Digital Challenges to Economic Opportunities: Ubiquitous Computing in Malaysia's Public Transportation Sector

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***Abstract*—This research paper explored the economic potential of ubiquitous computing, particularly the Internet of Things (IoT), within Malaysia's public transportation sector. It examines how the integration of IoT, AI and data analytics can address the current digital challenges within the sector which include service quality, connectivity limitations, real-time information gaps, multiple ticketing systems, and the integration of various transportation modes. Ubiquitous computing solutions, encompassing contactless payments, sensor-based real-time data, and IoT-driven smart systems, are explored as methods to boost efficiency, enhance passenger experience, and positively impact the economy. The paper also touches on the ethical considerations, infrastructure needs, and economic opportunities associated with IoT in various sectors. Overall, it focuses on the transformative potential of ubiquitous computing in Malaysia's journey toward economic growth and technological advancement.**

Keywords—Ubiquitous Computing, Internet of Things (IoT), Public Transportation Sector, Digital Economy

I. INTRODUCTION

Public transportation is crucial for economic and social progress as it enhances mobility, benefiting the national economy by supporting the movement of people and goods. It also boosts economic growth by reducing transportation costs, road and parking expenses, vehicle operating outlays, accidents, and pollution. Additionally, public transportation meets societal needs by connecting urban and rural areas and providing essential transit services, facilitating access to airports, train stations, and ports. The public transportation sector in Malaysia is characterized by a comprehensive network that includes rail transport, extensive bus services, taxi and ride-sharing options, as well as water-based transport (HSS Engineers Berhad, 2020). Notably, Malaysia has well-developed systems such as light rail transit (LRT), mass rail transit (MRT), and electric train service (ETS) for urban and intercity travel.

Ubiquitous computing, often known as the Internet of Things (IoT) has gained global attention over the past two decades. Emerging technologies like the Internet of Things (IoT), Artificial Intelligence (AI), data analytics, and connected and autonomous vehicles bring benefits that could contribute to the economic growth of the country (Loh et al., 2021). Integration of these technologies in the transportation sector would also gear towards improving the efficiency, service quality and sustainability of the transportation sector. Malaysia exemplifies this trend through its national IoT program initiated in 2015, which reflects a commitment to this transformative technology (Badarudin et al., 2018).

According to Tech for Good Institute (2022), Malaysia has a highly connected digital economy, set to contribute 22.6% of its GDP by 2025, up from 17.8% in 2015. The COVID-19 pandemic has boosted digital engagement, with Malaysia leading Southeast Asia in the percentage of digital consumers at 83%. However, digital inclusion remains uneven across the nation. To balance digital growth and challenges, the Malaysian Digital Economy Blueprint, known as MyDigital was introduced in 2021. It is a strategic plan that outlines the path for the advancement of Malaysia's digital economy (Povera & Yusof, 2021) where key priorities such as nurturing digital talent, promoting inclusivity in the digital society, and ensuring a secure digital environment are included. This reflects the government's aim to make Malaysia a high-income nation and a regional leader in the digital economy.

While recognizing the significant possibilities of IoT, it is essential to recognize the various obstacles that must be tackled during this digital transformation. These obstacles encompass the requirement for a strong digital foundation, apprehensions about safeguarding data, insufficient access to real-time information, efforts to ensure digital inclusion, and the adjustment of regulatory structures. The research paper centres on exploring how the incorporation of ubiquitous computing in various sectors can potentially offer economic advantages to the public transportation sector as well.

II. OVERVIEW OF DIGITAL CHALLENGES

A. Current Digital Challenges

Amidst the arrival of Industrial Revolution (IR) 4.0, industries around the world underwent a transformative phase as they embraced cutting-edge technologies, ushering in a new era of automation, connectivity, and data-driven decision-making. In Malaysia, this digital transformation would not just be an abstract concept but has tangible implications for economic growth which is widely recognized as a pivotal driver of economic expansion, optimizing efficiency across diverse industries like transportation, healthcare and education. However, digital challenges need to be addressed to fully realize the benefits of this digital transformation in various industries.

Land and rail-based public transport plays a vital role in the transportation infrastructure in Malaysia. Both of these modes of transportation are diverse including buses, LRT,

MRT, monorails, commuter trains, taxis, and e-hailing vehicles. In the urban areas such as Kuala Lumpur and its surrounding regions, there is a well-developed and expanding network of rail transit systems which make it easier for commuters to navigate around the city. The ETS provides convenient rail connectivity for residents in the greater Kuala Lumpur area and beyond. Moreover, the extensive network of intercity express buses connects various regions of the country, facilitating long-distance travel. However, despite the rising enhancement of public transport services, the public transportation sector in Malaysia faces various challenges in adapting to digital transformation.

The continuous enhancement of public transportation services aims to reduce car dependency and mitigate issues like air pollution, traffic jams, and accidents. However, the adoption by the public remains low despite the significant investments in public transport (Ibrahim et al., 2020). Factors contributing to low ridership include service quality, limited connections especially in rural areas, real-time information, multiple ticketing systems, and integration between various modes of public transportation (Bernama, 2019). Despite these challenges, Malaysia is making efforts to improve its land and rail public transport through cutting-edge technologies to better serve the people.

B. Economic Impact

The economic impact of digital challenges refers to the financial consequences of various issues and obstacles which arise in the context of the digital economy. These challenges can affect businesses, industries, and even the economic state of a country in several ways such as low productivity rate caused by system downtime or inadequate digital infrastructure, and increased costs as additional expenses would be required for digital enhancement and market competition.

The economic development of a country is shaped by the intricate interaction of diverse factors and circumstances. In this section, focus will be placed on the economic impact of the public transportation sector in Malaysia. Potential factors that affect the public transportation sector in Malaysia:

1) Service Quality: Inadequate service quality can have a profound economic impact as passengers' satisfaction and willingness to use public transportation are directly influenced by the quality of service. Passengers may opt for alternative modes of transport such as e-hailing services or private cars when service quality is low which leads to a decrease in ridership and resulting in low revenue for public transportation operators.

2) Limited Connections: The lack of well-established and convenient transportation connections in some of the urban areas like Putrajaya (Ladin et al., 2014) and most of the rural areas can impede economic development and limit access to opportunities. Rural areas being left behind in terms of economic growth could lead to economic disparities as the rural areas struggle to keep pace with urban development. Improved connectivity can stimulate economic activity not only in rural areas but also in urban areas which will in turn improve the overall economic growth, reducing the economic disparities between rural and urban areas in Malaysia.

3) Real-Time Information: The lack of real-time information and updates regarding public transportation schedules and delays can lead to passenger frustration and inconvenience. When travellers cannot depend on precise and current information, they may be more likely to opt for alternative means of transportation. This shift contributes to a decrease in the number of passengers and, subsequently, a drop in revenue for public transportation operators. Therefore, ensuring the accessibility of real-time information is vital for both attracting and retaining passengers.

4) Multiple Ticketing Systems: In Malaysia, a range of public transportation options is available to the public, featuring several distinct ticketing systems. For instance, passengers would need to get multiple tickets to go from one place to another. This complexity can discourage passengers from using public transportation, as it might not be seen as a convenient or user-friendly option (Bernama, 2019). The economic impact is twofold where public transportation operators may experience lower ticket sales and fare revenues, and passengers may face higher travel costs due to the lack of integrated ticketing options.

5) integration between Various Modes of Public Transportation: The lack of seamless integration between different modes of public transportation, such as buses and trains, can result in passengers having to navigate inconvenient and disjointed journeys. Inefficiencies caused by poor integration can lead to longer travel times, service disruptions, and higher costs for passengers. It can also negatively affect the economic prospects of businesses located along transportation routes, as reduced accessibility can lead to decreased customer numbers.

C. Ubiquitous Computing Solutions

Ravi & Chelliaih, (2023) states that Malaysia has been working to position itself as a leading player in the digital economy, leveraging its strengths in areas such as technology infrastructure and talent. The author also notes that emerging technologies like AI and IoT are transforming various industries and economics around the world, including Malaysia. The author explored the application of AI in sectors like banking and healthcare, highlighting benefits such as improved efficiency, cost reduction, and enhanced customer experience. Moreover, the author also indicates that IoT has the potential to address challenges related to traffic congestion, safety, and environmental sustainability.

Ubiquitous computing offers a promising set of solutions to address the prevailing challenges in the public transportation sector. These solutions leverage technology to enhance various aspects of the system, resulting in improved efficiency, passenger experience, and overall economic impact. For instance, the implementation of contactless payment methods could allow passengers to have a more convenient and streamlined experience which reduces the hassle of carrying physical tickets. The development of sensor-based systems that deliver up-to-the-minute data on routes, schedules, and potential delays could significantly enhance the overall quality of the public transportation service.

Leveraging smart systems that incorporate IoT and data analytics enables the monitoring of traffic conditions, addressing road congestion and public transportation operations. These systems can predict traffic patterns, identify bottlenecks, and suggest optimal routes for public transportation, leading to reduced congestion and improved traffic flow. Additionally, ubiquitous computing facilitates the creation of integrated platforms that allow passengers to seamlessly switch between different modes of public transportation. This user-friendly approach streamlines journey planning, booking, and payment across various transportation systems through a single interface. This integration enhances accessibility and attractiveness, positively influencing ridership and revenue in the public transportation network.

III. UNDERSTANDING UBIQUITOUS COMPUTING

A. *Definition Key Concepts, and Principles of Ubiquitous Computing*

Ubiquitous computing was introduced by Mark Weiser in 1991, with a focus on the widespread integration of information technology and computer capabilities into everyday objects (Friedewald & Raabe, 2011). The term ubiquitous computing is similar to terms such as pervasive computing and diffuse computing (Aky et al., 2019). Ubiquitous computing is a transformative concept that involves embedding small, interconnected microprocessors with sensors into various objects, enabling them to record their environment, process information, and communicate wirelessly. These smart objects gain the ability to "know" their location, surroundings, and past interactions. This technology holds great promise across numerous domains, including enhancing home comfort and energy efficiency, improving road safety with smart vehicles, increasing office productivity through personal assistance systems, and monitoring user health with implantable sensors.

Ubiquitous computing has evolved into ambient intelligence, which involves the creation of intelligent electronic environments capable of adapting to human actions and the needs of objects. This development enriches the environment through the deployment of technologies such as sensors, actuators, and processors, enabling the capture, processing, and decision-making of data to benefit users. Ambient intelligence encompasses the entire environment and its interactions with humans, often referred to as a smart environment. A smart environment is a network of interconnected smart objects physically located in a particular space, providing data capture, action, and computing capabilities to various services. With this definition, the Internet of Things (IoT) can be seen as a smart environment, connecting smart objects via Internet communication standards (Aky et al., 2019). In general, ubiquitous computing has wide-ranging implications for individuals, businesses, and society, offering the potential for a more connected and efficient world.

Research by Friedewald & Raabe (2011) states that ubiquitous computing and related concepts have been integrated into the research policies of various developed nations, each with its specific objectives. In the United States, the focus has been on technological excellence, without a comprehensive socio-political vision. Japan has aimed to create a Ubiquitous Network Society with a strong emphasis on fast, wireless networks and consumer-oriented services. South Korea also aspires to become a leading ubiquitous network society but emphasizes universal societal benefits. Singapore has already established extensive broadband and wireless networks and seeks to become a ubiquitous information society, addressing both economic and societal goals. The European Union has long emphasized ambient intelligence, prioritizing human needs and societal considerations while promoting competitiveness and the transition to a knowledge-based society. In Germany, ubiquitous computing gained significant attention in 2005 with a focus on industrial applications, particularly the Internet of Things. These countries have incorporated ubiquitous computing into their research policies, each with a distinct focus and vision.

The foundation of ubiquitous computing rests upon several core principles that steer its implementation and advancement. Bran et al., (2021) highlight the principles that drive the intelligent environment. The author states that invisibility is one of the fundamental principles emphasizing that technology should seamlessly integrate into the environment and become imperceptible to users. This means that the presence of technology should not disrupt or distract from daily life but should enhance it. The ubiquitous computing systems should also be context-aware, where they can adapt and respond to the changing circumstances and needs of users in real-time. Moreover, the idea of user-centred design is crucial to ensure that technology solutions are tailored to meet the specific requirements and preferences of individuals. Privacy and security are essential principles in ubiquitous computing. Protecting user data and ensuring that the technology respects individual privacy is of utmost importance. This involves implementing robust security measures and transparent data handling practices. Scalability and interoperability are vital to accommodate the ever-expanding landscape of interconnected devices. Ubiquitous computing systems must be designed to grow and adapt, allowing the integration of new technologies and ensuring they can work together seamlessly. These principles collectively drive the development of ubiquitous computing, making it a powerful and user-centric approach to technology integration.

B. *Overview of Technologies and Infrastructure Required for Implementing Ubiquitous Computing in Malaysia*

The realm of information and communication technology (ICT) in the past was used by various tools, devices, hardware and software. However, recent technological advancements such as ubiquitous computing have introduced a new dimension to the world of computing. The successful implementation of ubiquitous computing in Malaysia requires a comprehensive technological infrastructure. This infrastructure encompasses various elements and technologies to create a seamless and efficient ubiquitous computing environment such as wireless connection, sensors and IoT devices, and cloud computing.

Research done by Mohammad (2019) states that cloud computing can be described as a model that facilitates the sharing of network-accessible and configurable computing resources among organizations with minimal interaction between the cloud service providers and users. The study distinguishes between two main entities in cloud computing: the user and the provider. Users usually access cloud services

through the internet, although in certain situations, they may connect to these services within a private cloud of an organization. Cloud computing operates by requiring users to submit specific service requests to the cloud before the requested service can be provided. Within the cloud infrastructure, a central server is typically situated to manage the operating system.

Another study by Hong & Varghese, (2019) identifies and classifies the architectures and the infrastructure for managing resources in fog/edge computing. Fog/edge computing is a distributed computing paradigm that extends cloud computing to the edge of the network, organized into a hierarchy of nodes. This hierarchy includes end devices like sensors and IoT devices at the lowest level, intermediate fog nodes that offer computing and storage resources closer to end devices, and cloud data centres at the highest level with centralized computing and storage resources. Three main categories of fog/edge computing architectures exist: cloud-centric, relying on centralized cloud resources; fog-centric, utilizing distributed fog nodes closer to end devices; and hybris, which combines both cloud and fog resources. Additionally, these architectures can be classified based on the level of abstraction, including hardware-centric, software-centric, and service-centric models. The choice of architecture depends on factors like application requirements, network conditions, and available resources.

IV. THE ECONOMIC POTENTIAL OF UBIQUITOUS COMPUTING IN MALAYSIA

Ubiquitous computing presents substantial economic opportunities in Malaysia, mirroring its potential in other nations. It can improve various industries, including smart cities, agriculture, manufacturing, healthcare, and education. Despite initial challenges in the early stages of digital transformation, through resource optimization, service enhancement, and investment attraction, the Internet of Things (IoT) can stimulate economic expansion and elevate Malaysia's global competitive standing.

A. Improved Connectivity and Digital Infrastructure

In the initial phase of digital transformation, the digital divide focused on disparities in internet access in Malaysia but has since evolved to encompass various dimensions of digital inequality which include quality of service, affordability, and digital literacy. Research by Gong et al. (2021) states that internet access can influence socio-economic outcomes like education, job opportunities, health literacy, and political engagement. The concept of meaningful connectivity has also emerged, which involves a multidimensional approach, focusing on daily internet use, access to an appropriate device, sufficient data, and a fast connection, rather than a simple binary measure of internet penetration.

MyDigital was developed in 2021 to align with the national development policies of Malaysia, such as the 12th Malaysia Plan and the Shared Prosperity Vision 2030, as well as the Sustainable Development Goals of the United Nations (MyGOV, 2023). It focuses on the digital economy as a key driver of economic growth to achieve sustainable and equitable development in Malaysia. The digital economy is defined as economic and social activities involving digital technology used by individuals, businesses, and the government (Loh et al., 2021). This digital transformation is driven by the fourth industrial revolution, characterized by the integration of digital, physical, and biological domains, leading to rapid and unprecedented changes in various industries and accelerating the growth of the digital economy.

B. Smart City Initiatives and Economic Development

The Malaysian government has recognized the significance of smart city development and implementation in the context of digital economy transformation, leading to the development of the Smart City Framework Malaysia (MSCF). The government sees smart cities as the future of urban planning, offering solutions to urban issues like inefficient services, pollution, and traffic congestion, ultimately enhancing urban living. The framework aligns with national and global objectives, particularly the Sustainable Development Goals (SDGs), and ensures Malaysia stays current with global urban development trends (MyGOV, 2023). Smart city in Malaysia comprises seven major components (Lim et al., 2021):

1) Smart Economy: The smart economy component focuses on boosting competitiveness and economic development. It includes sub-components like fostering innovation, enhancing the economic image, entrepreneurship, labour market flexibility, productivity, and global connectivity. MSCF outlines strategies involving technology adoption, e-payment promotion, workforce development, technology support structures, and investment attraction in high-value-added industries.

2) Smart Living: This domain focuses on enhancing the quality of life which includes components like cultural facilities, individual safety, housing quality, health conditions, education, social cohesion, and tourism. The MSCF emphasizes safety, efficient emergency responses, quality housing, urban farming and healthcare through digital tech. Crime reduction is a key initiative that involves technologies like CCTV and IoT lightning.

3) Smart Environment: The smart environment domain seeks to conserve natural resources such as the appeal of natural conditions, environmental protection, pollution control, and sustainable resource management. Strategies involved in MSCF include enhanced waste management, green space preservation, energy efficiency promotion, air and quality improvement, non-revenue water management, disaster risk management, and a low-carbon city concept.

4) Smart People: This domain focuses on social and human capital which include improving moral education, enhancing skilled human capital, promoting civic duties, gender sensitization, boosting public participation, and adapting to emerging technologies that align with the IR 4.0 policy. Citizen participation and community empowerment are important in smart city initiatives as they emphasize genuine involvement in decision-making and agenda-setting.

5) Smart Government: This domain revolves around political participation that focuses on public services, decision-making, and transparent governance. The MSCF emphasizes expanding e-government services, improving their quality, promoting information disclosure and open

data, enhancing data sharing among government agencies, and addressing issues of government agency performance and data sharing efficiency.

6) Smart Mobility: The smart mobility domain centres on transportation and ICT in which strategies like intelligent transport management, demand-based ridesharing, smart parking, AI-based predictive maintenance, electric vehicle adoption, and collaboration with academia for EV research and development are included in the MSCF. This domain promotes people-centric and environmentally friendly transportation, encouraging public transport over car usage, cycling, and walking, especially in cities like Kuala Lumpur with heavy car dependency and traffic congestion.

7) Smart Digital Infrastructure: This domain focuses on enhancing digital infrastructure development by service providers, facilitating communication infrastructure, improving internet speed and connectivity, strengthening personal data protection policies, enhancing cybersecurity, and expanding network coverage. The IoT is a key aspect of digital infrastructure, connecting billions of devices globally.

C. Internet of Things (IoT) Applications and Economic Opportunities

The IoT is a global network of interconnected objects with unique addresses and standard communication protocols, forming a dynamic infrastructure where physical and virtual "things" seamlessly integrate. According to Lampropoulos et al. (2019), IoT aspires to create autonomous, secure connections and data exchange, allowing machine-to-machine communication and intelligent decision-making by devices, ultimately aiming for a world where these "things" understand and respond to human needs without explicit instructions. IoT applications can be applied in various domains which can be categorized into:

- **Transportation and logistics:** Uses IoT to manage logistics, support assisted driving, facilitate mobile tracking, monitor the environment, and enhance augmented mapping.
- **Healthcare:** Applications include activities like tracking, verifying identity, collecting data, recognizing, and sensing.
- **Smart environment:** Applications such as creating pleasant living and working environments, enhancing the functionality of museums, and optimizing operations in industrial facilities.
- **Personal and social:** This domain includes historical inquiries, social networking, and addressing issues related to losses and thefts.
- **Futuristic:** Applications like autonomous taxi services, improved gaming environments, and urban information modelling.

The IoT has the potential to revolutionize various industries and create significant economic opportunities. Some examples are:

1) Healthcare: Bhuiyan et al. (2021) review on application of IoT technologies in the healthcare industry. The author provides examples of IoT healthcare applications such as predictive analytics to reduce emergency room waiting times, hospital bed occupancy monitoring with IoT sensors and wireless networks for disaster event tracking. Telehealth could benefit from real-time patient monitoring and engagement. Patient tracking and medication management are improved through IoT devices, enhancing health outcomes. Automated nutritional monitoring and glucose level tracking assist individuals in maintaining their health. Electrocardiogram (ECG) and Blood Pressure (BP) monitoring become more efficient with IoT solutions, and continuous oxygen saturation monitoring is achieved using wearable pulse oximeters. Smart rehabilitation systems address the needs of ageing populations by providing automated training and healthcare services. These IoT applications enhance healthcare, reduce errors, and improve the quality of patient care, ultimately enhancing the quality of life.

2) Retail: Caro & Sadr (2019) discusses various IoT applications in the retail industry which focus on both the demand and supply *sides*. The author mentioned that high-throughput IoT devices like camera networks are used on the demand side for customer and employee behaviour analysis and inventory management which includes smartphones for tracking and smart cards for loyalty and credit-card-based data collection. While on the supply side, high-density IoT devices are required to monitor large quantities of products. Passive RFID tags are commonly used to achieve real-time inventory visibility. Selecting the right IoT strategy that aligns with business goals is important as it improves the efficiency of the operation. The author also highlights other applications of IoT, like anti-counterfeiting, size-level replenishment, optimizing merchandise placement, and dynamic pricing which can lead to improved customer experiences and competitive advantages.

3) Agriculture: IoT technologies are revolutionizing agriculture with a wide range of applications that empower farmers with tools to manage their farms remotely, improving efficiency and productivity. Sinha & Dhanalakshmi (2022) state several key IoT applications in smart agriculture where some examples include

4) water management with sensors and automated irrigation systems to prevent water wastage, soil management with IoT sensors to monitor soil properties and improve crop productivity, weather management for precise decision-making based on weather forecasts, waste management using intelligent trash cans and streamlined algorithms, and tracking and tracing of agricultural parameters using RFID and GPS. These IoT applications offer substantial benefits, such as increased agricultural productivity and sustainability while reducing costs and waste.

5) Public Transport: The research conducted by Luo et al. (2019) presents instances and advantages of employing IoT technology in public transportation systems. One illustration is the utilization of RFID for offering services like vehicle recovery and optimizing bus routes for the

benefit of passengers. Another case in point is the implementation of IoT technology for cruise control in public transportation, where environmental and traffic sensors provide driving guidance. The author also emphasizes that an IoT-integrated public transportation system can provide a variety of real-time data that are valuable in reducing system uncertainties and enhancing its responsiveness. The incorporation of IoT in public transportation in general holds the potential to enhance system control, management, efficiency, and quality.

V. CHALLENGES AND CONSIDERATIONS

A. *Ethical and Privacy Considerations*

Ubiquitous computing has the potential to collect and process vast amounts of personal data in various contexts, ethical and privacy considerations are important in the implementation of this concept. Kumar et al. (2020) address the possible negative applications of user behavioural data originating from ubiquitous computing devices, encompassing surveillance and advertising. The author acknowledges that while this data can enhance service quality, it also opens the door to problematic uses, including tracking and profiling individuals for commercial or political motives, as well as potential discrimination against specific groups of people. The paper underscores the essential requirement for ethical principles to be incorporated into the creation and advancement of AI systems to mitigate these undesirable uses of user behavioural data.

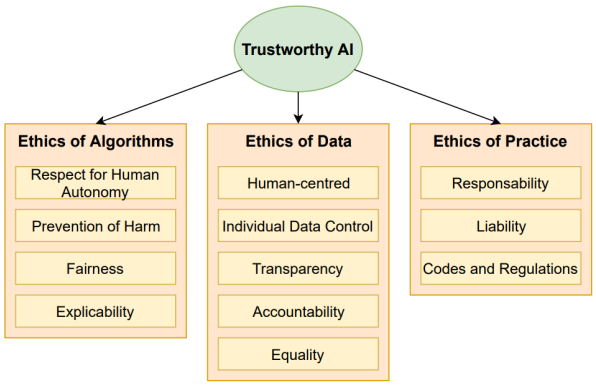

Fig. 1. Components of Trustworthy AI(Kumaret al., 2020)

AI systems have the potential to gain trustworthiness when their criteria are established from an ethical standpoint. The aspects can be integrated into the design and development of the system including the ethics of algorithms, data and practice which are the three components of building a trustworthy AI (Figure. 1).

The key ethical considerations in the development and use of AI include transparency, justice and fairness, non-maleficence, privacy, freedom and autonomy, trust, responsibility, dignity, solidarity, and sustainability. Moreover, there are economic concerns related to fairness and justice, specifically concerning data ownership and the distribution of benefits from emerging technologies. Privacy and data protection emerge as crucial ethical concerns, especially in the context of AI driven by machine learning, which introduces risks related to data bias, discrimination, and unauthorized data access (Stahl, 2021). There are concerns about access to justice in the legal sense and how AI will transform the justice system, as well as potential impacts on access to other services, which could further exclude segments of the population that are already excluded.

To ensure that emerging digital technologies bring benefits to society as a whole, a collaborative approach involving a diverse set of stakeholders is essential. This approach should engage technical and ethical experts, policymakers, industry leaders, civil society organizations, and the general public suggested by Stahl (2021). It should place a high priority on transparency, accountability, and responsibility throughout the development and deployment of AI and other new digital technologies. Moreover, these technologies must be designed with a focus on justice, fairness, non-harm, privacy, beneficence, freedom, autonomy, trust, sustainability, dignity, and solidarity. Achieving this entails the establishment of ethical guidelines and standards, as well as the implementation of regulatory frameworks that encourage responsible innovation and safeguard the rights and interests of all involved parties. Lastly, fostering public awareness and involvement regarding the ethical aspects of emerging digital technologies is vital. Continuous dialogue and debate among stakeholders are needed to ensure that these technologies align with societal values and objectives.

B. *Infrastructure and Implementation Challenges*

Ubiquitous computing involves interconnected devices with computational capabilities, which can transfer data without human intervention. Despite the advancement, the development of the IoT brings about challenges in various dimensions. In the business realm, challenges involve devising investment strategies and business models for different IoT product categories. Societal challenges centre around comprehending customer needs, evolving requirements, and ensuring privacy and security practices. In the technological domain, areas like component miniaturization, energy harvesting, reliability, self-configuration, standard protocols, and security demand further development to facilitate the growth of IoT.

Based on studies by Lombardi et al. (2021), Alsamhi et al. (2022), Svorobej et al. (2019), and Lampropoulos et al. (2019) some of the common challenges found include:

- Ensuring scalability to effectively handle the growing number of devices and services while maintaining performance.
- Promoting interoperability, enabling devices from various manufacturers to collaborate in achieving common objectives.
- Establishing a distributed environment that facilitates data collection from diverse sources and distributed processing by different entities.
- Safeguarding data confidentiality and addressing security and privacy issues, including vulnerability to cyber attacks.
- Developing resilient IoT architectures, and protocols, and engaging in standardization efforts to establish a cohesive framework.

IoT architectures remain in a state of continuous development, with numerous suppliers offering their platforms for similar use cases. The diagram represented as

Figure. 2 illustrates the prevailing IoT architecture. Hence, the creation of a unified reference architecture is a complex task due to the wide-ranging diversity of IoT applications and the existence of vendor-specific platforms.

VI. CASE STUDIES AND SUCCESS STORIES

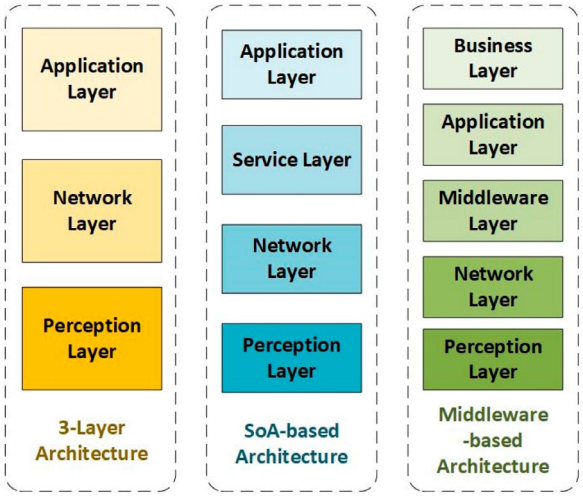

Fig. 2. Common IoT Architecture Used

A. *Global Success Stories in Ubiquitous Computing*

Smart cities can be seen as a global phenomenon, as it is characterized by both global and local aspects. Smart cities are a global phenomenon because they spread all over the world and emerge with similar features and interdependencies at the global level. Smart city is a fuzzy concept that can be described with various terms such as digital city, intelligent city, and green city. Dameri et al. (2019) made a comparison of smart city development in Italy and China. Italy adopts a decentralized, bottom-up approach, fostering diverse smart city projects across the nation, driven by EU funding and sustainability goals. On the other hand, China employs a centralized, top-down approach guided by the national government. Smart city initiatives in China are driven by the challenges posed by rapid urban growth, limited resources, and environmental concerns. These initiatives are incorporated into national strategies and prioritize the convergence of industrialization and the use of information technology.

Ghazal et al. (2021) discussed the application of AI-powered IoT in the healthcare sector. Patients are now utilizing mobile applications and wearable devices to log their health information, which can be subsequently processed by artificial intelligence (AI) algorithms. This integration of AI technology enables the development of novel preventive strategies, facilitates research into rare diseases, and supports the personalization of therapies. AI is also playing a crucial role in refining diagnostic techniques, empowering patients to take charge of their health, and contributing to the early identification of diseases. Additionally, the paper also discusses how AI-assisted surgical robots are performing highly precise surgeries, ultimately reducing potential risks to patients. In the context of chronic illnesses, AI is streamlining medication dispensing, enabling early detection of psychological issues, and providing invaluable support. All of these applications have ushered in numerous benefits to the healthcare sector, marking a successful implementation of these technologies.

Apart from the healthcare sector, the use of ubiquitous computing has found its way into numerous areas related to sports and exercise. Baca et al. (2022) stated some notable examples of smart tools in sports and physical activity analysis involve conducting motion studies under real-world conditions, employing assistive technology to support recreational and health-conscious athletes, and conducting performance and tactical analyses of soccer matches with immediate post-game insights. The incorporation of ubiquitous computing in this domain offers several advantages, including the development of automated decision-making systems for both training and competitive settings, as well as the promotion of a user-centred and environmentally conscious approach to learning and training processes.

B. *Success Stories of Ubiquitous Computing in Malaysia*

Studies showed that a proactive delivery system employing innovative artificial intelligence (AI) in urban services might perform better. This has become an important national policy for many countries including Malaysia as well. According to Samsurijan et al. (2022), some examples of AI being used in urban services in Malaysia include Public Transport Optimization, Air Quality Monitoring, Safer Streets for Women, Traffic System Management, Water Leakage Detection, Optimization of Garbage Collection Recycling, and Video Monitoring. The innovative progress in AI has created a platform that facilitates urban services in the delivery, monitoring, enforcement, and community services. The emergence of AI in the urban services system has made the city the focus of human habitat. The development of global digital technology has enhanced the need for urban governance and has led to the digitalization of urban governance to improve urban services and the development of city governance.

The widespread adoption of electric buses (EBs) offers a promising solution for reducing greenhouse gas emissions in the transportation sector. Electric bus technologies have been introduced on a global scale lately, including in Malaysia. According to research done by Al-Ogaili et al. (2021), multiple manufacturers, including the New Energy and Industrial Technology Development Organization (NEDO), China's Foshan Feichi Automobile Manufacturing Co Ltd., and BYD K9, have introduced various electric bus technologies in Malaysia. The author also points out that life cycle assessments of electric buses in Malaysia have demonstrated lower greenhouse gas (GHG) emissions and energy consumption when compared to traditional buses.

VII. CONCLUSION

In conclusion, public transportation in Malaysia plays a crucial role in economic growth, societal progress, and environmental sustainability, despite quality and integration challenges. Ubiquitous computing and IoT technology offer a promising solution to improve service quality, ticketing systems, real-time information, and integration of transportation modes. To make this a reality, Malaysia needs a robust technological infrastructure. Beyond transportation, these technologies have the potential to revolutionize multiple industries, but ethical and privacy concerns must be addressed. Success stories show their transformative potential and eco-friendly electric buses offer a sustainable

transport option, emphasizing the importance of responsible and ethical implementation.

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