Proceedings of CONF-FMCE 2025 Symposium: Semantic Communication for Media Compression and Transmission
DOI: 10.54254/2755-2721/2025.GL28017

NFC Technology: Fundamentals and Current Development

Xinyi Zhao

Cambridge International School Litai College SISU, Shanghai, China
2440471661@qq.com

Abstract. With the in-depth popularization of the Internet of Things technology, short-range wireless communication has become a key link connecting the physical world and digital services. Benefiting from its "touch-and-interact" feature and low-power consumption, Near Field Communication (NFC) technology has developed rapidly in consumer electronics and public services. This paper explains the working principles of NFC technology, outlines its applications in daily life and commercial sectors, and analyzes the challenges it faces at the current stage. The findings show that relying on its convenience, NFC has achieved large-scale use in scenarios such as mobile payments and public transportation ticketing. However, its limitations are evident: mobile payments are efficient but risk unauthorized transactions, and although NFC improves logistics efficiency, its tags are significantly more costly than Radio Frequency Identification tags. In addition, technical shortcomings and market competition from alternative technologies further constrain its promotion. The conclusion points out that NFC remains in the early stage of application. To overcome current bottlenecks, it is necessary to advance core technology iteration, promote cross-technology integration, and simplify operation processes. With the synergy of Internet technology, NFC is expected to expand from fixed application scenarios to broader popularization.

Keywords: NFC, Near Field Communication, Mobile Payment, Transportation

1. Introduction

With the deep integration of the Internet of Things (IoT) technologies, short-range wireless communication has become a pivotal link between the physical world and digital services. Near Field Communication (NFC), characterized by its "tap-and-go" interaction and low power consumption, has developed rapidly in consumer electronics and public services. In 2002, Philips Semiconductors and Sony Corporation jointly proposed NFC as a more interactive communication method based on contactless card technology. At that time, Radio Frequency Identification (RFID) was already used in logistics and access control, but it only supported one-way identification and lacked flexible two-way communication between devices. The emergence of NFC was intended to fill this gap. A turning point came in 2004, when Nokia, Philips, and Sony established the NFC Forum to promote standardization. In 2006, the ISO/IEC 18092 (NFCIP-1) standard was released, defining key communication parameters based on electromagnetic inductive coupling at 13.56 MHz.

DOI: 10.54254/2755-2721/2025.GL28017

In 2012, NFCIP-2 further expanded NFC’s three operating modes, greatly enhancing its application potential in mobile payments, data transmission, and identity recognition.

With maturity of the technology, NFC achieved rapid global adoption. In 2006, China completed its first NFC mobile payment test; in 2011, Google Wallet drew widespread attention; and the launch of Apple Pay in 2014 firmly established NFC as a mainstream consumer technology. As smartphones became more prevalent, NFC applications expanded beyond mobile payments to device pairing and IoT interconnection, giving rise to new business models and application scenarios. This paper will examine NFC technology from its fundamental principles and communication modes, analyze its applications in major fields, discuss the challenges it currently faces, and provide reasonable prospectives on future development.

2. NFC working principal

2.1. NFC protocols

Commonly used general protocols include: (1) ISO/IEC 14443: This ISO standard describes the modulation and transmission protocols between card and reader to create interoperability for contact-less smart card products. There are two main communication protocols supported by the ISO/IEC 14443 standard, they are addressed as Type A and Type B. It is used for applications requiring high security, such as bank cards and ID cards [1]. (2) ISO/IEC 15693: This standard is used for long-range non-contact communication, suitable for scenarios where a longer read distance is required.They are sometimes referred as Vicinity cards. Examples are NXP I Code, TI Tag-IT, Infineon MyD [1]. (3)ISO/IEC 18092: This protocol enables point-to-point communication between NFC devices, allowing them to exchange data. It is one of the core standards of NFC technology.

In NFC communication protocols, POLL and LISTEN are the two fundamental operational modes for establishing communication. The primary difference between them lies in whether a radio frequency field is actively generated and whether a communication request is initiated. These two modes dynamically switch, forming the underlying logic for NFC's near-field interaction [2].

2.2. NFC communication modes

NFC’s communication modes are divided into Passive Mode and Active Mode, as shown in Figure 1. In Passive Mode, the NFC initiating device (Initiator) provides power to the communication,. The target draws power from the NFC reader [3]. This mode is convenient for creating. Since NFC targets using stickers without needing a battery, this is referred to as the Passive Mode [4]. Active Mode, on the other hand, involves both NFC devices generating radio frequency fields. Both devices generate electromagnetic fields alternately to communicate. This mode typically has a longer communication range, up to 20 cm, and, when using PSK modulation, the data transmission rate can reach up to 6.78 Mbit/s [5,6].

DOI: 10.54254/2755-2721/2025.GL28017

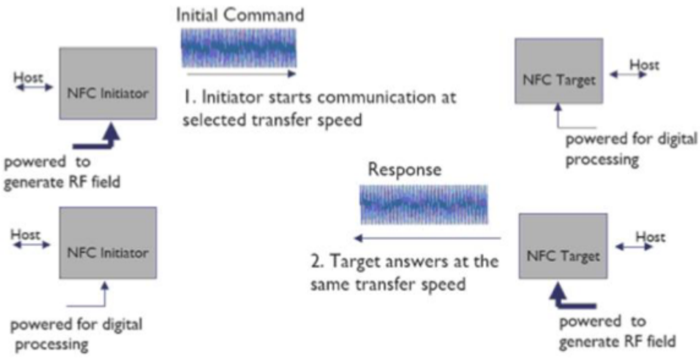

Figure 1. NFC's communication modes based on power

2.3. NFC communication process

The complete lifecycle of NFC communication can be divided into four core stages: initialization, device activation, data transmission, and device suspension. Initialization is the transition from physical proximity to establishing a logical connection. It involves frame listening, collision detection, and technology discovery.

During the frame listening state, the device listens to the external radio frequency field and can switch to become the initiator. Collision detection checks whether the radio frequency field should be activated, ensuring that signals are not distorted by overlapping fields from multiple devices. Technology discovery follows a poll-response pattern. The initiator sends polling frames sequentially in accordance with the preset technical priority (typically NFC-A → NFC-B → NFC-F → proprietary technologies, compatible with standards such as ISO/IEC 14443 and ISO/IEC 18092) [7]. Peripheral devices in a listening state respond by modulating the magnetic field, indicating support for the corresponding technology without providing device-specific data (see Table 1). After receiving a response, the initiator confirms the existence of a compatible device, stops polling, and locks the technical standard for subsequent parameter negotiation.

Table 1. Comparison of command inquiries and their corresponding responses

TYPE	TYPE A	TYPE B	TYPE F
Initiator	REQA or WPUB	REQA or WPUB	POLL_F
Target	ATQA	ATQB	SENSF_RES

Completion of the initialization phase clarifies the communication role (initiator/target), technical standard (e.g., NFC-A), and basic parameters (e.g., initial magnetic field strength), providing a standardized context for device activation, data transmission, and device suspension.

2.4. NFC working modes

The three essential NFC parameters—technology type (NFC-A/B/F), communication method (Active or Passive), and mode (POLL or LISTEN)—form different operating states: (1) NFC-A, POLL, Passive Communication: This mode indicates that NFC is operating in reader mode. (2) NFC-A, LISTEN, Passive Communication: In this case, NFC is functioning in card emulation mode. (3) NFC-F, POLL, Active Communication: This mode represents point-to-point communication between two devices [8]. The flexible application of NFC technology largely relies on the accurate

DOI: 10.54254/2755-2721/2025.GL28017

adaptation of its three core operating modes: reader/writer mode, card emulation mode, and peer-to-peer mode (see Figure 2). These three modes enable it to switch roles in different scenarios and meet diverse communication requirements.

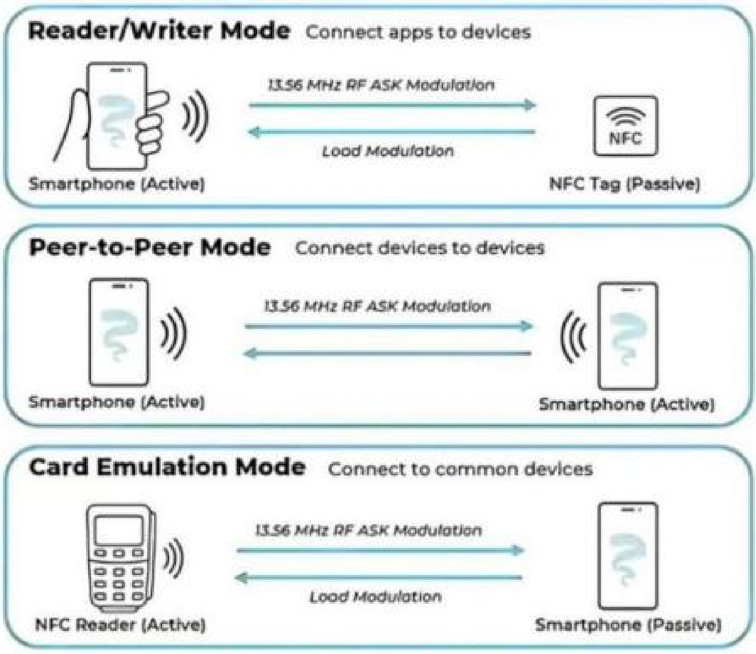

Figure 2. The three working modes of NFC

In Reader/Writer mode, the NFC device acts as an initiator to actively generate a 13.56 MHz radio frequency (RF) field, which provides energy for passive tags and transmits polling commands The device generates an alternating magnetic field through electromagnetic inductive coupling; once the passive tag acquires energy from the magnetic field, its internal chip is activated. The device can read the information stored in the tag or write data to it, with the communication distance controlled within 10 cm. Typical applications include product traceability (reading information from packaging tags) and smart poster interaction (touching to jump to associated content), with core characteristics embodied as "active power supply + one-way/bidirectional data interaction."

In Card Emulation mode, the device acts as a target to emulate the communication protocol and data format of a contactless card, passively responding to commands from an external reader. The magnetic field emitted by the reader provides energy for the device, and the device feeds back emulated card information by modulating the magnetic field to complete identity verification or transaction processes. This mode is divided into active emulation (e.g., a mobile phone emulating a bank card) and passive emulation (e.g., an NFC wristband emulating an access control card), widely used in scenarios such as mobile payments and transportation. It offers the advantages of "no physical card dependency + encryption security" [9].

In Peer-to-Peer mode, two NFC devices negotiate communication as equal roles (divided into initiator and target), realizing bidirectional interaction by alternately transmitting and receiving data. It supports a transmission rate (106 kbit/s-424 kbit/s), with a communication distance usually between 0 and 10 cm. No network configuration is required—connection can be established with a single touch. It is suitable for temporary data exchange scenarios such as file transfer and rapid device pairing, with core features of "touch-to-connect + bidirectional peer-to-peer communication". A common application is device pairing: when a mobile phone touches the NFC area of a Bluetooth

DOI: 10.54254/2755-2721/2025.GL28017

speaker, Bluetooth pairing can be completed automatically, eliminating the need for manual searching and password input.

An NFC device can dynamically switch modes according to application requirements. Through a protocol mechanism, the device can flexibly switch roles based on scenario needs, providing efficient adaptation capabilities for near-field communication. The exploration of new modes is also in progress. For example, the NFC 15 version (2025) further optimizes the operating experience of the three modes by extending the communication distance.

3. Application of NFC working principle technology

3.1. Daily life

NFC technology has significantly transformed everyday life, especially in mobile payments, transportation, and identity verification. For example, in mobile payments, consumers can simply bring their NFC-enabled smartphone close to a compatible POS terminal, completing the payment without the need for QR codes or cards. In this process, the smartphone operates in card emulation mode, mimicking the data of a bank card and communicating securely with the terminal. In urban transit, NFC has streamlined the travel experience. Many cities have adopted NFC-based systems for metro and bus fare collection. Commuters can tap their NFC-enabled transport cards or smartphones on readers to validate their tickets.

In locations such as residential communities and office buildings, NFC technology is often integrated into access control systems. Residents or employees can complete identity verification and unlock the access control by bringing their NFC access cards or NFC-enabled devices close to the access control card reader. The access card runs in Card Emulation Mode, and the card reader functions in Reader/Writer Mode; information interaction is carried out through specific communication protocols, ensuring that only authorized cards or devices can pass verification. This application not only addresses the issues of traditional keys being prone to loss and duplication but also facilitates unified management and modification for administrators, improving management efficiency.

3.2. Commercial sector

NFC technology offers an opportunity for the intelligent upgrading of the retail industry. Some brand stores embed NFC tags in product packaging or shelf labels; when consumers tap these tags with their NFC-enabled smartphones, they can quickly access detailed product information—such as origin, material, usage instructions, and user reviews. This breaks the limitations of delayed and incomplete information access in traditional shopping, reducing information asymmetry. For instance, certain beauty stores attach NFC tags to their products, allowing consumers to conveniently learn about product ingredients and suitable skin types while browsing. This not only reduces the need for human resources dedicated to product explanations but also helps consumers make purchasing decisions.

Furthermore, NFC technology plays a crucial role in logistics and supply chain management, enabling full traceability of the product circulation process. Enterprises attach NFC tags (which store data such as product production information, batch numbers, warehouse locations, and transportation records) to products. At each stage of logistics and transportation, staff can quickly read and update product information by tapping the tags with NFC readers, synchronizing the data to the system. This not only avoids human errors but also enables real-time monitoring of the

DOI: 10.54254/2755-2721/2025.GL28017

product's location and status, allowing for timely handling of any abnormal situations. For example, in the cold chain logistics of fresh food, NFC tags work in conjunction with temperature sensors to record real-time temperature changes during transportation. Managers can check this data at any time via the system, ensuring that food is transported within the specified temperature range and safeguarding food quality and safety.

4. NFC technology challenges

4.1. Technical problems

Certain inherent characteristics of NFC technology have become constraints on its development.

First, the communication distance is excessively short. The effective communication range of NFC technology is typically limited to within 10 centimeters. While this ensures communication security to a certain extent, it significantly restricts its application scenarios. In situations requiring data interaction over slightly longer distances—such as contactless payment in parking lots—NFC technology struggles to perform, being outperformed by other communication technologies like Bluetooth and RFID.

Second, the data transmission rate is relatively low. Currently, the mainstream transmission rate of NFC technology ranges from 106 kbit/s to 424 kbit/s. For applications involving large-volume data transmission—such as the rapid sharing of high-definition images and videos—its transmission efficiency fails to meet user demands. This leads users to prefer technologies with higher transmission rates like Wi-Fi Direct in such scenarios, thereby undermining NFC's competitiveness in the data transmission domain.

Third, its anti-interference capability is weak. Operating at a frequency of 13.56 MHz, NFC technology is susceptible to electromagnetic signal interference from surrounding electronic devices. Particularly in places with dense electronic equipment—such as shopping malls and subway stations—issues like communication interruptions and data transmission errors may occur, affecting user experience and the accuracy of data interaction.

4.2. Market environment

From the perspective of the market environment, the development of NFC technology faces challenges:

First, the intense market competition. In the field of short-range communication, besides NFC technology, there are various alternative technologies such as Bluetooth, Wi-Fi, and RFID. These technologies have already established relatively mature industrial ecosystems and technical accumulations. For instance, Bluetooth technology, with its higher transmission rate, is widely used in device interconnection; RFID technology, on the other hand, finds extensive applications in supply chains, inventory management, and related fields. To gain greater market recognition, NFC technology must continuously highlight its unique features and advantages in competition with these technologies.

Second, cost factors exert an influence. Although the cost of NFC chips has been decreasing, in terms of payment applications, compared with traditional QR code payment, integrating built-in NFC technology and procuring compatible devices both include additional costs. In terms of tag applications, the cost of NFC chips is also higher than that of RFID chips. This leads some manufacturers to weigh costs against functions during product design, and they may choose to abandon NFC integration, thereby limiting the popularization of NFC technology.

DOI: 10.54254/2755-2721/2025.GL28017

4.3. User experience

On one hand, security concerns persist. Although NFC technology adopts security measures such as encryption to ensure the security of data transmission, the increasing diversification of cybersecurity threats has left users still worried about the security of NFC application scenarios. For example, in payment scenarios, users remain hesitant about using NFC payments, fearing that if their devices are stolen, resulting in unauthorized transactions. In access control management scenarios, users also worry that if NFC cards are maliciously duplicated, unauthorized individuals may use the duplicates to illegally enter controlled areas. Undoubtedly, these concerns exacerbate users' distrust in the security performance of NFC technology, making some users adopt a cautious attitude toward NFC and related applications. On the other hand, device compatibility issues occur from time to time. NFC devices of different brands and models may differ in aspects such as communication protocols and frequencies, leading to failed or unstable communication between devices. For example, NFC payment failures may occur between a smartphone of a certain brand and a POS machine of another brand. This not only impairs user experience but also brings unnecessary troubles to merchants.

5. NFC future development trends and optimization directions

NFC technology is evolving in three main directions for optimization: (1) Adaptive extension of communication distance: By improving RF circuit design and signal modulation algorithms, NFC's effective communication range has been extended from the traditional 10 cm to approximately 30 cm. This adjustment supports moderate-distance interactions while maintaining secure data transmission through dynamic adjustment of magnetic field strength,, mitigating the risk of signal interception.

(1) Low-power, scenario-specific design: Optimizations in chip architecture (e.g., adopting the RISC-V reduced instruction set) and sleep-wake mechanisms have reduced NFC module standby power consumption by over 60%. This improvement eliminates the need for frequent battery replacements in NFC-enabled devices, significantly lowering operational and maintenance costs of IoT devices.

(2) Enhanced collision detection: with multiple NFC cards often embedded in smartphones, "card confusion" can prevent readers from correctly identifying the intended card. Future optimizations include hardware-level isolation (e.g., integrating multiple sets of RF front-ends) or strict software timing control (assigning unique response time slots to each card). Meanwhile, dynamic priority scheduling ensures that only the target card responds within a specified distance.

(3) Cross-technology integration: NFC is increasingly integrated with emerging technologies to form complementary ecosystems. For example, in smart home systems, NFC tags can be attached to refrigerator doors. When users tap the tag with their smartphones, near-field communication activates the Bluetooth module built into the refrigerator, synchronizing real-time data on food freshness periods to a mobile app—enabling the minimalist "tap-and-interact" operation. In supply chain management, NFC tags are mapped to blockchain certification systems, addressing the trust issue of easy tampering with traditional tags from a technical perspective. NFC technology can also integrate with other existing communication technologies: Leveraging its ability to establish connections quickly, NFC can directly transfer WiFi local area network (LAN) passwords after device pairing, enabling efficient collaboration between NFC and WiFi while eliminating the tedious step of manual password entry [10]. Additionally, by utilizing the interactive advantages of NFC's peer-to-peer mode and the instant connection capability of two NFC devices, the complex process of

DOI: 10.54254/2755-2721/2025.GL28017

traditional Bluetooth pairing can be replaced, achieving seamless integration between NFC and Bluetooth technologies [11].

(4) Reducing the usage threshold: To deliver a more user-friendly experience, terminal manufacturers are implementing "seamless activation" of NFC functions through system-level optimization: Smartphones keep the NFC module enabled by default, and when a tag is tapped, the device automatically identifies the technology type and launches the corresponding application—eliminating the need for users to manually enable the function or select an app. This "zero-learning-cost" design is particularly suitable for elderly users and digitally vulnerable groups.

6. Conclusion

This paper systematically investigates NFC technology, encompassing its technical fundamentals, application scenarios, practical challenges, and future directions: At the technical level, this paper elaborates on NFC's core attributes, including 13.56 MHz electromagnetic inductive coupling principle, active and passive communication modes, and the communication lifecycle from initialization to suspension. The three operating modes enable flexible adaption to diverse application scenarios, laying a theoretical foundation for understanding NFC's technical applications. In practical applications, NFC has been widely integrated into daily life, such as mobile payments, transportation, and access control, demonstrating convenience and efficiency. However, limitations remians: mobile payments face potential security risks if devices are lost or stolen, and NFC tags are generally more expensive than RFID tags, restricting adoption in certain scenarios.

NFC development continues to face multiple challenges. First, the technology itself has inherent limitations, such as short communication distance, low transmission rate, and weak anti-interference capability. Second, at the market level, it must compete with other short-range communication technologies like Bluetooth and Wi-Fi; furthermore, the additional costs associated with device integration and tag usage have restricted the adoption willingness of some manufacturers. Third, during usage, compatibility issues between protocols of different devices further hinder the popularization of NFC technology.

Overall, NFC technology is entering an early but promising stage. With ongoing advancements—such as extended communication distance, reduced module power consumption through RF circuit optimization, and enhanced application scenarios like IoT-enabled smart homes and blockchain-linked supply chains—NFC is expected to gradually overcome its current bottlenecks. Future development will expand its application from mobile payments and transportation to industrial interconnection and smart environments, providing consumers with secure, convenient experiences while supporting the digital transformation of industries.

References

[1] nfc-tools. (2015). NFC devices. https: //nfc-tools.github.io/resources/standards/iso14443/

[2] Zhao, F.L. & Yang, W.M. (2008) Mobile Applications Based on NFC Technology. China New Communications, (1): 22-25.

[3] Li, G. (2018) Exploration of RFID Communication and NFC Technology Applications. China New Communications, 20(14): 84.

[4] Zhang, X.F., Zhou, Z.M., Wang, Y.G. & Wan, Y. (2019) Principles and Applications of NFC Technology. Science & Technology Review, (5): 69-70+75. https: //doi.org/10.19392/j.cnki.1671-7341.201905060.

[5] Liu, A. (2014) Security Analysis and Implementation of WLAN Access Protocol Based on NFC Authentication (Master's Thesis, Tianjin University).

DOI: 10.54254/2755-2721/2025.GL28017

[6] Yang, J. (2009) NFC Technology: Applications, Standards Progress, and Testing. Modern Telecommunication Technology, 39(10): 1-5.
[7] Pan, X.F. & Mao, M. (2013) Study on the Underlying Principles of NFC Near Field Communication Technology. Science & Industry, 13(5): 120-122.
[8] CSDN. (2025-07-18) A Detailed Explanation of NFC Technology. https: //blog.csdn.net/m0_50146396/article/details/149432487
[9] Liu, H. (2010) Exploration of Near Field Communication Applications Based on NFC Technology. China Radio, (12): 34-35.
[10] Jiao, J.J. (2017) Wi-Fi Transmission Connection Scheme for Near Field Communication Based on NFC Technology. Electronic Technology & Software Engineering, (18): 39. https: //doi.org/10.20109/j.cnki.etse.2017.18.026.
[11] Wang, W.J., Chen, J.Y. & Zhu, J. (2013) NFC Technology and Its Application Prospects. Communications and Information Technology, (6): 67-69.