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Empirical study on near field communication (NFC)

Mudassara Perveen

Department of computer science, Government college university of
Faisalabad.

*Corresponding author: mudassaraperveen123@gmail.com

Abstract: Near Field Communication (NFC) as a promising short range wireless communication technology facilitates mobile phone usage of billions of people throughout the world that offers diverse services ranging from payment and loyalty applications to access keys for offices and houses. Eventually NFC technology integrates all such services into one single mobile phone. NFC technology has emerged lately, and consequently not much academic source is available yet. On the contrary, due to its promising business case options, there will be an increasing amount of work to be studied in the very close future. This paper presents the concept of NFC technology in a holistic approach with different perspectives, including communication essentials with standards, ecosystem and business issues, applications, and security issues. Open research areas and further recommended studies in terms of academic and business point of view are also explored and discussed at the end of each major subject's subsection. This comprehensive survey will be a valuable guide for researchers and academicians as well as for business world interested in NFC technology.

Keywords: Near field communication NFC Survey, Communication essentials, NFC Security Applications, Application development, secure element.

Introduction

Near-field communication (NFC) is a radio-frequency identification system (RFID) that enables fast communication between devices over a short range using the 13.56-MHz RFID band [1]. Although near-field communication has existed for over a decade [2], this technology did not become widespread until its extensive use in payment systems. NFC technology enables simple and safe two-way interactions between electronic devices, enabling consumers to perform contactless transactions, access digital content, and connect electronic devices with a single tap. Most current smartphones also incorporate an NFC reader. NFC systems are, therefore, gaining importance in the Internet of Things (IOT) scenario [3,4]. NFC is also interesting for the development of low-cost sensors since it provides a quick and easy way of obtaining data from them simply by approaching the reader to the tag without having to pair the devices. The upcoming fifth generation (5G) of communication technology is expected to unleash a massive IoT ecosystem where networks can serve the communication needs for billions of connected devices, with the right trade-offs between speed, latency, and cost. RFID is one of the most important technologies for the massive deployment of IoT. It can bring IoT to unpowered objects with its ability to connect the unconnected. In addition, NFC can put IoT devices under a user's control and is easy to use with its "tap-and-go" nature. In particular, green NFC sensors based on energy harvesting can help in the design of a new generation of low-cost smart wearables and in the simplification of the man–machine interface, which opens the door to cooperative IoT for smart cities and Industry 4.0 applications. Batteries in many electronic devices should be managed as hazardous waste because of their toxic contents or reactive properties [5]. In this context, green electronics technology provides solutions that are well suited to the broad needs of an energy-efficient society. Ambient energy harvesting is the process whereby energy is converted from the environment and stored for use in electronic applications [6]. This technology is usually applied to energy harvesting for low-power and small autonomous devices such as wireless sensor networks. Numerous sources, including solar power, ocean waves, piezoelectricity, thermoelectricity, and physical motion (active/passive human power), are available for energy scavenging [6]. Energy can be harvested from existing ambient radio-frequency sources (cellular networks, etc.). However, as available power is low and depends on distance and source availability [7], a long time is needed to charge the storage device (batteries or super capacitors) before the device becomes operational. A review of the literature shows that no single power source is sufficient for all applications and that the energy sources must be selected according to the characteristics of the application [6]. From the energy-harvesting point of view, passive RFID systems can be considered devices that scavenge energy from an intentional RF source (the reader). Another technology related to energy harvesting is wireless power transfer (WPT) for battery charging using inductive links at high frequency (HF). Wireless battery charging was recently standardized by the Wireless Power Consortium (WPC) [8]. It became popular in modern smartphones [9] and was proposed for electric-vehicle charging [10]. In this context, interest in batteryless (passive) RFID sensors grew in the last few years. Ultra-high frequency (UHF) RFID technology is now commercially available and is used in logistics, inventory, and supply-chain applications. Although UHF readers are expensive ($1000–$2000), the inlays are cheap, and return on investment (ROI) is achieved thanks to a large number of units and the benefits associated with traceability [11]. Improvements in chip integrated circuit (IC) sensitivity (e.g., −22 dBm for Impinj Monza R6) allows reaching several meters (about 15 m considering free space and read mode). Consequently, the tag is more tolerant to environmental conditions such as losses or detuning due to the proximity of metals and materials with high permittivity and high losses, such as the body, or multipath fading [12]. In these cases, special designs to improve the read range are required [13,14]. The read range in write mode is noticeably lower than in read mode due to the higher power consumption needed during the memory writing process, and the write sensitivity is between 2 and 6 dB lower than in read mode, depending on the IC model. This not only permits a digital code to be associated with an object, but also allows RFID tags to be equipped with a large variety of sensors. Examples of UHF RFID sensors based on a modification of the antenna's electromagnetic response [15,16] or integration of electronic pressure controller (EPC)-compatible integrated circuits with sensor functionalities [17,18] can be found in the literature. These can operate in passive mode or battery-assisted passive (BAP) mode. The EM4325 from EM Microelectronics integrates a temperature sensor and a serial parallel interface (SPI) connection to an external microcontroller, while the SL900 from Austria Microsystems integrates a temperature sensor and an analog-to-digital converter (ADC). The SPS1M002 from On Semiconductor uses the Magnus−S2 Sensor IC from RF Micron, which integrates a moisture contact sensor. In this case, changes in antenna detuning due to moisture contact are digitized by the sensor, which can then be read by a standard EPC Gen 2 compliant reader. Like Impinj R6, this IC technology incorporates an input internal tuning capacitance in order to combat the effect of detuning due to materials [19]. Several sensors (temperature, strain, and pressure) based on UHF technology were commercialized by Farsens using a proprietary IC. In passive mode, these UHF tags have read sensitivities on the order of −9 dBm (e.g., EM4325); therefore, the read range is considerably lower (about 2–3 m) than inlay tags without sensor capabilities. Another interesting technology is chipless RFID [20], where the identification code is encoded in the frequency or time domain. The read range is a few centimeters for the frequency-coded tag (<m) or up to 2–3 m for the time-domain-coded tags [21]. Several studies [20,22–24] focused on increasing the number of bits to encode in order to compete in cost with chip-based competitive technologies (HF or UHF). The number of bits depends on the frequency bandwidth; thus, chipless RFID is usually designed at ultra-wideband (UWB, 3.1–10.6 GHz). Another important challenge for chipless technology is the lack of standardized commercial low-cost readers. In spite of these challenges for identification, chipless technology aroused much interest in sensor applications [25–27]. Some challenges can be softened; for example, narrowband readers may be used since the identification can be done by other methods and the number of sensors in the read range may be small. Concerning NFC, the most important NFC IC manufacturers, such as NXP, TI, ST Microelectronics, AMS, and Melexis, recently introduced advanced integrated circuits (IC) with energy-harvesting capabilities [28]. These chips collect part of the energy received by the magnetic field generated at the reader to provide an analog voltage output that can be used to power external electronics such as low-power microcontrollers or sensors. The progressive introduction of these ICs into the market enables the development of low-cost battery less portable sensors [29,30]. A comparison of RFID technologies is shown in Table 1. Bluetooth low energy (BLE) is also included as an example of low-power, short-range wireless technology. The availability of low-cost standardized technology and the custom of users to use NFC technology and wireless power transfer makes NFC technology one of the keys to the development of a new generation of green sensors for IOT applications.

Table 1. Comparison of radio-frequency identification (RFID) sensor technologies. NFC—near-field communication; UHF—ultra-high frequency; BLE—Bluetooth low energy; UWB—ultra-wideband; IC—integrated circuit; BAP—battery-assisted passive; ISM—industrial, scientific, and medical.

Property	**Chip less RFID**	**NFC**	**UHF RFID**	**Bluetooth BLE**
Typical read range	<50 cm frequency coded 2-3m, time coded UWB	1-2 cm for proximity cards with energy harvesting, 0.5 m for vicinity cards	Up to 15 m with inlay tags with −22 dBm read IC sensitivity. Up to 3 m UHF sensors (with −9 dBm read IC sensitivity). Up to 30 m BAP.	10 m
Power source	Passive	Passive or semi-Passive	Passive or semi-Passive	Active
Tag price	Moderate	Low	Low	High
Reader cost	High, no commercial	Low, smartphone	High, $1000–$2000	Low, smartphone
Standard	No	Yes	Yes	Yes
Universal frequency regulation	No, often used UWB	Yes, ISM	No, by regions	Yes, ISM
Tag size	Large	Medium	Medium	Small
Memory capacity	<40 bits	<64 kilobits	96bits EPC, typically 512 bits for users (<64 Kbytes)	Several kilobytes depending on the microcontroller
ID rewritable	No	Yes	Yes	Yes
Energy harvesting	No	Approx. 10mW	Few µW	No
Tag substrate	Low loss microwave substrates	Low cost or FR4	Low cost or FR4	FR4
Tag flexibility	Depends on the substrate	Depends on the substrate	Depends on the substrate	Yes
Tag robustness	High	Low (inlays)	Low (inlays)	Moderate

Recent advances in NFC-based sensor technologies are reviewed in this paper. The paper is organized as follows: in Section 2, several practical considerations for the design of NFC-based sensors are provided. Firstly, wireless power transfer between the NFC reader and the IC is described. After that, the factors that limit the read range such as antenna coupling, the quality factor of the antennas, and detuning due to the metallic surfaces are examined. In this section, a survey of existing NFC IC with energy-harvesting capability is also conducted.

NFC Communication:

NFC communication occurs between two NFC compatible devices placed within a few centimeters of each other using the 13.56 MHz operating frequency .It provides easy communication between various NFC devices on ISO/EC 18000-3 air interfaces, with transfer rates of 106, 212, and 424 Kbits per second. The device that starts the communication is called the initiator, while the respondent is known as the target. NFC smartphone and NFC readers uses their own power, hence are active devices, whereas an NFC tag uses the power of the other party, and hence is called a passive device. All initiator devices are usually active devices, however a target device can be either active or passive, depending on the operating mode.

Each operating mode uses its own communication interfaces and standards; ISO/IEC 18092 NFCIP-1 [31], ISO/IEC 21481 NFCIP-2 [32], JIS X 6319-4/Felica [33] and ISO/IEC 14443 [34] contactless smart card standards (referred to as NFC-A, NFC-B and NFC-F, respectively) in the NFC Forum specifications on RF layers. Moreover, each operating mode has different technical, operational and design requirements (see the next sections). The NFC protocol occurs using two communication modes: active and passive mode [31]. In active communication mode, both devices use their own energy to generate their RF field to transmit the data. In the passive communication mode, only the initiator generates the RF field while the target device makes use of the energy that is already created. In NFC communication that occurs from an active device to a passive device, the Amplitude Shift Keying (ASK) modulation technique is used at all possible data rates. In the case of communication from a passive device to an active device, the load modulation technique is used. In terms of coding schemes, it uses Non-Return-to-Zero Level (NRZ-L), Manchester, or Modified Miller coding techniques, which depend on the data rates and standards used on the RF interface (i.e., JIS X 6319-4/Felica and ISO/IEC 14443 contactless smart card standards). There exist several studies on improving the efficiency of NFC communication through novel modulation techniques. One study [35] deals with the increase of data rates for proximity coupling of NFC devices at 13.56 MHz, and compares the performance of the ASK and PSK modulation schemes in a real environment. It concludes that PSK performs 23% better than ASK in terms of field strength requirements and energy efficiency. Another study [36] focuses on a highly efficient 13.56 MHz NFC transmitter to improve the efficiency of ASK modulation. Some authors have proposed a modulation technique called Active Load Modulation (ALM) to overcome the limitations of using passive load modulation [36]. Another study [37] handles the load modulation bottlenecks and provides ALM concepts, which enhances the card emulation mode operation. The authors of [38] focus on high-speed NFC transmissions based on Extended Binary Phase Shift Keying (EBPSK) modulation and they present its advantages over the existing NFC system. The authors of [39] present a multi-level Phase Shift Keying (PSK) modulation to increase the data rate of 13.56 MHz inductively coupled systems. The authors of [40] examine Quadrature Phase Shift Keying (QPSK) in which modulation with additional data transmission is studied to enhance NFC transactions. The authors of [41] propose a Direct Antenna Modulation (DAM) technique to increase the performance of NFC link since most NFC systems operate at low RF frequencies.

NFC Security: NFC services are subject to store and manage users' private and monetary information, so NFC services must be able to provide a secure framework to reassure users and thereby motivate demand. The security of NFC technology can be analyzed in the following domains:

- Security of NFC Tags.
- Security of NFC Readers.
- Security of Secure Elements.
- Security of NFC Communication.

Secure Elements:

As smart cards have been used for storing private information, additional issues including where to save multiple applications and their credentials, how to provide authentication and identification, and how to satisfy PIN management and signatures have arisen. These issues have forced major standard providers to define a new concept known as SE, which is defined as the concept of storing and processing sensitive data on mobile components such as smartcards and smartphones. Creation of an SE requires a secured and controlled environment so that security requirements such as secrecy, authentication, or signature can be satisfied.

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