (Figures 4-10). This visualization provides a graphical representation of the device's movement, making it easy to follow and understand. If the device is lost at any stage, the application can instantly show the latest scanned location of the lost object and send an alert to the system administrators. For example, if no new location data for a device is received after a certain period of time, the system could conclude that the device has disappeared.

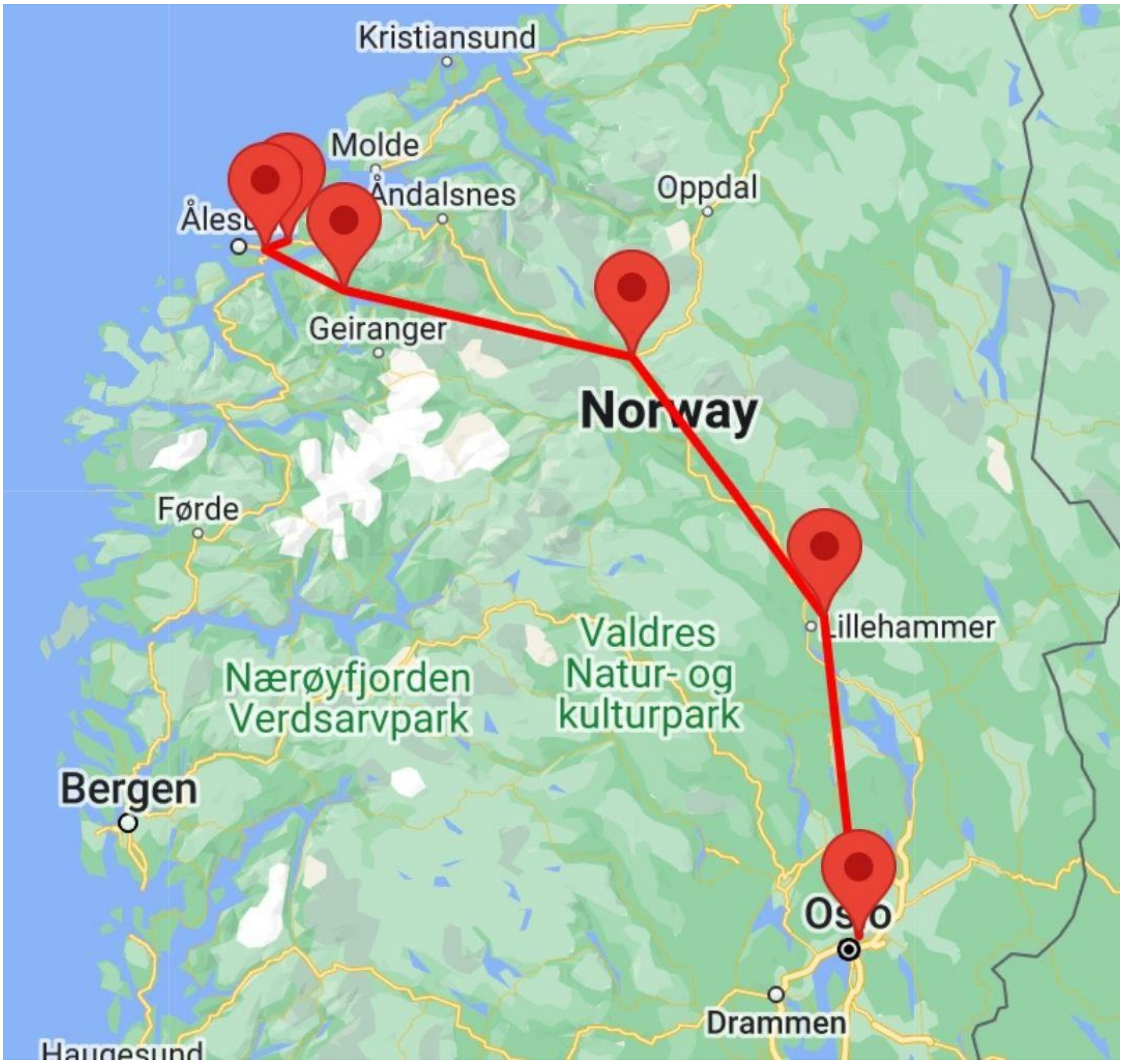


Figure 4-10: Visualizing the device's movement on the map.

4.5.4 Administration

This section has been developed particularly for system administrators to monitor the system status and track the devices that are currently in the system (Figures 4-11, 4-12). The administrative panel displays a summary of the system's current state, device counts, active trackers, and other vital statistics.

Track Code	Package	Creation Date	Map
19	Other.Google.20221206	2022/12/06 22:48	View
18	Phone.Google.20221206	2022/12/06 22:47	View
17	Other.Samsung.20221206	2022/12/06 22:47	View
16	Laptop.HP.20221206	2022/12/06 22:46	View
15	Tablet.Asus.20221206	2022/12/06 22:45	View
14	Computer.Dell.20221206	2022/12/06 22:45	View
13	Computer.Sony.20221206	2022/12/06 22:45	View
12	Tablet.Samsung.20221206	2022/12/06 22:44	View
11	Phone.Samsung.20221206	2022/12/06 22:43	View

Figure 4-11: Tracking the different devices with different tracking code.

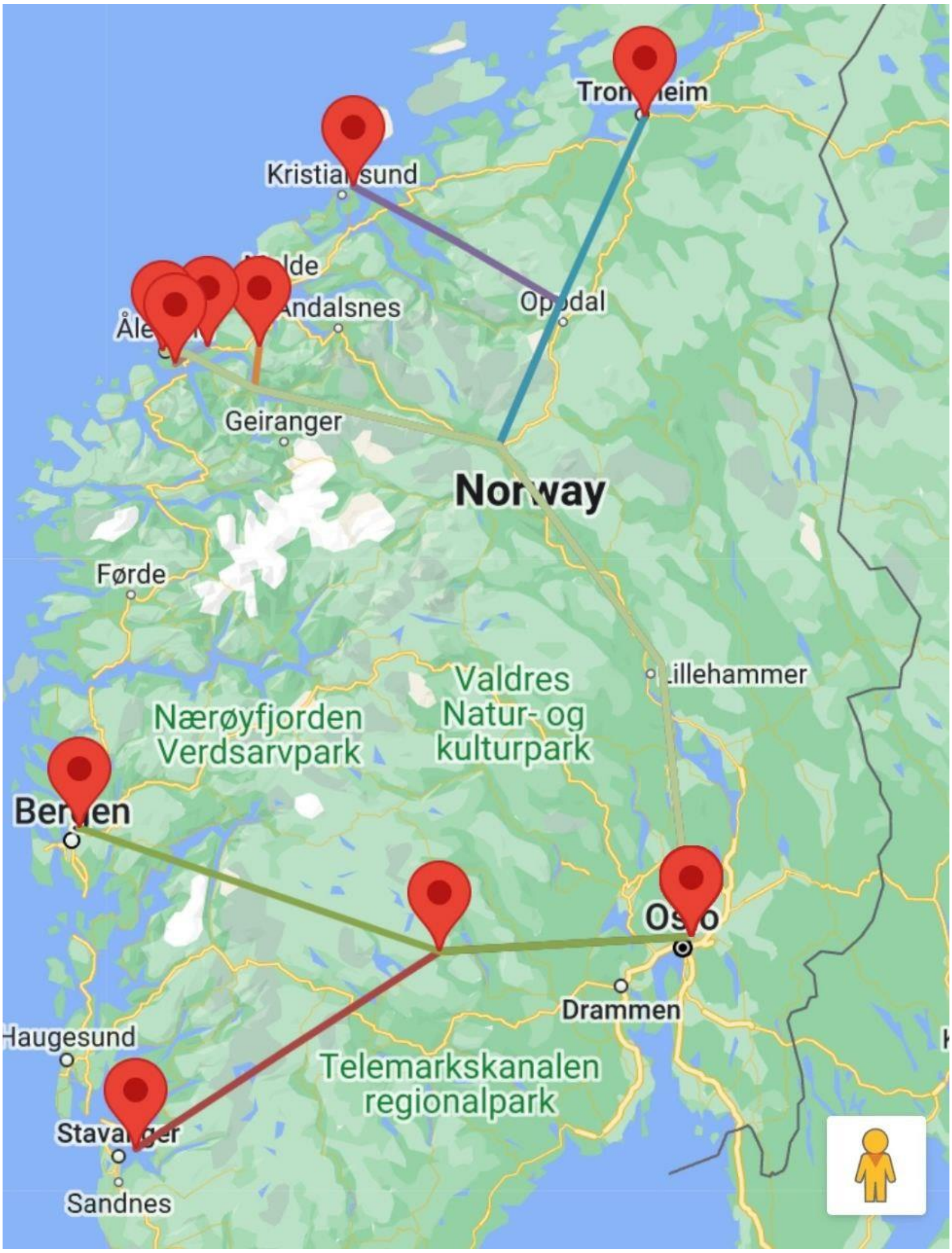


Figure 4-12: Visualizing the devices that are currently in the system.

4.5.5 Storing data

This step has been dedicated to storing data collected during the tracking process. The main goal of this part is to securely store the tracking data in a way that ensures its integrity and availability.

The platform uses cutting-edge data storage technologies to securely store all e-waste tracking data (Cloud computing technology). This includes the device IDs, specifications, tracking data (GPS locations and timestamps), and final destination information. To ensure maximum security, all data is stored securely in databases and encrypted at rest as well as during transit.

Data is backed up on a regular basis to prevent data loss and ensure data availability even in the case of a system failure. The data storage system is scalable, which ensures that the platform can handle an increasing volume of e-waste tracking data as the number of tracked devices grows over time.

The pseudocode for the tracking platform is shown in the below algorithms.

Algorithm 1 Function to register e-waste

```
function RegisterDevice(deviceSpecifications)
    uniqueID = GenerateUniqueID(deviceSpecifications)
    Database.AddDevice(uniqueID, deviceSpecifications)
    QR_code = GenerateQRCode(uniqueID)
    return uniqueID, QR_code
end function
```

Algorithm 2 Function to track e-waste

```
function TrackDevice(deviceID, location)
    Database.AddLocation(deviceID, location) if IsDeviceLost(deviceID, location) then
        SendAlert(deviceID, location)

    return location
end function
```

Algorithm 3 Function to visualize the movement of e-waste

```
function VisualizeDeviceMovement(deviceID)
    locationHistory = Database.GetLocationHistory(deviceID)
    PlotLocations(locationHistory)
    return locationHistory
end function
```

Algorithm 4 Function to administer the system

```
function AdministerSystem
    systemStatus, listOfDevices = Database.GetSystemStatus()
    return systemStatus, listOfDevices
end function
```

Algorithm 5 Function to automate the tracking and management of e-waste

```
function AutomateEwasteTrackingAndManagement(deviceSpecifications, deviceID, location)
    uniqueID, QR_code = RegisterDevice(deviceSpecifications)
    location = TrackDevice(deviceID, location)
    locationHistory = VisualizeDeviceMovement(deviceID)
    systemStatus, listOfDevices = AdministerSystem()
    return uniqueID, QR_code, location, locationHistory, systemStatus, listOfDevices
end function
```

Figure 4-13 The pseudocode for the tracking platform

5 Results

This chapter discusses the results of implementing the developed e-waste tracking platform, created according to the outlined methodology. To achieve this goal, extensive testing and evaluation of the platform were conducted in order to ensure it would perform as expected.

5.1 Registration

The process of registration was thoroughly tested by generating unique QR codes for several kinds of e-waste devices. The registration system was observed to have successfully developed a unique ID for each piece of e-waste and recorded the data that was required in the database. Each unique ID was additionally embedded into a QR code, which could be printed and placed on the e-waste device to help track it in the future. The QR code generator part of the platform worked efficiently and quickly, so a lot of devices could be registered in a short amount of time. This showed how the system could be expanded to handle huge volumes of e-waste without compromising the registration process's speed and efficiency.

5.2 Tracking

The tracking system additionally demonstrated high levels of accuracy and efficiency. Different smartphone models and operating systems were used in scan compatibility tests. The system was able to successfully connect the location of the mobile device with the scanned e-waste, allowing for real-time monitoring of the waste stream. It was also noted that the system recorded the time log of each tracking action promptly, resulting in a reliable and accurate timeline of the e-waste device's movement.

Furthermore, it was found during the testing phase that the platform is capable of handling multiple simultaneous tracking processes, allowing for multiple devices to be tracked at the same time without any system errors or delays, which reinforces the platform's scalability.

5.3 Visualization

The platform's visualization component provided a clear and interactive representation of the tracked movement of e-waste. Based on time logs, the system successfully plotted location trends. The plotted visualizations were simple to understand and provided a clear visualization of the e-waste devices during their journey.

In the unlikely scenario of any flaws or a device being lost during any stage, the system was able to accurately indicate the device's last scanned location. This information was especially useful in troubleshooting, solving problems, and finding solutions when devices were lost or misplaced.

5.4 Administration

The administration system provided a broad perspective on the state of the system and the devices being tracked. The system's ability to give system administrators real-time updates on the state of the system and the tracked devices served as evidence of its effectiveness. This not only facilitated efficient management but also ensured that any issues and flaws with the system would be detected and fixed quickly, which led to preserving the system's efficiency and dependability. The platform's administrative features were found to work as intended, with different permissions for various levels of users being managed and controlled through an intuitive user authorization system in a way that is simple to understand. Different user roles, such as administrators, tracking personnel, and regulatory authorities, can be granted varying degrees of access to the system's features, functionalities, and data thanks to the fine-grained nature of the access control provided by the user authorization system.

The system administrators were provided with the highest level of access and were able to observe both the overall state of the system and the details of each tracked device. Access to location history, device details, and specifications, as well as the ability to manage user permissions, are all part of this level of access. The access control system prevented unauthorized access, increasing the general security level of the platform.

However, tracking staff and regulatory authorities were only granted limited access, with permissions centered around their role-specific responsibilities and the fact that this data was necessary for them to carry out the duties they have. The tracking personnel tasked with keeping track of things could simply scan the QR codes to update location information, while authorities could access and check the tracking data to ensure compliance with regulations.

As a result, the user authorization system minimized the possibility and risk of data breaches and improved system security by making sure that only authorized users could access sensitive data which explain in section 4.3 in detail. This proved the platform could handle large amounts of sensitive data about e-waste while keeping it secure and anonymous.

In conclusion, the e-waste tracking platform was found to be effective in addressing many of the challenges in the e-waste management sector due to its efficiency, security, and scalability. The platform's security was further enhanced through the incorporation of user authentication and authorization systems, making it a trustworthy option and reliable solution for e-waste tracking and management. Improved location tracking and automated device recognition using machine learning methods are two areas that could be incorporated in the near future.

5.5 Storing data

The reliability and efficiency of the data storage system were also checked and evaluated. All the tracking data was securely stored in the cloud and could be retrieved immediately as needed by the system or whenever needed by the users. The platform's scalability was demonstrated by its ability to process a large amount of data without negatively impacting performance. The cloud-based data storage also provided flexibility, as it could be accessed from any location at any time, allowing for remote monitoring and management of the e-waste tracking system.

As a result, the developed e-waste tracking platform was able to provide a robust, efficient, and reliable e-waste tracking solution, fulfilling the functionality for which it was designed and developed. It overcame problems that had been impacting e-waste tracking systems in the past and showed great promise in enhancing the state of the art in e-waste management. The platform has the potential to become an even more effective tool for e-waste management with further development and customization based on the needs of individual users in different layers of accessibility.

5.6 Challenges and User Feedback

Several challenges came up during the development and implementation of the e-waste tracking platform that needed to be addressed. One major challenge was ensuring the platform's scalability to handle large amounts of data while maintaining high performance. Because of the use of cloud-based technologies and strong data management strategies, the platform was able to scale effectively as the volume of tracked e-waste increased.

Another challenge was to ensure that the QR code on the e-waste devices was easily readable and durable enough to survive the extreme conditions that e-waste is frequently exposed to. The solution was to print the QR codes on highly durable materials and to ensure that the printed codes were of high quality and large enough to be easily scanned.

Throughout the platform's development and after its initial implementation, tester feedback was also gathered. The feedback was mostly positive; users mentioned the platform's ease of use and efficiency in managing e-waste. They discovered the QR code scanning feature to be simple and convenient, making it easier to track the movement of e-waste. It is worth noting that, due to a lack of time and the fact that the testers are only a few NTNU students, this section could be improved by conducting surveys and measuring user satisfaction. However, the user authorization feature should have been tested by users, which was not possible.

Some testers, however, mentioned the need for more robust location tracking, implying that the platform could benefit from the incorporation of other geolocation technologies. This feedback will be invaluable in informing future platform improvements.

Despite these obstacles, the e-waste tracking platform achieved its goal of improving the efficiency and transparency of e-waste management. The positive feedback from testers and the effective resolution of issues highlights the platform's potential to revolutionize e-waste management.

6 Discussion

6.1 Implications of the Findings for E-Waste Management

Wide-ranging effects of the e-waste tracking platform's implementation can be expected in this area of waste management, providing a robust, user-friendly, and cost-effective tracking system that addresses significant existing challenges.

Using QR codes has significantly simplified the procedure for keeping track of and managing electronic waste. The platform provides an efficient, simple, and straightforward method for keeping track of electronic waste, which can be an enormous boost to the efficiency and effectiveness of businesses by improving their operations that deal with e-waste.
Transparency in the handling of electronic waste is likely to increase as a result, which has a significant implication. Manufacturers, waste collectors, recyclers, regulators, and even normal users can all benefit from real-time e-waste tracking by having access to accurate and up-to-date information about the status and location of e-waste. This unprecedented transparency has the potential to reduce instances of illegal disposal or mismanagement of electronic waste and encourage more sustainable and responsible approaches to recycling. It also increases the attitude toward recycling personal e-waste by boosting the trustworthiness of end-users, who were concerned about personal information being saved on devices in the past.

6.2 Comparison with Existing Methods

There are several advantages to the proposed platform in comparison with conventional approaches to e-waste management. Manual tracking and paper-based documentation are usual in conventional approaches and traditional methods, but these procedures are not only inefficient but also highly vulnerable to errors. In contrast, the digital nature of the proposed platform considerably decreases the possibility and risk of errors and boosts the efficiency of the tracking process.

In addition, it is difficult to accurately track the movement of e-waste using traditional methods due to a lack of real-time tracking capabilities. This makes it very difficult to keep track of exactly where e-waste is going. However, the platform that has been proposed in the present study makes real-time tracking possible and offers a reliable and highly accurate approach to e-waste management.

6.3 Future Challenges and Developments

As the e-waste management landscape continues to evolve, several challenges and issues can be anticipated, and potential improvements and opportunities will invariably arise. One challenge, for example, is integrating emerging tracking technologies. While QR codes provide a simple and efficient method for tracking e-waste, the incorporation of additional tracking technologies, such as RFID or GPS, can further enhance the platform's tracking capabilities, despite the associated challenges of implementation. Future iterations of the platform will investigate the feasibility of incorporating these technologies, as well as other possibilities.

Integration of machine learning and artificial intelligence technologies to automate the process of identifying and classifying e-waste is another promising future direction and potential development. This can improve the platform's efficiency and reduce manual workload. Machine learning algorithms, for example, could be used to predict the lifespan of electronic devices or to identify patterns in e-waste generation, providing useful insights for improving e-waste management strategies.

Incorporating blockchain technology into the tracking system is an exciting new future direction. Blockchain's decentralized nature can add an extra layer of security and transparency by providing an immutable and tamper-proof record of e-waste movement. This transparency can boost stakeholder trust in the e-waste management process and prevent any potential mismanagement or illegal e-waste disposal. However, implementing blockchain technology will also present challenges, such as the need for significant computational resources and dealing with the slow transaction speeds of some blockchains. It would be critical to address these issues thoughtfully in future platform iterations.

Finally, the e-waste tracking platform proposed in this study not only represents a significant improvement over traditional e-waste management methods but also serves as a model for sustainable and responsible e-waste management. The platform's efficiency, reliability, and transparency have the potential to revolutionize e-waste management and contribute to a more sustainable and responsible approach to e-waste management. Its **user-friendly design, cost-effectiveness, emphasis on personal confidentiality**, and potential to incorporate blockchain for enhanced safety and privacy all point to its transformative potential. As technology advances, ongoing efforts to continually update and improve this platform will be required to meet the changing landscape of e-waste management.

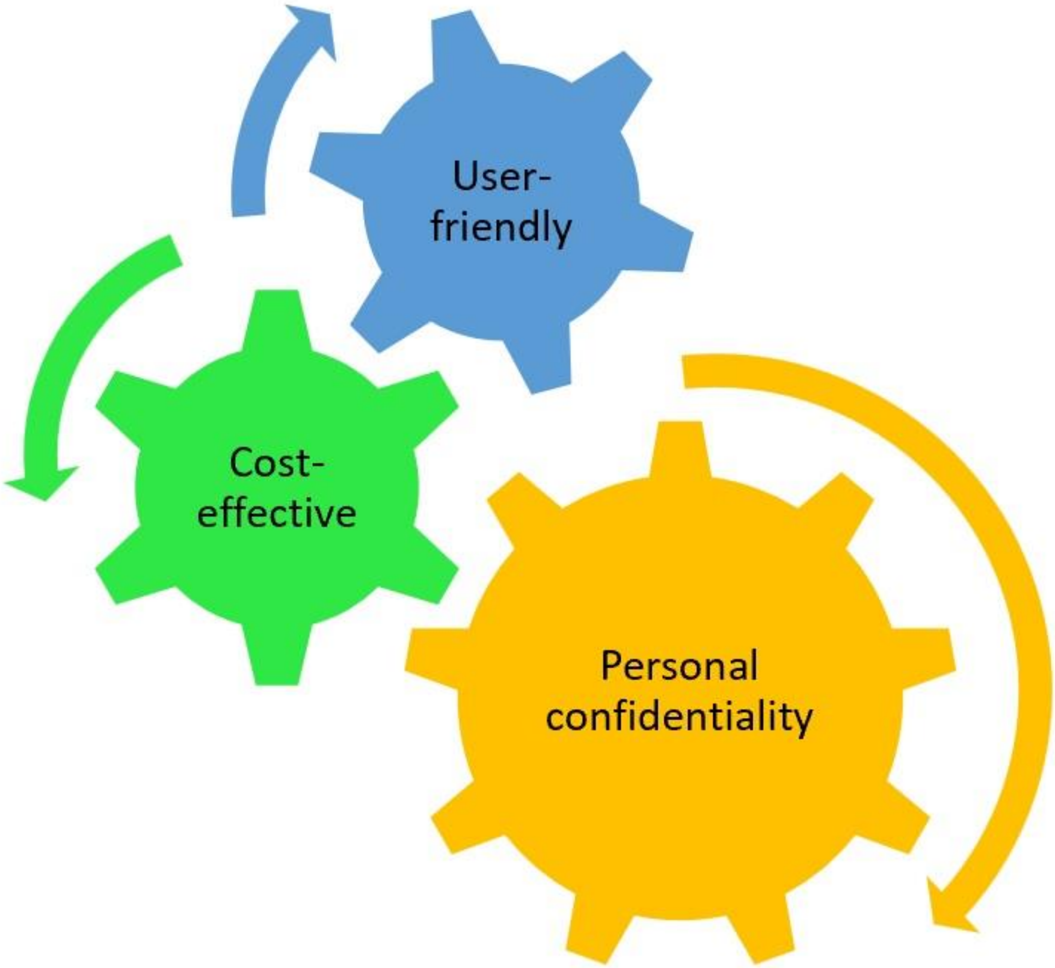


Figure 6-1 The proposed platform's benefits and impacts

7 Conclusion

7.1 Contributions

The research conducted in this thesis is extremely valuable in the context of e-waste management, implementing multiple significant contributions. The development and implementation of a robust, user-friendly, and cost-effective e-waste tracking platform have been the main output. The use of QR codes for e-waste tracking has simplified or even revolutionized the process, providing an innovative and straightforward solution that considerably enhances e-waste management business operations.

Another important contribution is the platform's ability to improve transparency throughout the e-waste management chain. The platform empowers all stakeholders, from manufacturers, waste collectors, recyclers, and regulators to individual users, by providing real-time tracking and timely access to data about the status and location of e-waste, promoting an environment of accountability, and promoting responsible recycling practices.

Finally, the study has made significant progress in addressing critical concerns about personal confidentiality in e-waste management. The platform's dedication to data privacy reflects a nuanced understanding of the e-waste tracking landscape. The proposed future integration of blockchain technology, which would ensure increased safety and privacy, is evidence of this effort.

7.2 Future work

Looking in advance, this research opens up numerous possibilities for future platform exploration and enhancement. One such direction is the incorporation of various tracking technologies, such as RFID or NFC, to supplement the QR code system and improve the platform's tracking capabilities.

Another exciting development that will be pursued is the use of artificial intelligence and machine learning to automate the process of identifying and categorizing e-waste. This type of integration could help to streamline the e-waste management process, providing predictive insights about the lifespans of electronic devices and identifying patterns in e-waste generation.

Furthermore, the incorporation of blockchain technology represents a promising future direction. The decentralized nature of blockchain can add an additional layer of security and transparency to the tracking process, providing an immutable, tamper-proof record of e-waste movement.

Finally, the e-waste tracking platform presented in this thesis represents a significant advancement in the field of e-waste management. It lays the groundwork for a more sustainable and responsible approach to managing e-waste in the future with its user-centric design, commitment to transparency and confidentiality, and vision for incorporating emerging technologies. As we move forward, it is critical that we constantly refine and improve the platform to keep up with evolving technological advancements and environmental needs.

References

Abalansa, S., El Mahrad, B., Icely, J., & Newton, A. (2021). Electronic waste, an environmental problem exported to developing countries: The GOOD, the BAD and the UGLY. *Sustainability*, *13*(9), 5302.

Abbas, S., Nasir, Q., Nouichi, D., Abdelsalam, M., Abu Talib, M., Abu Waraga, O., & Khan, A. U. R. (2021). Improving security of the Internet of Things via RF fingerprinting based device identification system. *Neural Computing and Applications*, *33*(21), 14753-14769.

Abd Elmonem, M. A., Nasr, E. S., & Geith, M. H. (2016). Benefits and challenges of cloud ERP systems–A systematic literature review. *Future Computing and Informatics Journal*, *1*(1-2), 1-9.

Alghazo, J., Ouda, O. K., & Hassan, A. E. (2018). E-waste environmental and information security threat: GCC countries vulnerabilities. *Euro-Mediterranean Journal for Environmental Integration*, *3*, 1-10.

Alvarez, J. L., Larrucea, M. A., Quero, S. F.-C., & del Valle, A. J. (2008). Optimizing the collection of used paper from small businesses through GIS techniques: The Leganés case (Madrid, Spain). *Waste management*, *28*(2), 282-293.

Andeobu, L., Wibowo, S., & Grandhi, S. (2021). A systematic review of e-waste generation and environmental management of Asia Pacific countries. *International journal of environmental research and public health*, *18*(17), 9051.

Anderson, R. (2020). *Security engineering: a guide to building dependable distributed systems*. John Wiley & Sons.

Aparna, H., Bhumijaa, B., Avila, J., Thenmozhi, K., Amirtharaja, R., Praveenkumar, P., & Umamaheswari, B. (2021). IoT assisted Waste Collection and Management system using QR codes. 2021 International Conference on Computer Communication and Informatics (ICCCI),

Arthurs, P., Gillam, L., Krause, P., Wang, N., Halder, K., & Mouzakitis, A. (2021). A taxonomy and survey of edge cloud computing for intelligent transportation systems and connected vehicles. *IEEE Transactions on Intelligent Transportation Systems*.

Awasthi, A. K., & Li, J. (2017). Management of electrical and electronic waste: A comparative evaluation of China and India. *Renewable and Sustainable Energy Reviews*, *76*, 434-447.

Aziz, M. F., Khan, A. N., Shuja, J., Khan, I. A., Khan, F. G., & Khan, A. u. R. (2022). A lightweight and compromise-resilient authentication scheme for IoTs. *Transactions on Emerging Telecommunications Technologies*, *33*(3), e3813.

Bajaj, R., Ranaweera, S. L., & Agrawal, D. P. (2002). GPS: location-tracking technology. *Computer*, *35*(4), 92-94.

Bakhiyi, B., Gravel, S., Ceballos, D., Flynn, M. A., & Zayed, J. (2018). Has the question of e-waste opened a Pandora's box? An overview of unpredictable issues and challenges. *Environment international*, *110*, 173-192.

Baldé, C., Kuehr, R., Blumenthal, K., Gill, S., Kern, M., Micheli, P., Magpantay, E., & Huisman, J. (2015). *E-waste statistics: Guidelines on classifications, reporting and indicators*.

Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). *The global e-waste monitor 2017: Quantities, flows and resources*. United Nations University, International Telecommunication Union, and ….

Bhutta, M. K. S., Omar, A., & Yang, X. (2011). Electronic waste: a growing concern in today's environment. *Economics Research International*, *2011*.

Bibi, F., Guillaume, C., Gontard, N., & Sorli, B. (2017). A review: RFID technology having sensing aptitudes for food industry and their contribution to tracking and monitoring of food products. *Trends in Food Science & Technology*, *62*, 91-103.

Borthakur, A., & Govind, M. (2017). Emerging trends in consumers' E-waste disposal behaviour and awareness: A worldwide overview with special focus on India. *Resources, Conservation and Recycling*, *117*, 102-113.

Breivik, K., Armitage, J. M., Wania, F., & Jones, K. C. (2014). Tracking the global generation and exports of e-waste. Do existing estimates add up? *Environmental science & technology*, *48*(15), 8735-8743.

Buyya, R., Vecchiola, C., & Selvi, S. T. (2013). *Mastering cloud computing: foundations and applications programming*. Newnes.

Caro, M. P., Ali, M. S., Vecchio, M., & Giaffreda, R. (2018). Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. 2018 IoT Vertical and Topical Summit on Agriculture-Tuscany (IOT Tuscany),

Chaudhary, K., Padmanabhan, P., Verma, D., & Yadav, P. D. (2021). Blockchain: a game changer in electronic waste management in India. *International Journal of Integrated Supply Management*, *14*(2), 167-182.

Condemi, A., Cucchiella, F., & Schettini, D. (2019). Circular economy and E-waste: an opportunity from RFID TAGs. *Applied Sciences*, *9*(16), 3422.

Conti, M., & Orcioni, S. (2019). Cloud-based sustainable management of electrical and electronic equipment from production to end-of-life. *International Journal of Quality & Reliability Management*.

Cucchiella, F., D'Adamo, I., Koh, S. L., & Rosa, P. (2015). Recycling of WEEEs: An economic assessment of present and future e-waste streams. *Renewable and Sustainable Energy Reviews*, *51*, 263-272.

Das, A., Debnath, B., Modak, N., Das, A., & De, D. (2020). E-waste inventorisation for sustainable smart cities in India: A cloud-based framework. 2020 IEEE International Women in Engineering (WIE) Conference on Electrical and Computer Engineering (WIECON-ECE),

Dasaklis, T. K., Casino, F., & Patsakis, C. (2020). A traceability and auditing framework for electronic equipment reverse logistics based on blockchain: The case of mobile phones. 2020 11th International Conference on Information, Intelligence, Systems and Applications (IISA,

Dey, S., Saha, S., Singh, A. K., & McDonald-Maier, K. (2022). SmartNoshWaste: Using blockchain, machine learning, cloud computing and QR code to reduce food waste in decentralized web 3.0 enabled smart cities. *Smart Cities*, *5*(1), 162-176.

Dua, A., Dutta, A., Zaman, N., & Kumar, N. (2020). Blockchain-based E-waste management in 5G smart communities. IEEE INFOCOM 2020-IEEE conference on computer communications workshops (INFOCOM WKSHPS),

Dutson, P. (2013). *Creating QR and Tag codes*. Sams Publishing.

Dwivedy, M., & Mittal, R. (2010). Future trends in computer waste generation in India. *Waste management*, *30*(11), 2265-2277.

Dwivedy, M., & Mittal, R. (2012). An investigation into e-waste flows in India. *Journal of Cleaner Production*, *37*, 229-242.

Fathi, B. M., Ansari, A., & Ansari, A. (2022). Threats of Internet-of-Thing on Environmental Sustainability by E-Waste. *Sustainability*, *14*(16), 10161.

Fernandes, L., Rosado da Cruz, A. M., Cruz, E. F., & Lopes, S. I. (2023). A Review on Adopting Blockchain and IoT Technologies for Fostering the Circular Economy in the Electrical and Electronic Equipment Value Chain. *Sustainability*, *15*(5), 4574.

Fernando, A., & Jorge Jr, M. (2015). Cost assessment and benefits of using RFID in reverse logistics of waste electrical & electronic equipment (WEEE). *Procedia Computer Science*, *55*, 688-697.

Forti, V., Balde, C. P., Kuehr, R., & Bel, G. (2020). The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential.

Gammelgaard, B., & Nowicka, K. (2023). Next generation supply chain management: the impact of cloud computing. *Journal of Enterprise Information Management*.

Gentile, C., Alsindi, N., Raulefs, R., & Teolis, C. (2012). *Geolocation Techniques*

Principles and Applications. https://doi.org/10.1007/978-1-4614-1836-8
Golev, A., Schmeda-Lopez, D. R., Smart, S. K., Corder, G. D., & McFarland, E. W. (2016). Where next on e-waste in Australia? *Waste management*, *58*, 348-358.
Gopalakrishnan, P. K., Hall, J., & Behdad, S. (2020). A blockchain-based traceability system for waste management in smart cities. International Design Engineering Technical Conferences and Computers and Information in Engineering Conference,
Grant, K., Goldizen, F. C., Sly, P. D., Brune, M.-N., Neira, M., van den Berg, M., & Norman, R. E. (2013). Health consequences of exposure to e-waste: a systematic review. *The lancet global health*, *1*(6), e350-e361.
Ilankoon, I., Ghorbani, Y., Chong, M. N., Herath, G., Moyo, T., & Petersen, J. (2018). E-waste in the international context–A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. *Waste management*, *82*, 258-275.
Iranpak, S., Shahbahrami, A., & Shakeri, H. (2021). Remote patient monitoring and classifying using the internet of things platform combined with cloud computing. *Journal of Big Data*, *8*, 1-22.
Ismail, H., & Hanafiah, M. M. (2020). A review of sustainable e-waste generation and management: Present and future perspectives. *Journal of environmental management*, *264*, 110495.
Jang, S. H. (2012). A qr code-based indoor navigation system using augmented reality. GIScience–Seventh International Conference on Geographic Information Science, USA,
Janssen, M., & van den Hoven, J. (2015). Big and Open Linked Data (BOLD) in government: A challenge to transparency and privacy? In (Vol. 32, pp. 363-368): Elsevier.
Jechlitschek, C. (2006). A survey paper on Radio Frequency Identification (RFID) trends. *Reports on Recent Advances in Networking*.
Jim Puckett, L. B., Sarah Westervelt, Richard Gutierrez, Sheila Davis, , & Asma Hussain, M. D. (2002). *Exporting Harm: The High-Tech Trashing of Asia* (Exporting Harm, Issue. S. V. T. C. S. The Basel Action Network (BAN).
Kahhat, R., & Williams, E. (2012). Materials flow analysis of e-waste: Domestic flows and exports of used computers from the United States. *Resources, Conservation and Recycling*, *67*, 67-74.
Kang, K. D., Kang, H., Ilankoon, I., & Chong, C. Y. (2020). Electronic waste collection systems using Internet of Things (IoT): Household electronic waste management in Malaysia. *Journal of Cleaner Production*, *252*, 119801.
Kapoor, N., Sulke, P., & Badiye, A. (2021). E-waste forensics: An overview. *Forensic Science International: Animals and Environments*, *1*, 100034.
Kaya, M. (2016). Recovery of metals and nonmetals from electronic waste by physical and chemical recycling processes. *Waste management*, *57*, 64-90.
Kaya, M., & Kaya, M. (2019). Sorting and Separation of WPCBs. *Electronic Waste and Printed Circuit Board Recycling Technologies*, 143-176.
Kazancoglu, Y., Ozbiltekin, M., Ozkan Ozen, Y. D., & Sagnak, M. (2021). A proposed sustainable and digital collection and classification center model to manage e-waste in emerging economies. *Journal of Enterprise Information Management*, *34*(1), 267-291.
Khaliq, A., Rhamdhani, M. A., Brooks, G., & Masood, S. (2014). Metal extraction processes for electronic waste and existing industrial routes: a review and Australian perspective. *Resources*, *3*(1), 152-179.
Khan, A. U. R., & Ahmad, R. W. (2022). A blockchain-based IoT-enabled E-Waste tracking and tracing system for smart cities. *IEEE Access*, *10*, 86256-86269.
Khetriwal, D. S., Kraeuchi, P., & Widmer, R. (2009). Producer responsibility for e-waste management: key issues for consideration–learning from the Swiss experience. *Journal of environmental management*, *90*(1), 153-165.
Kiddee, P., Naidu, R., & Wong, M. H. (2013). Electronic waste management approaches: An overview. *Waste management*, *33*(5), 1237-1250.
Kshetri, N. (2018). 1 Blockchain's roles in meeting key supply chain management objectives. *International Journal of information management*, *39*, 80-89.

Kumar, A., Holuszko, M., & Espinosa, D. C. R. (2017). E-waste: An overview on generation, collection, legislation and recycling practices. *Resources, Conservation and Recycling*, *122*, 32-42.
Kumar, V., & Vidhyalakshmi, P. (2012). Cloud computing for business sustainability. *Asia-Pacific Journal of Management Research and Innovation*, *8*(4), 461-474.
Lee, D., Offenhuber, D., Duarte, F., Biderman, A., & Ratti, C. (2018). Monitour: Tracking global routes of electronic waste. *Waste management*, *72*, 362-370.
Lepawsky, J. (2015). The changing geography of global trade in electronic discards: time to rethink the e-waste problem. *The Geographical Journal*, *181*(2), 147-159.
Lepawsky, J. (2018). *Reassembling rubbish: Worlding electronic waste*. MIT Press.
Lepawsky, J., & McNabb, C. (2010). Mapping international flows of electronic waste. *The Canadian Geographer/Le Géographe canadien*, *54*(2), 177-195.
Leszczynski, A. (2019). Platform affects of geolocation. *Geoforum*, *107*, 207-215.
Li, J., Liu, L., Zhao, N., Yu, K., & Zheng, L. (2013). Regional or global WEEE recycling. Where to go? *Waste management*, *33*(4), 923-934.
Li, Z., Liu, G., Liu, L., Lai, X., & Xu, G. (2017). IoT-based tracking and tracing platform for prepackaged food supply chain. *Industrial Management & Data Systems*, *117*(9), 1906-1916.
Loesche, D. (2017). *Mining Gold From E-Waste*. Statista. https://www.statista.com/chart/12332/value-and-volume-of-raw-materials-in-e-waste-worldwide/
Lundgren, K. (2012). *The global impact of e-waste: addressing the challenge*. International Labour Organization.
Martin, C., & Leurent, H. (2017). Technology and innovation for the future of production: Accelerating value creation. World Economic Forum,
McNeill, P., Woodard, R., & Williams, M. (2021). Waste Duty of Care regulations: Evaluation of enforcement strategies by local authorities in England. *Journal of Cleaner Production*, *312*, 127654.
Mell, P., & Grance, T. (2011). The NIST definition of cloud computing.
Miller, T. R., Duan, H., Gregory, J., Kahhat, R., & Kirchain, R. (2016). Quantifying domestic used electronics flows using a combination of material flow methodologies: A US case study. *Environmental science & technology*, *50*(11), 5711-5719.
Milner, G. (2016). What is GPS? *Journal of Technology in Human Services*, *34*(1), 9-12.
Mishima, K., Rosano, M., Mishima, N., & Nishimura, H. (2016). End-of-life strategies for used mobile phones using material flow modeling. *Recycling*, *1*(1), 122-135.
Mougayar, W. (2016). *The business blockchain: promise, practice, and application of the next Internet technology*. John Wiley & Sons.
Namen, A. A., da Costa Brasil, F., Abrunhosa, J. J. G., Abrunhosa, G. G. S., Tarré, R. M., & Marques, F. J. G. (2014). RFID technology for hazardous waste management and tracking. *Waste management & research*, *32*(9_suppl), 59-66.
Nowakowski, P., Kuśnierz, S., Płoszaj, J., & Sosna, P. (2021). Collecting Small-Waste Electrical and Electronic Equipment in Poland—How Can Containers Help in Disposal of E-Waste by Individuals? *Sustainability*, *13*(22), 12422.
Omondi, E. A., Ndiba, P. K., & Koech, G. C. (2022). Complexity of E-Waste and its Management Challenges in Developing Countries–A Review. *management*, *8*, 10.
Ongondo, F. O., Williams, I. D., & Cherrett, T. J. (2011). How are WEEE doing? A global review of the management of electrical and electronic wastes. *Waste management*, *31*(4), 714-730.
Parajuly, K., Kuehr, R., Awasthi, A. K., Fitzpatrick, C., Lepawsky, J., Smith, E., Widmer, R., & Zeng, X. (2019). Future e-waste scenarios.
Patil, R. A., & Ramakrishna, S. (2020). A comprehensive analysis of e-waste legislation worldwide. *Environmental Science and Pollution Research*, *27*, 14412-14431.
Petrescu, M., & Krishen, A. S. (2018). Analyzing the analytics: data privacy concerns. In (Vol. 6, pp. 41-43): Springer.
Petrova, K., Romaniello, A., Medlin, B. D., & Vannoy, S. A. (2016). QR codes advantages and dangers. 13th International Joint Conference on e-Business and Telecommunications,

Priyanka, E., Thangavel, S., & Gao, X.-Z. (2021). Review analysis on cloud computing based smart grid technology in the oil pipeline sensor network system. *Petroleum Research*, *6*(1), 77-90.
Rada, E. C., Ragazzi, M., & Fedrizzi, P. (2013). Web-GIS oriented systems viability for municipal solid waste selective collection optimization in developed and transient economies. *Waste management*, *33*(4), 785-792.
Ren, Y.-J., Shen, J., Wang, J., Han, J., & Lee, S.-Y. (2015). Mutual verifiable provable data auditing in public cloud storage. *網際網路技術學刊*, *16*(2), 317-323.
Rong, C., Nguyen, S. T., & Jaatun, M. G. (2013). Beyond lightning: A survey on security challenges in cloud computing. *Computers & Electrical Engineering*, *39*(1), 47-54.
Rosário, A. T., & Dias, J. C. (2023). The New Digital Economy and Sustainability: Challenges and Opportunities.
Ruponen, I.-S. (2017). Identifying the wastes in a transportation company's office processes.
Sahoo, S., & Halder, R. (2020). Blockchain-based forward and reverse supply chains for E-waste management. Future Data and Security Engineering: 7th International Conference, FDSE 2020, Quy Nhon, Vietnam, November 25–27, 2020, Proceedings 7,
Sahoo, S., Mukherjee, A., & Halder, R. (2021). A unified blockchain-based platform for global e-waste management. *International Journal of Web Information Systems*, *17*(5), 449-479.
Schwartz, P. M., & Solove, D. J. (2011). The PII problem: Privacy and a new concept of personally identifiable information. *NYUL rev.*, *86*, 1814.
Shevchenko, T., Laitala, K., & Danko, Y. (2019). Understanding consumer E-waste recycling behavior: introducing a new economic incentive to increase the collection rates. *Sustainability*, *11*(9), 2656.
Shevchenko, T., Saidani, M., Danko, Y., Golysheva, I., Chovancová, J., & Vavrek, R. (2021). Towards a smart E-waste system utilizing supply chain participants and interactive online maps. *Recycling*, *6*(1), 8.
Shinkuma, T., & Huong, N. T. M. (2009). The flow of E-waste material in the Asian region and a reconsideration of international trade policies on E-waste. *Environmental impact assessment review*, *29*(1), 25-31.
Song, Q., Wang, Z., Li, J., Duan, H., Yu, D., & Zeng, X. (2017). Characterizing the transboundary movements of UEEE/WEEE: is Macau a regional transfer center? *Journal of Cleaner Production*, *157*, 243-253.
Song, X., Hu, S., Chen, D., & Zhu, B. (2017). Estimation of waste battery generation and analysis of the waste battery recycling system in China. *Journal of Industrial Ecology*, *21*(1), 57-69.
Stallings, W., & Brown, L. (2018). Computer Security: Principles and Practice, Global ed. In: Pearson: New York, NY, USA.
Stone, R. (2000). {CenterTrack}: An {IP} Overlay Network for Tracking {DoS} Floods. 9th USENIX Security Symposium (USENIX Security 00),
Svantesson, D., & Clarke, R. (2016). 'Privacy and Consumer Risks in Cloud Computing', Computer Law and Security Review, 26, pp. 391-97. In *Privacy in the Information Society* (pp. 355-361). Taylor & Francis.
Tansel, B. (2017). From electronic consumer products to e-wastes: Global outlook, waste quantities, recycling challenges. *Environment international*, *98*, 35-45.
Tapscott, D., & Tapscott, A. (2016). *Blockchain revolution: how the technology behind bitcoin is changing money, business, and the world*. Penguin.
Tezyapar Kara, I., Kremser, K., Wagland, S., & Coulon, F. (2023). Bioleaching metal-bearing wastes and by-products for resource recovery: a review. *Environmental Chemistry Letters*, 1-22.
Thakur, P., & Kumar, S. (2022). Evaluation of e-waste status, management strategies, and legislations. *International Journal of Environmental Science and Technology*, *19*(7), 6957-6966.

Tiwari, D., Raghupathy, L., & Khan, A. S. (2018). Evolving an E-waste tracking system for India to mitigate the problems of e-waste management. *International Journal for Research in Applied Science and Engineering Technology*, *6*(1), 1865-1873.

Tong, X., Wang, T., Chen, Y., & Wang, Y. (2018). Towards an inclusive circular economy: Quantifying the spatial flows of e-waste through the informal sector in China. *Resources, Conservation and Recycling*, *135*, 163-171.

Van Yken, J., Boxall, N. J., Cheng, K. Y., Nikoloski, A. N., Moheimani, N. R., & Kaksonen, A. H. (2021). E-waste recycling and resource recovery: A review on technologies, barriers and enablers with a focus on oceania. *Metals*, *11*(8), 1313.

Veenstra, A., Wang, C., Fan, W., & Ru, Y. (2010). An analysis of E-waste flows in China. *The International Journal of Advanced Manufacturing Technology*, *47*, 449-459.

Vincent Wang, X., Lopez N, B. N., Ijomah, W., Wang, L., & Li, J. (2015). A smart cloud-based system for the WEEE recovery/recycling. *Journal of Manufacturing Science and Engineering*, *137*(6).

Wang, F., Huisman, J., Stevels, A., & Baldé, C. P. (2013). Enhancing e-waste estimates: Improving data quality by multivariate Input–Output Analysis. *Waste management*, *33*(11), 2397-2407.

Wave, D. (2010). QR code features. *QR Code. com*.

Widaningsih, S., & Suheri, A. (2021). Design of Waste Management System Using QR Code for Effective Management in Wastebank. Journal of Physics: Conference Series,

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., & Böni, H. (2005). Global perspectives on e-waste. *Environmental impact assessment review*, *25*(5), 436-458.

Xavier, L. H., Ottoni, M., & Abreu, L. P. P. (2023). A comprehensive review of urban mining and the value recovery from e-waste materials. *Resources, Conservation and Recycling*, *190*, 106840.

Xiao, Y., Yu, S., Wu, K., Ni, Q., Janecek, C., & Nordstad, J. (2007). Radio frequency identification: technologies, applications, and research issues. *Wireless Communications and Mobile Computing*, *7*(4), 457-472.

Xu, B., Xu, L., Cai, H., Jiang, L., Luo, Y., & Gu, Y. (2017). The design of an m-Health monitoring system based on a cloud computing platform. *Enterprise Information Systems*, *11*(1), 17-36.

Xu, M., Li, Q., Niu, J., Su, H., Liu, X., Xu, W., Lv, P., Zhou, B., & Yang, Y. (2021). ART-UP: A novel method for generating scanning-robust aesthetic QR codes. *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)*, *17*(1), 1-23.

Yenugula, M., Sahoo, S., & Goswami, S. (2023). Cloud computing in supply chain management: Exploring the relationship. *Management Science Letters*, *13*(3), 193-210.

Yoshida, A., Tasaki, T., & Terazono, A. (2009). Material flow analysis of used personal computers in Japan. *Waste management*, *29*(5), 1602-1614.

Zeng, X., Mathews, J. A., & Li, J. (2018). Urban mining of e-waste is becoming more cost-effective than virgin mining. *Environmental science & technology*, *52*(8), 4835-4841.

Zhang, K., Cang, P., Geldermann, J., & Song, F. (2010). Research on innovative information-flow management of e-waste recycling network based on cloud computing. 2010 Chinese Control and Decision Conference,

Appendices

Appendix 1: Hybrid Uplink-Time Difference of Arrival and Assisted-GPS Positioning Technique

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Hybrid Uplink-Time Difference of Arrival and Assisted-GPS Positioning Technique

M. Abo-Zahhad, Sabah M. Ahmed, M. Mourad
Electrical and Electronics Engineering Department, Faculty of Engineering, Assiut University, Assiut, Egypt
Email: zahhad@yahoo.com

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ABSTRACT

A hybrid positioning system is merely one in which multiple systems are used for positioning purposes. This virtually always, though not necessarily, includes Global Positioning System (GPS) as it is the only global positioning network currently. Combination of mobile network and GPS positioning techniques provide a higher accuracy of mobile location than positions based on a standalone GPS or mobile network based positions. High accuracy of mobile position is mainly essential for emergency, military and many other location based services such as productivity enhancement, entertainment, position-based advertising, navigation, asset management and geographic information access. Assisted GPS, also known as A-GPS or AGPS, enhances the performance of the standard GPS in devices connected to the cellular network. This paper introduces a new hybrid technique for mobile location determination utilizing Universal Mobile Telecommunication System (UMTS) network, Mobile Station (MS) and GPS positioning characteristics. Different positioning techniques are chosen according to positioning parameters. The minimum required number of UMTS base stations, location measurement units and GPS satellites are calculated in this paper. The required number of GPS satellites is reduced from four satellites to three ones while using three dimension positioning and from three satellites to two ones at two dimension positioning. Moreover, MS receiver main functions including both network and GPS received paths to achieve output assisted data are discussed. In this paper many drawbacks such as indoor positioning, receiver high power consumption, delay in first time to fix position, low position accuracy as well as large number of required satellites and base stations are improved.

Keywords: A-GPS; Hybrid Positioning System; Mobile Positioning

1. Introduction

There are a lot of vital applications based on mobile user location concerning both civilian and military services. Positioning accuracy plays an important role in achieving such applications. In literature [1-5] many methods of mobile user positioning in UMTS network have been introduced; each has its fundamentals, requirements and levels of accuracy. Cellular positioning can be categorized into two main techniques:

1) Network-based cellular location positioning;
2) Mobile-based cellular location positioning.

Network-based cellular location positioning technique depends on network structure and network equipments to calculate locations of mobile subscribers. A lot of methods are developed to achieve this target with different positioning accuracies such as: Cell Identifier plus Round Trip Time (CID + RTT), Enhanced Cell Identifier plus Round Trip Time (ECID + RTT), Pilot Correlation Method (PCM), Observed Time Difference of Arrival (OTDOA), Uplink Time Difference of Arrival (UTDOA) and Network Assisted Global Navigation Satellite Systems (NA-GNSS). The major advantage of this technique is a minimization of the impact on terminal implementation. Thus, time to market of such positioning technology can be substantially improved through avoidance of the user terminal replacements. Logically, network-based positioning is preferred by network operators. Thus, in this paper network-based solution is implemented.

Mobile-based cellular location positioning technique depends on mobile equipment circuits to calculate locations of mobile subscribers. This type of positioning aims to minimize the network involvement in the position estimation process. A lot of methods are developed to achieve this target with different positioning accuracies such as: Cell Identifier plus Signal Strength (CID + Signal Strength), Delay spread-based hybrid method and Assisted GPS (A-GPS) which can be based on mobile or network location positioning techniques.

Location based services (LBS) are the most recent and useful applications depend mainly on mobile user location. Federal communication commission (FCC) stated the required positioning accuracy for both operators and mobile manufacturers. E911 Phase II report issued in 1999 requires that all cellular operators must have location-enabled technology providing accuracy of 100 m for 67% of calls and 300 m for 95% of calls for network-based solutions and correspondingly 50 m and 150 m for mobile-based solutions [6].

2. Positioning Techniques of Mobile Users

There are many developed positioning techniques participate in detecting location of mobile user with different accuracies. Time-biased positioning methods starting with Time of Arrival (TOA) till Up-link Time Difference of Arrival (U-TDOA) in addition to GPS positioning fundamentals are summarized in the following.

2.1. Mobile Based Time of Arrival Technique

This technique depends on the absolute time measurement of the signal which arrived from handset to base station. This measurement can be achieved using single or multiple base stations. However, this technique requires a very accurate timing reference at the mobile which need to be synchronized with the clock at the base stations. Clearly, this solution is very difficult to achieve, as having an accurate and synchronized clock in the mobile is a difficult technical challenge and would again result in increased cost and size of the mobile handset.

2.2. Mobile Based Time Difference of Arrival Technique (TDOA)

Secondary network of base stations at fixed locations are acting as dummy handsets in the TDOA method. The mobile handset and a nearby dummy base station both capture a portion of the forward link signal from the actual base stations at a synchronized time period. Thus, the time difference of the signal arrival at the mobile and the dummy station is known. Since the coordinates of the dummy stations and the actual network base stations are known, this gives the distance between the mobile and the actual base station. Performing three such measurements with three different actual base stations, the position of the mobile can be found using the triangulation method. This technique requires considerable change in the handset software along with additional hardware installations.

The mobile measures the arrival time differences of at least three pilot tones transmitted by three different cells. By intersecting hyperbolas the mobile's position can be estimated. This method requires all the processing to be done at the handset and then requires the location estimated to be transmitted to the system on the reverse link. Thus, handset costs and bulk will be increased due to such needed additions to meet the synchronization and estimation requirements [7].

2.3. Network-Based Uplink Time Difference of Arrival (U-TDOA) Technique

U-TDOA technology locates wireless phones by comparing the time it takes a mobile station's radio signal to reach several Location Measurement Units (LMUs) installed at an operator's base stations, as shown in **Figure 1**. U-TDOA approach is used to enable location-based services such as emergency location, asset tracking, and mobile concierge services. The wider UMTS bandwidth coupled with significant processing gain available to network based location systems provide higher level of accuracy in UTRAN networks and in situations where other location techniques may not be able to perform well. This increased accuracy can be achieved at reduced complexity over implementations of downlink OTDOA or A-GPS. Additionally, critical for future success of network operators, the uplink TDOA method provides significant flexibility for implementation of future location service enhancements. Many methods based on signal attenuation can't be applied in UMTS network due to the near-far effect [8].

In uplink method the processing functions to calculate user position is done in the network equipment especially location measurement unit (LMU) instead of mobile equipment processing used in downlink method. In addition, uplink method has increased processing capacity available to analyze signal information and to calculate subscriber locations. The uplink method provides increased power from 20 to 30 dB greater in processing gain than a DL-OTDOA solution through long integration times. In the DL-OTDOA system, the mobile station must make measurements of pilot signals from several sites, one by one, while still providing the other mobile station functions. The DSP processors of many LMUs work simultaneously to locate a single mobile subscriber. So, downlink method latency problem is solved. Simultaneous location of many subscriber units can be detected using U-TDOA approach utilizing increased power solution. Also, this solution includes acquisition of location information from many more distant location receivers.

2.4. Global Positioning System (GPS)

Global positioning system is based on satellite communication which comprises three main steps:

Identification of satellites: Receivers must identify satellites used in measurements. Receiver selects a subset of at least four satellites that are actually considered during the measurements depends on the geometry between each satellite and receiver.

Range measurements: Code phase ranging and carrier phase ranging are common methods for range measurement in GPS system depending on the required accuracy and application in use.

Position calculation: Accurate geometric position is calculated by compensating certain error budget of pseudo range obtained in the previous step. Satellite positioning using GPS suffers from many short comes as positioning start time latency, environmental limitations (*i.e.* indoor, satellite out coverage) and high power consumption at GPS receivers. These defects can be overcome using cellular positioning techniques whether using network based or mobile based cellular positioning technique. Among these techniques, Differential GPS (D-GPS) is one of the most efficient techniques.

The principle of D-GPS is to observe the pilot signal from the satellite at a fixed well-known position, reference station, and to determine the difference between the measured range and an approximation of the true range derived from the known position of observation. This difference represents the correction value for GPS receivers nearby the reference station. As shown in **Figure 1**, reference station permanently observes all visible satellites. From these observations accurate range and pseudo range measurements are obtained according to the following two equations respectively.

$$r_{i,rs} = \sqrt{(x_i - x_{rs})^2 + (y_i - y_{rs})^2 + (z_i - z_{rs})^2} \quad (1)$$

$$P_{i,rs} = r_{i,rs} + c.\Delta t_{i,rs} + \varepsilon_{i,rs} \quad (2)$$

where, $r_{i,rs}$ is the range between the accurate position (x_{rs}, y_{rs}, z_{rs}) of the reference station and the position (x_i, y_i, z_i) of the *i*-th satellite, which is derived from the ephemeris contained in the navigation message and which might be subject to slight deviations from the satellite's true position owing to perturbing forces. Whereas $p_{i,rs}$ is the measured pseudo range, $\Delta t_{i,rs}$ is the time offset between the clocks of the satellite and receiver. $\zeta_{i,rs}$ represents ionospheric and tropospheric refraction, multipath propagation, and other error sources. The reference station calculates the difference between true range and pseudo range for each visible satellite and broadcast the estimated correction data via wireless network to the nearby mobile receiver. D-GPS is not only an efficient means for significantly improving the accuracy of position, but also for reducing the Time to First Fix (TTFF).

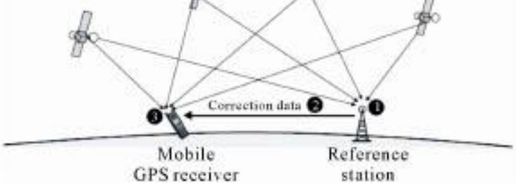

Figure 1. Differential GPS overview.

3. Assisted GPS Positioning Technique

Assisted GPS (A-GPS) is an extension of the conventional Global Positioning System (GPS) which increases start-up sensitivity by as much as 25 dB relative to conventional GPS and reduces start times to less than six seconds as discussed in [9]. A-GPS technology follows the principle of D-GPS with additional assistance data from cellular network which is used to reduce acquisition time, enhance positioning accuracy and provide communication facilities. By integrating GPS into cellular networks, the GPS positioning is supported by additional D-GPS reference stations as integral part of the cellular infrastructure and by additional signaling procedures between network and terminal. The resulting positioning method is commonly known as A-GPS, as discussed in [10]. Assistance data is done using variety of UMTS mobile network positioning types such as AOA, TDOA, O-TDOA [11] and UTDOA or in GSM mobile network as introduced in [12]. It was found that an AGPS receiver provided a 13 dB improvement in acquisition sensitivity over an HS receiver and a 20 dB improvement over a conventional GPS receiver as proven in [13]. A-GPS has the following improved prosperities compared to standard GPS method:

- Higher position accuracy.
- Lower power consumption at GPS receiver terminal.
- Higher receiver sensitivity.
- Lower TTFF and acquisition time.
- Fewer number of satellites needed in position detection.

As shown in **Figure 2**, A-GPS requires the following infra-structure components:

GPS receiver unit at target mobile terminal to be capable of acquiring assistance data from both satellite and cellular network.

Reference stations inside the cellular infrastructure for calculating correction data and compiling the raw material for assistance data as shown in [10]. One reference station for areas with a radius of approximately 200 km is sufficient as proven in (3GPP TR 25.850).

Serving Mobile Location Center (SMLC) is used to coordinate positioning process. Signaling is performed between SMLC and both reference station and target terminal especially in point to point signaling.

The A-GPS modes of operation are summarized in the followings:

1) Mobile Station Assisted (MSA) mode—In this mode, the A-GPS has capable device receives acquisition assistance, reference time and other optional assistance data from the A-GPS server. With the help of these data,

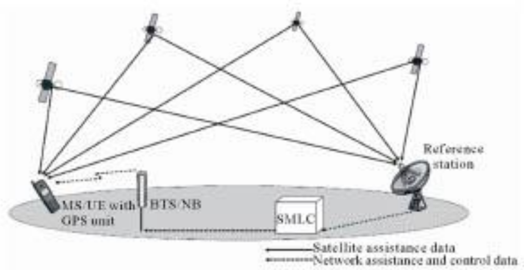

Figure 2. Conventional A-GPS infrastructure.

the A-GPS device receives signals from the visible satellites and sends the measurements to the A-GPS server. The A-GPS server or LMU calculates the position and sends it back to the A-GPS device [14].

2) Mobile Station Based (MSB) mode—In MSB mode, the A-GPS device receives ephemeris, reference location, reference time and other optional assistance data from the A-GPS server. With the help of these data, the mobile equipped with GPS receiver receives signals from the visible satellites and calculates the target position in mobile station as discussed in [15].

4. The Proposed Hybrid Positioning Technique

In this section the proposed hybrid A-GPS positioning technique based on U-TDOA cellular position assistance is developed. It is based on the integration between GPS data and cellular network infrastructure based on U-TDOA assisted data. This yield to accurate positioning of mobile user and to overcome short comes of both techniques while being used individually. From **Table 1**, it is observed that GPS is the most accurate positioning technique with position accuracy (5 - 30 m). Moreover U-TDOA is the most accurate positioning technique depending upon cellular based networks with approximately less than 50 m accuracy. So, the integration between the two methods produces highly accurate positioning technique valid for most environments and with a higher performance than that used by each technique in stand-alone mode.

4.1. Time to First Fix Using Hybrid Positioning Technique

Conventional GPS consumes more than one minute to get first reading of mobile user location. Although each GPS satellite transmits at the same frequency, the signals are not observed at the same frequency because of the Doppler shift caused by the satellite motion, the receiver motion and any frequency offset in the receiver reference oscillator. Receiver would scan all possible frequencies till reach the accurate frequency. Also, GPS receivers find

Table 1. Comparison between positioning techniques.

Technique	Network	Handset	Accuracy
Cell ID	Both	Both	100 m - 3 km depending on cell size
Cell ID + TA	GSM	Both	500 m depending on bandwidth
EFLT	UMTS	Both	250 - 350 m
AFLT	UMTS	Upgrade	50 - 200 m
AOA	Both	Both	100 - 200 m
U-TDOA	Both	Both	<50 m
EOTD	GSM	Upgrade	50 - 200 m
A-GPS	Both	Upgrade	5 - 30 m

a correct code delay for the correlators to generate a correlation peak within about more than thirty seconds. This delay is named frequency/code delay search space [16].

The expected Doppler frequencies can then be computed and the frequency delay search space is reduced. The correlation peak varies with frequency as a $\sin c$ function:

$$\sin c(ftc/2) = 1/2\sin(\pi ftc)/(\pi ftc)^{1/2} \quad (3)$$

where f is the frequency error and tc is the coherent integration time, as shown in [16]. Also, the Doppler Effect result from receiver speed is:

$$L_1 * s * \cos(q/c) \quad (4)$$

Network assisted data is necessary to have at least a rough a priori position and a priori time and satellite orbits. A-GPS is mainly used to reduce the frequency and code-delay search space. To reduce the frequency search space it is necessary to have at least a rough a priori position and a priori time and satellite orbits. The expected Doppler frequencies can then be computed. Similarly, to reduce the code-delay search space, it is necessary to have a good a priori position and a priori time. Where, the a priori time must be known to better than 1 ms which is known as fine-time assistance else it is a coarse-time assistance. By these means of frequency/code search space reduction, TTFF will be reduced significantly. Practically, improvement in TTFF by about 30% - 45% at −142 dbm signal strength within 250 and 500 µs timing accuracy respectively is proven in [17].

4.2. Elements Required in Hybrid System

Four satellites are needed at least to determine the three dimensions of the mobile equipment position in conventional GPS. The four satellites are used to determine the following position parameters (x_i, y_i, z_i, t) where x, y and z are the three dimensional cartezian location coordinates,

i indicates the satellite number and t is the synchronization time error.

Each satellite has its position detection sphere which introduces one position equation. By solving such four equations, the four mentioned unknowns can be determined and mobile equipment position is detected. By suggesting distance between the i-th satellite and the receiver position as R_i, satellite position (x_i, y_i, z_i) and receiver position (X, Y, Z) and receiver time clock error t, Equations (5) represent the four satellites equations adopted for position determination. By solving these equations, the four unknowns X, Y, Z and t can be determined using Equation (5).

A-GPS technique already has network GPS receivers, included in NodeB or separated, which are synchronized with satellites. Since the time delay data (t) can be determined using mobile network, we need only three satellites for mobile position determination instead of four satellites had used in conventional GPS. The accuracy of position determination depends upon the code used in calculations. In case of neglecting Z-coordinate "altitude of the mobile receiver", we will need only three satellites to get (X, Y, t) unknowns of the receiver position in conventional GPS positioning. Whereas, the two satellites are sufficient to detect two-dimensional receiver's position in hybrid positioning.

$$\left.\begin{aligned} R_1 &= (x-x_1)^2+(y-y_1)^2+(z-z_1)^2+t^2 \\ R_2 &= (x-x_2)^2+(y-y_2)^2+(z-z_2)^2+t^2 \\ R_3 &= (x-x_3)^2+(y-y_3)^2+(z-z_3)^2+t^2 \\ R_4 &= (x-x_4)^2+(y-y_4)^2+(z-z_4)^2+t^2 \end{aligned}\right\} \quad (5)$$

4.3. Choice of Most Accurate GPS Satellites

There are about 31 satellites catering to the worldwide GPS systems. In A-GPS as we need only four GPS satellites to determine mobile user position, the best four satellites should be chosen. GPS signal strength is the main factor which is used to choose the best satellites needed for measuring process. There are several methods to measure GPS signal strength. The most common method used by civilians is the ones related to telecommunications, including the Received Signal Strength Indication (RSSI) based on the IEEE802.11 protocol. On the other hand, many GPS manufacturers build their own GPS algorithm to create code for calculating GPS signal strength. By the same way for two or three needed GPS satellites as mentioned in Section 4.2, choice will be according to GPS signal strength. Received signal strength is used to select the most accurate NodeBs/LMUs required in location determination process. The higher the RSSI number, less negative, the stronger the received signal.

4.4. Hybrid Positioning Technique's Parameters

As mentioned in Section 2, each of the mentioned positioning technique has its advantages and drawbacks. Positioning techniques are classified according to the following main parameters: 1) Accuracy; 2) Latency; 3) Call state; 4) Environment; 5) System loading.

Table 2 illustrates the used suitable positioning technique according to the main positioning parameters. Suitable positioning technique such as A-GPS, stand alone GPS or U-TDOA, is selected according to the location based service application needed.

Table 2. Positioning parameters versus positioning technique.

		Accuracy		Latency		Call state		Environment		System loading	
		High	***Low***	***Sensitive***	***Insensitive***	***On-call***	***Idle***	***Indoor***	***Outdoor***	***Heavy***	***Light***
Accuracy	***High***			Hybrid	Hybrid	Hybrid	Hybrid	UTDOA	Hybrid	UTDOA	Hybrid
	Low			UTDOA	GPS	UTDOA	UTDOA	UTDOA	UTDOA	UTDOA	UTDOA
Latency	***Sensitive***	Hybrid	UTDOA			UTDOA	Hybrid	UTDOA	Hybrid	UTDOA	Hybrid
	Insensitive	Hybrid	UTDOA			UTDOA	GPS	UTDOA	GPS	UTDOA	Hybrid
Call state	***On-call***	Hybrid	UTDOA	UTDOA	UTDOA			UTDOA	Hybrid	UTDOA	Hybrid
	Idle	Hybrid	Hybrid	Hybrid	GPS			UTDOA	Hybrid	UTDOA	Hybrid
Environment	***Indoor***	UTDOA	UTDOA	UTDOA	UTDOA	UTDOA	UTDOA			UTDOA	UTDOA
	Outdoor	Hybrid	UTDOA	Hybrid	GPS	Hybrid	Hybrid			UTDOA	Hybrid
System loading	***Heavy***	Hybrid	UTDOA	UTDOA	Hybrid	UTDOA	Hybrid	UTDOA	Hybrid		
	Light	Hybrid	Hybrid	Hybrid	GPS	UTDOA	Hybrid	UTDOA	Hybrid		

- Mobile tracking applications: The major property of these applications is latency sensitive, so stand alone GPS isn't a suitable positioning technique. Accuracy is the second parameter in these applications so, if application need accuracy less than fifty meter, then hybrid technique is being used. Otherwise U-TDOA will be the most suitable technique here.
- Emergency applications: These applications require high accuracy without time delay. Then, hybrid method is selected in outdoor applications whereas U-TDOA will be more precise in indoor applications.
- Commercial advertisements and general information: Most information like weather, traffic, advertisements are highly used in city center and crowded regions. So, system loading is the most positioning parameter that should be taken into consideration. So, U-TDOA is the most suitable positioning technique for heavy system loading.

4.5. Secure User Plane Location Protocol

In order to decrease system loading problem especially in crowded locations and city centers secure user plane location protocol is used instead of Radio Resource Control (RRC) protocol which is used by UMTS mobile network as discussed in [9]. Secure User Plane Location Protocol (SUPL) is a network layer based on IP technology that was developed to support Location-Based Services (LBS) for wireless communications. SUPL employs available user plane data bearers for transferring location information, GPS assistance data, and for carrying positioning technology-related protocols between a SUPL Enabled Terminal (SET) and the mobile network. This developed protocol permits hybrid developed technology to be used in heavy loaded networks' systems. SUPL provides low cost and complexity in network implementation than conventional RRC protocol which is based on control plane.

5. Network Elements and Positioning Sequence

twork equipments used in mobile location determination using hybrid technique is called Position Determination Equipment (PDE). PDE is mainly consists of Location Gateway (LG), Serving Mobile Location Center (SMLC), Location Measurement Unit (LMU) and NodeB [16]. As shown in **Figure 3**, plenty of network elements are needed within hybrid positioning technique. For more arrangement and decrease among network components the following actions are suggested:

a) Integrate each LMU into corresponding NodeB with common processor, as shown in **Figure 4**. Processors are mainly responsible for network management and provide a centralized pool of digital signal processing resources used in location calculation.

b) Integrate SMLC into corresponding RNC/BSC.

The procedure of detecting mobile location using hybrid positioning technique can be logically summarized into the following steps:

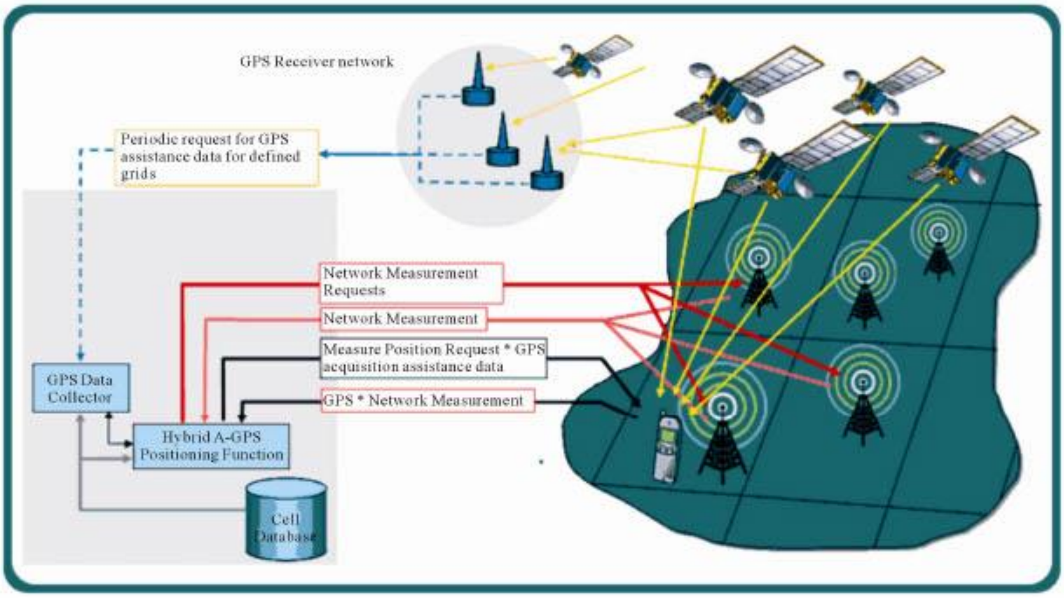

Figure 3. Hybrid GPS_UTDOA network platform.

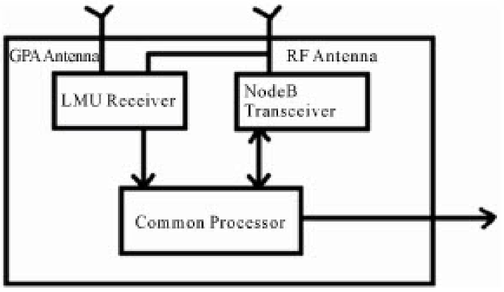

Figure 4. Common processor LMU and NodeB.

1) MS sends request to LG including serving NodeB, cell ID, associated frequency, code, communication parameters and authentication.

2) LG receives the location request from MS, check authorization and validation.

3) LG sends the request to the SMLC which serve the MS and controls the entire positioning process, including allocation of resources, evaluation of timing measurements, and calculation of position fixes.

4) SMLC receives the request and selects the nearest LMUs for serving MS from a list of LMUs included in SMLC database. The database contains the latest data of satellite locations and motion parameters related to each LMU.

5) LMU receives GPS navigation message periodically and extract Doppler shifts, pseudo ranges and navigation messages, correction data and sends these data to SMLC.

6) SMLC receives satellite data from LMU and periodically or on demand evaluates satellites' locations and update current list of assisting satellites' IDs, Doppler shift and pseudo range domains appropriate for each LMU.

7) SMLC send the determined GPS data to LG which redistribute its location parameter to MS to be able to detect satellite rapidly and decrease TTFF.

8) SMLC request location related data from all LMUs selected to cooperate in providing measurements.

9) LMUs respond to SMLC by the extracted, measured and obtained data related to the MS of interest.

10) LG receives the GPS data measured by the MS GPS receiver and sends them to the SMLC.

11) SMLC calculates the optimal integration of MS GPS data with the LMU measurements which represent the most accurate location of MS and send it to LG.

12) LG receives location determination from SMLC and send it to the MS as a response of original location request.

Positioning requests by external applications can be done using the same steps from Step 4 to step 11. Then, the calculated position is sent from LG to the requester such as application server. **Figure 5** shows the flow chart of the main functions and their procedure of the hybrid UTDOA and A-GPS technique.

6. Modified MS Receiver Architecture

Mobile station main components are shown in **Figure 6**. Bidirectional antenna 1 is adapted to receive both UMTS and GPS signals. Duplexer 2 allows bidirectional communication, transmit and receive, into single channel. Electrical switch 3 is implemented to switch between GPS signal and 3G signal. Low noise amplifier 4, first band pass filter 6, first mixer 10 and second band pass filter 14 are the first part of receiver of UMTS signal which are used to down convert the RF signal into intermediate frequency band. The IF band signal represents the first step to get the base band source signal.

By the same way, the path contains 5, 7, 11 and 15 circuits is used to down convert GPS radio signal into intermediate frequency band. Dual phase locked loop PLL 9 controls the local oscillators 12 and 13 at specific reference frequencies to down convert both UMTS and GPS radio signals. Clock generator 8 extracts clock from UMTS signal, as LMU sends it via Node B to MS thus GPS, Node B, LMU and MS will be synchronized. IF Demodulator 16 is the first part of the Application Specific Integrated Circuit (ASIC). This provides the second stage of IF to base band down conversion, sampling and A/D conversion as discussed in [13]. Second switch 17 is analogues to switch 3 and they controlled by the same controller unit to separate CDMA and GPS received signals at radio and intermediate frequency bands.

As explained before, LMU provides GPS data to MS via Node Bs. So, this data will be extracted by MS using Decoder 18 to extract almanac, Doppler shift, etc. for each of GPS satellites. The Doppler frequency Fd that is recognized by decoder 18 is added to local oscillator Fif to control the GPS mixer 19. This mixer is used to convert IF signal to base band signal as the last stage of base band signal down conversion in GPS received path. The output of automatic gain control AGC 21 circuit is fed to analog to digital converter A/D 22. The output of the A/D consists of the (I,Q) in phase and quadrature components as a first and second output digital streams respectively. The digital streams are fed to the digital signal processor DSP 24 to produce the required pseudo measurements. Buffer 23 is used to store data streams in case of the rate of flow of data is faster than that of DSP rate of processing. Pseudo ranges are sent via MS transmitter to LMUs to calculate the user position accurately.

7. Position Calculation

Location determination and measurements using hybrid technique are classified into two main measurements.

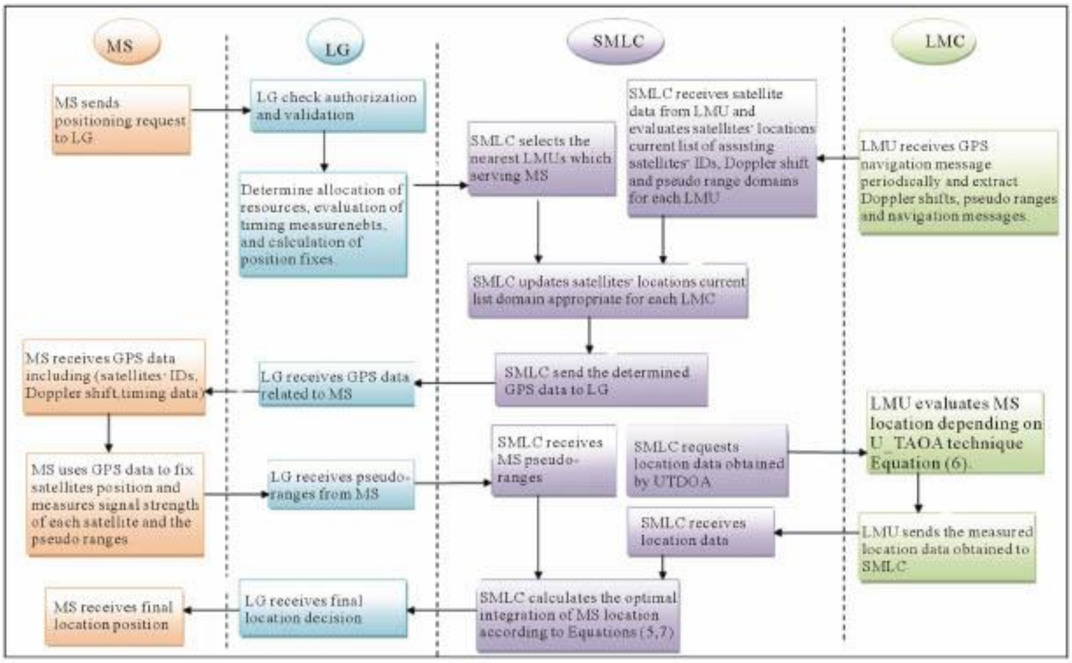

Figure 5. Flow chart of main functions and their procedures of hybrid UTDOA and A-GPS technique.

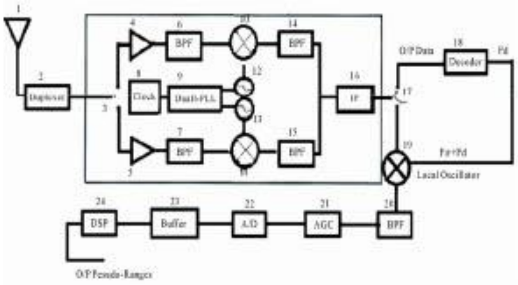

Figure 6. Block diagram of MS receiver.

7.1. Position Calculation Using U-TDOA Technique

This type of measurement is one of distance related measures where distance is calculated through mobile network. Measurements are based mainly on the difference between two Times of Arrivals (TOA) for two distinct signal receptions at least. MS is a common transmitter for signal to the distinct and different LMUs as receiving stations positioned at locations XR1 and XR2 respectively. TDOA technique is directly related to the difference in TOA at different receivers. This leads to difference in signal propagation distances (DR_1, and DR_2) at receivers.

$$\mathrm{TDOA}_{21} = \mathrm{TOA}_2 - \mathrm{TOA}_1 = \left(\mathrm{DR}_2 - \mathrm{DR}_1\right)/2 = \frac{\left(\left(x_T(\mathrm{TOT}) - x_{R_2}(\mathrm{TOA})\right) - \left(x_T(\mathrm{TOT}) - x_{R_1}(\mathrm{TOA})\right)\right)}{2} \quad (6)$$

where *c* is the propagation speed of RF signal, $x_R(TOA)$ is the three dimensional vector coordinates of receiving position at time of signal arrival. Determination of transmitter's location doesn't require knowledge of the TOT common epoch at which MS signal was transmitted. Then synchronization between MS and NodeB isn't necessary from Equation (6) it can be deduced that at least two NodeBs are required to enable U-TDOA technique to calculate the position of mobile terminal.

7.2. Position Calculation Using Hybrid Positioning Technique

The optimum estimation of mobile user location depends on the location-related information available which is extracted from the following sources:

1) Measurement of received signal characteristics.

2) Collateral information that indicate the relative probability of MS position.

Using Bayes probability relation the relative probability of occurrence of measurements under condition of a priori state condition is expressed as:

$$p(x/z) = [p(z/x) * p(x)] / p(z) \quad (7)$$

where x is the state vector of location parameters, z is a vector set of location measurements and $p(x/z)$ represents the probability of the state vector components are evaluated for x under condition that the observations have the values of measurement values z. Whereas $p(x/z)$ represents the probability that the values of vector z would be observed under condition that the state variables are of the values in x. $p(x)$ is the marginal probability that the state values of x occurred. Whereas, $p(z)$ is the total probability of occurrence of measured parameter values for the observation vector z. The jointly combined probability of independent data elements are the product of the probability of independent data sets alone [18]. Using the proposed system, the data of various types from diverse sources, satellite and mobile network, integrates statistically independent data. Then, the probability product relation is accumulated as a sum of "log likelihood". Sum of probabilities will introduce higher location probability than product formula and higher results can be obtained. This way leads to accumulation and integration between both GPS and UTDOA techniques to get higher positioning technique than obtained from standalone technique.

8. Conclusion

There are many positioning techniques based on mobile stations, network stations or GPS. Each technique has its specific advantages and drawbacks. Hybrid techniques are applied to overcome drawbacks of some positioning techniques by using advantages of others. In this paper, hybrid UTDOA and A-GPS positioning technique In UMTS network has been introduced. Network elements' functions and its procedure for location determination are explained. Advanced GPS receiver structure to achieve procedure requirements and generate the required pseudoranges is implemented. The developed technique theoretically has the following advantages:

- Reduction of TTFF by utilizing assisted data from LMU in mobile network.
- High positioning accuracy than obtained by standalone GPS or UTDOA.
- Number of needed GPS satellites is less than that needed in conventional GPS as discussed according to two/three dimension applications.
- The optimal positioning technique such as GPS, U-TDOA or hybrid is obtained depending on the positioning parameters such as accuracy, latency, call state, environment and system loading.
- Problems caused by system loading can be solved using SUPL protocol between MS and mobile network.

REFERENCES

[1] J. Borkowski and J. Lempiäinen, "Practical Network-Based Techniques for Mobile Positioning in UMTS," *EURASIP Journal on Applied Signal Processing*, Special Issue on Wireless Location Technologies and Applications, 2006, pp. 1-16.

[2] J. Borkowski, J. Itkonen and J. Lempiäinen, "Impact of UMTS Topology Configuration on Cell ID + RTT Positioning Accuracy," *Proceedings of the 15th IST Mobile Communications & Summit*, Myconos, 4-8 June 2006.

[3] J. Borkowski and J. Lempiäinen, "Novel Mobile-Based Positioning Techniques for UMTS," *Proceedings of the 9th IEEE International Symposium on Wireless Personal Multimedia Communications*, San Diego, 17-20 September 2006.

[4] J. Borkowski, J. Niemelä and J. Lempiäinen, "Cellular Location Technologies Supporting AGPS Positioning in UMTS Networks," *Proceedings of the 62nd IEEE Vehicular Technology Conference*, Dallas, 25-28 September 2005.

[5] M. Abo-Zahhad, S. M. Ahmed and M. Mourad, "Map Based Intra-Cell Method for Location Prediction over UMTS Network Platform," *Journal of Engineering Science*, Vol. 39, No. 5, 2011, pp. 1-26.

[6] 3GPP TS 25.433, "UTRAN Iub Interface Node B Application Part (NBAP) Signaling," Version 7.6.0, Release 7.

[7] A. Urruela, A. Pages-Zamora and J. Riba, "Divide-and-Conquer Based Closed-form Position Estimation for AOA and TDOA Measurements," *Proceedings of IEEE International Conference on Acoustics, Speech, and Signal Processing*, Toulouse, 14-19 May 2006, pp. 921-924. doi:10.1109/ICASSP.2006.1661120

[8] R.-T. Juang, "Hybrid SADOA/TDOA Mobile Positioning for Cellular Networks" *IET Journal on Communications*, Vol. 1, No. 2, 2007, pp. 282-287.

[9] P. Kashyap, A. Samant, *et al.*, "An Assisted GPS Support for GPS simulators for Embedded Mobile Positioning," *Proceedings of SPIE-IS&T Electronic Imaging*, San Diego, 2-6 August 2009.

[10] A. Küpper, "Location Based Services Fundamentals and Operation," John Wiley and Sons, Hoboken, 2005.

[11] C. Fritsche, "On the Performance of Hybrid GPS/GSM Mobile Terminal Tracking," *IEEE International Conference on Communications Workshop*, Dresden, 14-18 June 2009, pp. 1-5.

[12] M. D. Karunanayake, M. E. Cannon and G. Lachapelle, "Evaluation of Assisted GPS (A-GPS) in Weak Signal Environments Using a Hardware Simulator," *The ION GNSS Conference*, Long Beach, 21-24 September 2004.

[13] D. W. Lim, "Design of an Assisted GPS Receiver and Its Performance Analysis," *IEEE International Symposium on Circuits and Systems Conference*, New Orleans, 27-30 May 2007, pp. 1742-1745. doi:10.1109/ISCAS.2007.377931

[14] J. Syrjarinne, "Supporting an Assisted Satellite Based Positioning," US Patent No. US7701387B2, 2010.

[15] 3GPP TS 25.305, "UMTS, User Equipment (UE) Posi-

tioning in Universal Terrestrial Radio Access Network (UTRAN)," Version 7.3.0, Release 7.

[16] F. van Diggelen, "A-GPS: Assisted GPS, GNSS, and SBAS," Library of Congress Cataloging-in-Publication Data, 2009.

[17] M. D. Karunanayake, M. E. Cannon and G. Lachapelle, "Evaluation of Assisted GPS (A-GPS) in Weak Signal Environments Using a Hardware Simulator," *The ION GNSS Conference*, Long Beach, 21-24 September 2004.

[18] R. J. Anderson and J. E. Maloney, "TDOA/GPS Hybrid Wireless Location System," US Patent No. US7925274-B2, 2011.

Appendix 2: E-waste tracker: a platform to monitor e-waste from collection to recycling

E-WASTE TRACKER: A PLATFORM TO MONITOR E-WASTE FROM COLLECTION TO RECYCLING

Sara Artang
Ibrahim A. Hameed*
Department of ICT and Natural Sciences
Norwegian University of Science and Technology
Larsgårdsvegen 2, 6009 Ålesund, Norway

Afshin Ghasemian
Crayon
Gullhaug Torg 5, 0484 Oslo, Norway

*Corresponding author: ibib@ntnu.no

KEYWORDS

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ABSTRACT

E-waste stands for electronic devices, such as phones, computers, and televisions, that are disposed of when they reach the end of their useful lives. E-waste is becoming one of the most rapidly growing waste streams globally. The production of e-waste is rapidly increasing due to various factors, including the rapid advancement of technology, changing customer preferences, the widespread use of non-repairable parts, and deliberate planned obsolescence during the design of such products to encourage consumers to replace their products more often, boosting sales and profits. E-waste contains precious and rare metals such as gold, silver, copper, indium, and palladium. When these materials are not properly recovered, recycled, and reused, the production of new electronics will require the mining of finite natural resources, leading to environmental damage and the depletion of resources.

As of early 2019, Norway has established an Extended Producer Responsibility (EPR) system, which requires producers and importers to finance and ensure proper collection and recycling of end-of-life (EoL) e-waste, resulting in an increase in the e-waste recycling rate to approximately 91% in Norway. However, electronic waste such as mobile phones and computers often goes unrecycled. Currently, 82% of Norwegian households have at least one extra mobile phone that they are not using. People may hesitate to dispose of their electronic waste and tend to stockpile it at home for several reasons. These include feeling emotionally attached to the item due to personal memories, not knowing where or how to dispose of it, being unaware of the potential environmental and health hazards associated with improper disposal and having concerns about the data security and personal information stored on the device.

To address these issues, the paper introduces a cutting-edge tracking and tracing platform that features an intuitive user interface for both users and administrators. With the proposed platform, users and administrators can easily access essential information regarding their e-waste disposal. This convenient and efficient system offers a practical solution for tracking e-waste, thereby promoting trust between device owners and the disposal process. Furthermore, the platform incentivizes users by providing them with valuable information regarding their e-waste disposal, creating a positive impact on environmental sustainability.

I. INTRODUCTION

E-waste, a critical issue of the modern era, is often disregarded, even though it poses a significant threat to our environment and health. The improper disposal of e-waste, which is continuously increasing in volume, results in the release of toxic chemicals that endanger both the environment and human life. Moreover, it leads to the loss of valuable and precious metals that can be reused (Andeobu et al., 2021; Forti et al., 2020). Therefore, the global issue of e-waste has become a serious problem that requires urgent attention and action. In 2019, the amount of e-waste generated worldwide was 53.6 million tons (Mt), which is a staggering amount that exceeds previously predicted figures. According to Forti et al., the volume of e-waste generated globally is expected to exceed 74 million tons (Mt) by 2030 (Forti et al., 2020). Unfortunately, the rate of recycling is not keeping up with the rate of e-waste production, which exacerbates the problem further. Moreover, the current rate of e-waste generation is increasing at an alarming rate of 3–5%, posing a significant challenge to our environment and health. Therefore, it is essential to take concrete steps towards better e-waste management and responsible disposal practices to mitigate the adverse effects of this growing problem.

The rate of e-waste generation has been increasing at an alarming pace and is outpacing the global population's growth. In fact, the amount of e-waste produced globally has increased three times faster than the global population (Andeobu et al., 2021). Despite this, only a mere 17.4% of electronic waste was formally collected and recycled across the globe in 2019 (Van Yken et al., 2021).

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Measures implemented to improve global e-waste recycling have not been sufficient to keep up with the rate of e-waste generation (Ilankoon et al., 2018). In fact, the recycling rate has only slightly increased since it was last calculated in 2014 (17%) (Andeobu et al., 2021) This means that the remaining 82.6% of e-waste is either not recycled or not formally tracked, leading to their sale on black markets and eventual disposal in landfills (Forti et al., 2020; Li et al., 2013) Such practices are extremely harmful to the environment and human health, as e-waste contains hazardous materials such as lead, cadmium, and mercury, which can leach into the soil and groundwater, polluting the ecosystem and posing a threat to human life. Therefore, it is crucial to implement more effective and sustainable measures for e-waste management to mitigate the adverse effects of this growing problem.

Recycling and resource recovery of electronic waste is a critical issue due to the potential hazards it poses to both the environment and human health (Mmereki, 2016). Improper disposal of electronic waste can lead to massive environmental and health problems, making it crucial to address this issue urgently (Balde et al., 2015; Zuo et al., 2020; Sharma and Jain, 2020; Andrade et al., 2019; Schumacher and Agbemabiese, 2019). In fact, electronic waste is the fastest-growing waste category worldwide, and its impact on the environment is becoming increasingly significant (Islam and Huda, 2020).

While recycling electronic waste can produce tangible byproducts, it also contains hazardous substances that must be treated before the waste is destroyed (Islam and Huda, 2020; Kumar et al., 2017; Thakur and Kumar, 2022). Such substances include lead, mercury, and cadmium, among others, which are harmful to the environment and human health if not handled appropriately. Therefore, proper management and disposal of electronic waste are critical to mitigate the adverse effects of this growing problem. Measures such as improved collection and recycling systems, responsible disposal practices, and public awareness campaigns can help reduce the negative impact of electronic waste on the environment and human health.

Despite numerous attempts to manage e-waste, there is a lack of long-term sustainability plans, including collection, segregation, storage, transportation, and treatment methods, as well as laws and regulations to support them (Adanu et al., 2020; Al-Salem et al., 2022). This has contributed to the ongoing issue of improper disposal of electronic waste worldwide.

Figure 1 presents the expected projection of electronic waste from now until 2030, highlighting the urgent need for effective management and disposal strategies. It is estimated that electronic waste currently accounts for 5% of global solid waste (SW), making it a significant contributor to the overall waste problem (Hazra et al., 2019). Clearly articulating the issue of e-waste is a critical first step in addressing the problem. Measures such as establishing effective collection and recycling systems, implementing regulations and laws to ensure responsible disposal practices, and increasing public awareness about the importance of proper e-waste management are essential to reducing the impact of electronic waste on the environment and human health.

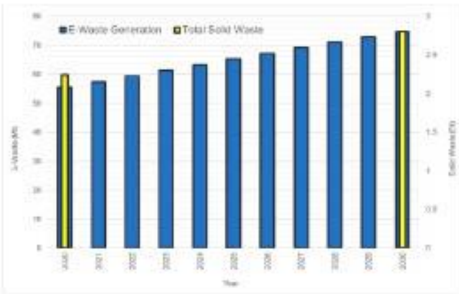


Figure 1: The projected generation of e-waste and total solid waste, in millions and billions of tons respectively, is estimated to occur between 2020 and 2030 (Forti et al., 2020; Kazancoglu et al., 2021).

A. Definition of e-waste

The word "electronic waste" (e-waste) is used when electrical and electronic equipment (EEE) reaches the end of its useful lifetime. There are a total of 54 different product types that fall under the classification of e-waste, but they are categorized into six categories: large equipment, small equipment, temperature exchange equipment, screens and monitors, small information exchange equipment, and lamps (Forti et al., 2020). The term "WEEE" refers to any electrical and electronic equipment (EEE) and its associated components that have been discarded or are intended for such disposal without the owner's intention of reuse (European Union, 2012).

B. E-waste regulation and legislation

Many nations have taken steps to curb the growth of electronic waste and profit from the advantages of this potentially valuable secondary resource. More than 2000 sections of legislation from more than 90 jurisdictions are currently in force worldwide to regulate the negative effects of WEEEs (Ilankoon et al., 2018). In the past, environmental protection was the driving force behind most regulations and strategies, but nowadays, human health concerns are at the forefront of most management strategies (Thakur and Kumar, 2022). There have been several international groups and initiatives that have advanced the cause of proper monitoring and recycling. Each of these groups is working together to inform consumers and investigate potential e-waste management solutions (Thakur and Kumar, 2022; Patil and Ramakrishna, 2020).

The structure of the paper is organized as follows: the related works are reviewed in Section II. Section III briefly recalls the current challenges for e-waste tracking.

A detailed description of our methodology and platform are presented in Sections IV and V, respectively. Section VI describes the test scenarios with the proposed platform. Section VII presents some offers for future work. Finally, Section VIII concludes our work.

II. LITERATURE REVIEW

The flow of e-waste has also been the subject of various studies. Some studies have attempted to quantify the transboundary movement of e-waste (Breivik et al., 2014; Lee et al., 2018; Lepawsky and McNabb, 2010; Lepawsky, 2015; Shinkuma and Nguyen Thi Minh Huong, 2009; Song et al., 2017a; Song et al., 2017b; Tong et al., 2018), while others have focused on the domestic flow of e-waste through tracking and tracing the flow of e-waste (Dwivedy and Mittal, 2012; Kahhat and Williams, 2012; Miller et al., 2016; Mishima et al., 2016; Veenstra et al., 2010; Yoshida et al., 2009). To effectively manage e-waste, it is necessary to embrace appropriate technological solutions that address the following aspects:

- Transparency in the electronic waste movement.
- Extended producer responsibility (EPR) implementation.
- Traceability of e-products across their entire life cycle, from manufacturing to e-waste conversion to recycling back into raw materials.
- Constructing appropriate channels for reaching out to e-waste.
- A sufficient number of recycling facilities and their connectivity to a technology-driven e-waste management system is essential (Sahoo et al., 2021). According to the literature, it is evident that there is a gap in the field of electrical and electronic waste collection, particularly concerning the implementation of track-and-trace technologies and smart collection systems (Lopez Alvarez et al., 2008; Rada et al., 2013; Martin and Leurent, 2017; Kazancoglu et al., 2021).

III. CURRENT CHALLENGES FOR E-WASTE TRACKING

Particularly in developing countries, the tremendous volume of waste and the lack of information about waste movement are the greatest challenges to the waste management sector. By 2025, it is expected that 2.2 billion metric tons of solid waste will have been produced. E-waste is expanding at a rate three times that of traditional waste types. Less than a quarter of all electronic waste was collected for formal recycling in 2016. In 2017, the raw materials in e-waste were worth $47 million, as reported in (Baldé et al., 2017; Yadav et al., 2021). Based on waste generation data in 2019, metals could be recycled worth $57 billion and used to meet metal demand brought on by the manufacture of new electrical equipment (Forti et al., 2020).

Of all the countries in the world, only 41 countries have provided official statistics on their e-waste. Furthermore, statistics from previous studies for 16 countries were obtained, explaining the low collection rate for e-waste and leaving 34.1 metric tons of WEEE unaccounted for (Baldé et al., 2017). Although many countries provide information on their e-waste, there is no guarantee that this information is correct. When it comes to recycling waste electrical and electronic equipment (WEEE), many third-world countries have relied heavily on the informal sector (Ackah, 2017). This means that official statistics on e-waste may not provide a useful step toward a long-term solution to the problems associated with disposing of e-waste. Strong legislation is needed to prevent the informal sector from collecting WEEE. To dispose of their illegal e-waste, developed countries often ship it to developing countries with weak or average economies (Rais, 2022). This occurs because either the guidelines are inadequate, or law enforcement is ineffective. In addition, undocumented electronic waste poses a risk to personal confidentiality. Data and information security are at risk from the many types of storage devices that make up e-waste (Rais, 2022; Debnath, 2023).

IV. METHODOLOGY

In this paper, a qualitative review of the literature in the area of e-waste and its tracking system has been done. Use cases of tracking system implementations were studied in detail, and application development experts were consulted to take input related to developing the architectural framework for tracking implementation in e-waste management. Figure 2 shows the research methodology, and Figure 3 presents the architectural framework for tracking implementation.

Figure 2: The applied research methodology.

Figure 3: Architectural framework for tracking implementation.

V. PLATFORM DESCRIPTION

The process for creating an e-waste tracking platform includes four steps, as shown in Figure 4. The 4 steps are presented in detail in the following subsections.

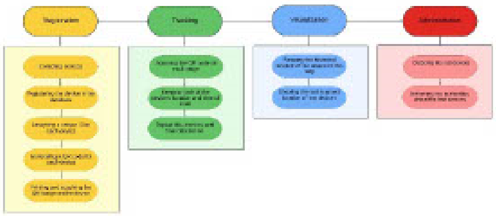


Figure 4: The process of creating an E-waste tracking platform.

A. The first step: Registration

This step, as shown in Figure 5, includes collecting devices as e-waste during their end-of-life period (EOL) and then recording the device's specifications. Then the device is registered in the database, and a unique ID is assigned to each device. In this paper, a unique QR code is generated for each device, as shown in Figure 6.

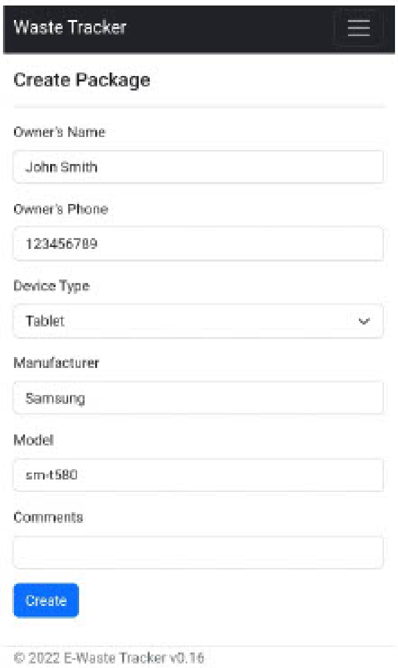


Figure 5: Device Registration user interface in the Platform.

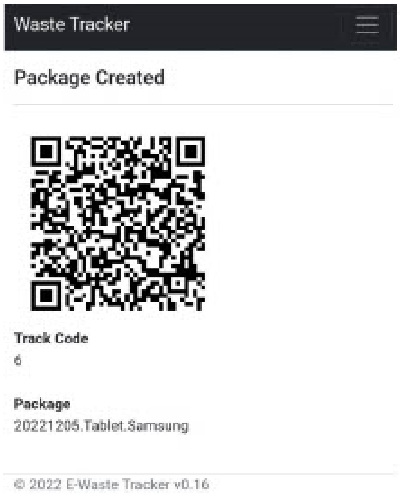


Figure 6: QR code generate of an e-waste device.

This QR code can be printed and attached as a badge on each device. More often, e-waste recognition can be performed by either a machine-learning or deep-learning approach, but for simplicity, these methods have been ignored.

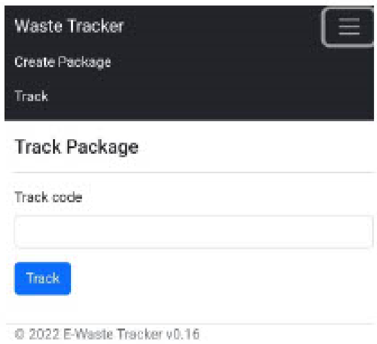


Figure 7: User interface design for E-waste tracking.

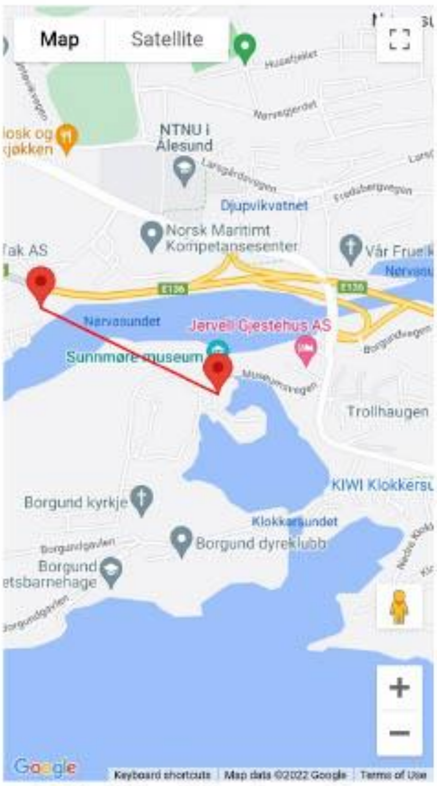
B. Second step: Tracking

The process of tracking e-waste is made simple with the QR code on each stage, such as the collection station, which can be scanned using a mobile phone. This platform enables the association of tracked e-waste with the location of the mobile device that scanned the QR code and the time log of this action. This procedure is repeated until the e-waste device reaches its final destination, which can be specified by the user. All tracking data is saved at each destination in a database, providing a complete record of the disposal journey. The end user can easily track each device by entering the tracking code created during the registration step. The tracking information of each device, including its current location, is then displayed on the platform, as shown in Figure 7.

C. Third step: Visualization

When the e-waste movement is tracked, the platform retrieves this information, including the location at various checkpoints, and visualizes it based on time logs, as shown in Figure 8. The platform offers a dynamic and user-friendly dashboard that allows users to track the movement of e-waste in real-time on an interactive map. With our intuitive visualizations, users can easily monitor the location of their e-waste at every stage of the disposal process.

This innovative feature provides a comprehensive overview of the e-waste disposal journey, ensuring transparency and accountability throughout the entire process. If a device is lost at any stage, the application can show the latest scanned location of the missing object and send an alert to the tracking party. For example, if no new location data for a device is received after a certain period of time, the system could conclude that the device has disappeared.



Figures 8: Visualizing dashboard to track the movement of e-waste in real-time on an interactive map.

D. Fourth step: Administration

The purpose of developing this part is to provide system administrators with an overall perspective of the system states and devices that are currently being tracked. The pseudocode for the tracking platform, shown in Figure 9, is designed to monitor the movement of e-waste through the recycling process.

```
Algorithm 1: Function to register e-waste
  Data: device specifications
  Result: device ID and QR code
  begin
    device_id ← generate_device_id(device_specifications);
    database.add_device(device_id, device_specifications);
    qr_code ← generate_qr_code(device_id);
    return device_id, qr_code;
  end
```

```
Algorithm 2: Function to track e-waste
  Data: device ID, location
  Result: location
  begin
    database.add_location(device_id, location);
    if is_device_lost(device_id, location) then
      send_alert(device_id, location);
    end
    return location;
  end
```

```
Algorithm 3: Function to visualize the movement of e-waste
  Data: device ID
  Result: location history
  begin
    location_history ← database.get_location_history(device_id);
    plot_locations(location_history);
    return location_history;
  end
```

```
Algorithm 4: Function to administer the system
  Result: system status and list of devices
  begin
    system_status, devices ← database.get_system_status();
    return system_status, devices;
  end
```

Figures 9: Pseudocode of the e-waste tracking platform.

The pseudocode is presented in a series of steps, beginning with the creation of a new transaction to record the initial movement of the e-waste. The transaction includes information about the origin, destination, and type of e-waste being moved.

The next step involves validating the transaction, which involves verifying the authenticity of the information provided and ensuring that the transaction complies with the regulations and standards for e-waste management.

The ledger can be accessed by authorized parties, such as government regulators and recycling companies, to track the movement of e-waste and ensure compliance with environmental regulations.

Additional steps in the pseudocode include monitoring the storage and disposal of e-waste, as well as the issuance of certificates of destruction to confirm that the e-waste has been properly disposed of.

Overall, the pseudocode of the tracking platform provides a clear and structured overview of the processes involved in monitoring the movement of e-waste through the recycling process.

VI. FUTURE WORK

Waste management operations are becoming more sustainable and advantageous for the future thanks to digital innovations like robotic systems, smart tracking, sensors, RFID applications, mobile apps, and autonomous vehicles. Tracking is one of the most lost stages and needs to be integrated with digitalization, especially in the e-waste category. The proposed platform will be implemented and disseminated to track e-waste practices in future studies. In addition, the asserted benefits can be improved with blockchain technology to save tracking data with a privacy-focused identity validation process while maintaining privacy and safety. Another research topic would be to integrate this tracking method with the circular economy approaches of the proposed platform in order to evaluate the effect of the black market for e-waste. Comparative studies can be conducted through the counties of Norway in order to reveal the common and differentiating issues among them. In future studies, the tools, and techniques, especially blockchain technology, will be embedded within the proposed platform.

CONCLUSION

E-waste has become a significant environmental problem because of the high pace of production and its massive volume. This study initially defines "e-waste," which is separated into six major categories in order to better understand and manage it. Following that, it describes the current e-waste regulations and legislation that apply throughout the world. Then, e-waste's tracking procedure and its challenges are evaluated, and the current official statistics on countries' e-waste tracking are reviewed. Ultimately, it focuses on the design and development of a tracking system by scanning the e-waste and visualizing the trend of its movement in order to avoid any disappearances along its journey, which is our motivation for minimizing the quantity of information stolen. This platform is a more simple, user-friendly, and cost-effective tracking system for dealing with e-waste, particularly e-waste flow, which addresses the issue of personal confidentiality, and finally, as a future solution, this paper proposes the blockchain method for increased safety and privacy protection.

REFERENCES

Ackah, M. (2017). "Informal E-waste recycling in developing countries: review of metal(loid)s pollution, environmental impacts and transport pathways". In *Environmental Science and Pollution Research*, 24(31), 24,092–24,101. https://doi.org/10.1007/s11356-017-0273-y

Adanu, S. K., Gbedemah, S. F., & Attah, M. K. (2020). "Challenges of adopting sustainable technologies in e-waste management at Agbogbloshie, Ghana". In *Heliyon*, 6(8), e04548. https://doi.org/10.1016/j.heliyon.2020.e04548

Al-Salem, S., Leeke, G. A., El-Eskandarany, M. S., Van Haute, M., Constantinou, A., Dewil, R., & Baeyens, J. (2022). "On the implementation of the circular economy route for E-waste management: A critical review and an analysis for the case of the state of Kuwait". In *Journal of Environmental Management*, 323, 116181. https://doi.org/10.1016/j.jenvman.2022.116181

Andeobu, L., Wibowo, S., & Grandhi, S. (2021). "A Systematic Review of E-Waste Generation and Environmental Management of Asia Pacific Countries". In *International Journal of Environmental Research and Public Health*, 18(17), 9051. https://doi.org/10.3390/ijerph18179051

Andrade, D. F., Romanelli, J. P., & Pereira-Filho, E. R. (2019). "Past and emerging topics related to electronic waste management: top countries, trends, and perspectives". In *Environmental Science and Pollution Research*, 26(17), 17135–17151. https://doi.org/10.1007/s11356-019-05089-y

Baldé, C. P., Wang, F., Kuehr, R., & Huisman, J. (2015). The global e-waste monitor–2014, United Nations University, IAS–SCYCLE, Bonn, Germany. ISBN Print, 978-92.

Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). The global ewaste monitor 2017: Quantities, flows and resources. United Nations University, International Telecommunication Union, and International Solid Waste Association, 2017. https://ewastemonitor.info/gem-2017/

Breivik, K., Armitage, J. M., Wania, F., & Jones, K. C. (2014). "Tracking the global generation and exports of e-waste. Do existing estimates add up?". In *Environmental Science & Technology*, 48(15), 8735–8743. https://doi.org/10.1021/es5021313

Chaudhary, K., Padmanabhan, P., Verma, D., & Yadav, P. D. (2021). "Blockchain: a game changer in electronic waste management in India". In *International Journal of Integrated Supply Management*, 14(2), 167-182. https://doi.org/10.1504/IJISM.2021.115680

Debnath, B., Alghazo, J. M., Latif, G., Roychoudhuri, R., & Ghosh, S. K. (2020). An Analysis of Data Security and Potential Threat from IT Assets for Middle Card Players, Institutions and Individuals. In *Sustainable Waste Management: Policies and Case Studies: 7th IconSWM—ISWMAW 2017, Volume 1* (pp. 403-419). Springer Singapore. https://doi.org/10.1007/978-981-13-7071-7_36

Directive, E. C. (2012). "Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment, WEEE". *Official Journal of the European Union* L, 197, 38-71. https://doi.org/10.5040/9781782258674.0030

Dwivedy, M., & Mittal, R.K (2012). "An investigation into e-waste flows in India". In *Journal of Cleaner Production*, 37, 229–242. https://doi.org/10.1016/j.jclepro.2012.07.017

Forti, V., Balde, C. P., Kuehr, R., & Bel, G. (2020). "The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential". United Nations University/United Nations Institute for Training and

Research, Internationa Telecommunication Union, and International Solid Waste Association.

Hazra, A., Das, S., Ganguly, A., Das, P., Chatterjee, P. K., Murmu, N. C., & Banerjee, P. (2019). "Plasma Arc Technology: A Potential Solution Toward Waste to Energy Conversion and of GHGs Mitigation". In *Waste Valorisation and Recycling 7th IconSWM—ISWMAW 2017, Volume 2* (pp. 203-217). Springer Singapore. https://doi.org/10.1007/978-981-13-2784-1_19

Ilankoon, I. M. S. K., Ghorbani, Y., Chong, M. N., Herath, G., Moyo, T., & Petersen, J. (2018). "E-waste in the international context–A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery". In *Waste management*, *82*, 258-275. https://doi.org/10.1016/j.wasman.2018.10.018

Islam, M. T., & Huda, N. (2020). "Assessing the recycling potential of "unregulated" e-waste in Australia". In *Resources, Conservation and Recycling*, 152, 104526. https://doi.org/10.1016/j.resconrec.2019.104526

Kahhat, R., & Williams, E. (2012). "Materials flow analysis of e-waste: Domestic flows and exports of used computers from the United States." In *Resources, Conservation and Recycling*, 67, 67–74. https://doi.org/10.1016/j.resconrec.2012.07.008

Kazancoglu, Y., Ozbiltekin, M., Ozkan Ozen, Y. D., & Sagnak, M. (2021). "A proposed sustainable and digital collection and classification center model to manage e-waste in emerging economies". In *Journal of Enterprise Information Management*, 34(1), 267–291. https://doi.org/10.1108/JEIM-02-2020-0043

Kumar, A., Holuszko, M., & Espinosa, D. C. R. (2017). "E-waste: An overview on generation, collection, legislation and recycling practices". In *Resources, Conservation and Recycling*, 122, 32– https://doi.org/10.1016/j.resconrec.2017.01.018

Lee, D., Offenhuber, D., Duarte, F., Biderman, A., & Ratti, C. (2018). "Monitour: Tracking global routes of electronic waste". In *Waste Management*, 72, 362–370. https://doi.org/10.1016/j.wasman.2017.11.014

Lepawsky, J., & McNabb, C. (2010). "Mapping international flows of electronic waste". *The Canadian Geographer / Le Géographe canadien*, 54(2), 177–195. https://doi.org/10.1111/j.1541-0064.2009.00279.x

Lepawsky, J. (2015). "The changing geography of global trade in electronic discards: Time to rethink the e-waste problem". In *The Geographical Journal*, 181(2), 147– https://doi.org/10.1111/geoj.12077

Li, J., Lopez, B. N., Liu, L., Zhao, N., Yu, K., & Zheng, L. (2013). "Regional or global WEEE recycling. Where to go?". In *Waste Management*, 33(4), 923–934. https://doi.org/10.1016/j.wasman.2012.11.011

Lopez Alvarez, J. L., Aguilar Larrucea, M., Fernandez-CarriÅLon Quero, S., & Jimenez del Valle, A. (2008). "Optimizing the collection of used paper from small businesses through GIS techniques: The LeganÅLes case (Madrid, Spain)". In *Waste Management*, 28(2), 282–293. https://doi.org/10.1016/j.wasman.2007.02.036

Martin, C., & Leurent, H. (2017). "Technology and Innovation for the Future of Production: Accelerating Value Creation (Tech. Rep.)". In *World Economic Forum*. (pp. 1-38).

Miller, T. R., Duan, H., Gregory, J., Kahhat, R., & Kirchain, R. (2016). "Quantifying Domestic Used Electronics Flows using a Combination of Material Flow Methodologies: A US Case Study". In *Environmental Science & Technology*, 50(11), 5711–5719. https://doi.org/10.1021/acs.est.6b00079

Mishima, K., Rosano, M., Mishima, N., & Nishimura, H. (2016). "End-of-Life Strategies for Used Mobile Phones Using Material Flow Modeling". In *Recycling*, 1(1), 122–135. https://www.mdpi.com/2313-4321/1/1/122

Mmereki, D., Li, B., Baldwin, A., & Hong, L. (2016). "The Generation, Composition, Collection, Treatment and Disposal System, and Impact of E-Waste". In *E-Waste in Transition - From Pollution to Resource* (pp. 65–93). https://dx.doi.org/10.5772/61332

Patil, R. A., & Ramakrishna, S. (2020). "A comprehensive analysis of e-waste legislation worldwide". In *Environmental Science and Pollution Research*, 27(13), 14412–14431. https://doi.org/10.1007/s11356-020-07992-1

Rada, E., Ragazzi, M., & Fedrizzi, P. (2013). "Web-GIS oriented systems viability for municipal solid waste selective collection optimization in developed and transient economies". In *Waste Management*, 33(4), 785–792. https://doi.org/10.1016/j.wasman.2013.01.002

Rais, M. U. (2022). "Smart E-waste Tracking and Monitoring Model: A Modern Approach to Counter E-waste Management Issues". In *Technology Innovation in Mechanical Engineering: Select Proceedings of TIME 2021* (pp. 757-765). Singapore: Springer Nature Singapore https://doi.org/10.1007/978-981-16-7909-4_69

Sahoo, S., Mukherjee, A., & Halder, R. (2021). "A unified blockchain-based platform for global e-waste management". In *International Journal of Web Information Systems*, 17(5), 449–479. https://doi.org/10.1108/IJWIS-03-2021-0024

Schumacher, K. A., & Agbemabiese, L. (2019). "Towards comprehensive ewaste legislation in the United States: Design considerations based on quantitative and qualitative assessments". In *Resources, Conservation and Recycling*, 149, 605–621. https://doi.org/10.1016/j.resconrec.2019.06.033

Sharma, K. D., & Jain, S. (2020). "Municipal solid waste generation, composition, and management: the global scenario". In Social Responsibility Journal, 16(6), 917–948. https://doi.org/10.1108/SRJ-06-2019-0210

Shinkuma, T., & Nguyen Thi Minh Huong. (2009). "The flow of E-waste material in the Asian region and a reconsideration of international trade policies on E-waste". In *Environmental Impact Assessment Review*, 29(1), 25–31. https://doi.org/10.1016/j.eiar.2008.04.004

Song, Q., Wang, Z., Li, J., Duan, H., Yu, D., & Zeng, X. (2017a). "Characterizing the transboundary movements of UEEE/WEEE: Is Macau a regional transfer center?". In Journal of Cleaner Production, 157, 243–253. https://doi.org/10.1016/j.jclepro.2017.04.149

Song, X., Hu, S., Chen, D., & Zhu, B. (2017b). "Estimation of waste battery generation and analysis of the waste battery recycling system in China". In *Journal of Industrial Ecology*, 21(1), 57–69. https://doi.org/10.1111/jiec.12407

Thakur, P., & Kumar, S. (2022). "Evaluation of e-waste status, management strategies, and legislations". In *International Journal of Environmental Science and Technology*, 19(7), 6957–6966. https://doi.org/10.1007/s13762-021-03383-2

Tong, X., Wang, T., Chen, Y., & Wang, Y. (2018). "Towards an inclusive circular economy: Quantifying the spatial flows of e-waste through the informal sector in China". In *Resources, Conservation and Recycling*, 135, 163–171. https://doi.org/10.1016/j.resconrec.2017.10.039

Van Yken, J., Boxall, N. J., Cheng, K. Y., Nikoloski, A. N., Moheimani, N. R., & Kaksonen, A. H. (2021). "E-Waste Recycling and Resource Recovery: A Review on Technologies, Barriers and Enablers with a Focus on Oceania". In *Metals*, 11(8), 1313. https://doi.org/10.3390/met11081313

Veenstra, A., Wang, C., Fan, W., & Ru, Y. (2010). "An analysis of E-waste flows in China". In *The International Journal of Advanced Manufacturing Technology*, 47(5-8), 449–459. https://doi.org/10.1007/s00170-009-2356-5

Yoshida, A., Tasaki, T., & Terazono, A. (2009). "Material flow analysis of used personal computers in Japan". In *Waste Management*, 29(5), 1602–1614. https://doi.org/10.1016/j.wasman.2008.10.021

Zuo, L., Wang, C., & Sun, Q. (2020). "Sustaining WEEE collection business in China: The case of online to offline (O2O) development strategies". In *Waste Management*, 101, 222–230. https://doi.org/10.1016/j.wasman.2019.10.008

AUTHOR BIOGRAPHIES

IBRAHIM A. HAMEED is a Professor at the Department of ICT and Natural Sciences, Faculty of Information Technology and Electrical Engineering, Norwegian University of Science, and Technology (NTNU), Norway. Hameed is an IEEE senior member, elected chair of the IEEE Computational Intelligence Society (CIS) Norway section, and ACM member. Hameed has a PhD degree in Industrial Systems and Information Engineering from Korea University, Seoul, South Korea and a PhD degree in Mechanical Engineering from Aarhus University, Aarhus, Denmark. He is the author of many journal and conference articles in areas of AI, machine learning, robotics, and automation. His e-mail address is: `ibib@ntnu.no` and his Webpage can be found at `https://www.ntnu.edu/employees/ibib`.

SARA ARTANG is an MSc student at the international master program in simulation and visualization, Department of ICT and Natural Sciences, Faculty of Information Technology and Electrical Engineering, Norwegian University of Science, and Technology (NTNU), Norway.

AFSHIN GHASEMIAN is a senior developer at Crayon, Norway.

NTNU
Norwegian University of
Science and Technology