Analysis of NFC technology evolution

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***Abstract* — An analysis of the development and capabilities of NFC technology has highlighted its growing role in short-distance data exchange between modern devices. Operating at a frequency of 13.56 MHz, NFC technology is an advanced iteration of the RFID contactless data transfer system, enabling devices to interact within a few centimeters of each other. This article examines the primary characteristics of NFC operation, historical aspects of its evolution, the current state of the technology, and future development prospects and its influence on contemporary technological solutions. NFC offers several modes of operation, contributing to its versatility and adaptability to various usage scenarios. Presently, it finds applications in a wide range of fields, from simple mobile payments to medical equipment. Despite its numerous advantages, there are certain challenges, such as data security concerns. However, its prevalence and relevance persist because NFC is often used in conjunction with software solutions that provide additional, more robust layers of protection. Thanks to active development and the incorporation of modern innovations, NFC offers new opportunities for effective application in the field of telecommunications.**

***Keywords* — NFC, technology, wireless exchange, NFC Forum, NFC-tags, NFC usage, RFID, contactless payments**

I. Introduction

The modern world of information technology and communications is in constant flux, offering innovations that enhance our daily lives and reshape the ways we interact with the world around us. One such innovation is the contactless communication technology known as NFC (Near Field Communication). What began as a simple contactless payment method has evolved into a multifaceted tool, encompassing a broad range of applications and exerting significant influence both at the national and regional levels, as well as globally.

In this article, we offer you a detailed analysis of NFC technology, examining its evolution and its impact on contemporary society and the economy. We will trace the development of this technology on a global scale, considering its influence on various sectors, from finance to healthcare and retail.

By exploring the history of NFC, its development process, and its implementation in different parts of the world, we can identify key trends and lessons that can guide the further evolution of this profound and intriguing technology. We will delve into the captivating world of NFC and discuss how it has transformed and continues to reshape our lives and the business landscape, as well as how it will define the future of global communications and innovations.

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II. Essence of NFC technology

NFC stands for Near Field Communication. It is a wireless short-range technology that operates at a frequency of 13.56 MHz. This technology is actively used in industries, healthcare, and scientific research. NFC is a revolutionary field that has been actively evolving and undergoing significant transformations in the past decade. NFC enables portable wireless interaction between two NFC-enabled devices and is characterized by high frequency, low bandwidth, and relatively short communication range.

RFID (Radio Frequency IDentification) is the technology on which NFC is based. The primary difference between them is the range of operation. While RFID tags can be read from distances of several hundred meters, NFC is specifically designed for close-range interactions (within 10 centimeters).

NFC always involves an initiator (most commonly a smartphone or NFC-enabled device) and a target. The initiator generates a radio frequency field that interacts with the passive target.

NFC supports two main operating modes: active and passive. In active mode, the initiator actively transmits data to the passive target, such as during contactless payments. In passive mode, the target (e.g., an NFC tag) awaits the initiator's action to transmit data.

III. NFC: The Technology Changing the Game

NFC technology was developed to facilitate wireless communication between devices over short distances. The design of NFC encompassed various stages and considerations, aiming to ensure ease of data handling, security, low power consumption, and versatility. The technology was envisioned for simple and rapid data exchange between devices. It operates on the globally unlicensed ISM[1] radio frequency band of 13.56 MHz.

In terms of data transfer speed, NFC's invention plays a pivotal role. The technology offers almost instantaneous connection – with a single touch or by bringing devices close to each other, users can instantly share contacts, files, payment information, and much more. It's this convenience and speed that have made NFC a widely adopted technology, especially in the realms of contactless

[1] ISM (Industrial, Scientific, and Medical) frequency band is an internationally approved set of radio frequency ranges designated for use by industrial, scientific, and medical devices not intended for traditional radio communications or broadcasting. Although these bands were initially reserved for non-commercial applications, they have become popular for various wireless communication systems due to the lack of licensing requirements. However, devices operating within the ISM bands must adhere to specific standards to minimize potential interference with other radio services.

payments, contact sharing, and device management, solidifying its place in modern mobile devices and gadgets.

In the tech world, security is a paramount aspect that determines user trust and the success of new solution implementations. The primary quality and popularity metric of any technology can undoubtedly be its security. When developers were crafting NFC technology, security was at the forefront of their considerations. One of NFC's key security features is its short operational range, approximately 10 cm. This distance limitation makes the technology less susceptible to unauthorized data interception attempts, as a malicious actor would need to be near the device to disrupt the signal or inject malicious data during transmission. Although NFC's range is limited, its high-level security makes it a reliable tool for data exchange in various sectors where security is paramount.

Encryption, used to protect transmitted data, is now a cornerstone of NFC security. Information shared between devices is encrypted using encryption algorithms, and only devices with the correct keys can decrypt and read it. NFC employs both symmetric and asymmetric encryption algorithms to ensure data confidentiality and integrity. Symmetric encryption is used for encrypting the transmitted data, while asymmetric encryption is used for encrypting the shared access key. This provides a high degree of security since even if a malicious actor decrypts the data, they cannot decrypt the shared access key without the correct key. This combination of encryption algorithms is termed mutual authentication. It prevents "man-in-the-middle" attacks, as both interacting devices verify each other's identity before establishing a connection.

Moreover, NFC can employ various authentication methods, such as passwords, fingerprints, or even facial recognition, further bolstering data transfer security. These multi-layered security measures make NFC an attractive choice for various applications, including contactless payments, building access, and confidential data transfer.

NFC technology is ideally suited for mobile devices due to its low power consumption. This is attributed to the technology's limited application scope and its design. When devices use NFC for data exchange, they don't require as much power as when using Bluetooth or Wi-Fi. The primary energy-saving advantage stems from two communication modes: active and passive. In active mode, both NFC devices operate on independent power. Each device generates an electromagnetic field for data transmission. This means both devices must consume energy to generate and maintain this field, increasing overall power consumption but ensuring a more stable connection. Passive mode operates differently. In this mode, only one device (typically the initiator) generates an electromagnetic field. The target device, on the other hand, doesn't generate a field but uses the initiator's field modulation to transmit data. This significantly reduces power consumption since the target device doesn't generate an electromagnetic field but merely "responds" to the initiator's field. Owing to these properties, NFC is widely used in various mobile device applications – from contactless payments to activating NFC tags. The technology can also work in tandem with other power-saving methods, like standby mode, which prolongs device operation without recharging.

NFC has also emerged as a highly versatile technology. It's based on standardized protocols, ensuring its compatibility and universality on a global scale. Below are some of the key standards and protocols related to NFC:

1) ISO/IEC 14443: Defines the protocol for contactless smart cards used for identification and short-range data exchange.
2) ISO/IEC 18092: Specifies the data exchange mode between devices using NFC and is based on RFID technology.
3) NFC Data Exchange Format (NDEF): Describes the data format used for exchanging information between devices via the NFC protocol.
4) Logical Link Control Protocol (LLCP): Allows devices to establish a connection and exchange data using the NFC protocol.
5) Simple NDEF Exchange Protocol (SNEP): Enables devices to send and receive NDEF messages via the LLCP protocol.
6) NFC Connection Handover: Describes how devices can use NFC to connect with other wireless technologies, such as Bluetooth and Wi-Fi.
7) NFC Connection Handover: Describes how devices can use NFC to connect with other wireless technologies such as Bluetooth and Wi-Fi.

NFC supports various operating modes, including read/write mode, card emulation mode, and peer-to-peer mode. This allows devices not only to exchange data but also to emulate the functions of contactless cards or interact with other devices on equal terms. Below is a description of each operating mode.

A. Read and Write

In this mode, NFC devices can read and write data on NFC tags or labels. This mode is widely used in various sectors, such as storing information on smart posters or displays. It also allows for reading transport schedules, tourist markers, and routes.

B. Peer-to-Peer[2]

In this mode, two NFC devices interact with each other to exchange information and files. This mode can be used to exchange Bluetooth, Wi-Fi connection settings, or photos. It can also be used to transfer data between devices without the need to connect to the internet or establish wireless connections.

C. Card Emulation

In this mode, NFC devices behave like existing contactless cards. This mode is widely used in contactless payments, where the NFC device can emulate a bank or credit card for a secure transaction. This allows users to make secure payments without the need to carry a physical card.

IV. Process of NFC Development

As mentioned earlier, the origins of NFC technology can be traced back to RFID technology. Therefore, when considering the history of NFC technology, it is essential to note one of the key figures in the development of this technology, Charles Walton.

[2] In information systems, peer-to-peer communication refers to a connectivity model where nodes or devices have equal rights and functions. This allows for direct data exchange without the need for a centralized server or intermediary.

The first patent related to RFID was granted to Charles Walton on May 17, 1983. His inventions, including the digital version of RFID, improved upon earlier passive models, and found dozens of applications. However, the expiration of some of Walton's key patents in the mid-1990s prevented him from reaping significant financial benefits from the subsequent rapid spread of RFID. Nevertheless, Walton made a significant contribution to the development and commercialization of this wireless technology. His inventions impacted various industries, including security, retail, and supply chain management, and paved the way for the development of NFC technology.

Furthermore, on June 26, 1997, Andrew White and Marc Borrett from Innovision Research and Technology patented an early form of NFC technology, which was initially used in "Star Wars" character toys for Hasbro [1]. This device allowed for data exchange between two devices that were near each other. Although the specific application in "Star Wars" toys is not described in the sources, we can understand the general concept. NFC technology could have been used to introduce interactive elements into toys, such as allowing them to interact with each other or with a separate device. For example, when two toys approached each other, they could exchange data and trigger specific actions, such as sounds, lights, or movements.

These toys from "Star Wars"[3] became one of the first consumer products to utilize NFC technology, marking an important milestone in the commercialization and popularization of NFC. They demonstrated the potential of NFC beyond industrial applications, such as RFID, and opened the possibility of its use in a wide range of consumer electronics. Later, NFC was also used in other toy lines to enhance interactivity. For example, in Nintendo's Amiibo toy line, NFC technology is used to store game data and unlock features in video games. However, it is important to note that while NFC technology has become more common in toys and other consumer goods since 1997, specific applications and functions can vary greatly depending on the product and the manufacturer's design.

Special contributions to the development of technology were made by the companies Sony, Nokia, and Philips. It is worth noting that the main contribution from Philips came from the NXP Semiconductors division, which later became a separate company in 2006. Sony, a Japanese corporation headquartered in Tokyo, had a significant influence in the fields of electronics, gaming systems, and digital technologies at that time. Philips Electronics, a multifunctional company headquartered in the Netherlands, specialized in semiconductor technologies, including the design, production, and marketing of analog and digital integrated circuits for various industries. The NXP Semiconductors division specialized in the creation and production of high-performance mixed-signal and standard semiconductor components. The Finnish company Nokia was one of the leading global players in the mobile communication and electronics industry.

An important step in the development of NFC technology happened on March 25, 2002, when companies agreed to create a technological specification and developed a technical draft [2]. In 2004, they established the NFC Forum, a non-profit industry association aimed at promoting NFC technology and developing standards for its implementation [10].

The Forum contributed to the development and promotion of NFC technology by establishing standards for device compliance testing. These standards include communication protocols and data formats based on RFID standards such as ISO/IEC 14443 and FeliCa. The forum introduced the Simple NDEF Exchange Protocol (SNEP) into the specifications, which is used for sending and receiving messages between NFC devices. They also defined the common data format NFC Data Exchange Format (NDEF), which can store and transmit various types of data, including URLs.

The company NXP Semiconductors applied for six fundamental NFC patents, which were invented by Austrian and French engineers Franz Amtmann and Philippe Maugars [3]-[8]. Later, in 2015, they received the European Inventor Award[4] for their contribution [9].

V. Industry Analysis: The Impact of NFC Technology

The development and implementation of NFC technology have revolutionized various industries worldwide. Below is a list of key areas significantly impacted by NFC.

A. Mobile Payments

NFC has transformed the way payments are made it's now used for contactless transactions on mobile devices, eliminating the need for cash or bank cards. This technology has been adopted by numerous financial institutions and retail businesses globally, making transactions faster and more convenient.

Before NFC, mobile payments were primarily limited to SMS transactions[5]. These operations involved sending a text message with payment information to a specific short code, which then processed the transaction. This method was cumbersome and insecure.

With the advent of NFC, providing contactless payments, the way mobile payments were made underwent a radical change: users can make purchases by simply tapping their mobile device to a payment terminal. This makes transactions quicker, more convenient, and safer; NFC payments also eliminate the need for physical cards, reducing the risk of theft and fraud. Today, mobile payments have advanced even further with the emergence of technologies like Apple Pay, Google Pay, and Samsung Pay. These digital wallets allow users to store payment information on their mobile devices and merely touch the device to a payment terminal to transact. These digital wallets often incorporate additional security measures, such as biometric verification from pay.com, making them more convenient and safer compared to traditional NFC

[3] "Star Wars" is an iconic cinematic universe created by George Lucas, encompassing movies, TV shows, books, and other works. It delves into intergalactic battles, the Jedi, the Sith, and the intricate personal dramas of its characters set against the timeless struggle between good and evil.

[4] The European Inventor Award, established by the European Patent Office (EPO) in 2006, is an annual accolade presented to distinguished inventors and innovators. It recognizes their profound contributions to scientific, technical, and social advancements that foster progress and well-being across Europe.

[5] SMS transactions in mobile payments refer to the method of conducting payment operations using short text messages (SMS) via a mobile phone. Users send or receive instructions to facilitate payments or fund transfers. While convenient, this method is often viewed as less secure due to the potential for SMS interception or fraud.

payments. However, NFC technology still plays a crucial role in mobile payments. For instance, when making a contactless payment using Apple Pay or Google Pay, the mobile terminal employs NFC technology to interact with the payment terminal. The introduction of this technology has revolutionized payment methods, making them faster, more convenient, and safer.

B. Internet of Things (IoT)

Over the past few years, the Internet of Things (IoT) has come a long way, and its capabilities have further expanded thanks to NFC integration. The IoT concept took root when household appliances, such as refrigerators and thermostats, began connecting to the Internet. This allowed for remote control and monitoring of these devices. The first IoT device was a toaster, invented by John Romkey in 1990 [13].

The integration of NFC into IoT devices further enhances their functionality: NFC provides a simple and secure connection between IoT devices. This adds complexity to the system and elevates the overall efficiency and functionality of IoT devices. Today, NFC is an integral part of many IoT devices. It facilitates real-time data collection, enhances data collection efficiency, and eases remote control of production processes. NFC also plays a significant role in the development of “smart cities” and can be employed for efficient waste management, energy conservation, and other applications. In manufacturing, NFC and IoT technologies can be used for real-time equipment monitoring, predictive maintenance, and other applications.

Experts believe that the IoT realm has a promising future, and NFC will play a pivotal role in this evolution. Predictive analytics and machine learning will take center stage, helping devices recognize patterns, anticipate needs, and act before we realize we need them. For instance, a refrigerator could notice product usage patterns and notify us when it's running out of, say, milk.

In conclusion, the integration of NFC into IoT has significantly broadened the capabilities of IoT devices, making them more efficient and functional.

C. Retail Industry

In the past, to make a purchase, shoppers had to carry cash or plastic cards, while sellers had to process these payments manually. This approach was labor-intensive and prone to errors. Moreover, cash and cards increased the risk of theft and fraud.

The retail industry has undergone a significant transformation thanks to contactless payments: now, a simple tap of a mobile device on a terminal is enough for payment. This has sped up and simplified transactions, making them more secure. Thanks to NFC, retailers can now offer customers personalized promotions based on their preferences, enhancing the shopping satisfaction level. NFC has become an integral component of the retail industry. Retailers use NFC tags to provide product information, streamline payment processes, and offer discounts. This has transformed the shopping experience, making it more dynamic and engaging. Furthermore, with NFC, cashier-less stores have emerged, where visitors, using their gadgets, can select products and pay for them without the intervention of cashiers.

D. Healthcare

Before the introduction of NFC into healthcare, patient record-keeping, tracking, and medication administration were primarily done using physical methods. Patient medical records were typically stored in paper format, and communication between professionals took place over the phone. Manual oversight of medication intake posed risks of errors and misunderstandings.

Now, real-time patient tracking, secure access to their medical data, and automated drug administration are actively used. NFC tags serve to store patient information, providing medical staff with instant access to the necessary data. This has significantly improved the quality of service and operational efficiency of medical institutions. With NFC, one can determine a patient's location, know the time of the last nurse visit, or the most recent prescribed treatment. There are “smart” medication dispensers based on NFC that automatically dispense drugs at the right moment. Even in home settings, NFC finds its application: bracelets with this technology can track vital health indicators. When connected to a smartphone or tablet, the data is instantly sent to a doctor for analysis.

E. Marketing and Advertising

Previously, marketing and advertising largely relied on traditional approaches such as print publications, radio broadcasts, and mailings. While these methods proved effective, they didn't offer enough interactivity for customers, who often had to seek out the information they needed on their own.

Thanks to NFC tags, consumers can now access product information, coupons, feedback forms, or even social media links by simply bringing their device close to the tag. This not only makes marketing more interactive but also enhances customer engagement and loyalty. One of the advantages of NFC tags is the ability to update them remotely, giving marketers flexibility in changing content based on various factors, such as context or location. NFC is used to create an interactive experience in physical retail points, for instance, on in-store displays. NFC tags embedded in promotional materials provide customers with instant access to promotions, information, or other offers with a tap of their device.

F. Transportation

Before the introduction of NFC into the transportation system, it largely relied on traditional methods of selling and paying for travel documents. Passengers had to buy tickets at stations or through vending machines. This approach was not only time-consuming but also created problems during peak demand times when long queues formed in front of ticket counters.

Now, to purchase and pay for a ticket, it’s enough to bring a mobile device close to a specialized terminal. This has not only sped up the process but also made it more comfortable for passengers. As a result, ticket machines and checkpoints have become much more efficient, serving more clients simultaneously. NFC is actively used in buses and trains, providing convenience in purchasing and paying for travel. Moreover, the technology has found its application in car rentals, allowing clients to control the car using a mobile device, interacting with an NFC reader.

G. Education

Before the introduction of NFC into the educational sector, much of the learning process relied on traditional methods. Teachers distributed educational materials manually, which was labor-intensive and prone to errors. Attendance was also recorded manually, which did not guarantee data accuracy. For identification in educational institutions, students used plastic cards.

Educational materials and attendance in many institutions have already been digitized, simplifying, and accelerating many processes. Using NFC cards for automatic attendance tracking increases data accuracy. There are also features like digital lockers for storing educational materials. There are "smart" classrooms filled with digital boards. While the education sector still largely retains its traditional format, NFC is paving its way to the future.

VI. Disadvantages of NFC

Despite the limited range of NFC by just a few centimeters, simple NFC can't provide a completely secure connection. This technology is not resistant to many types of attacks. [12].

For example, one common attack is information interception when an attacker is near an NFC device, and they may attempt to covertly intercept the data being transmitted between devices. This can be achieved using specialized equipment, such as NFC relays[6] or NFC scanners[7], which can capture data during communication. Such attacks can pose a risk to confidential data, such as financial information or personal identification data.

Furthermore, NFC is not protected against DoS (Denial of Service) attacks. A DoS attack on NFC is a type of cyberattack aimed at reducing or stopping the normal operation of systems, devices, or applications using this technology. This attack can involve various methods and techniques with the goal of overloading or disrupting the functioning of NFC-enabled devices. This can be achieved by generating many requests to the device or network, overloading the communication channel, or blocking memory buffers.

Another typical type of attack is a phishing attack, in which an attacker can interfere with the data exchange process between two NFC devices, attempting to modify or intercept information. This attack may go unnoticed by users, and they may not realize that their data is at risk.

Therefore, despite the simplicity and convenience of NFC technology, it requires additional security measures such as data encryption and authentication to protect information from potential attacks and malicious actors.

[6] NFC relays are devices that allow remote control of other devices using Near Field Communication technology. They operate by transmitting signals over short distances, enabling users to manage various devices such as lighting, locks, and other security systems.

[7] NFC scanner is an electronic device capable of reading and transmitting information from NFC tags over extremely short distances. Building on contactless radio-frequency identification technology, NFC scanners are prevalent in a range of applications, from cashless payments and ticketing systems to access controls and device-to-device data exchange. While offering a convenient and swift solution to many everyday tasks, it's vital to implement security measures to prevent unauthorized access or fraud.

VII. Development perspectives

The future of NFC development was disclosed at the NFC Forum on June 21, 2023 [11]. The main development priorities for the technology are increasing power for wireless charging devices, increasing the range, multi-purpose tap, upgrading connectivity, and increasing the number of data formats for exchange.

Wireless charging devices are becoming increasingly popular due to their convenience and ease of use. They do not require wires, making them ideal for use during travel and on the go. Furthermore, wireless charging devices typically have a higher charging speed compared to wired charging devices.

The NFC technology is used in wireless charging devices, but their power is currently lower than that of other models on the market. At the moment, the specification provides power up to 1 watt, but there are plans to increase it to 3 watts. This will allow the use of such chargers in new, more compact devices, change industrial design, and open new markets.

One of the priority directions in the development of NFC technology is increasing the range. Currently, NFC connections are limited to 5 millimeters. However, the NFC Forum is exploring possibilities to expand this range by 4-6 times, which will significantly speed up contactless transactions and enhance the convenience of their use.

Another important direction of development is the implementation of the multi-purpose tap. This feature will enhance the user experience when using contactless devices and enable performing multiple actions with a single touch. For instance, it can be convenient for payment transactions for goods or services, allowing users to confirm the payment and receive a receipt with a single touch.

The modernization of inter-network connectivity is another key development direction in NFC technology. This will improve the compatibility of various devices and simplify their integration with other technological solutions. For example, NFC-enabled devices can easily integrate with security systems or access control systems.

Currently, it is understood that the primary standards supported by NFC include ISO/IEC 14443, NDEF, LLCP, SNEP, and FeliCa. However, in a world where consumer and regulatory requirements are constantly changing, NFC technology must be capable of exchanging data in various formats. This will help ensure a healthy economic circulation, the transmission of product composition data, and methods of disposal.

As a result, by 2028, NFC technology is planning to evolve towards improving the user experience, increasing data transfer speeds, and expanding capabilities for data exchange in different formats.

VIII. Conclusion

In today's world, technology plays a crucial role in creating the future of mankind. One of the most significant innovations has been NFC wireless communication technology.

The impact of NFC technology on mobile payments, Internet of Things, retail, healthcare, transportation, and education has become undeniable. NFC is a catalyst for increased efficiency, convenience, and comfort in these areas. NFC defines efficiency and comfort in each of these areas. Despite all the successes achieved, many challenges

remain, the solution to which will be central to the future development of NFC technology.

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