



A Bird's Eye View of Near Field Communication Technology: Applications, Global Adoption, and Impact in Africa

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Abstract

Owing to the ease and efficiency of contactless communication between intelligent devices, near-field communication (NFC), a wireless communication technology, is attracting the attention of customers. In today's world, NFC is useful for mobile payment apps, electronic ticketing, access control, and authorization. Despite the widespread adoption of NFC technology, quite little is known about how to analyze its adoption with typical technology acceptance methods. Furthermore, there is an insufficient adoption of NFC technology in Africa. Therefore, this study provides a bird's-eye view of NFC technology, encompassing both the worldwide adoption models and the African market ecology. We conclude that this technology offers significant advantages over the status quo in areas such as mobile payment systems, public transit, event tickets, and medical care applications. Due to the significant smartphone penetration in South Africa, Nigeria, and Kenya, we select these nations to model the impact and downsides of adopting NFC in sub-Saharan Africa. Reports from the facts presented in this article about smartphone penetration rate, industrial acceptance, etc., show that NFC is finding useful applications on the African continent and has the potential to revolutionize various sectors of the African economy. The time is right for NFC to take off in Africa for mobile payments and other useful applications. Interestingly, the scope of this assessment extends beyond just the influence of NFC technology in Africa; it will also be useful to researchers, industry experts, product manufacturers, and NFC investors everywhere across the globe.

Keywords Near-field communication (NFC) · Mobile-enabled NFC · Mobile money (MM) · Smartphone market · Radio frequency identification (RFID) · Mobile payment technology · Next-generation mobile system · Network security

Introduction

Wireless communication technologies have, since their inception, gradually improved how we use our smart phones and internet of things (IoT) devices making communication between two devices easier and faster and introducing great flexibility in the usage of these devices [1]–[3]. For example, some standard wireless technologies are 5G, 4G, 3G, Wi-Fi [4], Bluetooth, ZigBee, barcodes, and radio frequency identification (RFIDs) [5–7]. More specifically, radio frequency identification technologies (RFIDs), since their inception in the 1980s, have gained traction among the contemporary wireless technology protocols due to important features such as short working range, minimal power consumption, and the ease in establishing connections between active and passive devices (reader and tag, respectively) [8]–[10]. These features enable RFIDs outperform other shorter range technologies like Bluetooth and barcodes, which require extra time to establish a connection between two actively enabled

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devices [11]. A unique type of RFID technology is the near field communication technology (NFC) [12].

Near field communication (NFC) is a non-contact short-range wireless communication technology that allows devices to communicate within 4–10 cm proximity using inductive coupling [13]. Precisely, NFCs operate using a very-low power quasistatic magnetic field at a frequency of 13.56 MHz, making them fall in the industrial, scientific, and medical (ISM) band with a data transfer rate of 106 to 424 kbits/s and almost zero power dissipation [14]. Besides, while RFIDs are more suitable for industrial use like inventory tracking, NFCs are ideal for consumer-centric applications. For this reason, NFCs are generally adopted in mobile payment systems, smart ticketing, in-vehicular communication, access control and authorization, agricultural management, identification, location-based services, information supply, and network access [15]. For instance, instead of using debit or credit cards, a user may perform secure transactions using contactless cards or, more interestingly, their NFC-enabled mobile devices or smartphones [16, 17]. According to the research statistics of Blue Bite, these possibilities have exponentially increased the global adoption of NFC technology [18].

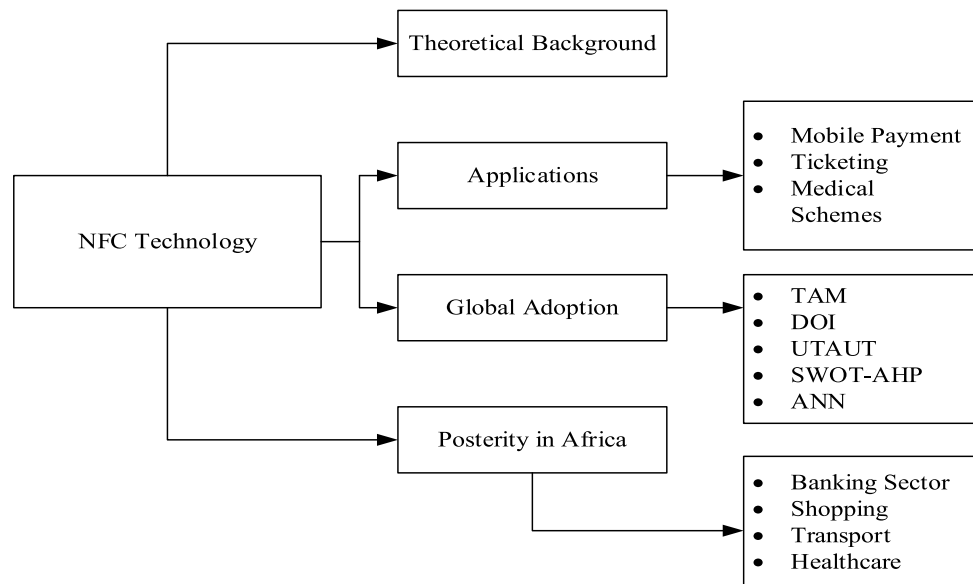
Despite this massive adoption of NFC technology globally, Africa currently lags in growth touching NFC support [19]. This slow growth owes to: (1) the slow penetration of smartphones into African countries, (2) the limited adoption of NFC technology by companies and merchants in Africa, and (3) the limited awareness of the use of this technology among consumers. Interestingly, there has been a sudden jolt in smartphone penetration into sub-Saharan Africa in recent times. GSMA intelligence 2020 reports that smartphone usage in sub-Saharan Africa should rise from 50% in

2020 to 65% in 2025, with Nigeria, South Africa, and Kenya projected to lead the mobile market by 2025 [20]. Therefore, these countries are perfect models to understudy the successful adoption of NFC technology in Africa. They can be considered case studies to observe how NFC technology can influence sub-Saharan Africa as a continent.

In this study, we examine different areas of applications of NFC technology. Additionally, we examine the global adoption of NFC technology using different technological acceptance models such as the technology acceptance model (TAM); diffusion of innovation (DOI); unified theory of acceptance and use of technology (UTAUT); strengths, weaknesses, opportunities, and threats-analytical hierarchy process (SWOT-AHP); and artificial neural networks (ANN). Following this, we consider the current state and posterity of NFC-based applications in Africa. Furthermore, we consider the potential impact of this technology in sub-Saharan Africa with a binocular focus on Nigeria, South Africa, and Kenya as case studies. A layout of the survey is presented in Fig. 1. We make the following contributions to this survey;

1. We present a comprehensive theoretical background of NFC technology.
2. We highlight the adoption of NFC technology in mobile payment systems, healthcare systems, and ticketing schemes.
3. We present a survey on customer perception, intention, adoption, and continued use of NFC technology using diverse technological acceptance models on a global scale.

Fig. 1 A layout of NFC technology theory, adoption, application, and future



4. We present a comprehensive discussion on the adoption of NFC technology in the African market using Nigeria, South Africa, and Kenya as suitable case studies.
5. We consider the future of NFC adoption in banking schemes, medical applications, and transportation systems.

This survey is organized as follows; section presents related works and contributions. Next section considers the theoretical background of near field communication (NFC) technology and provides a detailed description of certain key areas of application of NFC technology, particularly in Africa. Additionally, we survey the customer perception, intention, adoption, and continued use of NFC Technology on a global scale. Following section presents a discussion on the current state of NFC adoption in Africa. Next section highlights the future of NFC technology in the African market. Following section presents the lessons from this study. Next section presents open issues and future research directions for NFC technology. In the last section, an appropriate conclusion is drawn.

Related Work and Contributions

Several works of literature have surveyed NFC technology, current trends, issues, applications, and future possibilities of the technology. For example, Ok et al. [21] reviewed the current benefits and possible future directions of NFC services in the academia and industry. In particular, the research pointed out NFC modes as essential factors required to investigate NFC applications. To investigate NFC technology more thoroughly, the work in [22] presented an overview of NFC technology from a technical perspective. Specifically, the authors reviewed the RFID and NFC technology's working principles and concepts, including security schemes. Further, Rahul et al. [23] investigated NFC technology modes of operation, applications, current vendors, and security measures. Busold et al. [24] investigated NFC issues, capabilities, and applications in vehicle anti-theft security systems. Additionally, Hamzah et al. [15] reviewed several applications of NFC technologies. In [12], Singh considered NFC an alternative to RFID in libraries. Specifically, this research discusses NFC as a key tool in advancing the traditional library system. Chandrasekar and Dutta [13] considered recent developments in near field communication and reviewed NFC usage with sensors.

Our survey considers existing research on NFC applications and the global adoption of the technology analyzed using developed models on the customer's intention and adoption of use. Precisely, we consider models such as TAM, DOI, UTAUT, SWOT-ANN, etc., and present the implications and limitations of the relevant literature.

Furthermore, we present NFC applications and the posterity of its adoption in the African space. A compilation of related works, their limitations, and our significant contributions are presented in Table 1.

NFC Technology

Technical Background

NFC technology is a short-range wireless technology used to communicate between two NFC-enabled devices that could be active or passive [14]. Communication is established via Inductive coupling utilizing a frequency of 13.56 MHz with a maximum data transfer speed of 424 kbits/s [32]. NFC technology's working range spans between 1 and 4 cm of NFC-enabled devices [33]. The active device could be a reader or writer, while the passive device could be a tag or card. An active device has its internal power source and can generate its alternating electromagnetic field by passing a current through the antenna's loops [34–37]. The passive device does not have an internal power source and uses the field generated by the active device to power itself [2, 38]. Active devices can read, share, or transmit data to another NFC-enabled device, while passive devices can hold information and bytes of data without an internal power source. Communication is such that the active device generates an electromagnetic field, which the passive device uses to power itself and subsequently respond to the request from the active device [39–42]. NFCs operate in three modes—reader/writer (active and passive) mode, card emulation, and peer-to-peer mode [43], all based on ISO/IEC 18092 NFC-1, ISO/IEC 14443, and ISO 15693 standards [1, 24], as shown in Tables 2 and 3.

NFC Technology Implementation in Various Applications Areas

Near-field communication has found useful applications in diverse areas of human endeavor outperforming other wireless communication technologies. In this section, we take a close look at the application of NFC in specific areas such as changing the face of mobile payment schemes with security analysis; in tourism; developing innovative medical and wearable devices; and in chemical and biochemical areas. We present possibilities, limitations, and drawbacks as reviewed in diverse literature to realize a holistic view of NFC technology applications in diverse areas.

Mobile Payment Schemes

Mobile payment systems consist of one of the most promising usages of NFC technology globally. For example,

Table 1 Related work, limitations, and our contributions

Year	References	Focus and coverage	Limitations	Our paper's contribution
2012	Hussein and Mohammad [25]	NFC technology applications and security issues	Does not consider the adoption of use or look at NFC technology adoption in the context of a regional survey	We present an overview of regional adoption of use on a global scale and focus on African posterity
2013	Vibhor et al. [26]	Comparison of NFC technology with RFID and Bluetooth and security issues	Does not consider applications and adoption of the use	We present a survey of applications, adoption of use, and posterity using Africa as a case study
2013	Busold et al. [24]	NFC issues, capabilities, and applications to target vehicle anti-theft security systems	No information is presented regarding the customer's intention to use using acceptance models	We survey diverse acceptance models to predict and explain the intention to adopt NFC technology
2014	Areese et al. [27]	NFC technology and market trends using SWOT analysis	Does not consider other acceptance models	We present an overview of both applications and adopt different models such as TAM, DOI, UTAUT, etc
2015	Coskun et al. [1]	NFC technology concepts and applications	Missing consumer reception to NFC technology use	We present different models that predict and explain consumer intention to use the technology
2015	Rahul et al. [23]	Survey on NFC technology, working principles, protocols, modes of operation, application, and security	Does not consider the intention of use of NFC technology	We examine NFC intention to adopt technology on a global scale and present a binocular vision of adoption within the African space
2020	Chandrasekar and Dutta [13]	NFC application areas for both sensor and sensor-less schemes	Generic NFC applications, No discussion on the adoption of the use of NFC technology	We look at critical applications and the adoption of applications in the African space. In addition, we consider the global acceptance of the use of NFC
2019	Hamzah et al. [15]	A review of NFC technology applications in different areas	No discussion on the adoption of use models of NFC technology	We consider applications and adoption of the use of technology regionally and present the posterity in the African space
2021	Selin et al. [28]	Considered the future of near-field communication wireless sensing	There is no discussion on the adoption of use models of NFC technology	We examine the applications and the adoption of use of the technology in Africa and other countries
2021	Kulkarni [29]	Presented an overview of near field communication technology, applications, and security	Does not examine adoption of use of NFC technology	We take a critical look at the acceptance and adoption of use of NFC technology, thereby providing a wider perspective of the technology
2022	Samir et al. [30]	Reported an overview of the security of NFC-based banking transactions focusing on possible attacks and solutions	Focuses on security in banking transactions without considering other possible applications of NFC technology	We broadened the view of NFC usage in mobile payment, medical systems, and ticketing schemes
2023	Liu et al. [31]	Presented a tutorial review of near field communication to support 6G network technology	Focuses on new types on antenna designs. Does not review applications of NFC technology	We widen the scope of NFC applications, global adoption, and impact on the African Continent

Table 2 A table showing NFC modes

Operation mode	Device 1	Device 2	R.F. generation	Communication mode
Peer to peer	Active ¹	Active	Both devices	Active
Reader/writer	Active	Passive ²	Device 1	Passive
Card emulation	Passive	Active	Device 2	Passive

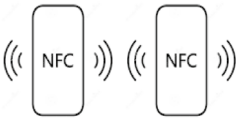


¹Reader or writer

²Tag or card. This table shows the two communication modes and the three operating modes of NFC Technology

Ondrus and Pigneur [45] assessed the usage of NFC technology for future mobile payment systems using a multi-actor multi-reactor approach. The results of this research revealed that NFC payment schemes perform well given the required criteria for a successful mobile payment scheme, such as universality, simplicity, interoperability, security, etc., as given by Carr [46]. Furthermore, NFC mobile payment systems promise to proffer solutions to the limitations

of standard mobile payment systems such as short message service (SMS), unstructured supplementary service data (USSD), wireless application protocol (WAP), and interactive voice response (IVR) [45]. Some literature has proposed different NFC payment techniques. For instance, Kadambi et al. [47] developed a mobile payment solution for multiple payments using NFC technology with secure end-to-end transactions. The payment scheme integrates mobile devices with existing Point-of-Sale payment solutions using payment authorization tokens. Although tokenization addresses security concerns in user data protection, there are still issues concerning accessing card number data when a payment card is swiped or used to complete a transaction. Additionally, Rodrigues et al. [48] developed an NFC-based mobile payment scheme called MOBIPAG for payments, ticketing, and couponing. A critical drawback of the proposed payment scheme is the unfavorable user experience caused by communication failure in certain situations. In [49], Rehman and Coughlan proposed an NFC-based mobile payment scheme for Pakistani-based mobile transactions with authentication

Table 3 A comprehensive description of the NFC modes of operation

Mode of Operation	Pictorial View	Description	Common Usage Examples
Peer to Peer		In this mode of operation, the two devices involved in communication are active, typical examples of NFC enabled smart phones. Both devices generate electromagnetic fields to exchange information when brought within proximity. The peer-to-peer mode was standardized on the ISO/IEC 18092 standard.	Document and media exchange via Bluetooth or Wi-Fi.
Card Emulator		Communication is carried out between an active device, an NFC reader (point-of-sale), and a passive device in this mode. An NFC enabled smart phone emulating a contactless card. The reader generates an electromagnetic field that initiates a transaction between the NFC enabled smart phone emulating one or more contactless cards and the reader. The card emulator mode was standardized on the ISO/IEC 14443 standard	Mobile payments, smart-ticketing, transit access control
Reader/Writer		Communication is carried out between an active device (smartphone) and a passive device (NFC tag or sticker) in this mode. This mode allows NFC smart phones to fetch or modify the NFC tag or sticker information. NFC mobile can read data from NFC forum-mandated tag types (type 1, type 2, type 3, and type 4). The reader/writer mode is standardized on the ISO/IEC 14443 and the ISO/IEC 15693 standards	Reading timetables, validating items during purchase, fetching relevant information about products

done via pin exchange between the user and the bank. This scheme could thus create an unfavorable user experience and previous security issues. In addition, Pourghomi, Qasim, and Ghinea [50] proposed a cloud-based NFC payment scheme to target mobile network operators. However, cloud computing technology is vulnerable to cyber-attacks because user data is transferred to distant servers for processing. Olufemi et al. [51] developed an NFC-based shopping payment scheme. In this research, security issues were not investigated. Table 4 shows some mobile payment schemes based on NFC technology.

NFC technology is gradually establishing itself in the mobile payment scheme globally. However, certain drawbacks can slow down its acceptance amongst consumers, such as security concerns and user experience. Security is a major issue when making mobile payments and consumer ease of use of the payment scheme. We investigate the consumer acceptance of NFC using different technology acceptance models.

Ticketing Schemes

NFC techniques are being adopted in diverse ticketing applications. For instance, Chaumette et al. [56] investigated and compared two user-oriented NFC-based event ticketing applications. Specifically, the authors develop an offline and online e-ticketing system for transportation and events management. Overall, both systems are compared in user experience, security, economic aspects, reliability, and speed. Further, Saminger et al. [57] developed a new approach to develop an NFC-based ticketing system using the reader/writer mode instead of the contemporary card emulation or peer-to-peer mode. The proposed method offers the advantage of implementing lightweight protocols compatible with existing mobile phones. To address the challenge of financial cost and complexity, Ivan and Balag [58], proposed an NFC-based mobile ticketing system for transportation applications. The proposed system is then compared with existing e-ticketing systems such as Oyster and U'Go. However, the performance of the system was not rigorously evaluated owing to the limitation in the amount of data and users. Widmann et al. [59] proposed an NFC-based electronic fare management scheme to change the public transportation system. A critical drawback in adopting this scheme is the unavailability of the card emulation mode support in most user devices, security concerns and communication failure. In addition, Nasution et al. [60] investigated an NFC-based mobile train ticketing scheme. Although prototyped, the scheme poses to create a fast and user-friendly ticketing experience. However, Security issues are not given adequate consideration, a key concern in NFC technology applications. Table 5 presents different NFC-based ticketing applications.

NFC technology has been successfully implemented in diverse transport ticketing systems such as trains, buses and ships. However, Security and, in some cases, ease of use and sometimes governmental interference pose drawbacks to fully accepting these ticketing schemes globally.

Medical Schemes

Medical applications are a major sphere where NFC technology finds useful applications, particularly in wearable electronics [67]. An et al. [68] surveyed NFC-based wearable devices, pointing out that NFC technology is a next-generation communication technology for wearable electronics owing to its compatibility, high security, miniaturization, and low power usage. Kassal et al. [69] developed a smart biosensor bandage shifting the acute/chronic wound care paradigm to time-based management. The smart bandage was based on the electrochemical detection of uric acid (U.A.) as the primary generic physiological indicator correlating with wound severity. The sensor was designed to send data to the server via NFC. Jeong et al. [70] extended NFC-enabled wearable research to develop a stretchable liquid metal system to monitor human motion using a biocompatible gel-like GaInSn sensor, showing the future potential of NFC-wearable technology as the human-robotic interface for prosthetics. Kim et al. [71] developed a low-power consumption wearable device based on NFC technology. The authors introduced a battery-less active optoelectronic system functioning entirely wireless with magnetic inductive coupling and near-field communication schemes for multicolor light emissions and detection. It allowed precise measurement of the skin's optical properties to detect coloration, vascular disease, and environmental detection based on color-responsive materials. The research shows up to 30% uniaxial strain. Therefore, possible to design optimized soft and conformal wearable lamination on the skin. This technology can be used to monitor heart rate through backscatter light measurement from an infrared. In addition, Freudenthal et al. [72] investigated the possibility of adopting NFC technology to provide convenient and effective low-power distribution and communications in medical devices. This scheme is particularly useful when implanting RFID into patients but, if corrupted, could be harmful to the patient. Hence, reliability is a major parameter to be considered in NFC-based medical schemes. Table 6 presents some NFC-based medical system schemes.

NFC technology is finding useful applications in the medical sector, particularly in the powering of implantable devices powered by NFC radio frequency. However, corruption of the device is also a key issue of concern which could be detrimental to the health of the patient [81]. This

Table 4 Some NFC-based mobile payment schemes

References	Description	Comments	Year
Kadambi et al. [47]	NFC-based mobile payment solution to target the mobile banking environment. The system was developed for secure end-to-end transaction payments and informs flexible and multiple payment options	The proposed solution integrates NFC-enabled mobile devices with standardized POS retail payment schemes securing users' data. The system is vulnerable to some security attacks, and the user experience, which determines the adoption of use, is not considered	2009
Google [52]	An NFC-based mobile wallet for banking transactions	Satisfactory user experience with a high global acceptance but vulnerable to security attacks	2011
Verizon [53]	An NFC-based mobile payment system built on existing payment networks	Rivals Google wallet with satisfactory user experience	2011
Rehman and Coughlan [49]	An NFC-based mobile payment scheme for item purchases in a grocery store	Security is not considered. User experience is also not considered	2013
Pourghomi et al. [50]	An NFC payment application based on cloud computing (NFC cloud wallet)	Security is a major concern	2013
Dias et al. [54]	A charge collection system using NFC techniques to retrieve tolls for open road tolling infrastructures	The system adopts an easy user interface, but NFC-based payments have limitations such as security, proximity concerns, etc., which the authors do not consider when developing the charge collection system	2014
Rodrigues et al. [48]	An NFC-based payment solution integrates mobile payment, ticketing and couponing (MobiPag)	The system is an open architectural solution introducing flexibility to the system. The proposed payment model is vulnerable to two major security attacks, and the user experience is not encouraging	2014
Olufemi et al. [51]	NFC-based payment scheme for item purchase	Security is a concern	2020
Shaik Shakeel [55]	Reports a secure NFC-based mobile payment scheme for merchant transactions	Security is considered as the main context of the study. Specifically, the payment scheme protocol overcomes security concerns such as denial of service attack (DoS), distributed denial of service attacks (DDoS), and phishing attacks	2021

Table 5 Some NFC-based ticketing schemes

References	Description	Comments	Year
Chaumette et al. [56]	Comparison of an offline and online version of an NFC based Event ticketing system	The work addresses the concerns of user experience, security, economic aspects, reliability, and speed of use	2011
Widmann et al. [59]	Integration of an NFC-based ticketing system into contemporary public transport infrastructure	The proposed system suffers from available user devices, which support card emulation mode	2012
Nasution et al. [60]	An NFC-based train ticketing system using an android device	The system is not implemented, only prototyped	2012
Saminger et al. [57]	An NFC-based ticketing system implemented in reader/writer mode	The system is easy to implement using lightweight protocols and is compatible with existing mobile devices	2013
Ivan and Balag [58]	An NFC based Mobile ticketing system for transportation	The proposed system is not rigorously tested; hence there exists a lack of confidence in the results	2015
Kurniawan et al. [61]	A Ship ticketing system based on NFC technology for Batan Island Transportation	The proposed ship ticketing system is implemented using a spiral software development framework model [62, 63], and an e-ID card is used as the transaction medium. Security is, however, not thoroughly examined	2018
Hargude et al. [64]	An NFC-based bus ticketing and tracking system	The system is implemented successfully using the reader/writer mode of NFC communication. However, security is not given thorough attention	2020
Marta et al. [65]	A novel micro-location mobile ticketing scheme using near field communication technology and Bluetooth	The ticketing solution is implemented using both NFC and Bluetooth technologies. However, security concerns are not investigated thoroughly	2021
Zadorozhnyi et al. [66]	An innovative NFC-based validation system for accounting of income and expenses of a public transport enterprise	The study targets the improvement of NFC validation schemes particularly for transport services. The method adopts the procedure of distributing income from the sale of electronic tickets. However, security concerns are not examined	2022

Table 6 Some NFC-based medical system schemes

References	Description	Comments	Year
Freudenthal et al. [72]	A suitable NFC-based medical device for communication and power delivery	The system developed is susceptible to radio-based power consumption attack	2007
Costescu [73]	An implantable medical device based on NFC technology	The hardware development is complex and may be simplified using micro-controllers based on FPGA and PCB designs. In addition, security is a major concern	2013
Razmi and Sangar [74]	Mobile Medical Record Device based on NFC technology for enhanced medical and treatment	The proposed system improves services, reduces errors, etc. However, security is not considered, which is a key concern	2016
An et al. [68]	An NFC-based Smart Sensor system for wearable electronic devices	Interference of noise distorts sensor data reading, and power requirement is a key challenge	2017
Deshpande [75]	A Smart implanted System based on NFC technology targeted at enhancing medical treatment	The available storage memory is limited, and security is a major concern because patients' data are not secure	2018
Ayyar [76]	An NFC-based Mobile Health Care system for reducing medical errors and health record management	The proposed system is in its simulation stage and has not been successfully implemented	2018
Ayyalraj and Balamurugan [77]	An NFC-based mobile healthcare system for monitoring patient's health	Security is not examined in the development of this system which is a key concern	2019
Bouklachi et al. [32]	A wearable medical device powered by NFC-based energy harvesting techniques	The power recovered by the proposed system is unstable and requires a matching circuit to be maintained	2019
Suijiredjeki et al. [78]	An NFC-based IoT device for enhancing healthcare delivery	The proposed system is still in its prototype stage, and the system is limited to text data alone	2020
Dedy et al. [79]	Investigated an NFC-based mobile application of electronic medical records	Patient medical data are highly sensitive. Thus, security of user's information is key to the effectiveness of the application. However, security is not considered	2021
Ogechi et al. [80]	Developed an NFC tag-based mobile health (mhealth) patient healthcare tracking system	In addition to the development of the mhealth system, the authors utilized the TAM to evaluate the health scheme's adoption and acceptance of use	2022

poses a drawback for the successful adoption of NFC in the medical environment.

Customer's Perception, Intention, Adoption, and Continuance of Use of NFC Technology

This section investigates consumers' intent, acceptance, and continuance of NFC technology on a Universal scale. Several models have been developed and recommended to address NFC adoption and the continuance of its use. These include the Unified Theory of Acceptance and Use of Technology (UTAUT), Technology Acceptance Model (TAM), TAM model 2 (TAM2), Theory of Planned Behavior (TPB), Diffusion of Innovation (DOI), and Theory of Reasoned Action (TRA). We review these models and provide research implications following our study.

The TAM Approach

The Technology Acceptance Model (TAM), developed by Davis [82], focuses on pursuing better measures for predicting and explaining the consumer acceptance of information technology [83]. The Model adopts two key metrics, Perceived usefulness and Perceived Ease of Use, in predicting and explaining the acceptance of information technology. Perceived usefulness describes the extent to which a person admits the system facilitates work performance. In contrast, perceived ease of use describes the extent to which the system would be effortless. Consequently, to study the degree of consumer acceptance of NFC technology, some literature has adopted this model to examine diverse areas of NFC technology applications. Although the TAM approach is simple and popular, it is necessary to integrate additional variables such as perceived security, trust, general complexity, etc., to improve its predictive power [84].

Hong et al. [85], examined the factors that influence NFC-based payment adoption in China. Specifically, this study was performed using the TAM approach. Precisely, the research utilized perceived ease of use and perceived usefulness as the two main parameters to evaluate the user's intention to use the technology. From the evaluation method, the authors recommend that NFC-based payment operators should pay additional attention to developing multi-functional systems, which conventional payments cannot perform. Further, Xiaodie et al. [86], considered the determinants that influence the behavioral intention to use NFC-based mobile payment schemes in the Chinese space. More specifically, the study adopted the TAM method to investigate the emergence of Apple pay in China. From the evaluation results, perceived usefulness and trust are observed as the significant factors that propel

the behavioral intention to use Apple Pay in the Chinese mobile service space.

Luarn and Juo [87] investigated the acceptance of NFC technology for making mobile payments using the TAM model in Taiwan. The research integrated trust with the standard perceived usefulness and ease of use metrics to predict the subscriber's behavioral intentions regarding the NFC-based mobile payment scheme. The survey results reveal that trust in the firm does not influence the subscriber's behavioral intention; it indirectly influences the subscribers' trust in the technology. Although the model-fit indices exceed the acceptance levels in previous research, the study has certain limitations. The study only engaged 476 mobile network subscribers, which is quite low and consequently reduces the confidence in the overall performance of the proposed model. In addition, the scope of the survey is limited only to mobile network subscribers rather than general consumers.

Dutot [84] developed an extended TAM approach to investigate the factors influencing the adoption of NFC technology for mobile payment in France. The TAM approach is extended to include key factors that concern mobile payments, such as trust, perceived security, and technology availability in addition to the standard TAM metrics (perceived usefulness and ease of use). The proposed model is tested using a combined structural equation modeling (SEM) and Partial Least Square (PLS) approach with 320 smartphone users. The results reveal a 30% variance in NFC technology adoption, which shows strong support for NFC in making mobile payments. However, the research is limited by the number of users engaged in the survey. In addition, factors such as cost, compatibility, and interoperability are not incorporated in the model, which are key factors that influence mobile payment adoption.

Han et al. [88] researched the determinant of NFC reuse intention and perception in Tourism in Korea. The authors noted that NFC information quality and organization support greatly influenced expo-visitors satisfaction with NFC. The study further proved that customer satisfaction generates continuous vitality backing NFC use in tourism expo loyalty. Tan et al. [89] adopted an extended TAM approach to investigate the acceptance of NFC-based mobile payment schemes in Malaysia. The model integrates four constructs: personal innovativeness in information technology, social influence, perceived risk, and perceived financial cost to the standard TAM metrics in determining the degree of NFC mobile payment schemes. The data were collated from 156 users and analyzed using structural equation modeling and multi-group analysis. The study results revealed that NFC-based mobile payment methods are only marginally adopted in Malaysia.

Unified Theory of Acceptance and Use of Technology (UTAUT)

UTAUT was proposed by Vankatesh et al. [90] and adopted to explain information technology acceptance and use. The model adopts four constructs, which are gender, age, experience, and voluntariness, to predict the acceptance of information technology [91]. Some literature has adopted the UTAUT approach in explaining and predicting the acceptance of NFC technology for different applications. Boes et al. [92] adopted the UTAUT model to explore the various determinants that influence the acceptance of NFC Smart Posters for Tourism in Salzburg, Austria. The UTAUT model adopted in the study was extended to include a perceived trust for security and privacy concerns and perceived quality. The constructs used in this study include perceived effort expectancy, perceived performance expectancy, perceived trust, social influence and perceived quality. The results of this study show that unawareness is one of the key factors that affect the acceptance of this technology. In addition, the intention of use of NFC smart posters is greatly influenced by the usefulness and quality while social influence and effort expectancy contribute little to the adoption of the technology. The limitation of this study is that only one smart poster is examined and age, gender and experience, which are key constructs, were omitted. Khalilzadeh et al. [93] examined the factors that influence the adoption of NFC-based mobile payments using an extended UTAUT model in North America. The model integrated the UTAUT model with the TAM model and tested the design using the SEM on an empirical data provided by 412 restaurant customers. The results of the study show that risk, security and trust on the customer's intention to use the NFC-based mobile payment scheme.

Diffusion of Innovation (DOI)

The DOI theory is based on the dimensions of diffusion, such as innovation, communication channels, social systems, and time. The model entails five constructs, which are relative advantage (RA), compatibility (CA), complexity (CL), observability (OB), and trialability (TR) [94]. The DOI model can explain a 49–87% variance in adoption [95]. Balachandran and Tan [96] proposed a regression model using DOI to predict the adoption of NFC technology for mobile payment in Malaysia. The proposed model adopted five constructs replacing trialability and observability with three constructs, namely, amount of information (AOI), perceived financial resources (PFR), and variety of services (VOS). The study results revealed that CL, CA, AOI, VOS, and PFR greatly influence the intention of adopting NFC-based mobile payment. The results of this research cannot be generalized because the data used were only gathered from

consumers who own a smartphone. Voges [97] carried out a study of NFC adoption in the German Market using the DOI approach. The study aims to answer the question of whether NFC multi-application platforms are accepted and diffuse into the German Market. The results of this study revealed that a multi-application platform is accepted, the NFC-based technology is only viable when used in combination with a smartcard.

SWOT-AHP Approach

Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis is a model often adopted to evaluate an organization, a plan, a project, or a business. It is a simple but powerful tool for evaluating the internal factors (strengths and weaknesses) of a plan and the external factors (opportunities and threats) [98]. To address the basic drawback of SWOT Analysis, touching on the limitation in quantitative computation, Mehmood et al. [99] complemented the SWOT analysis with the analytical hierarchy process (AHP) to address this drawback. The SWOT-AHP is adopted to investigate the adoption of NFC as a means of mobile payments in the Italian economy. The study results show an optimistic prospect of NFC adoption and acceptance. The findings from 23 qualitative questionnaires filled by Italian telecom experts with adequate NFC knowledge concluded that the positive factors (strengths and opportunities) outweigh the negative factors (weaknesses and threats). The limitation of this research concerns the incorporation of only one Telecommunication Company, which reduces the confidence in the results.

Artificial Neural Networks (ANN) Approach

ANN is a brain-inspired model that explains linear and non-linear relationships in a given data set. Leong et al. [94] extensively evaluated the determinant factors influencing NFC-enabled mobile credit cards' adoption as a contactless payment method. The research entailed using an extended TAM model to include trust, psychological science, and behavioral control theories. SEM-ANN and multi-group analysis were subsequently used to examine different determinants such as social influence, personal innovativeness, trust, etc. Structural equation modeling (SEM) evaluated the causal relationship to extract significant factors fed as the artificial neural networks (ANN) [100]. The model consistently captured the relationship between predictors and collectors with a root mean square of error (RMSE) range of 0.1071–0.1128 in the training dataset and 0.1020–0.1055 in the test dataset. The research results revealed that Perceived ease of use and perceived usefulness have a significant and direct influence on the consumer's intention. However, the research results are limited to Malaysia, and the number of users who participated in the study was low (300). Last,

a detailed summary of the usage of the models mentioned above is given in Table 7.

Research Implications from Models Studied

We present some research implications from the comprehensive study of different models developed to understudy consumer perception, adoption, intention, and continuance of the use of NFC technology. These implications may be used as important guidelines to improve the penetration of NFC technology in any region.

1. Security is a major concern in adopting NFC technology for applications such as mobile payment schemes, transport ticketing schemes, etc. Consumers are wary of the security of their user data and privacy and thus require effectively secure platforms to trust NFC-based payments or ticketing. Thus, security should be given enough attention when developing a payment or ticketing scheme in any region, Africa inclusive.
2. NFC technology adoption is also greatly influenced by consumers' perception of ease of use. Thus, NFC-based schemes should be designed and developed to be user-friendly and innovative. In addition, the time to secure transactions should be minimized to prevent a bad consumer experience.
3. Awareness of NFC technology is also a key factor that influences consumer adoption. Meticulous research reveals many consumers are not aware of the technology. Thus, social influencers may be employed to increase the awareness of the technology while network operators and financial institutions emphasize usefulness and reliability.
4. The unavailability of NFC-supported smartphones discourages NFC application providers. Hence, mobile phone developers should invest in NFC technology support on their Smartphones to encourage users and NFC technology industries.
5. An agreement should be reached between governmental institutions, software developers [101], and financial institutions regarding standards to improve the user experience when using NFC-enabled technologies for diverse applications.

Current State of NFC Applications in Africa

Over the years, the world has experienced a remarkable increase in the number of NFC enabled smartphones as can be observed in Fig. 2. However, NFC support in Africa is the slowest when compared to other continents of the globe as displayed in Fig. 3. Particularly, the African continent has experienced a gradual adoption of NFC technology in

different areas such as mobile payment schemes, ticketing applications, and transport systems. This section reviews the different areas of application where NFC technology is being adopted in key countries like South Africa, Nigeria, and Kenya.

Nigeria is the most populous country in Africa, with 206 million and 170 million mobile internet subscriptions as of 2020 (Statistica reports). This makes Nigeria the country with the highest mobile market in sub-Saharan Africa. Interestingly, several companies in Nigeria are fast integrating NFC technology into their business schemes. Some include the United Bank of Africa, Payattitude, Farepay, Sanwo, etc. This Industry acceptance of NFC would influence the Nigerian economy's diverse sectors such as Banking, Transportation, and even Shopping. One of the leading applications of NFC Technology is in making mobile payments. Mobile payments could be made using contactless cards or NFC Enabled Smart Phones running a payment application such as Google Wallet, Samsung Pay, Apple Pay, Android Pay, etc. In order to perform a payment transaction using contactless cards, the Card is brought within the range of the POS Reader field, and a transaction is made. This technique makes payment easier and faster than the contemporary EMV (Europay, Master, and Visa) cards, which require the Card to be inserted into the POS machine and authentication to be made before a transaction payment is completed. Also, NFC-based Smartphones running mobile payment applications make this process even easier. Here, it avoids the user from carrying different cards everywhere, which could get misplaced and even stolen. The Smart Phone emulates a contactless card (Card emulator mode), and the transaction is made with just one tap when brought in proximity to the NFC-enabled POS device. NFC-enabled mobile payment scheme prevents long queues at the payment terminal and promotes a good customer experience.

The Nigerian Mobile Market has seen a gradual adoption of NFC-based payment schemes. In 2014, a Bangalore-based mobile service provider, Ikaaz, partnered with Nigerian-based FCMB Bank to provide NFC Based payment options using NFC tags and Ikaaz NFC Enabled mobile POS. Subsequently, in 2015, Nigerian-based payment provider Unified Payments partnered with six banks (Access, UBA, Skye, Zenith, Diamond, and First Bank). This provides an NFC-based payment solution, PayAttitude using a Chip and pin enabled tag type device and an NFC Enabled POS device. In 2015, UBA issued over 3 million contactless cards to revolutionize their e-payment scheme using NFC Technology. Furthermore, by 2017, a Nigerian-based payment solution provider, Sanwo, developed an NFC-based payment system using NFC stickers, wristbands, and cards. In 2021, owing to the COVID-19 pandemic, the First Bank of Nigeria developed a virtual payment card using NFC technology. Besides

Table 7 Detailed summary of different acceptance models, implications, and limitations

References	Model	Constructs	Application	Region	Implications	Limitations	Year
Apanasevic [102]	TAM	Network externalities, perceived service security, Customer behavioral barriers, competition issues, unclear business model, interoperability	Mobile payment	Western Europe	The slow rate of NFC payment penetration is due to consumer acceptance, specifics of the business environment, and the technology	Limited to six pilots in western Europe, the biased scope of interviewers and few industry specialists were involved	2013
Luarn and Juo [87]	TAM	Trust in the firm, trust in technology, perceived usefulness, perceived ease of use	Mobile payment	Taiwan	Designers should Maximize ease of use, and network operators should emphasize usefulness, reliability, and security	Regional barrier, limited sample size	2013
Tan et al. [89]	Extended TAM	Perceived usefulness, ease of use, social influence, personal innovativeness, perceived risk, the financial cost	Mobile Payment	Malaysia	Innovation must be adopted. Perceived usefulness influences the adoption of mobile payment. Financial Institutions ought to invest in advertising	The model is constrained to some variables. Regional constrain	2013
Leong et al. [94]	Parsimonious TAM and ANN	Perceived usefulness, ease of use, control variable, experience, age, trust, perceived cost, social influence, personal innovativeness	Mobile payment	Malaysia	Perceived ease of use and perceived usefulness greatly influence the intention of use. Various new concepts should be created to meet the wants of the users	Regional barrier, Limitations in constructs adopted	2013
Mehmood et al. [99]	SWOT-AHP	Strengths, weaknesses, opportunities, threats	Mobile payment	Italy	Strengths and opportunities are more important than weaknesses and threats	The model adopted is limited in scope, sample size, and prediction power	2014
Dutot [84]	Extended TAM	Trust, Security, Technology availability, social influence	Mobile payment	France	Companies must deploy incentives to social influencers, and security must be properly examined	Limited by one region considered (France), limitation in the sample used	2015
Balachandran and Tan [96]	DOI	Relative advantage, complexity, compatibility, amount of information, variety of services, perceived financial resources, intention to adopt	Mobile Payment	Malaysia	Manufacturers and software developers to focus on providing additional NFC-based functions attractive to users	Limited sample size. Limited variables	2015

Table 7 (continued)

References	Model	Constructs	Application	Region	Implications	Limitations	Year
Boes et al. [92]	UTAUT	Perceived effort expectancy, perceived performance expectancy, perceived trust, social influence, perceived quality	Smart posters in Tourism	Austria	Many participants are unaware of the technology	Limitation of only one smart poster type. Limitation of sample scope and size	2015
De Luna et al. [103]	TAM	Perceived compatibility, security, usefulness, ease of use, individual mobility, attitude toward the use, subjective norms, the intention of use	Mobile payment	Brazil	Attitude, personal innovation, and perceived usefulness influence the adoption of NFC technology	Regional limitation, limitation in variables adopted in the acceptance model	2016
Cocosila and Trabelsi [104]	Extended TAM	Utilitarian value, Enjoyment value, Social value, Time risk, Social risk, Psychological risk, Privacy risk, Behavioral intention	Contactless mobile Payment	Canada	Consumers see more benefits than threats in the use of NFC smart-phones for payments because of gam factors	The sample size is larger than the standard recommended by PLS-SEM	2016
Ernest [105]	Extended TAM	Perceived usefulness, perceived ease of use, perceived risk, social norm, perceived cost, Behavioral Intention to use	Mobile Payment	Zambia	The study successfully extended the original TAM model with four constructs. The model explained a 56% variance in behavioural intentions. Service providers should create more awareness of the technology	There exists a limitation in the sample size, which was collected from a few respondents. The TAM model adopted is limited	2016
Jenkins and Ophoff [106]	Extended TAM	Intention to adopt, perceived ease of use, perceived financial resources, perceived risk, privacy concerns, security concerns, social influence, trust concerns	Mobile payment	South Africa	Perceived value is a multi-dimensional construct influenced by social influence and perceived ease of use	The study is limited by sample size and context	2016

Table 7 (continued)

References	Model	Constructs	Application	Region	Implications	Limitations	Year
Khalilzadeh et al. [93]	UTAUT, TAM	Risk, privacy, attitude, security, trust, effort expectancy, utilitarian performance expectancy, hedonistic performance expectancy, social influence, facilitating conditions	Mobile payment	North America	Security greatly influences Mobile payment adoption. In addition, social influence affects the intention to use	Limited market sample and industry category	2017
Fitriani et al. [107]	UTAUT	Performance expectation, effort expectation, social influence, perceived risk, perceived cost, facilitating condition	Mobile payment	Jakarta, Bogor, Depok, Tangerang and Bekasi	The model explains 67% of the variance of behavioral intention	Security is not examined. Limited sample scope and size	2017
Borowski-Beszta and Jakubowska [108]	TAM	Perceived usefulness, Perceived ease of use	Mobile and contactless payment	Poland	Contactless payments are quick and comfortable. However, security is a major concern	The TAM model adopted is limited to consumer interest	2018
Putra et al. [109]	TAM	Knowledge, trust, behavior, compatibility, perceived ease of use, perceived usefulness	Mobile Payment	Indonesia	Knowledge, behavior, and ease of use affect the adoption of the use	Limited sample space	2018
Prince et al. [110]	TAM	Perceived risk, trust, perceived ease of use, perceived usefulness, personal innovation, cost	Mobile Payment	Nigeria	The intention of use is dependent on subjective norms, self-efficacy, personal innovation, cost, trust, risk and usefulness	Limited sample size and scope	2019
Liébana-Cabamillas et al. [111]	TAM, UTAUT	Perceived usefulness, mobile skillfulness, personal innovation, effort expectation, convenience, perceived value, perceived risk	Mobile payment	Spain	Convenience and mobile user expertise influence perceived usefulness	The payment system analyzed has a low penetration in a non-probabilistic sampling design region; a cross-sectional study was adopted to collect data	2020
Al-Saedi et al. [112]	Extended UTAUT	Perceived risk, trust, cost, self-efficacy, performance expectancy, effort expectancy, social influence	Mobile payment	Oman	Explains 72% of the variance in behavioural intention. Developers ought to work towards interoperability	Regional limitation, Limited scope of articles	2020

Table 7 (continued)

References	Model	Constructs	Application	Region	Implications	Limitations	Year
Xiaodie et al. [86]	Extended TAM	Perceived usefulness, perceived ease of use, and trust	Mobile Payment	China	Customers prioritize the stability and error-free experience in deciding to adopt the technology	Limitation in scope as the study only considered Apple Pay	2020
M As'adi et al. [113]	Extended TAM	Social presence, perceived enjoyment, perceived ease of use, perceived usefulness, perceived compatibility, and attitude toward use	Tourism	Indonesia	Social presence, as an external factor, influences the users' perceived ease of use, perceived usefulness, and perceived enjoyment of the technology	An in-depth study of the relationship between the defined indicators is lacking	2021
Mohammed et al. [114]	TAM	Perceived security, perceived trust, and information quality	Mobile payment	Saudi Arabia	Educating users regarding the payment scheme safety is crucial	The generalization of the study is limited to a specific region	2022
Zhang et al. [115]	Extended mobile TAM	Mobile usefulness, mobile ease of use, perceived critical mass, perceived enjoyment, mobile self-efficacy, technology self-efficacy, and system and service quality	Mobile payment	Pakistan	NFC-based mobile payment saves time, is convenient, and secure	The generalizability of the results is constrained	2023

Fig. 2 The number of NFC-enabled cellular devices and non-NFC-enabled cellular devices with a global perspective from 2014 to 2020. From the delineation, we may observe that there is a considerable increase in the amount of NFC-enabled devices compared to non-NFC-enabled devices. This shows that NFC communication technology applications are experiencing remarkable growth all over the world

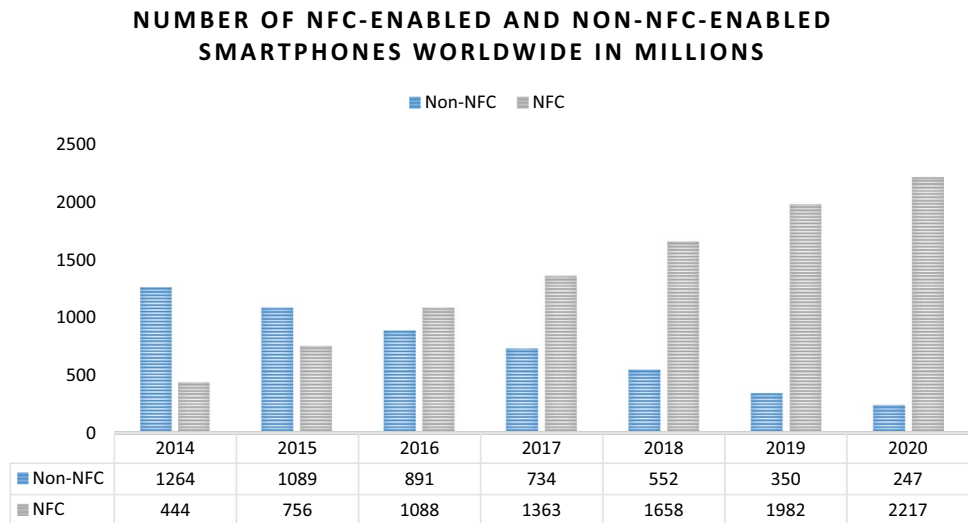
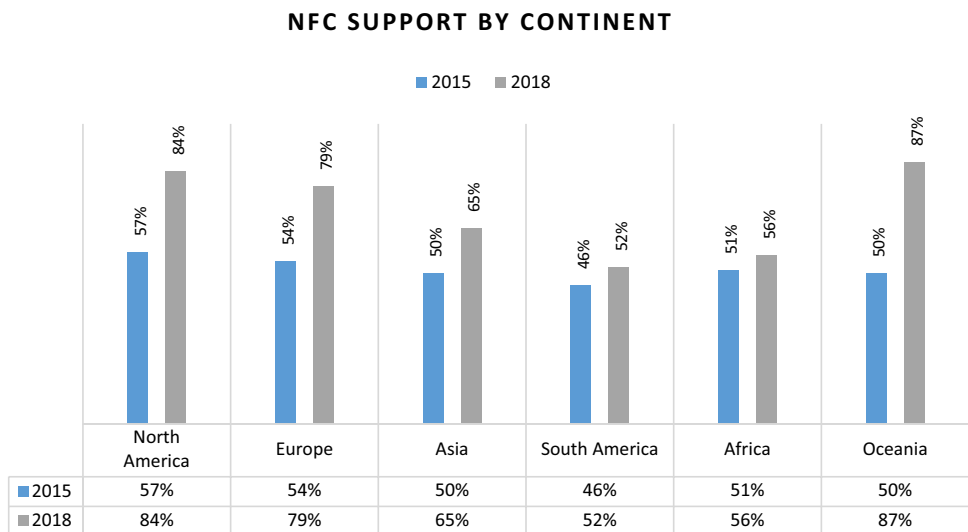


Fig. 3 A continental perspective to NFC support between 2015 and 2018. It can be observed that NFC support has increased in every continent with Africa experiencing the slowest percentage growth. This owes to the slow penetration smartphones in Africa, the limited adoption of NFC technologies by companies and merchants, and the limited awareness of the use of this technology



these, Samsung, iPhone, Huawei, Xiaomi, and HTC can use Samsung Pay, Apple Pay, and Android Pay, respectively.

Owing to the population of people in Nigeria, there usually exists huge traffic of people at ATM points all over the Nation. Cash withdrawals are the most common usage of ATM units in Nigeria. This traffic of people is primarily due to the current process of making ATM Withdrawals, which entails a slow method of inserting the master or visa card and following some required promptings before cash withdrawals can be made. This process could take from 2 min to about 10 min for those who are not adept with the ATM, thereby creating a long queue of people. NFC Technology may be effective in proffering lasting solutions to this problem by developing NFC-based ATM units. In 2020, First Bank of Nigeria, in partnership with Hyosung ATM OEM, launched their NFC-based ATM called FastTrack ATM, which is the first of its kind. With

the FastTrack ATM, users may perform quick cash withdrawals with their contactless cards or NFC Enabled Smart Phones.

Furthermore, bus rapid transport (BRT) was launched in Lagos, Nigeria, in 2008 to address congestion, air pollution, and road accidents that were on the increase. However, there have been issues with congestion at BRT terminals since their inception due to the slow purchase of tickets and slow validation of tickets by personnel before transit can be made. To address this concern, NFC Technology is currently being adopted to avoid long queues owing to slow ticket purchases, thereby informing a good customer experience. In 2018, a Nigerian-based payment solution provider, Farepay, developed a contactless card to replace sellers' contemporary purchasing tickets method that may not be available. This Card operates using NFC technology and is currently

being adopted by Lagosians making transportation easier and faster.

South Africa has also seen a gradual adoption of NFC-based services, with Samsung and Huawei (NFC-enabled devices) dominating the mobile market. Samsung pay was launched in 2018 in partnership with South African-based payment solution provider, Zapper, which launched Huawei pay in 2020 to make mobile payments. Besides, South African-based payment solutions provider Wallet Factory developed an NFC-based contactless card to make mobile transactions using Google Pay or Apple Pay. Although South Africa is still dominantly a cash-based economy, South African-based banks (Standard Bank, Nedbank, Absa bank, Sabric, and FNB) quickly integrate NFC technology into their POS terminals and develop contactless

cards. For product identification, South African-based solutions provider, Taggable, developed NFC stickers for products that could be highly useful in Shopping malls. In transportation, a British-based company, Aconite, 2011 announced a partnership with Proxama in bringing NFC ticketing to the South African transport system.

In 2012, in partnership with Kenyan-based Equity bank, Google launched an NFC-based payment scheme, Beba-pay, for cashless transit payments in Kenya. More recently, Safaricom launched an NFC-based mobile payment system called m-Pesa to enhance payment transactions in the Nation. A summarized table of the implementation of NFC-based applications in Africa using South Africa, Kenya, and Nigeria as case studies is described in Table 8.

Table 8 Summary of NFC-based applications in Nigeria, South Africa, and Kenya

Country	Smartphone users (2017–2020)	NFC device available	NFC-based application	Industries concerned	Application type	Year
Nigeria	40 million	Contactless cards, smartphones, ATMs, POS, Tags, wristbands, and stickers	NFC Based Payment	FCMB in partnership with Ikaaz	Mobile Payment	2014
			PayAttitude	Unified Payments in partnership with Access Bank, UBA, Skye Bank, Zenith Bank, Diamond Bank, and First Bank of Nigeria	Mobile Payment	2015
			PayWithCapture	Access Bank	Mobile Payment	2015
			Samsung Pay	Samsung in partnership with Standard Bank	Mobile Payment	2015
			SanwoPay	Sanwo technologies	Mobile Payment, Product Identification, Wearable technology	2017
			Farepay	Farepay	Transportation	2018
			Fast Track Mobile	First bank in partnership with Hyosung ATM OEM	Cash Withdrawal	2020
South Africa	53.4 million	Contactless cards, Smartphones, POS, Stickers	e-Ticketing	Aconite, in partnership with Proxama	Transportation	2011
			Samsung Pay	Samsung, in partnership with Absa and Standard bank	Mobile Payment	2018
			Huawei Pay	Huawei, in partnership with Zapper	Mobile Payment	2018
			Taggable	Taggable	Product Identification	2018
			mWallet	Wallet Factory's partnership with FNB	Mobile Payment	2018
			Tap-on-Phone	Nedbank	Mobile Payment	2020
Kenya	30 million	Contactless cards, Smartphones, POS, Stickers	Bebapay	Equity bank, in partnership with Google	Transportation	2012
			m-Pesa	Safaricom	Mobile Payment	2017

Impact of NFC Technology in Africa

NFC Technology adoption largely depends on NFC Enabled Smart Phones' availability, Industry acceptance and integration of the technology into their products and schemes, and the general awareness of the communication technology among the general populace [27]. For example, the 2018 Scantiamobile continental report showed that NFC Support growth was observed to be highest in continents with high iPhone usage (Oceania and North America (80%)) and lowest in continents with low iPhone usage (Africa and South America (50%)) [19]. According to world statistical data carried out by Scantiamobile, Africa experienced only a 5% increase in NFC support growth between 2015 and 2018. This slow growth primarily owes to (1) the slow penetration of Smartphones into African Countries, (2) slow industry acceptance and integration of this technology owing to implementation cost and (3) limited awareness of NFC Technology among the general populace. Informa Telecoms and Media reported that in 2011, the percentage of smartphones relative to mobile phones in Africa was just 3%, showing smartphones' slow penetration rate [116]. Interestingly, GSMA Intelligence 2020 reports have shown that Africa fast records a high smartphone penetration rate. South Africa, Nigeria, and Kenya have a good penetration percentage and will lead the mobile market by 2025 [20]. The availability of NFC Enabled Smart Phones promises to increase the percentage of NFC adoption in Sub-Saharan Africa.

NFC-Enabled Smartphone Usage in Sub-Saharan Africa

GSMA intelligence carried out an understudy of the mobile economy of sub-Saharan Africa, in 2020. This study reveals that the average percentage of smartphones in Africa will rise from 44% in 2019 to 65% in 2025, as shown in Fig. 4 [20]. Figure 4 presents the percentage of smartphones in Africa's different regions (Ethiopia, EAC, ECCAS, ECOWAS, and SADC). In addition, as described in Fig. 2, the top five brands of smartphones are presented with Samsung leading in all quarters except the last quarter. Interestingly, Samsung and Huawei have successfully integrated NFC chips into their products. By 2015, all Samsung devices incorporated NFC chips and successfully ran applications like Samsung Pay for mobile payments (Card Emulation Mode) and Android Beam to exchange media and documents between two NFC-enabled Smart Phones (Peer-to-Peer Mode). Also, since 2017, Huawei has integrated NFC chips into their devices, thereby making

them capable of running Android Pay and Android Beam. Furthermore, two smartphone brands, iPhone and Xiaomi, which have embedded NFC chips, gradually increase the African Mobile Market. These facts further validate the suitability of Africa for future NFC adoption.

Possible Future Applications of NFC in Africa

In the Banking Sector

Owing to the population of people in Nigeria, there usually exists huge traffic of people at ATM points all over the Nation. Cash withdrawals are the most common usage of ATM units in Nigeria. This traffic of people is primarily due to the current process of making ATM Withdrawals, which entails a slow method of inserting the master or visa card and following some required promptings before cash withdrawals can be made. This process could take from 2 min to about 10 min for those not adept with the ATM, thereby creating a long queue of people. NFC Technology may be effective in proffering lasting solutions to this problem by developing NFC-based ATM units. In 2020, First Bank of Nigeria, in partnership with Hyosung ATM OEM, launched their NFC-based ATM called FastTrack ATM, the first of its kind. With the FastTrack ATM, users may perform quick cash withdrawals with contactless cards or NFC Enabled Smart Phones. Interestingly, South African banking institutions adopt NFC technology in their ATM units. First National Bank (FNB), since 2018, has been rolling out NFC-enabled ATMs to make cash withdrawals easier and faster.

Shopping

Nigerian Shopping malls are also experiencing congestion owing to the population of Nigeria. This congestion is due to the slow process of validating the product information at the POS unit before payment can be made, causing very long queues and discouraging customer experience. NFC Technology may address this concern, because products may be embedded with NFC stickers containing the necessary product information. Subsequently, users may use their NFC-enabled smartphones to retrieve this information (Product type and cost) using the Reader/Writer mode of NFC. Payments may then be made at the POS terminal without creating any delays in validation using NFC-enabled readers. There is no such application in Nigeria, thereby creating an open area for research.

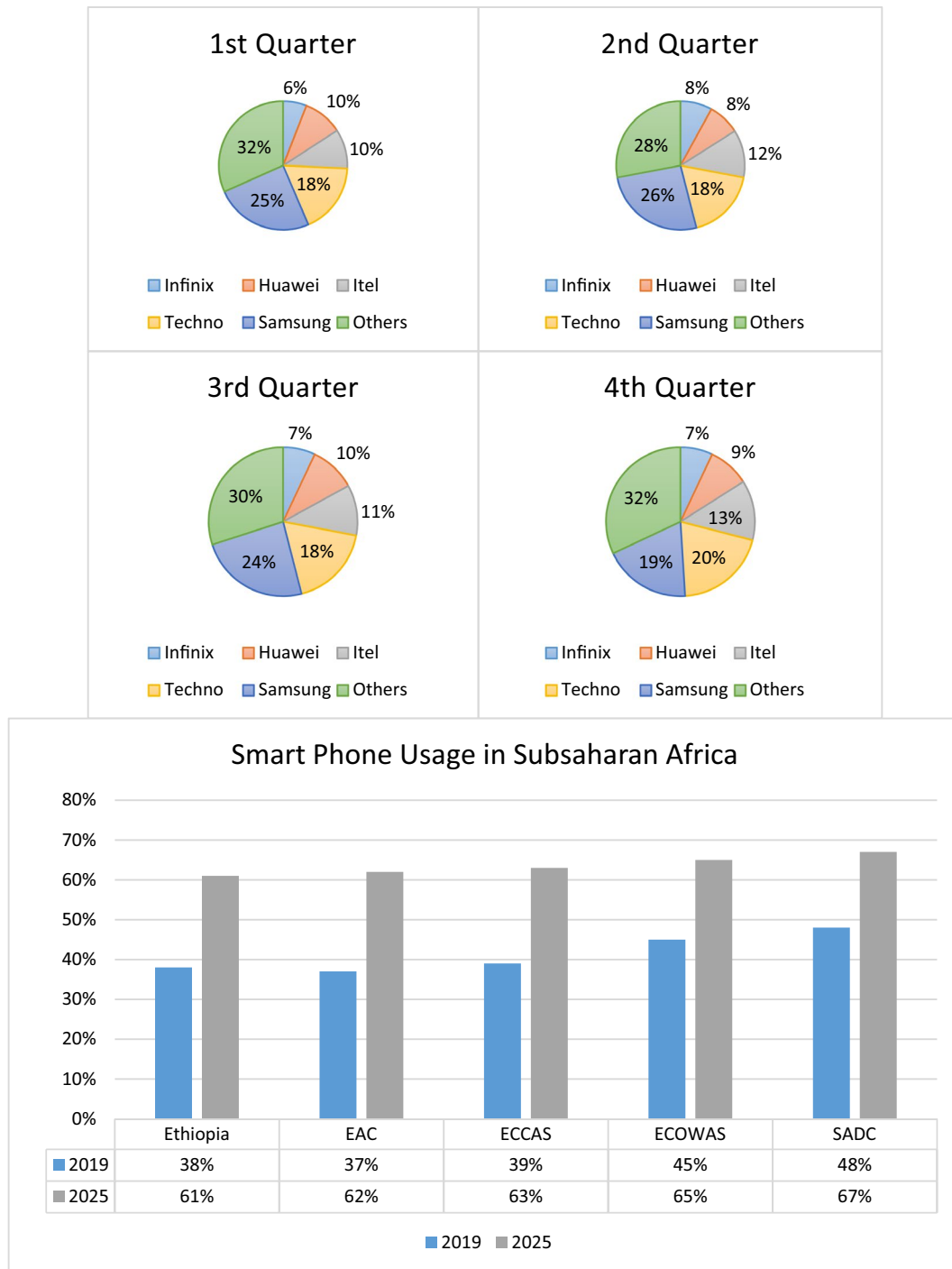


Fig. 4 The percentage of smartphones in Africa's different regions (Ethiopia, EAC, ECCAS, ECOWAS, and SADC). In addition, the top five brands of smartphones are presented, with Samsung leading

in all quarters in 2019. These statistics reveal how fertile the African space is for the adoption of NFC applications in diverse applications

Transportation

Transportation is also an exciting area where NFC technology may be adopted to make transport easier and faster through NFC-based ticketing schemes [13, 58, 61, 117].

These schemes reduce the bottleneck of congestion often caused by my ticket purchase and verification [118]. The user may use an NFC-enabled card or smartphone to purchase and verify ticket purchases at one tap. A few institutions currently provide NFC-based transport services in

Nigeria, Kenya, and South Africa, such as Farepay, Bebapay, Go, George, etc. However, NFC promises to transform the transport system of African Countries gradually.

Healthcare

A significant area of interest in NFC technology adoption is the Health sector [119]. Onyancha [120] reviews the adoption of NFC technology in the Kenyan healthcare system. In the study, the author investigates the adoption of NFC in storing patients' medical data to reduce medical costs and assist doctors in making quick clinical decisions. Jembi Health systems developed a platform (Journey Solutions) that uses NFC cards to allow individuals to carry their medical data to access their medical records. NFC schemes promise to transform the medical space through NFC-based data storage, payment systems, etc.

Lessons Learned This section presents the important lessons learned from the survey on NFC Technology and its impact on African Space. We present lessons learned from NFC technology performance, application, adoption, and acceptance in Africa using South Africa, Nigeria, and Kenya as models.

Lesson one: NFC Technology outperforms other short-range wireless technologies like Bluetooth, Wi-Fi, Zigbee, and QR-codes in that NFC makes communication between two NFC Enabled devices easier and faster at just "one tap" when brought in close proximity. The almost zero power dissipated when using NFC technology makes the technology very attractive for low-power consumer applications such as mobile payments, e-ticketing, smart packaging, etc.

Lesson two: NFC technology is based on RFID technology. An NFC Enabled device's performance depends on the active device's available power, the orientation of the passive device, and the antenna design. The higher the power, the longer the magnetic field's working range with a cost of power dissipation. The more perpendicular the passive device is, the more energy is trapped to power itself to communicate with the active device. Also, the larger the antenna size, the higher the magnetic field's working range, making antenna design a key consideration when developing an NFC-enabled device.

Lesson three: NFC technology is suitable for different applications such as mobile commerce, tourism, transportation, shopping, etc. However, the most widespread use of NFC Technology worldwide, and in Africa, where the technology is currently finding suitable adoption, is for mobile payment transactions opening the door to applications like Samsung pay, Android Pay, Huawei Pay, etc. It is worthy of note that these are fast proliferating in the global mobile commerce space and Africa, primarily due to the COVID-19

pandemic. NFC technology has opened the door to opportunities for banks to develop contactless cards, NFC-based ATM and POS units, etc., for users to make easy and fast transactions at a go.

Lesson four: The global adoption of NFC technology depends on certain important factors such as the security of the technology, the customer's perceived ease of use, the awareness of the technology, the availability of NFC-enabled devices, and government policies. These factors influence the customer's perception, intention, adoption, and continued use of the technology.

Lesson five: The Adoption of NFC technology largely depends on the availability of NFC Enabled devices such as contactless cards, NFC Enabled Smart Phones, NFC tags, embedded stickers, wristbands, etc. Without these devices, the adoption rate of the technology would be stringently slow. This is the major cause of the slow growth of NFC technology in Africa. Africa currently lags in the global scale of NFC technology Adoption owing to the slow penetration of smartphones into the continent, the slow adoption of the technology by industries, and the limited awareness of the technology by the individual African. Hence, growth in NFC Enabled devices' proliferation would lead to Growth in technology adoption on the continent.

Lesson six: South Africa, Nigeria, and Kenya are projected to lead the mobile market space in sub-Saharan Africa, making them suitable models to understudy NFC Technology's impact on Africa as a whole. The Smartphone penetration rate in these countries has gradually increased in recent years, accounting for almost the total usage of smartphones in sub-Saharan Africa. Interestingly, the mobile market vendors in sub-Saharan Africa and these countries are Samsung, Huawei, iPhone, etc. They have successfully integrated NFC Technology into most devices, making the market suitable for NFC Adoption. Nigeria currently leads in adopting NFC Technology, closely followed by South Africa and then Kenya.

Lesson seven: NFC-based transactions are vulnerable to security attacks such as denial of service (DoS) attacks, distributed denial of service (DDoS) attacks, phishing attacks, etc. Hence, this concerns greatly influences the user's acceptance and trust for the technology. However, not many studies have investigated the possible solutions to these limitations. Moreover, as the wireless communication technology develops, more investigation is required within this area. Nevertheless, some machine learning techniques such as convolutional neural networks (CNNs), long-short term memory (LSTM), etc. are emerging to provide a more convincing solution to this drawback.

Open Issues and Future Research

Since its inception in 2004, NFC Technology has been gradually permeating diverse areas of human life. However, certain issues need to be addressed to facilitate technology usage, particularly in Africa. Some of these issues like security concerns, adoption and acceptance in Africa, implementation cost, medical research, and power and antenna design considerations are presented in Table 9.

Conclusions

This paper presents a comprehensive review of NFC technology, its applications in several areas of human endeavors, its customer perception and acceptance on a global scale, and its impact on the African continent, using Nigeria, South Africa, and Kenya as suitable models owing to their high smartphone penetration rate. Specifically, we provide the customer's perception, intention, and continuance use of NFC technology on a global scale by understudying different models such as TAM, UTAUT, DOI, SWOT-AHP, and ANN. From these models, we derived important implications detailing the influence of certain factors, such as security, ease of use, awareness, availability of NFC-enabled smartphones, and government policies, on the adoption of NFC technology. Furthermore, the future of NFC technology is considered in mobile payment schemes and medical

applications, as a stepping stone to developing the smart cities of the future. Particularly, NFC is a zero power dissipation short-range wireless technology for communicating between two NFC Enabled devices, which may be active and/or passive. The reduced power dissipation, flexibility, and ease of carrying out transactions with just "one tap" make NFC Technology more attractive than other wireless technologies like Wi-Fi, Bluetooth, Zigbee, QR Code, etc. Although NFC technology may be applied in product recognition to retrieve product information from NFC Stickers embedded in products, this could create a better consumer experience at shopping malls, e-Ticketing for transportation, cinema access, football ticket purchase, etc. The most popular use of NFC globally and particularly in Africa is making mobile payments. NFC technology is gradually establishing itself in the African market as a key enabler of mobile payment transactions, which may relegate other payment methods like Debit and credit cards in the nearest future. This work reviews near-field communication penetration in Africa, highlights all application areas, and provides a holistic overview of NFC's potential. This survey presents researchers, NFC developers, industries, and entrepreneurs in Africa with a futuristic perspective on NFC adoption in the African market. Going by the reports from the statistics presented in this paper on population and the number of smart devices, we may conclude that NFC has found a place in Africa. The market is ripe for NFC adoption as a form of payment and other applications. Africa is progressively accepting NFC development initiatives due to the prospect

Table 9 Some future research directions

S/N	Key concerns	Possible focus
1	Global security	Security is a major concern in NFC technology, particularly in mobile payment. Although communication proximity reduces eavesdropping, particularly in Reader/Writer and Card Emulator modes, encryption is required in NFC technology to reduce the risk of data manipulation
2	Adoption in Africa	According to the statistics we gathered in this survey, the major drawback of NFC Adoption in Africa is the reduced penetration of NFC Enabled Smart Phones, Industry integration of this technology into their products and services, and limited awareness of the use of this technology. We believe a higher rate of smartphone penetration by mobile vendors, a better acceptance of this technology by African-based industries, and more enlightenment to the general public using adverts, etc. may address this issue
3	Cost in Africa	Cost is a major drawback in NFC Adoption because many Industries refrain from doing so due to the implementation cost of integrating NFC chips or stickers into all their services. Also, the cost of purchasing a smartphone is high, and thus many consumers refrain from purchasing these devices. We believe if the cost of purchase of smartphones were reduced, the proliferation of NFC Enabled devices would increase
4	Medical Research in Africa	It is worth noting that from the pieces of literature reviewed, the most significant percentage of work done on NFC fall under mobile payment with little or no research on the Medical application. We hope that research on Medical applications and other fundamental areas will take center stage in Africa in no distant time
5	Power and antenna design concerns	NFC communication depends on the available power in the active device because the field's strength is a function of the power output. Also, the antenna design is a major design issue as it also affects the strength and working range of the field. We believe more research may be carried out on power harvesting techniques for NFC-enabled devices and antenna design

of enhancing the quality of life along social-economic strata. Our future work will examine the impact of NFC adoption in Sub-Sahara Africa, focusing on economic liberation and democratization of government institutions.

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Declarations

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