Chapter

Near-Field Communications (NFC) for Wireless Power Transfer (WPT): An Overview

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Abstract

Recent advancements in the semiconductor integrated circuits and functional materials technologies have accelerated the demand of electronic and biomedical devices such as internet of things (IoT) and wearable sensors, which have low power consumption, miniature size and high data transfer efficiency. Wireless power transfer (WPT) has become the alternative solution to current electronic devices that rely on bulky batteries to supply the power and energy. Near Field Communication (NFC) technology is extensively used for wireless power transfer, where devices communicate through inductive coupling via induced magnetic fields between transmit and receive coils (loop antennas). Thin NFC sheets made of soft magnetic materials are inserted between antennas and metal case of wireless gadgets, such as mobile phones or tablets, to reduce the degradation of antenna gain and radiation efficiency due to generation of eddy currents. To enhance the efficiency of wireless power transfer, magnetic materials with superb properties such as high permeability, low magnetic loss and high resistivity are highly desirable. In this chapter, we will provide an overview of the current state of the art, recent progress and future directions in NFC based wireless power transfer, with the special focus on near field communications operating at 13.56 MHz.

Keywords: wireless power transfer, near field communication, inductive coupling, ferrites, power transfer efficiency

1. Introduction

At the start of 21st century, an emerging technology known as near field communication (NFC) was standardized in 2004 that gradually changed the consumer electronics market and facilitated the electronic transactions, mobile payments, data transfer, etc. NFC was first reported by joint venture of Sony and NXP Semiconductors in 2002 [1]. Since then, NFC has become a popular and evolving technology over the past decade and is being incorporated into more and more aspects of our daily lives than ever before. The NFC Forum was founded in 2004 by joint venture of Sony, Philip and Nokia to facilitate the enhancement of this NFC technology. Nokia 6131 was the first NFC enabled device which was launched in 2006 [2, 3]. In 2006, NFC technology was utilized to print disabled patrons in the libraries with enabled disables patrons [3]. In 2011, University of Bristol's M-Biblio started NFC enabled QR codes for students to utilize library resources. Samsung launched first NFC enabled android (Samsung NEXUS S) phone in 2010 [2].

Area	Growth (2018–2019)
NFC interactions	27%
NFC activators	22%
NFC reach	50%
No. of interactions per active NFC object	6%

Table 1.
NFC usage growth evolution from 2018 to 2019 [6].

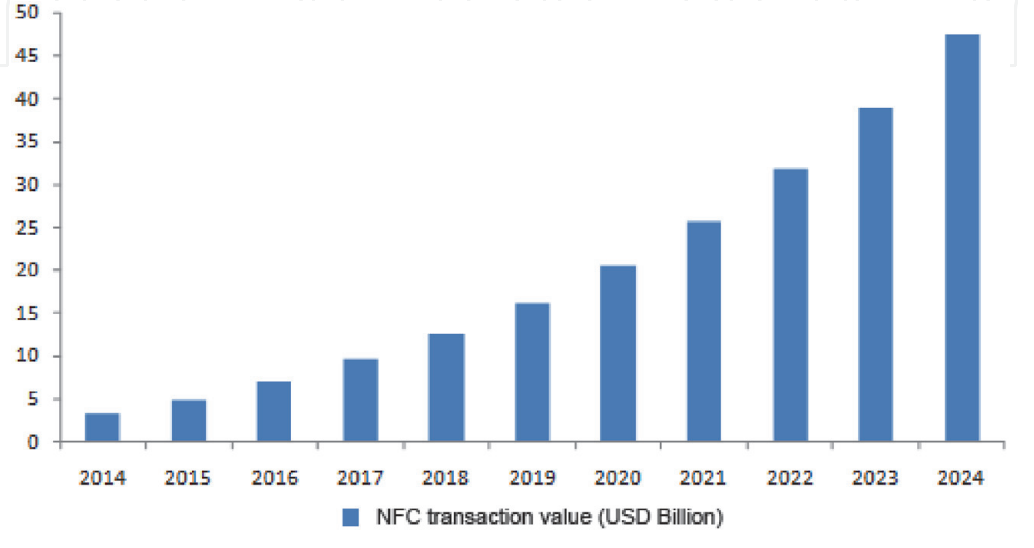

Figure 1.
Evolution of NFC transactions values between years 2014 and 2024 [7].

In 2011, PayPass functionality was launched for RIM's (Research in Motion/Black-Berry Limited) master card. Some of the early applications launched are, Samsung TecTile Programmable NFC tags in 2012, Sony's Xperia smart tags, NFC enable Smart Objects in 2011, NFriendConnector [4], Wallet in 2011, the joint venture of Google At&T, Verizon and T-mobile in 2012 to use mobile wallets [5]. NFC enabled functionality has been added to all new Apple products starting from iPhone XS (Apple Pay). **Table 1** shows NFC usage growth evolution in 2018–2019 [6]. From 2010 onward, new interesting applications of NFC was launched every year in communication sector by technology giants such as Google, Apple, Samsung, NXP, etc. The industry players are constantly introducing new advances and improved technologies in NFC enabled devices which have taken global market to 4.80 billion USD in 2015 and expected to reach 47.42 USD billion by 2024. **Figure 1** shows projected NFC transactions value from 2014 to 2024 [7].

2. Near field communication magnetism – NFC and RFID

NFC enables a subset of the Radio Frequency Identification (RFID) technology that works over a wide range of frequencies with three distinct bands — low, high, and ultra-high frequencies. The main difference between NFC and RFID technologies is their operating range. RFID operates in meters range, whereas NFC typically operates within three to five centimeters. All RFID's operate based on the same principle of one-way data transfer from the tag to the receiver and there is no power transfer the other way around [8, 9]. RFID is one of the oldest technologies that

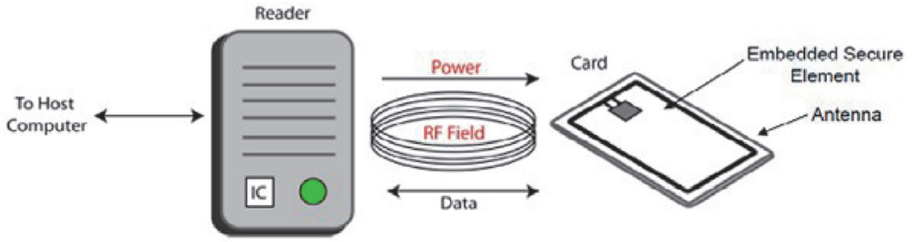

Figure 2.
Contactless transfer of data/signal between reader and tag at 13.56 MHz using NFC technology [16].

utilize near field magnetic communication. In 1960, an electronic articles surveillance system (EAS) was the first commercial application of RFID, which utilized one-bit tag and was used to detect the presence or absence of the tag. Between 1970 to 1980, more work on RFID systems was conducted utilizing microwave and inductive systems and, in late 1970s, the size reduction of RFID's was accomplished using low-power complementary metal-oxide semiconductors (CMOS) logic circuits. After 1980, RFID applications became widespread such as tracking for animals, business, electronic toll collection, and automation, which was rapidly expanded with the development of personal computer (PC) technology. In 1990s, electronic toll collection systems were the first successful application of RFID technology worldwide [10]. Presently, RFID is utilized in various commercial areas such as automobile, agriculture, transport, medical system, payment cards, supply chain, tracking, identification application and short range interactions in the Internet of Things (IoT) [11, 12]. However, communications which require initialization at both ends (e.g., Peer-to-peer communications as discussed below) cannot be supported by RFID technology. NFC is a great solution to this shortcoming of RFID, which support peer-to-peer communications also.

NFC is a short-range half duplex communication technology which provide secure communication between devices in near field region. Near field communication, is a technology that allows two devices in close range to securely exchange data wirelessly. NFC is a short-range (< 10 cm) wireless connectivity technology that operates at high frequency (HF) range with low bandwidth of radio waves, mainly at 13.56 MHz [13]. NFC comprises of three basic components - an antenna, a reader, and a tag. A reader (transmitter) sends a signal at the standard NFC frequency of 13.56 MHz and the tag antenna receives and processes the interrogation signal, and responds with requested information back to the reader that is then interpreted and stored as the data within few centimeters at 13.56 MHz [14, 15]. **Figure 2** shows the transfer of data between reader and tag (card) at 13.56 MHz based on NFC technology [16].

From 2004 onwards, NFC has been utilized in various applications. Nokia, Apple/Google/Samsung pay transactions, wireless energy/data transmission and wireless key card entry are a few popular examples of this technology [17]. Though NFC tag is passive in nature, NFC can transfer data both ways. NFC technology supports varying data transmission rates, typical three rates are - 106, 212 and 424 Kbps [18]. There is another 848 Kbps rate also, but it is not in compliant with NFC standards.

3. Basic principle of NFC

NFC works based on the principle of near field magnetic communication. This principle of inductive coupling is applied to all communications based on near field magnetism between transmitting and receiving devices. **Figure 3** shows the

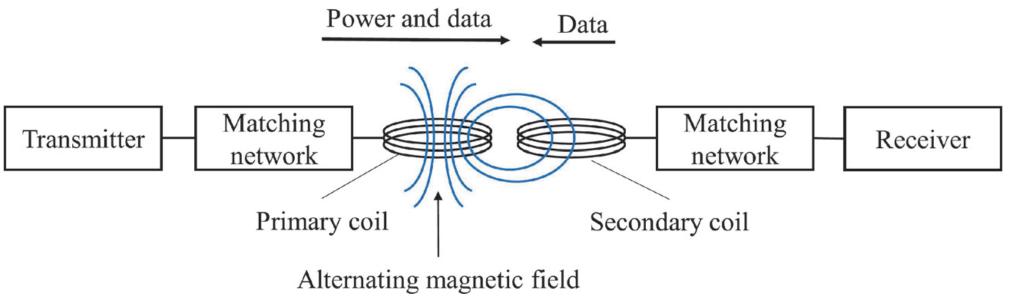

Figure 3.
Inductive coupling between transmitter and receiver coils [9].

simplified concept of inductive coupling. When a primary coil generates alternating magnetic field, secondary coil which is placed in the vicinity of the primary coil inductively coupled with the primary coil and generates induced alternating magnetic field according to the Faraday's law. This is the basic principle in transferring power wirelessly between the devices in near field region. The above stated principle also applied on RFID systems that are based on inductive coupling. Even though, there are some differences in other components such as network system and protocols between NFC and general RFID systems.

3.1 Inductive coiled system

The inductive coupled NFC system can be modeled by using expressions of self-inductance, mutual inductance and resistances [19]. A generalized analytical expression for calculation of self-inductance of circular or rectangular shaped coil is explained below. **Figure 4** shows a representation of single turn circular coil while illustrating the magnetic field pattern surrounding two circular coils [20].

The inductance, L_0, for a single turn circular coil can be given by Eq. (1) as seen below [21]:

$$L_0 = \mu_0 r ln\left(\frac{2r}{d}\right) \tag{1}$$

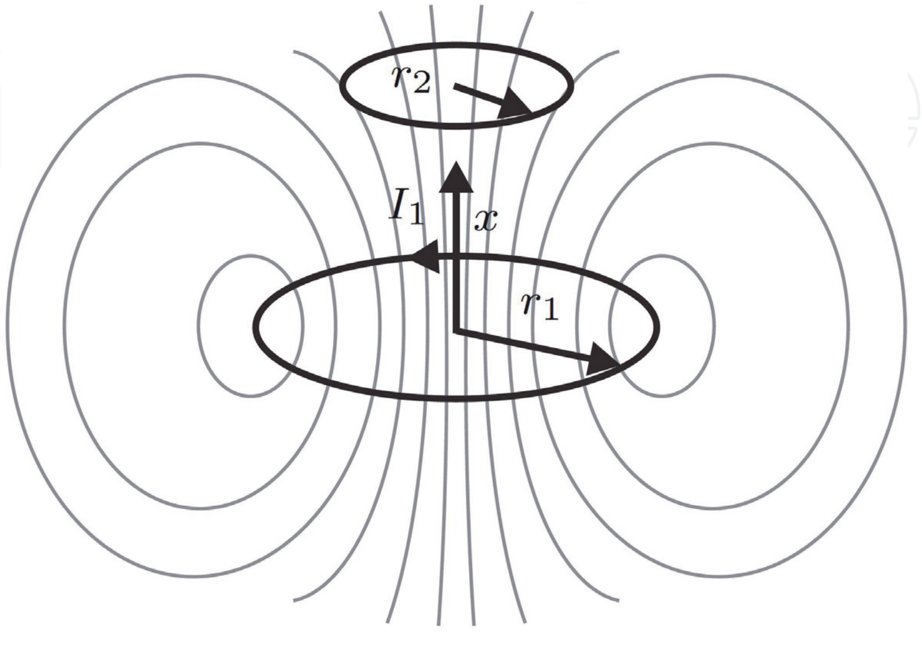

Figure 4.
Depiction of two magnetic inductive coil system (primary and secondary) [20].

Where μ_0 is permeability of free space, r is radius of the coil and d is the diameter of the wire. The single turn coil inductance can be utilized to calculate inductance of multiturn coil, L and is given by Eq. (2).

$$L = N^2 L_0 \tag{2}$$

$$L = N^2 \mu_0 r ln\left(\frac{2r}{d}\right) \tag{3}$$

where N is number of turns in a coil. This equation provides appropriate approximation for a cylindrical inductor, but for the case of spiral inductor this equation provides general parameter studies. A detailed study for calculation of inductance of spiral inductors is provided by S. Alturi et al. (2004) [22].

Another important figure of merit is mutual inductance of two coupled coils. The mutual inductance between the two coils can be expressed in Eq. (4).

$$M = \frac{\mu \pi N_1 N_2 r_1^2 r_2^2}{2\sqrt{\left(r_1^2 + x^2\right)^3}} \tag{4}$$

where, N_1 and N_2 are the number of turns in first and second coil, respectively, r_1 and r_2 are the radius of first and second coil, respectively, x is the axial separation and μ is the permeability. Eq. (4) is valid only for $r_2 < r_1 \ll x$, i.e., the magnetic field generated by current I_1 in first coil should be homogeneous in the mutually bounded area of the 2nd coil. Detailed calculation for mutual inductance for cylindrical coils is presented in [23].

Also, the coupling factor between 2 coils can be expressed in Eq. (5).

$$k = \frac{M}{\sqrt{L_1 L_2}} \tag{5}$$

Where k is coupling factor and lies between 0 and 1, L_1 and L_2 are inductance of first and second coil, respectively.

In case of complex geometries, numerical methods can be applied to calculate inductances of complex coil systems [24].

3.2 Wireless power transfer (WPT) efficiency

Power transfer efficiency between loop antennas for NFC system is expressed as the figure of merit that depends on inductive coupling. As NFC operates at small distance range between transmitter and receiver antennas, its efficiency depends on coupling between the antennas for wireless power transfer [25]. **Figure 5** shows schematic of two mutual magnetic coupled coil antennas for the WPT system [27]. To improve the power efficiency, an impedance matching on both coil antennas (receiver and transmitter) is required. In case of magnetic coupling between receiver and transmitter coil antennas, eddy currents are generated due to alternating magnetic field. This cause a shift of resonant peaks of the input impedance, which shifts resonance frequency of maximum power transfer. Insertion of a high permeability soft magnetic ferrite sheet between coil antenna and metal conductor shifts the frequency back to original resonance frequency [26]. When both circuits resonate at peak frequency, maximum transfer of power is achieved. **Figure 6** depicts the simplified equivalent circuit model of wireless power transfer systems [26].

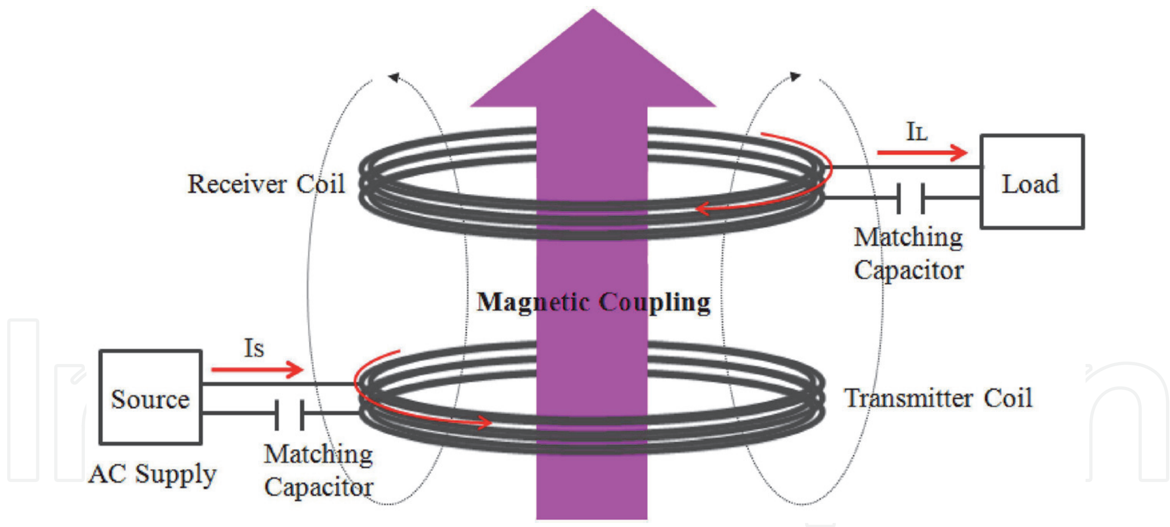

Figure 5.
Schematic drawing of mutual magnetic coupled coils for wireless power transfer systems [26].

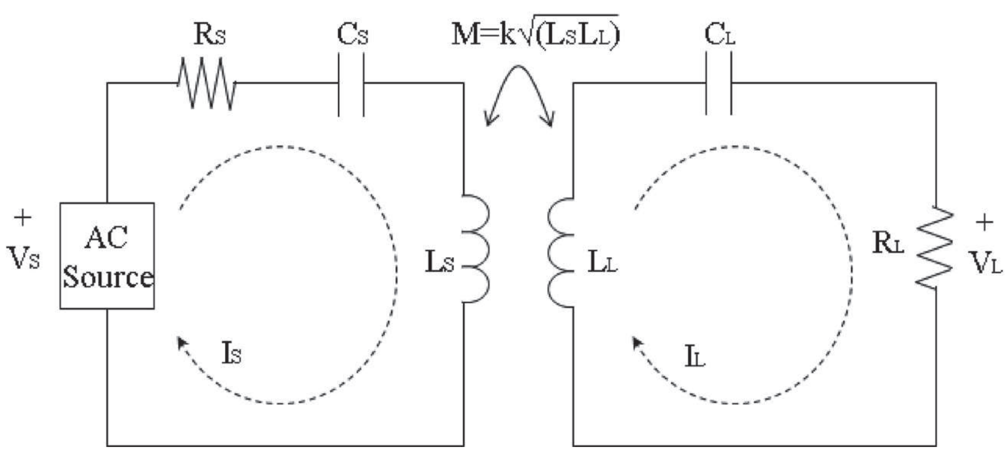

Figure 6.
A simplified equivalent circuit model of wireless power transfer systems [27].

The resonance frequency ω for coil antenna is given by,

$$\omega = \frac{1}{\sqrt{L_s C_s}} = \frac{1}{\sqrt{L_L C_L}} \tag{6}$$

Base on Kirchhoff voltage law and above circuit diagram, V_s can be calculated as [28]:

$$\begin{bmatrix} j\omega L_s + \frac{1}{jwC_s} + R_s & j\omega M \\ j\omega M & j\omega L_L + \frac{1}{j\omega C_L} + R_L \end{bmatrix} \begin{bmatrix} I_s \\ I_L \end{bmatrix} = \begin{bmatrix} V_s \\ 0 \end{bmatrix} \tag{7}$$

From Eq. (7), V_s can be calculated [29]:

$$V_s = I_s\left(R_s + j\omega L_s + \left(\frac{1}{j\omega C_s}\right)\right) - I_L(j\omega M) \tag{8}$$

$$0 = I_L\left(j\omega L_L + \left(\frac{1}{j\omega C_L}\right) + R_L\right) - I_s(j\omega M) \tag{9}$$

Using Eq. (8) and (9):

$$I_L = I_s\left(\frac{j\omega M}{j\omega L_L + \left(\frac{1}{j\omega C_L} + R_L\right)}\right) \tag{10}$$

Substituting Eq. (10) into Eq. (8):

$$V_s = I_s\left(R_s + j\omega L_s + \left(\frac{1}{j\omega C_s}\right)\right) - I_s\left(\frac{j\omega M}{j\omega L_L + \left(\frac{1}{j\omega C_L} + R_L\right)}\right)(j\omega M) \tag{11}$$

The input impedance is calculated based on the simplified equivalent circuit model. The input impedance is given by [26]:

$$Z_s = \frac{V_s}{I_s} = \frac{((j\omega C_s)R_s + 1 - \omega^2 L_s C_s)((j\omega C_L)R_L + 1 - \omega^2 L_L C_L) - \omega^4 M^2 C_s C_L}{j\omega C_s((j\omega C_L)R_L + 1 - \omega^2 L_L C_L)} \tag{12}$$

The power transfer efficiency is given by ratio of output power to the input power:

$$\eta = \frac{P_{Out}}{P_{in}} = \frac{I_L^2 R_L}{I_s^2 Z_s} \tag{13}$$

For resonance coupling system, assuming $C = C_s = C_{L.}$

By substituting Eq. (10)–(12) in Eq. (13), the effective power efficiency is calculated as:

$$\eta = \left(\frac{j\omega M}{j\omega L_L + \left(\frac{1}{j\omega C_L} + R_L\right)}\right)^2 \frac{R_L}{\left(\left(R_s + j\omega L_s + \left(\frac{1}{j\omega C_s}\right) + \left(\frac{\omega^2 M^2}{j\omega L_L + \left(\frac{1}{j\omega C_L} + R_L\right)}\right)\right)\right)} \tag{14}$$

where, M is Mutual inductance between the coil antennas, L_s and L_L are the inductance of transmitter and receiver coils, C_s and C_L are matching capacitor for transmitter and receiver coils, R_s and R_L are internal resistance and load resistance of the coils and V_s and V_L are source and load voltages.

The transferred power is maximum at resonance frequency when load current in the circuit becomes maximum, at a given resonance frequency, Eq. (15) describes the condition for maximum power transfer efficiency [29]:

$$M^2 = \frac{R_L^2}{\omega_0^2} \tag{15}$$

The wireless power transfer efficiency using inductive coupling can be greater than 90% within a limited transmission range. During the last decade, methods such as magnetic resonance coupling for WPT have been widely studied by researchers to increase the efficiency of power transmission with greater distance range. Two-loop and four-loop coil systems were studied for magnetic resonance coupling based WPT system [30]. In order to achieve maximum power transfer efficiency, several studies have been done such as loop to coil coupling manipulation [29], automated impedance matching [31], adaptive frequency tuning [32], circuit structure manipulation [33], improving WPT for future portable consumer electronics using large transmitter coil system [34] and improving efficiency by four-coil system for deep brain simulation [35]. There are studies, which focused on misalignment between receiver and transmitter coil for applications such as wireless EV charging system [36] and wireless mobile phone charging system [37, 38]. With the rapid development in consumer electronics, there is a substantial increase in applications of NFC based wireless power transfer technology.

4. Eddy currents challenge: role of ferrite materials in NFC

As NFC technology relies on generated mutual inductance between the transmit and receive coil antennas, the amount of magnetic flux between them should be maximized to induce more current, thus increasing data transmission range. However, by placing a NFC tag on a metal surface, the efficiency of data transmission is greatly suppressed due to the generation of eddy currents within the metal surface [39]. To increase the efficiency and range while minimizing the losses due to eddy currents, a soft magnetic ferrite sheet can be inserted between the metal case and the antenna. **Figure 7(a)** illustrates how the magnetic field generates in NFC communication due to nearby conductive surface/plate, and **Figure 7(b)** shows the magnetic field produced when NFC area is shielded by a ferrite sheet from a conductive surface [40]. One can see the shielding effects due to insertion of ferrite sheet [40]. To be amenable to NFC, the ferrite sheets should have high permeability and low magnetic loss to concentrate the magnetic flux generated between the transmit and receive coils (antennas) [39, 41]. Ni-Zn ferrites and Mn-Zn ferrites are the most widely used soft magnetic materials for the preparation of these NFC ferrite sheets at high frequencies. Ni-Zn ferrites have exhibited higher operating frequency range up to 100 MHz as compared to Mn-Zn ferrites (a few MHz), which limits the use of Mn-Zn ferrites in NFC devices. Mn-Zn ferrites have been used in mini dc-dc converters, inductors and power inductors due to their high saturation induction and low losses [42]. For NFC applications, Ni-Zn ferrites offer better suited properties because of its high resistivity, high permeability, low magnetic loss, high operation frequency, and chemical stability. In particular, the high

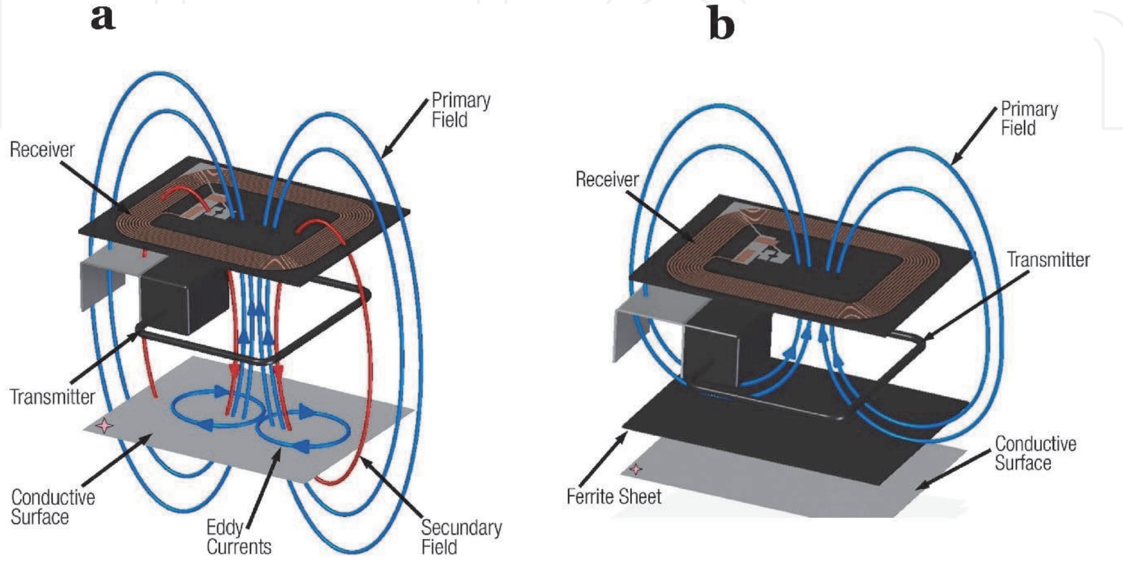

Figure 7.
(a) Eddy currents generated in NFC communication area due to conductive plate in vicinity; (b) magnetic field generated in NFC communication area with an incorporated ferrite sheet shielding [40].

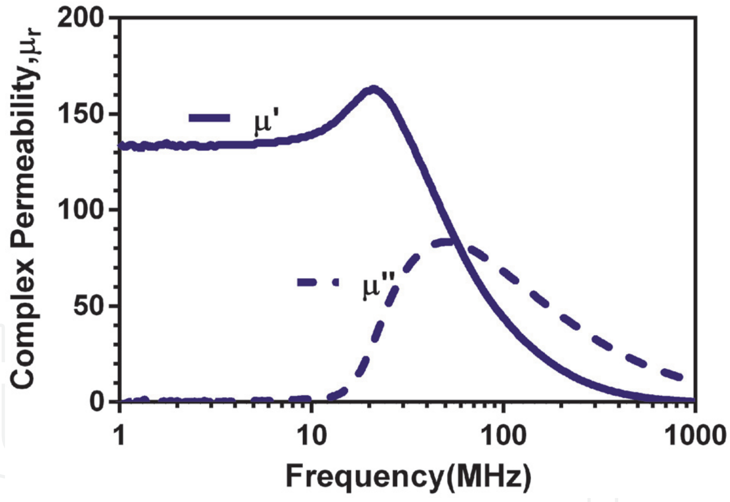

Figure 8.
A typical representation of relative permeability versus frequency of a ferrite sheet [45].

permeability and low magnetic loss of Ni-Zn ferrite sheets help to concentrate more magnetic flux and reduce eddy currents via magnetic shielding [42, 43].

To enhance the performance of NFC systems, the employment of high permeability and low loss magnetic sheets is highly desirable. The magnetic permeability and loss properties of Ni-Zn ferrites can be tailored by making strategic changes in crystallography, morphology and microstructure of the material. The relation between the complex relative permeability and frequency is termed as permeability dispersion. The frequency dependent relative permeability is given by Eq. (16) [44],

$$\mu_r = \mu' - j\mu'' \tag{16}$$

where μ_r is the ratio of the permeability of the material versus that of the free space (μ_0). μ' and μ'' are real and imaginary parts of the relative permeability, respectively.

The magnetic loss tangent is the ratio between the real and imaginary parts given by Eq. (17):

$$tan\ \delta_m = \frac{\mu''}{\mu'} \tag{17}$$

Figure 8 shows a typical relative permeability spectra of flexible ferrite sheet [45]. To achieve high signal transmission efficiency between NFC devices and increase the range of transmission, the relative permeability (μ') should be greater than 100 and the loss tangent ($tan\ \delta_m$) should be less than 0.05 at the standardized NFC operation frequency of 13.56 MHz [39]. Both μ' and μ'' of ferrite materials are greatly affected by the composition, microstructure and morphology, which are also quite sensitive to the processing parameters [46]. The key to achieve high performance ferrites for the targeted NFC applications is to tailor and optimize their synthesis process parameters. There are several different ways to synthesize Ni-Zn ferrites such as sol–gel method, citrate precursor method, hydrothermal synthesis and solid-state synthesis methods [42].

5. NFC modes of communication

NFC devices can communicate in either one of the two modes: active and passive mode. These modes determine how two NFC-enabled devices talk to each other. The distinction between modes depends on whether, a device generates its own RF field or used power from another device. In communication, initiator is the device that starts the communication, and target is the device that receives the signal from initiator. The main differences between main properties of passive technologies (NFC, Chipless RFID and UHF RFID) and active technologies (Bluetooth and Zigbee) are summarized in **Table 2** [47–49].

5.1 Active mode

In active mode, both NFC devices (initiator and target) send and receive data signals actively by using alternate RF (Radio frequency) field. Both NFC devices are self-powered and does not require to send power to target to perform the task, for example, devices such as smartphone or a self-powered tag. In active mode, the data

Feature	NFC	Bluetooth	UHF RFID	Chipless RFID	Zigbee
Read Range	1-2 cm for proximity cards with energy harvesting, 0.5 m for vicinity cards	10–100 m	Up to 15 m with inlay tags with 2 dBm read IC sensitivity, 3 m for UHF sensors with −9 dBm read sensitivity, 30 m BAP	<50 cm frequency coded and 2–3 m for time coded UWB	10–100 m
Memory capacity	<64 Kbytes	Several Kbytes depending on microcontroller	<64 Kbytes	<40 bytes	250–400 Kbytes
Energy source	Passive or semi-passive	Active	Passive or semi-passive	Passive	Active
Cost	Low	Low	Low	Moderate	Low
Universal frequency regulation	Yes	Yes	No	No	Yes
Security	High	Low	High	High	Low
Setup time	Less than 0.1 s	Approx. 6 s	Less than 0.1 s	—	Approx. 0.5 s
ID rewritable	Yes	Yes	Yes	No	Yes
Energy harvesting	Approx. 10 mW	No	Few μW	No	No
Reader cost	Low	Low	High	High	Low
Spectrum	13.56 MHz	2.4 GHz	433 MHz, 860–960 MHz	2.4–5.8 GHz	2.4 GHz (Globally), 915 MHz (as Z-Waves in U.S.) and 868 MHz (Europe)
Usability	Easy, human centric	Moderate, data centric	Easy, Data and human centric	Easy, Data and human centric	Easy, data centric

Table 2.
Comparison between different wireless technologies [47–49].

is sent between two devices using amplitude shift keying (ASK) i.e., the base RF field signal (13.56 MHz) is modulated with data using coding schemes (Miller and Manchester Coding). Data transfer rates are higher in this mode and it can work well at longer distances [50, 51].

5.2 Passive mode

In passive mode, the initiator sends the RF field to power the target. In turn, target used the RF field and sends back the stored data via a process called load modulation (Manchester coding) [52]. It is the most common mode for NFC, as it requires no battery and it is less expensive [53].

Three different combinations of communications are possible when two NFC device communicates with each other wirelessly, active-active, active-passive and passive-active. These are listed in **Table 3** [53].

While working in active and passive modes, the NFC devices perform different operation during communication. This means NFC device 1(initiator) must send signal first to NFC device 2 (target) to get the response back from device 2 (target). It is not possible for NFC device 2 (Target) to send data to device 1 without receiving any initial signal. All the possible interaction styles of NFC devices are listed in **Table 4** [14].

According to the NFC forum's device requirement, a device must have the functionality i.e., device needs to operate in reader/writer mode and in peer mode in order to be NFC-compliant [54]. i.e., a device must behave as an initiator during passive communication and an initiator or target during active communication. Initially, the NFC operating frequency of 13.56 MHz was unregulated. In 2004, NFC forum was established to standardize the tags and their operating protocols. There were three tasks standardized by the NFC Forum: including transferring power from a NFC device to a NFC tag, sending information from a NFC device to a NFC tag via signal modulation, and sensing the modulation by the load created on the NFC tag while performing load modulation to receive information from a NFC device. These three operation modes were designated by the NFC forum as reader/writer, peer-to-peer, and card emulation communications, as depicted in **Figure 9**. These are three main modes, under which a NFC device can operate [14]:

Device 1	Device 2	RF field generation
Active	Active	The RF field is generated by both devices
Active	Passive	The RF field is generated by device 1 only
Passive	Active	The RF field is generated by device 2 only

Table 3.
Various possible communication arrangements between two NFC devices [53].

Initiator device	Target device
NFC mobile	NFC tag
NFC mobile	NFC mobile
NFC reader	NFC mobile

Table 4.
Various possible interaction styles of NFC devices [14].

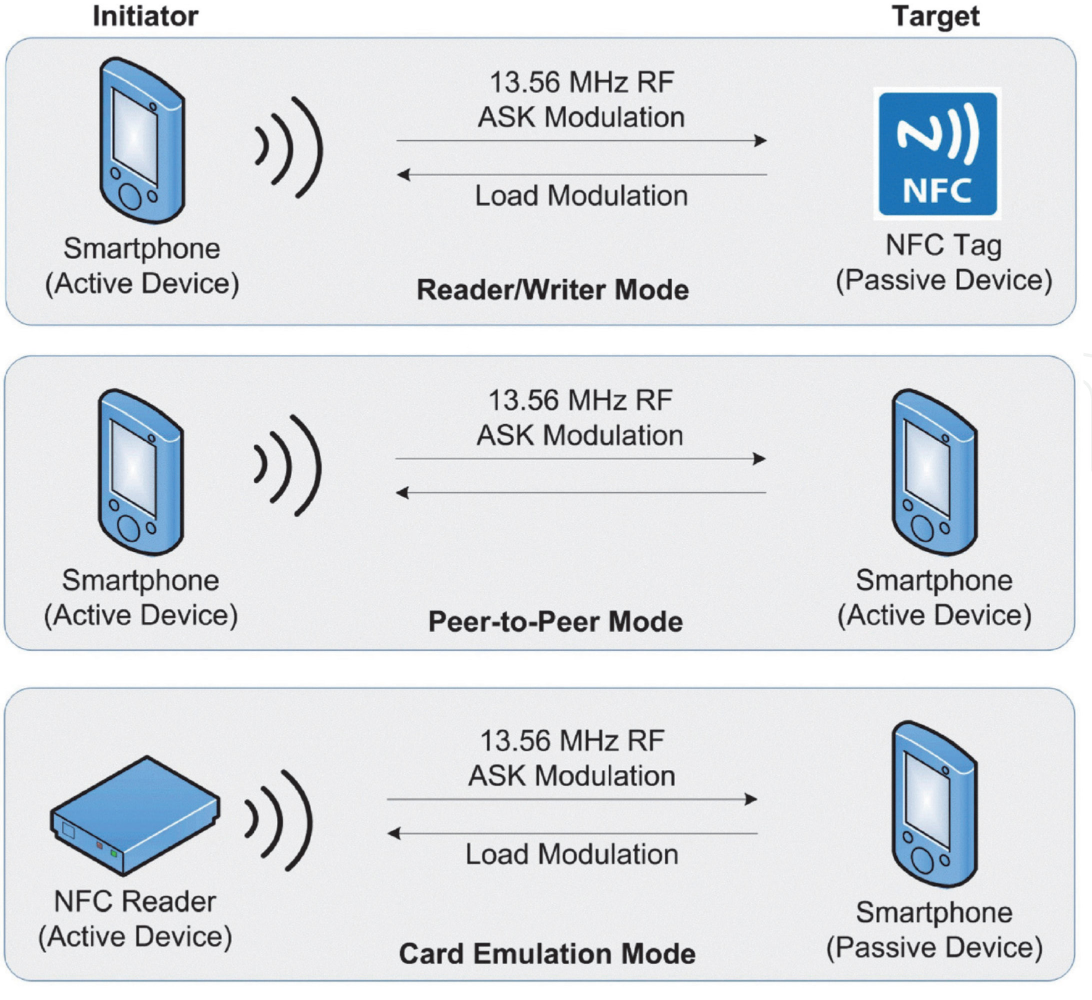

Figure 9.
Three different communication modes of a NFC device [14].

5.3 Reader/writer mode

In reader/writer mode, the device must be able to read and write with different types of NFC tags. This mode enables one NFC mobile to exchange data with one NFC tag. In reader/writer mode, most NFC devices act as readers and works in active mode to read the content of tag, such as contactless smart cards and RFID tags. In order to interact with tag appropriately, the device needs to detect the correct tag type. For that, the NFC device relies on an anticollision algorithm to select one tag when device comes across two tags simultaneously. An NFC device also works in writer mode, it can write data to the tags having writer application, such as TagWriter [55, 56]. In reader/writer mode, the NFC devices are compliant with ISO/IEC 14443A/B or Felica schemes tag types [14]. Some of the applications of reader/writer mode are smart posters, remote shopping, remote marketing, and so on [18].

5.4 Peer to peer mode

In peer-to-peer mode, two NFC specific devices can exchange data such as, pairing Bluetooth devices or WiFi link set-up, exchange business cards or text messages. This mode is standardized on the ISO/IEC 18092 NFCIP-1 standards. Both the devices operate in active mode during the communication and data is sent over a bi-directional half duplex channel, which means second device can only transmit data once first NFC device finish the transmission [14].

5.5 Card emulation mode

In card emulation mode, a NFC device behaves as an external reader traditional contactless smart card. This enables contactless payments through credit cards, debit cards, loyalty cards, etc. by using NFC device without changing the existing infrastructure. For example, NFC enabled mobile device can even store multiple contactless smart card applications in one phone. Card emulation mode supports ISO/IEC 14443 Type A and B, and Felica standards [14].

6. NFC tags

In an NFC system, there is always an element which functions as the receptor in passive mode, such as NFC tag. NFC tag, also known as the smart tag or information tag, is a small, printed circuit which act as a bit of storage memory along with a radio chip attached to an antenna [18]. It works in a passive mode, during which it does not have its own power source but uses power from the NFC device that communicates with it via magnetic induction. NFC tags have a few inches of working distance, NFC device must be very close to read the tag. NFC tags are used for a variety of applications in our day-to-day life, such as payments, launching websites, virtual visiting cards, lock/unlock doors, pet animals tagging, share photos, videos, and other information, etc. To ensure interoperability, a classification has been established for NFC tags by NFC-Forum that provides necessary specifications between different tag providers and the manufacturers of devices. Currently, there are five different types of NFC tags, depending on storage capacity, data transfer rate and read/write ability [1].

6.1 Type 1 NFC tags

Type 1 tags are based on standard ISO14443A with a memory of 96 bytes, expandable up to 2 Kbytes. The rate of data transfer is 106 Kbps and type 1 NFC tags have read/re-write capability.

6.2 Type 2 NFC tags

Like Type 1 tags, Type 2 tags are also based on ISO 14443A standard. It has a memory of 48 bytes, expandable up to 2 Kbytes. The rate of data transfer is 106 Kbps and type 2 NFC tags have read/re-write capability.

6.3 Type 3 NFC tags

Type 3 tags are Japanese Sony FeliCa standard (JIS X 6319–4). It has more memory and faster data transfer speed as compare to type 1 & 2 tags. The memory is 2 Kbyte, expandable up to 1 Mbyte with a transfer rate of 212 Kbps.

6.4 Type 4 NFC tags

Type 4 tags work on both ISO 14443 A & B communications. These are manufactured either in read only or read/re-write modes. Unlike other tags, a user cannot decide the mode. The memory is up to 32 Kbytes and, transmission rates are high; between 106 to 424 Kbps.

Type of NFC Tag	Standard	Memory	Data Transfer Rate	Data Capability	Anti-Collision	Available Market Products
Type 1	ISO 14443 A	96 bytes, expandable to 2 Kbytes	106 Kbps	Read-Write Read only	No	Innovision Topaz, Broadcom, BCM20203
Type 2	ISO 14443 A	48 bytes, expandable to 2 Kbytes	106 Kbps	Read-Write Read Only	Yes	NXP MIFARE Ultralight, NTAG203, NTAG 210, NTAG 212, NTAG 213/215/216, NTAG I^2C
Type 3	JIS X 6319–4	2 Kbytes, expandable to 1 Mbytes	212 Kbps, 424 Kbps	Read-Write Read Only	Yes	Sony FeliCa
Type 4	ISO 14443 A & B	Up to 32 Kbytes	106 to 424 Kbps	Read-Write Read Only (Factory Manufactured)	Yes	NXP DESFire, NXP SmartMX-JCOP,
Type 5	ISO 15693	Up to 64 Kbytes	26.48 Kbps	Read-Write Read Only	Yes	NXP ICODE Series

Table 5.
Summary of five different types of NFC tags [1, 54].

6.5 Type 5 NFC tags

NFC forum released type 5 tags recently in 2015 that is the newest NFC tag. It is based on ISO 15693. It has working range up to 1.5 m that allows the communication with RFID tags.

There are many factors, which decide the type of NFC tag used for a particular application, such as the type of the application, memory and transmission rate requirements, working distance, and cost involved, etc. Normally, an App needs to be installed on NFC devices, smart phone, or smart watch to use the NFC tags (e.g, Apple Pay and Google Pay for payments). In 2019, Ahold Delhaize, an European super market giant, enables its shelves with NFC-enabled electronics labels that allows shoppers to obtain detailed information of the product and add items to their cart for self-checkout using smart phones [57]. In 2020, Apple recently launched a new feature in its IOS operating system, "App Clip" that allows only clips/snippets of an App to do the communications with NFC tags without downloading the whole App [58]. **Table 5** summarizes the various features like standards, memory, data transmission rate, and so on, of five types of NFC tags along with their typical uses [1].

Apart from these five types of tags, there is a Type 6 NFC tags that are based on ISO 15693-3 standards and used to store NDEF messages or applications focused on identification cards [54]. It has memory capacity of 8 Kbytes and data transfer rate of 26.48 Kbps. The newly emerged 3-D printing technology has been exploited to develop new type of tags (e.g., Kovio's NFC Barcodes) [59]. New material and printing technologies can open endless opportunities in the area of NFC communications. In the last decade, there is dramatic increase in smart phones and tablets enabled with NFC function.

7. NFC applications

Many NFC applications have been developed since its inception and have become parts of our daily lives. Several of them are discussed below.

7.1 NFC mobile payments applications

With the technological advancement in the last decade, NFC enabled mobile devices are changing the way users receive data, make payments, and exchange information across devices all over the world. The advanced innovation has already been in use in Europe, Asia and North America because of powerful impact of influential mobile network operators (MNOs) in these parts of the world [60]. Different technologies such as RFID, contactless smart card, NFC, short message service (SMS), unstructured supplementary service data (USSD), wireless application protocol (WAP), interactive voice response (IVR), and so on, all contributed in the success of mobile payments. Presently, the integration of NFC technology in contactless mobile payments led to a tap-and-go tasks. In NFC enabled device, user needs to just touch or present phone to NFC enabled device and transfer or share data without any physical connection. For mobile payments, NFC has been set to be compatible with android, windows, and iOS operating system smartphones. Presently, there are many phones which are NFC compatible such as Samsung's Galaxy Series, Google's Nexus Series, and the iPhone. Some of the NFC payment applications for tap-and-go are Google Pay, Apple Pay, Android Pay, PayPal, Samsung Pay, Square Wallet, LifeLock Wallet and Visa payWave. NFC enabled mobile payment is reducing the need for physical form of payment between consumer and merchants. For example, mobile point of sale (mPOS) units are providing wireless devices to replace traditional cash registers and sale terminals [61]. These units are wire free and easy to install, for example, customers can buy apple products without going to cashier using mPOS device. Social shopping and, mobile wallets are some other examples of mobile payments. According to a recent report from Technavio, the global mobile payment market size is expected to grow at a CAGR (Compound Annual Growth Rate) of close to 36% by the end of 2021. A report from GATE Mobile Wallet Trends (Global Acceptance Transactions Engine) also highlighted that the number of mobile payment users were close to 2.1 billion in 2019 [62]. Some of the related work in mobile payment applications are utilization of electronic vouchers using offline NFC payment service [63], payment authorization process using secured system built on a service oriented architecture (SOA) [64], secure end-to-end NFC based mobile payments protocol for security purpose [65], software card emulation in NFC based contactless smart card system for security [66], and design and initial evaluation of a touch based remote grocery shopping process [67, 68]. **Figure 10** depicts the NFC payment transfer using mobile phone, the credit card transaction with virtual card stored in a distant location [69].

Figure 10.
NFC payment process using mobile phone; credit card transaction process with virtual card stored in a distant location [69].

7.2 Transportation and ticketing

Currently, around one third world population uses smartphone, and this number will go up significantly in years to come. Transport and ticketing are the well-known and promising applications of NFC system. Commuters around the world added adoption of mobility in all aspects of their transit such as journey planning, ticketing, information, and so on [70]. For purpose of transport, NFC forum has recognized three basic use cases, including connection, access, and transactions. The usage of NFC services in transport and ticketing depends on the consumers having NFC enabled mobile phones that are compatible with NFC standard ISO/IEC 14443 [71]. For example, a ticket for transit can easily download from NFC enabled kiosk using an NFC enabled smartphone and then smartphone can tap to a reader to gain the access to ticketing informations [72]. NFC tags can be easily embedded in posters, products, and maps etc., to provide transport related services to everyone. Smart posters containing these NFC tags provide a variety of information and/or links for transport service websites. Card emulation and card reader are the modes utilized in NFC enabled transit system [73]. **Figure 11** represents the evolution of consumer digital payments in public transport fare collection system using smartphone based NFC interface [74] . In past few years, NFC transport and ticketing applications have expanded in various aspects of the travel [54]. For examples, NFC forum and International Air Transport Association (IATA) jointly published the NFC reference guide for air travel [75]. Accenture's survey on public transport users reveals a big increase in use of smartphones for paperless travel and social media during the travel [76]. Virtual ticketing system and secure mCoupon protocol [77, 78], secure payment service by Smart Touch Project [79], an automated reservation and ticketing service for tourists, a system for car parking access, payment system for ticketing [80], offline Tapango system for electronic ticketing process including comparison with traditional paper ticketing process [81] are some of the prominent application of NFC that are used in travels and ticketing developed recently.

7.3 Healthcare applications

In last decade, various new materials and technologies including NFC based technology has gained ground in healthcare by adding convenience and providing efficient healthcare facilities [82–86]. According to a report issued by Transparency Market Research (TMR), healthcare is the fastest growing part of NFC, representing a CAGR of 20.4% [87, 88] . NFC provides user friendly benefits in healthcare e.g., secure physical access to buildings, medications and equipments, medical information, real time updates on patient care, medical alerts, home

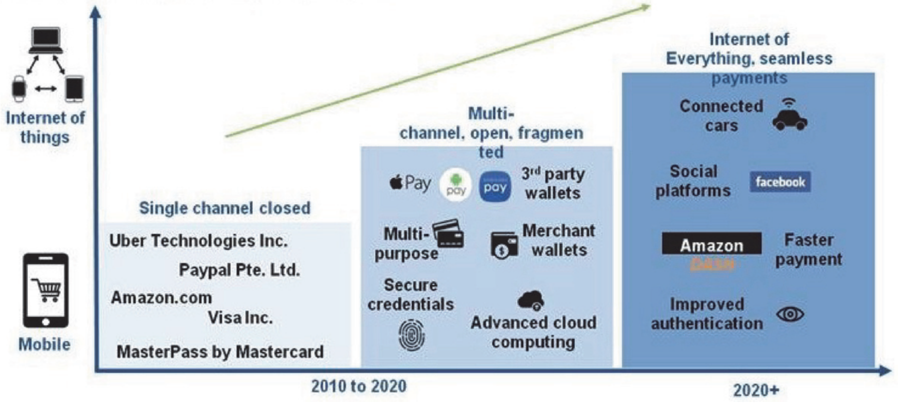

Figure 11.
The evolution of consumer digital payments including in public transport fare collection system using smartphone based NFC interface [74].

monitoring of patients, safer medications [89–92], storage of encrypted medical tags [93], adverse drugs and allergy detection system in hospitals [94] and electronic data recording services [95]. For example, recently Xiaomi launched Mi Band 5 wrist band, which supports NFC based payments and transactions through the band. Currently, in the time of COVID-19 pandemic, Silicon Craft Technology PLC (SICT) has launched an NFC enabled wearable band to track COVID-19 patients and those are under self-quarantine [96]. A major part of NFC in healthcare consists of health monitoring devices, such as NFC enabled blood pressure and activity monitors, wearable sensors [97, 98] and personal weight scale, etc., each of these devices send data to health centres connected via apps (TAPCheck blood pressure monitors, GENTAG, iMPAK Health for credit card-size RhythmTrak ECG device) [54]. There are more complex implementations of NFC technology in implantable health devices, such as heart monitors [99], cochlea implants [100–102], and optogenetics implants [103]. NFC enabled devices are also implanted in fitness and nutrition programs to promote overall health and wellness of users, such as, Apple watch, FitBit, Sony's Smart Band and Samsung Galaxy watch, and so on. There are affirmative studies that focus on improvement of health applications using NFC, such as self-diagnosis and medication, specific applications for the disabled, elderly and people with chronic diseases, etc. [49]. **Figure 12** shows few different applications of NFC in bio medical area [9, 98, 104, 105].

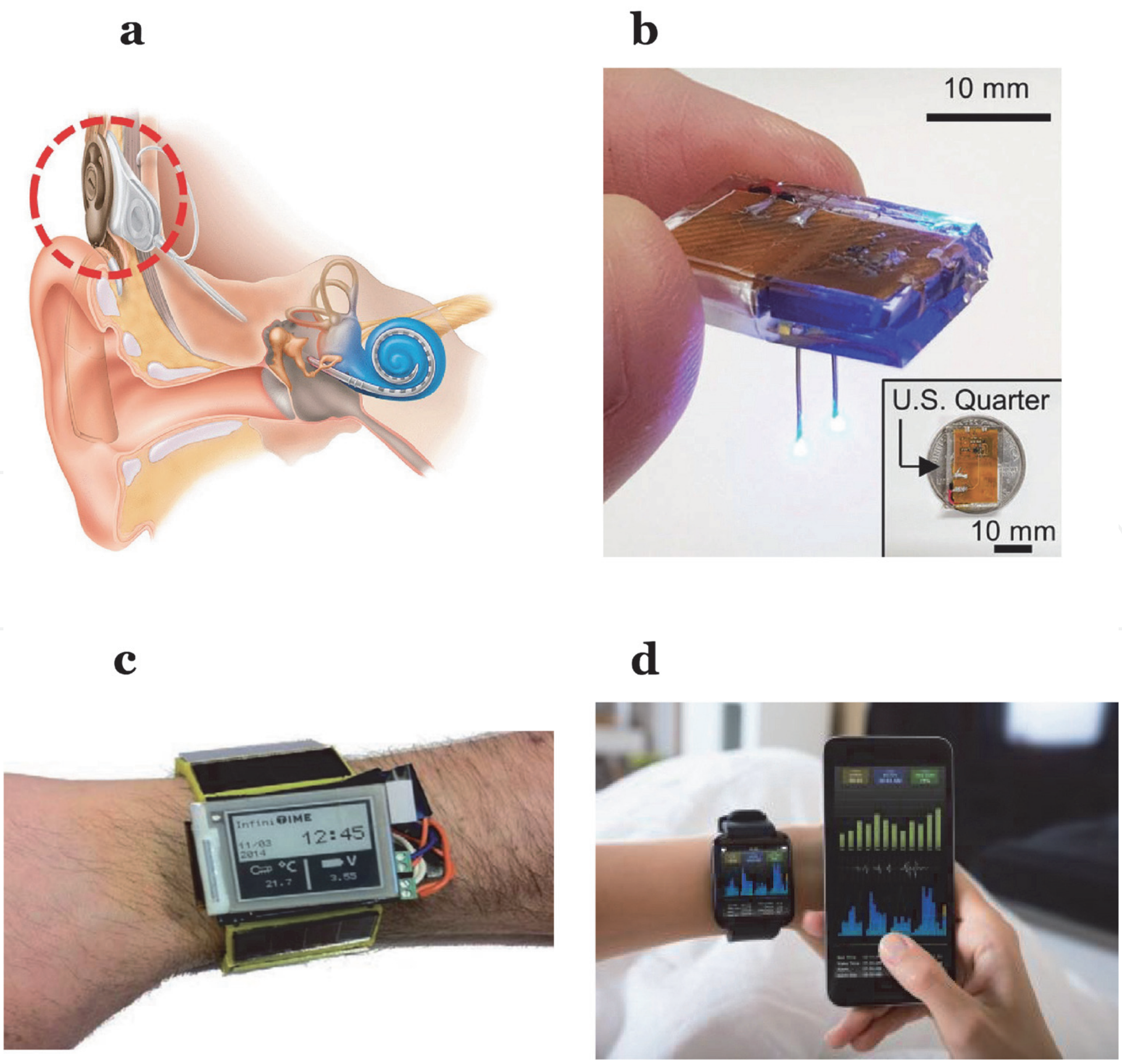

Figure 12.
Various healthcare applications of NFC; (a) cochlea implant with a circle showing the NFC communication part of the implant [9]; (b) Optogenetic implant for brain [104]; (c) wearable bracelet prototype [98]; (d) NFC enabled smart watch [105].

Reader/writer mode	Peer-to-peer mode	Card emulation mode
Increase mobility	Easy data exchange	Physical object elimination
Decrease physical effort	Device pairing	Access control
Ability to be adapted by many scenarios		
Easy to implement		

Table 6.
Benefits of NFC applications for each operating mode [14].

7.4 Access control and authentication

Access control services and authentication services using NFC technology has garnered much attention because of their initial promising results. The use of NFC enabled contactless smart cards for access, identification badges is similar to how users use the NFC enabled mobile phones to gain access in buildings. These types of applications indicates that NFC will play an important role in the next generation access control and identity management systems [54]. For example, two factor access control system for access in building using biometric fingerprint recognition for authentication and NFC for transferring the data to the computer controlled door [49]. Recently, the new 2021 BMW 5 Series launched NFC enabled digital car keys feature in their car which is compatible with Apple iPhone (Compatible with iPhone SE 2nd generation and iPhones with operating system above iOS 13) [96].

7.5 Gaming, social media and entertainment applications

The use of NFC enabled mobile games and social media has been brought to the market recently. In some of the NFC projects, gamers can tap each other phones together to receive access for new levels in the game and can score extra points. Similarly, social media users can establish social media connections and networking using peer-to-peer mode, where they can update their status and checked into the location also. Some of the examples are, Pass the bomb and Exquisite Touch games [106], smart phones are NFC enabled musical instruments [107], and Whack-a-Mole game [108].

7.6 Inventory and packaging

RFID and NFC enabled devices has been used in warehouses and stores for inventory control, labelling and packaging purpose. For example, NFC-enabled temperature sensors in tracking the food and drinks conditions, NFC tags for luxury products, NFC tags for authentication of instruments and linked to database to keep record of their repair date, NFC labels for food tracking (expiration date, gluten free, low calorie etc) [54].

Some of the other applications of NFC are location-based tracking, educational, work force and retail management applications. **Table 6** summarizes the benefits of each mode of NFC communications.

8. Privacy and security

Along with benefits, any new technology comes with new challenges and concerns. Similarly, NFC also has its own concerns, specifically the privacy and security concerns.

The data transfer in NFC technology relies on the magnetic flux strength, which is inversely proportional to the square of the distance between the NFC device and the tag antenna. Hence, magnetic flux strength decreases quickly as the distance between the NFC device and the tag antenna increases, thus restricting the range and effectiveness of NFC technology up to a few centimeters only. This disadvantage turns out be a great advantage and a flagship selling point for NFC technology as far as security is concerned. Along with the numerous benefits of NFC technology, researchers and technologists also are aware of the security and privacy concerns that comes along with technology. As this technology is managing our payment system and private information, the technology needs to be secure and safe from any kind of security threat [94, 109, 110]. Although NFC technology is based on contactless smartcards and payment technology and communicate in short range distance, yet there are chances of eavesdropping on communications [111]. Several types of attacks have been discussed in studies such as eavesdropping, data corruption or modification, relay attacks [112], man-in-the-middle attacks and DOS (Denial-of-Service). With an increase of NFC products in the market, the individual makers of product do not implement NFC technology perfectly. According to head of HP's Zero Day, in an annual hacking competition (Pwn2Own) in 2015, researchers used flaws of technology to compromise the NFC devices [113]. Several researchers tried to increase the range of NFC communication via different design topologies. For example, Range extension attacks on contactless smartcards [114], increase in range by placing metal plate under antenna, position and alignment of antenna to extend the range with a range extension to 13.4 cm by changing the antenna [115]. Many studies indicate that the usage of secure channels and examining the RF field can address most of these threats [116], while the high speed of data transfer and close distance handles the rest [117]. The close operating distance for NFC prevents an intruding signal from interrupting the signal or inserting threating data during the transfer [118, 119]. Some of the steps can help you safely use NFC technology for your mobile phone payments and other applications [113], including:

- Customers should read the fine print before using any NFC-enabled applications.
- Patch your device rapidly.
- Active your device only when it is in use.

9. Conclusion and future directions

In this chapter, we have covered an overview of NFC technology, including its current uses. NFC is an emerging technology and finding applications in every aspects of the daily life. In last decade, there has been explosion on both fronts, market applications and research. During the future years, it will expand further. NFC has potential to make personalized medicine and next generation point diagnosis at cellular and molecular levels realities. There is ongoing research to make NFC technology more affordable, easy to use, as well as more compact in size. There is a strong desire to improve the efficiency and wireless power transfer rates of these NFC devices. New materials research combined with evolving 3-D printing could led to new type of NFC tags, devices, and applications.

Presently, most NFC applications involve the use of mobile phones and exchange of sensitive personal financial and other data during the transitions. Most users have vast amount of other important data as well. This raises the concerns about privacy and security like spamming, unwanted contents on phones and so on. User privacy should be given top priority as NFC technology expands into new avenues. Cautions should be used while implementing NFC services. Data encryption, establishing secure channels between NFC devices and users' proper educations (locking code for the phone, regular update of antivirus software, erasing the phone in case its stolen) will be some key features in addressing the users' concerns about privacy and security. Overall, NFC is an exciting new technology that will present a wide variety of new applications along with renewed challenges in the years to come.

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