Experimental evaluation of NFC reliability between an RFID tag and a smartphone

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Abstract—**Near Field Communication (NFC) is a short range wireless technology that enables data transfer between two NFC devices. It is derived from Radio Frequency Identification (RFID) technology. However, NFC only operates at 13.56MHz frequency while RFID operates at both 125KHz and 13.56MHz frequencies. The success of NFC in replacing contact cards in payment systems can be duplicated in other industries. It is very critical that the operation of NFC is well understood so that future applications can make life easier for the users. The main purpose of this paper is to find out the parameters that can affect the optimal operation of passive NFC devices.**

Keywords— NFC; RFID; MIFARE; passive mode; active mode; reader/writer mode; inductive coupling

I. Introduction

The introduction of Near Field Communication (NFC) has created opportunities for different industries to design new applications that could not be easily developed with older technologies. Recently the number of smart phones embedded with NFC technology has increased and soon these smart phones will be replacing a number of smart cards carried around on a daily basis.

The NFC application can be regarded as a secure wireless technology due to its short-range of operation and it is for this reason that many bus fare payment systems have embraced the technology. The technology is based on the inductive coupling concept between the NFC initiator and target, and this concept makes it possible to support the passive mode of operation where the target tag does not have its own power supply. Another mode of operation is active mode whereby both initiator and target have their power supply [1].

Many authors have carried out and published results of their experiments regarding NFC and RFID topics. One of interesting experiments is determining the relationship between the mutual inductance of the NFC initiator and NFC tag and the reliability of the technology. Other experiments studied the challenges of maintaining operational reliability while the size of NFC tags gets smaller and smaller [2].

In this paper, three parameters that could affect the reliability of NFC between a NFC enabled smartphone and NFC tags are evaluated. The first parameter evaluated is NFC device orientation, the second is reader and coil distance and the third is the condition of the operating environment.

The remainder of the paper consists of Section II which provides a brief background summary of NFC concepts, standards and operation. Section III discusses related work in ensuring NFC communication reliability. The experimental set up is discussed in section IV and the results are discussed in section V. Finally, the conclusions are discussed in section VI.

II. Background Summary of NFC

A. NFC Standards

Near Field Communication is a short-range wireless technology that allows NFC enabled devices to communicate over distances less than 10 centimeters (cm). The ISO/IEC 14443 and the IOS/IEC 18000-3 are specifications for NFC technology. The ISO/IEC 18000-3 is a standard for all devices communicating wirelessly at the 13.56MHz frequency using Type A or Type B contactless tags [3]. Other standards that support NFC technology are ECMA and ETSI. NFC standard supports different data transmission rates such as 106kbps, 212kbps and 424kbps. These transmission rates are determined by the modulation scheme applied in the tag circuit [4].

B. Inductive Coupling

When current moves in a straight wire, a magnetic field is created around the wire and the direction of the circular magnetic field is determined by a right-hand rule. The strength of the magnetic field created is proportional to the amount of current flowing through the wire. When the wire is bent into a coil or into a solenoid, the magnetic field gets stronger, and in this case the strength of magnetic field is proportional to both the amount of current flowing in the coil and the number of coil turns. When a second coil is placed in the changing magnetic field, a current is induced in the second coil [5].

Fig. 1 [6] represents the inductive coupling between two coils. The magnetic field is created by a Reader/Writer (which can be an NFC capable phone) and the Data Carrier Antenna part represents the embedded circuit in the NFC tag. The magnetic field provides power to the NFC tag and data transfer between the two coils occurs through the same magnetic field [7]. For the NFC tag to work, the distance between the coils must be less than the wavelength of the magnetic field divided by two times π [2].

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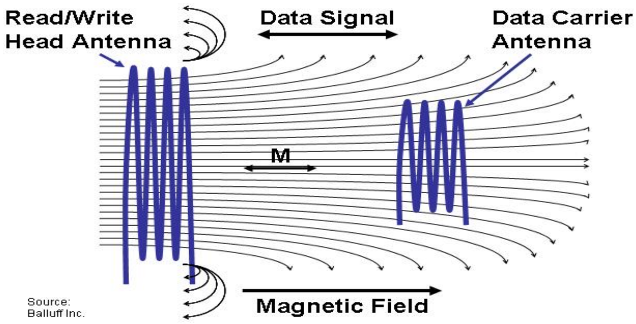

Figure 1. Coils Inductive Coupling .

The induced current in the NFC tag is proportional to the mutual inductance between the coils and the strength of the magnetic field. The coupling coefficient of the coils is not influenced by the number of turns if the two coils have an identical radius. Its value is influenced by the geometrical antenna shape [8], [9], [10].

C. NFC Modes of Communication

NFC devices can communicate in either Active mode or Passive mode.

Active Mode: in this mode both initiator and target devices provide their own power supply and create a magnetic field to transfer data between each other. Any device can be the initiator while the other will be the target. One device creates magnetic fields and the other device transfers data back to the initiator [1], [8] and [11].

Passive Mode: in this mode of operation only one device (initiator) has its own power supply to power the device and creates magnetic fields for the target device (tag) as well. Upon reaching the target, the magnetic fields induce current which gets rectified and powers the target circuit. The target transfers data back to the initiator using the magnetic field channel [1], [11] and [8].

D. NFC Reader/Wrte Operation

NFC devices can operate in one of three operation modes; Reader/Writer mode, Peer to Peer mode or Card Emulation mode. In this paper, only Reader/Writer mode is relevant to the experiments performed.

A NFC device operates as a reader for NFC tags. It detects NFC tags by using the collision avoidance, the method to detect the presence of a radio frequency field based on the carrier frequency and resolve collisions on the protocol level [12]. The application running in the NFC device can determine when the data must be read from the NFC tag or write data to the tag.

In reader mode, the initiator sends a request to a NFC tag; the tag then responds by sending the required data back to the NFC device for reading [13].

In write mode, the initiator specifies the data and the location of the tag to which data must be written. This mode can overwrite data already stored at a particular location within the tag. This mode can also be used to update the data depending on the application and type of data to be stored. Based on the NFC application, some NFC tags can be written once and locked for future writing operations [13].

III. Related Work

Azad and Wang conducted experiments to measure the inductive coupling in NFC devices. The energy from primary to secondary coils of NFC reader and NFC tag is transferred by inductive coupling. The inductive coupling is dependent on mutual inductance and the coupling coefficient between the two coils. The coupling coefficient was found to decrease with inverse cube of the distance between them while aligned in the same plain. Moreover, it was also concluded that for two coils in the same plain, the coupling coefficient is maximum at a particular distance and decreases to zero as the angle between the coils increases to 90 degrees [14].

The issue of coupling coefficient being zero between the primary and secondary coils at 90 degrees of each other can be understood, because the magnetic field cannot cross the other coil at 90 degrees. Gong and Xie constructed three overlapping loop antennas perpendicular to each other. The authors demonstrate that two or three overlapping antennas can function effectively at 13.56MHz without negatively influencing each other. This concept of overlapping antennas was proven using both simulation and experimental results [15].

According to experiments conducted by Langer, Saminger and Grunberger, the position and the size of a NFC antenna plays a critical role in the performance of NFC devices. While measuring performance of NFC smartphone, it was found that the antennas of three smart phones were placed in the different positions and had different sizes [16]:

- Integrated into the battery of the phone and has dimension of about 45 x30mm.
- Located around the cover of the phone and its size was about 107 x 45mm.
- Located on the top side of the phone and its size was 39 x 14mm.

Different NFC phone models transfer different power levels to NFC tags depending on the distance between NFC phone, angle of alignment between NFC phone and NFC tag.

The concept of using mutual inductance between two NFC devices has been identified as suitable to determine induced voltage at the passive tag. In addition, the same approach has been used to predict the maximum operation distance between the NFC reader and NFC tag with error ranging from 4.5% to 30% [10]. This error can be attributed to the electrical noise of the environment in which the experiments are being conducted.

Vena and Roux studies on near field coupling of small RFID objects concluded that the new small RFID tags poses challenges of maintaining acceptable reading range and interoperability. At the moment, the smaller the tags gets, the more efficiently the antenna has to be designed [2]. This size issue can pose a big challenge since the dimensions of the tags are as per NFC and RFID standards and antennas can only be implemented in two dimensions within the tag.

IV. Experimental Setup

The coil-module used in three experiments is an RLC circuit consisting of one loop inductor, two capacitors and two resistors. The resonant frequency was 13.56MHz while the Q factor could be adjusted from 35 to 40 for best performance. The NFC tag used was Philip MIFARE Classic 4 kilobytes and conforms to Type A (ISO/IEC 14443 Type A). An Android application called NFC Tag Info application was downloaded from the Internet and installed in a Samsung S3 smartphone.

A. NFC Device Orientation

The purpose of this experiment is to determine the effect on induced power in the NFC coil as the angle between the NFC reader and the NFC coil is increased from 0 degrees to 360 degrees. The angle was increased in intervals of 45degrees. A Samsung S3 phone which supports NFC communication is used as NFC reader. A coil-module tuned to 13.56MHz resonant frequency is placed on a table and a spectrum analyzer leads are connected to two ends of the coil to measure the induced power in the coil. Induced power readings in the coil are recorded against the angles as the NFC phone is rotated above the coil.

The same experiment was repeated but the coil was replaced by Philips MIFARE NFC tag to determine the angle at which the reader could read the tag data.

B. Reader and Coil Distance

The purpose of this experiment is to determine the effect on induced power in the NFC coil as the gap between the NFC reader and the NFC coil is changed. A Samsung S3 phone which supports NFC communication is used as NFC reader. A coil-module that is tuned to 13.56MHz resonant frequency is placed on a table and a spectrum analyzer leads are connected to two ends of the coil to measure the induced power in the coil. Induced power readings in the coil are recorded against the gap between the NFC phone and the coil. The gap was increased from 0cm until 20cm.

The same experiment was repeated but the coil was replaced by Philips MIFARE NFC tag to determine the distance at which the reader could read the tag data.

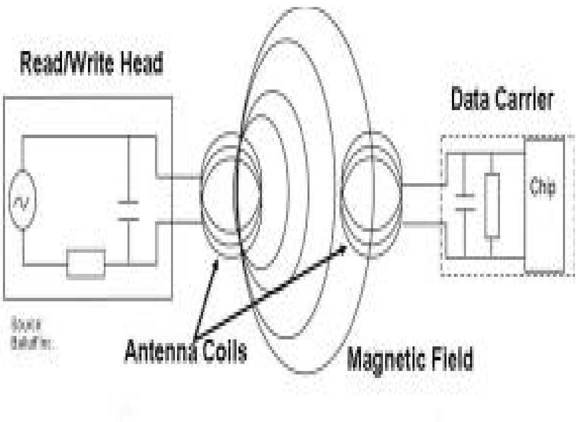

Figure 2. The NFC phone and NFC tag .

Fig. 2 [6] shows the scenario of determining the distance at which the NFC phone (Samsung S3) can read the data from the MIFARE tag.

C. Condition of Operating Environment

The purpose of this experiment is to determine the effect of the condition of the operating environment on the induced power in the NFC coil. A Samsung S3 phone which supports NFC communication is used as NFC reader. A coil-module tuned to resonant frequency of 13.56MHz is placed on a wooden table and a spectrum analyzer leads are connected to two ends of the coil to measure the induced power in the coil. Induced power readings in the coil are recorded against the gap between the NFC phone and the coil. The gap was increased from 0cm to 20cm. A second experiment is performed while the NFC coil is placed on the wooden table with steel sheet supporting the top.

V. Results and Discussion

A. NFC Device Orientation

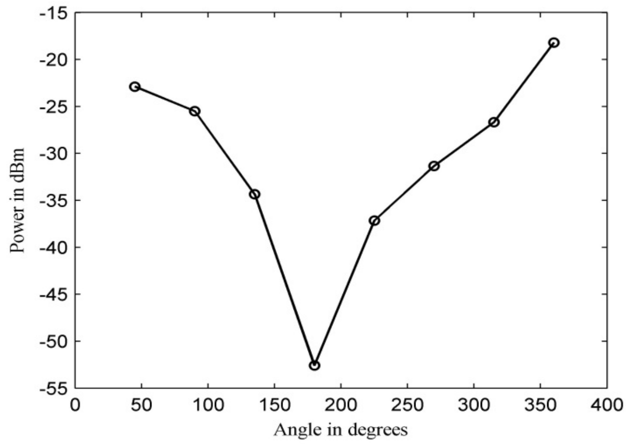

Figure 3. Induced power against angle.

Fig. 3 shows the induced power in the coil decreases from -18.19dBm to -52.59dBm as the phone is rotated from 0 to 180 degrees. From 180 to 360 degrees, the induced power in the coil increases at higher rate than the rate of decrease. The power value at 360 degrees was expected to be the same as the value at 0 degrees but it was slightly higher. One possible explanation could be that small amounts of induced current and voltage remains in the circuit and if the experiment is done continuously without allowing sufficient time to pass to allow the circuit to return to its passive state, then the induced power will be higher.

The graph is not symmetrical about 180 degrees because the NFC chip embedded in the phone is placed on one side of the phone (the back side opposite the phone screen). The fields from the NFC chip are weak on the front of the phone since it has to travel through other electronic components and the phone screen.

The phone was able to read the tag data when the phone NFC chip was facing the tag (angles are 0 and 180 degrees). Although the power was induced to the tag, it was not sufficient for its operation except for 0 degrees and 180 degrees.

Contrary to the above results, the results discussed in the related work section [12] show that at 90 degrees the induced power is minimal while above results show that induced power in the secondary coil is only minimal at 180 degrees. This difference could be explained in the context of smart phones having NFC antennas located at different places and having different dimensions. It is interesting to note that in the study of overlapping three antennas [14], it was proposed that implementation of two or three antennas that are aligned 90 degrees to each other work perfectly without any interference.

B. Reader and Coil Distance

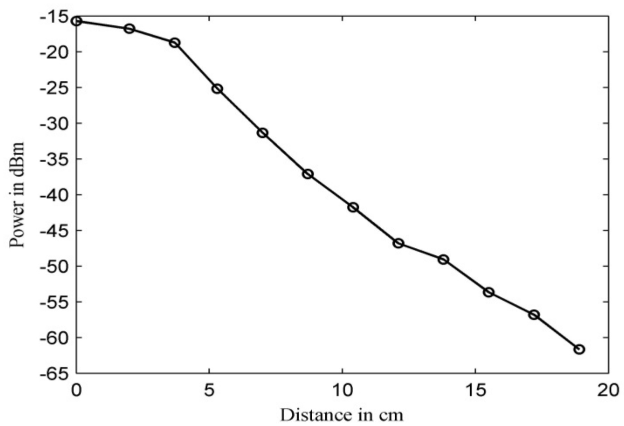

Figure 4. Induced power against distance.

Fig. 4 shows that induced power in the coil decreases as the distance between the NFC phone and the coil is increased. Although the power was induced to the tag as the distance was increased, it was not sufficient to operate the tag except when the distance was equal to or less than 1 cm.

In the section of inductive coupling, it was highlighted that for the tag to work properly the distance between the tag and the reader must be less than the wavelength of the magnetic field divided by two times π [2]. However, from the Reader and coil distance experiment, the distance is not the only factor that determines if the NFC devices can work properly or not. From general theory of electromagnetic theory, the transmitted power of the reader plays part in determining the distance within which devices can operate reliably.

The above results are not in line with one of the studies in section III highlighting that the coupling coefficient between primary and secondary coils decreases with inverse cube of the distance between them while aligned in the same plain [13]. Approximating the graph from Fig 4 can most likely result in a straight line and not a curve with inverse of cube of distance as a slope.

C. Condition of Operating Environment

In Fig. 5, the coil was placed on the wooden top table and the measurements were taken as the distance between the phone and NFC tag was increased from 0 cm to 18cm. The experiment was repeated while placing the coil on the table with wooden top with steel plate underneath.

The coil placed on table with wooden top induced more power than the coil placed on table with steel underneath the wooden top. The first three power readings for coils placed on the table with steel underneath the wooden top as the same. This could be explained in terms of power saturation in the coil due to the effect of steel plate underneath the wooden top. These results show that the environment can affect the operation of the NFC. It would be interesting to repeat the same experiment replacing steel with other metals having different permeability and evaluate the influence on the power induced in the coil. It is assumed that the higher the metal permeability might result in higher power induced in the coil. This could be explained in the context of the impact of steel permeability to magnetic waves even though the magnetic fields in this case are not passing through the steel.

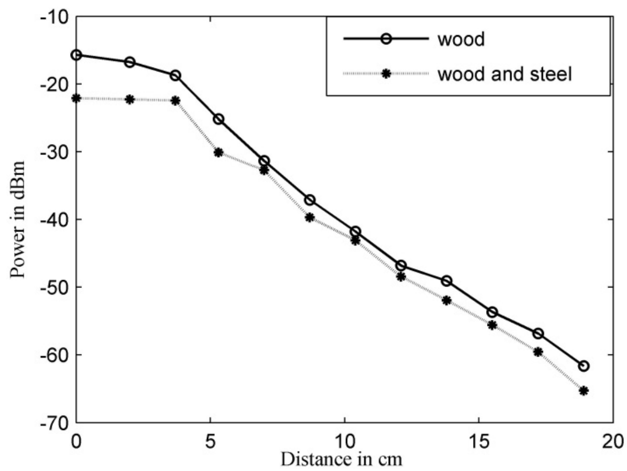

Figure 5. Induced power under different conditions.

VI. CONCLUSION

Passive mode of operation in Near Field Communication is accomplished by making use of the inductive coupling concept. The inductive coupling helps in transferring power from NFC initiator to the NFC tag over the air. The first experiment was performed to evaluate the effect of the angle between the initiator and the tag on the reliability for NFC system. The maximum power transfer occurs when the phone NFC chip is facing (closest to) the tag and the NFC phone can read the NFC tag data.

In the second experiment power transfer from the phone to the tag decreased as the distance between them increased. However, the phone could only read the tag data when the gap between the phone and tag is equal to or less than 1 cm. In the third experiment it was found that induced power in the coil depends on the environmental conditions in which the NFC is operating. There is more power induced in the coil placed on a wooden table top compared to the power induced for coil placed on the wooden table top with a steel sheet underneath.

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