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The PTF-Determinator: A run-time method used to save energy in NFC-Systems

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Abstract **- Near Field Communication (NFC) in mobile devices like smart phones shows potential for applications like payment, identification, etc. Unfortunately the needed functionality increases the battery drain of the device. As a countermeasure power-management techniques are implemented. However, these techniques commonly don't control the power transfer to the tag to prevent wasting energy.**

To adapt this transfer during run-time the properties of the reader, tag and the physical relation between them are needed. This paper proposes a method called PTF-Determinator. It determines the Power Transfer Function (PTF) during run-time and scales the provided power transfer accordingly to save energy.

As a case study the PTF-Determinator is integrated into the tag-detection algorithm. Investigations are made regarding the power consumptions and timings through simulation and measurement on a development platform for mobile phones. The results show that 12% of the energy can be saved on average.

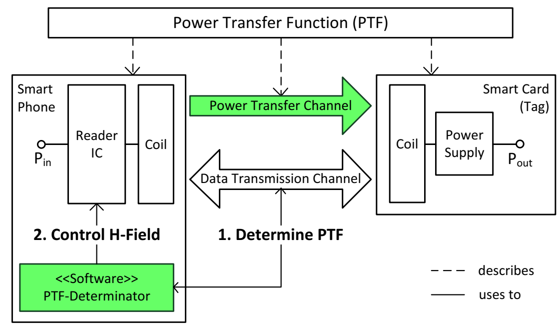

FIGURE 1 - PROPOSED PTF-DETERMINATOR AND THE INTEGRATION INTO THE NEAR FIELD COMMUNICATION SYSTEM

I. INTRODUCTION

Mobile devices like smart phones featuring a Near Field Communication (NFC) interface open a wide set of applications like payment, identification and ticketing. The integration of NFC increases the battery drain because of the additional power-consumption through the needed reader when active. Minimizing the consumption is the goal of the power-management algorithms implemented in software and hardware. These algorithms commonly focus on one component and not the whole system. In our case the component is the NFC-reader, which has to transfer power to the tag (see Figure 1). Currently the reader is able to scale the magnetic field strength during run-time, but has no access to information about the connected tag or the power transmission path between them. Therefore, the field strength is configured statically. In most cases the power output is set to a maximum value to ensure the expected (about 5-10 cm) transmission distance regardless of the tag-type. This power output produces losses in the antenna circuit. A dynamic configuration of the magnetic field strength during run-time reduces this losses and this waste of energy.

The challenge to perform the dynamic configuration is to collect the needed information during run-time and to determine the power transfer function (PTF) on the reader side. With the determined PTF the field strength can be dynamically scaled. To realize the above described steps the NFC-system has to be defined and examined. The scoped system consists of one reader and one tag. The wireless communication channel between them can be split into two main parts. The first part deals with the power transmission path. It describes how the provided power, which can be altered by the reader, is transfered to the tag. The physical principle of the power transmission is inductive coupling (see Figure 2). This can be represented through the the PTF. Several parameters for the PTF are needed for determination. These are the reader characteristics, and coil properties, the parameters needed to calculate the inductive coupling (e.g. physical relationship between the two coils), as well as the parameters of the tag's coil and power supply. The second part deals with the data-transfer path. This path can be used to obtain information about the available tag if enough power is provided by the power-transfer path. These both parts are available for realizing a dynamical approach to reduce the power consumption. The contribution of this paper consists of two parts:

- Introduction of the novel PTF-Determinator method, which determines the PTF during run-time and scales the magnetic field strength based on the result to save energy (see Figure 1).
- Implementation of the presented PTF-Determinator in a reader device and add a feature to set a maximum physical relation factor to avoid energy consuming transmissions, which are not necessary

The paper is split into five main parts. The first part describes the electrical characteristics used for this approach (see Section II.). As second part, which can be found in Section III., the method is shown in detail and how it is integrated into the system. The third part can be found in Section IV., which shows the related work and highlights our contribution. For evaluation the fourth part in Section V. presents experimental results when using this method. The fifth part in Section VI. finally concludes this work

II. ELECTRICAL CHARACTERISTICS

This Section explains the used replacement circuit and equations for the method to calculate the PTF. The equations describe how the power is transferred from the Reader-IC to the supply of the tag and the replacement circuit describes the connection between them, as shown in Figure 2. The calculation is split into four parts.

The first part describes the power control of the NFC-Reader, which can be configured by a resistance (R_{rel}) serial to a constant voltage-source (U_1). This is shown in Equation 1.

$$i_r = \frac{U_1}{Z_c + R_{rel}} \tag{1}$$

Increasing the resistance leads to a reduction of the overall power (decrease of i_r) consumption with the disadvantage of loosing transmission range [1]. The current i_r also depends on the configurable resistance R_{rel} and the input resistance Z_c of the circuit beyond. Z_c alters with the inductive coupling between reader and tag and is

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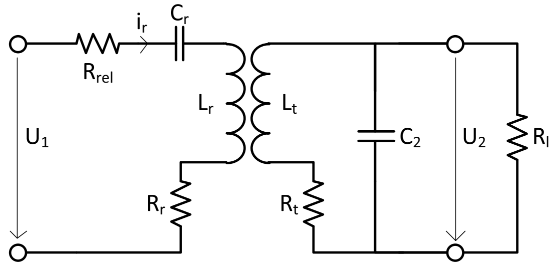

FIGURE 2 - REPLACEMENT CIRCUIT TO DESCRIBE THE POWER TRANSFER FROM THE READER TO THE TAG WITHOUT THE VOLTAGE REGULATION ON TAG- SIDE, ADAPTED FROM [2]

therefore not static. The second part consists of the equation used to calculate the provided magnetic field H of the reader, which is provoked by the electrical current i_r. The considered orientation of the sender and receiver coil is shown in Figure 3.

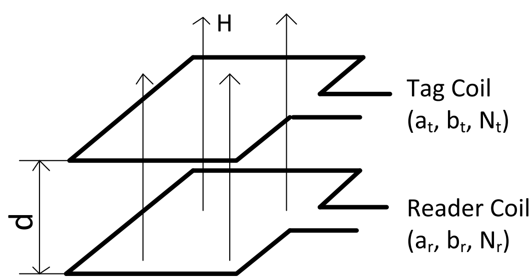

FIGURE 3 - CONSIDERED COAXIAL ORIENTATION BY USING RECTANGULAR SHAPED SENDER AND RECEIVER COILS

Equation 2 can be used for rectangular shaped sending coils and is based on the law of Biot-Savart. It is based on the physical principle of loose inductive coupling. The needed parameters are the dimensions a_r and b_r of the reader coil and the number of windings N_r. The distance to the coil can only be used when the coils are coaxial oriented [2].

$$H = \frac{i_r \cdot N_r \cdot a_r \cdot b_r}{4 \cdot \pi \cdot \sqrt{(\frac{a_r}{2})^2 + (\frac{b_r}{2})^2 + d^2}} \cdot (\frac{1}{(\frac{a_r}{2})^2 + d^2} + \frac{1}{(\frac{b_r}{2})^2 + d^2}) \tag{2}$$

The third part deals with the transformation of the magnetic field strength back to a voltage on tag side (see Figure 2). A resonance circuit, consisting of a parallel capacitance and the coils inductance, is used to amplify the received voltage. First of all the coupling coefficient is calculated with Equation 3 and 4. The coefficient represents an abstract relation between reader and tag and requires the magnetic field strength as input. Equation 5 calculates the resulting voltage on tag-side. This is only valid for a rectangular receiver coils. The needed parameters are the dimensions a_t and b_t, the number of windings N_t, and the coil's inductance L_t [2].

$$M_{12} = \frac{\mu_0 \cdot H \cdot N_t \cdot a_t \cdot b_t}{i_r} \tag{3}$$

$$k = \frac{M_{12}}{\sqrt{L_r \cdot L_t}} \tag{4}$$

$$u_2 = \frac{w \cdot k \cdot \sqrt{L_r \cdot L_t} \cdot i_r}{\sqrt{(\frac{(w \cdot L_t)}{R_l} + w \cdot R_t \cdot C_2)^2 + (1 - w^2 \cdot L_t \cdot C_2 + \frac{R_t}{R_l})^2}} \tag{5}$$

The fourth part describes that the output voltage is limited by a Zener-diode. The reason is the power supply of the tag which needs a certain operation voltage. It is also necessary to provide a minimum voltage. If the supply exceeds the minimum threshold voltage the circuit is set to power down. Figure 4 shows an example of the relation between the the distance between the reader and the tag and the supply voltage of the tag (the power consumption of the tag is considered static). Multiple power outputs are shown to visualize the dependency between the power output and the transmission distance.

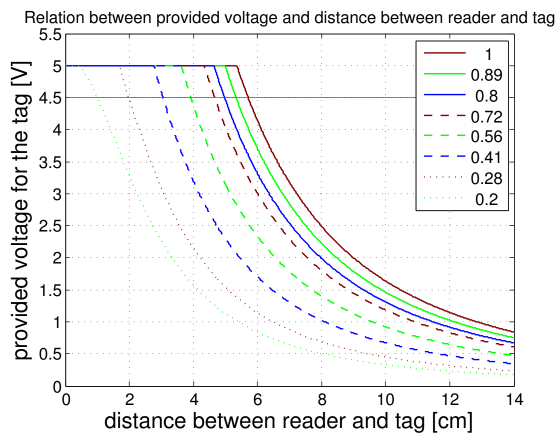

FIGURE 4 - RELATION BETWEEN THE SUPPLY VOLTAGE OF THE TAG AND THE DISTANCE TO THE READER USING. THE RELATION IS SHOWN USING DIFFERENT INPUT POWER LEVELS AS DESCRIBED IN THE LEGEND. THE TWO COILS ARE ORIENTED COAXIAL.

III. METHOD

In this Section the method is shown how to realize this PTF-Determinator. The realization is split into four considerations to be made. The first one deals with gathering the needed parameters from the reader and tag. The second relates to the evaluation of the physical relation factor, which can not be acquired directly. The third consideration deals with the integration of the method into the NFC-System's existing communication flow. The fourth consideration describes a library providing an interface to access the determined PTF. This library can be used can be used for power management methods.

3.1 Gathering needed parameters

As first consideration the needed parameters have to be collected from the NFC-System which are distributed between reader and tag. Some of them are physical values which have to be stored in digitalized form. Because of the system's variability during run-time (e.g. different tags), the storage of all parameters in a single location is inappropriate. Table 1 depicts the number of parameters, their location, and their required space.

These parameters shall be provided on the described location (see Figure 5). One approach is to store this data into a memory during the device's production phase (reader and tag). The needed storage space is 32 byte on tag-side if an accuracy of 32 bit is used. In practice the needed storage can be decreased by adapting the resolution of the values according to the needed PTF accuracy requirements. An example is shown in Table 1 where the needed space is reduced to 8 bytes.

location	number of parameters	accuracy [b]	space [B]
Mobile Reader	5	32	20
		8	5
Tag	8	32	32
		8	8

TABLE 1 - NUMBER OF PARAMETERS NEEDED FOR THE PTF-DETERMINATOR INCLUDING THEIR LOCATION AND NEEDED SPACE IN BYTES. THE SPACE IS SHOWN WITH DIFFERENT ACCURACIES OF THE PARAMETERS.

These values have to be transferred to a central processing unit. This can either be the reader or the tag. In this case the reader has been chosen because of its advanced computational resources and a direct control of the needed input parameters for the PTF (parameter of provided power). This also means that the parameter-values from the tag have to be transfered to the reader which can be costly in terms of time and power. For comparison, sending ping request to the tag requires 7 bit and results in a 2 byte response [2]. The request could be the same size but the response would be 16 times greater. If the bit length of the sent values is reduced to eight bits which should be enough in practice, the bytes to sent can be four times greater.

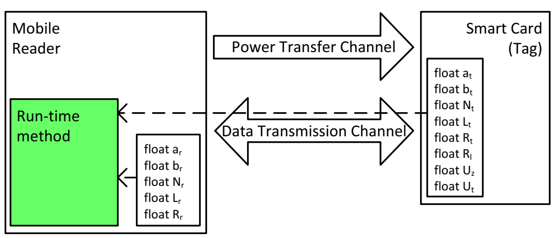

FIGURE 5 - DISTRIBUTION OF THE NEEDED PARAMETERS AND TRANSFER TO A CENTRAL PROCESSING UNIT

3.2 Evaluation of the physical relation factor

The second consideration regards the physical relation factor, which is independent from the type of reader and tag used. Furthermore, its value is unknown and has to be evaluated during run-time. It can not be directly measured because of the lack of sensing mechanisms on both sides.

To solve this problem the PTF described in Section II. is used. The equations described in Section II. have to be transformed to determine the physical relation using the power provided by the reader and the corresponding output voltage as input parameters. The output voltage is also unknown because of the lack of an integrated sensor at tag side. To approximate this value the current power state of the tag can be used. This means if the tag is not responding the supply voltage is too low for operation ($< U_t$) and if the tag responds the operation voltage is above the needed one ($> U_t$). If the reader's provided power is altered until the transition from power down to idle state is reached, the value of the supply voltage from the tag is slightly above U_t (see Figure 6). The approximation depends on the resolution of the power steps. To use this method in practice, a balance between power step resolution and the needed time of the algorithm has to be found. In case of ten steps this would also mean that four iterations have to be made with a successive approximation approach. This leads to a longer time needed for calculation and more needed energy compared to a simple card-detection. To keep this overhead as small as possible the operation to proof if the tag is responding should only invoke a small response and computation-effort for the tag. The request command to the tag can be used. To improve the approximation the tag

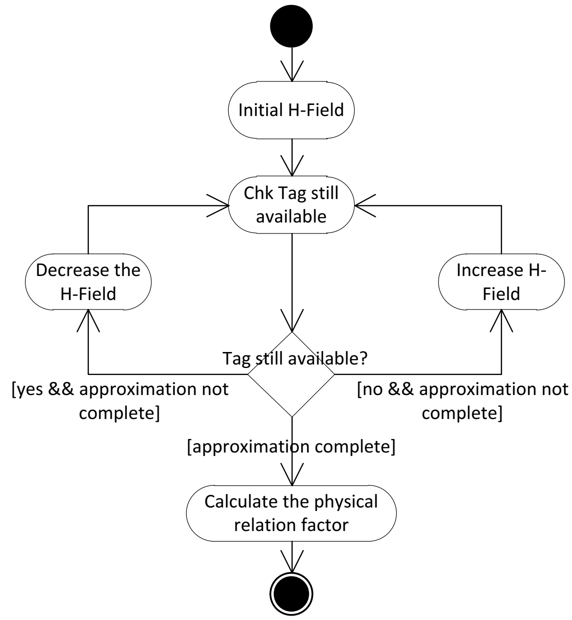

FIGURE 6 - USED ALGORITHM TO APPROXIMATE THE DISTANCE BETWEEN THE READER AND TAG

can provide information about the power consumption when sending this command.

3.3 PTF-Determinator flow integration

The third consideration deals with the inclusion of the PTF-Determinator into the existing communication flow of reader and tag. The tag has different states, which influence the provided functionality (see Figure 7).

When the tag gets enough power it switches to idle state. In this state a request from the reader is expected . All other commands are ignored. After the request is issued it is possible to select the card by sending a anti-collision- followed by a select-command with the appropriate unique identifier (UID). After this procedure, the tag enables extended commands like reading values from the memory. This command is needed by a part of PTF-Determinator. If the power supply drops below a certain threshold (e.g. through exceeding the maximum transmission distance between reader and tag) the state is set back to power down. To get back to the active state the navigation through the state-machine of the tag by sending a request and select has to be redone. To integrate the method into the existing flow, it is split into three parts. The first part is executing the approximation algorithm as shown in Figure 6 but without calculating the physical relation factor. This approximation does not need any parameter information of the tag, only a specified command to call. This can be REQA, which leads to a response which can be used to find out if the tag is available or not. The second part is gathering the needed parameters from the tag as shown in Figure 5, which needs to select the card to enable the command for reading. The third part is responsible for calculating the physical relation factor based on the gathered information from the other two parts. All needed information is now available to determine the PTF.

As last step of integration it has to be defined in which communication phase the PTF-Determinator is executed. As first approach the method is included into the card detection phase. If a new tag has been detected, the algorithm begins to determine the power transfer function, as described in the last paragraph, and is locked for operation until the method is finished. After that, the tag is set to ready state

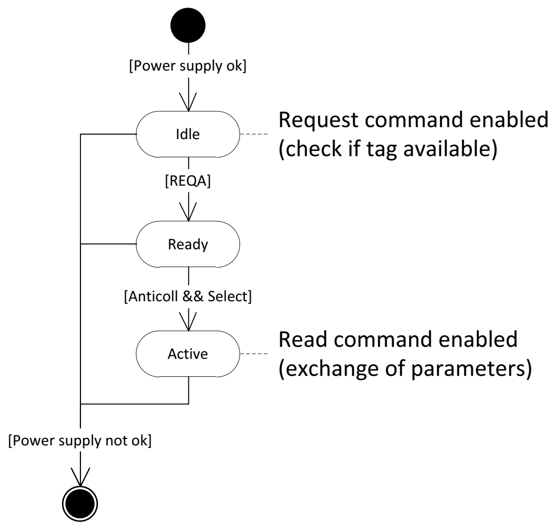

FIGURE 7 - SIMPLIFIED STATE MACHINE ADAPTED FROM [3] USED TO ESTABLISH A CONNECTION BETWEEN THE READER AND THE TAG INVOKED BY THE READER (READER TALKS FIRST)

and the wanted operations can be executed. Thanks to this approach, the knowledge of the PTF can be used in an early stage. Unfortunately the time needed to set-up the connection to the tag is also increased. Furthermore, changes after the set-up can not be detected. Another possibility is to periodically update the power transfer function while being connected to the tag. It has to be considered that this may be very costly in time and power consumption terms. Furthermore, the designed algorithm influences the power state of the tag and it may be necessary to reestablish the connection to the tag and restore the state.

3.4 Power transfer function library integration

The last consideration is to provide the determined PTF in form of a library, which can be used for power-management methods. This library is integrated on reader-side. It provides an interface for the application, which can be used to build a control loop to regulate the provided power of the reader according to the calculation result of the PTF. Furthermore, additional functions are provided by the interface to increase the optimization-possibilities (e.g. getting the current value of physical relation factor to prevent unwanted transmission ranges). This design also makes it possible to integrate this as a hardware component to decrease the calculation time and to be more power efficient.

IV. RELATED WORK

This Section is split into three parts. The first part deals with the state-of-the-art possibilities to acquire the physical relation factor. The second part shows investigations regarding the influence of the passive tag's power requirements. In the third and last part known system based concepts including reader and tag are shown.

4.1 Acquisition of the physical relation factor during run-time

One consideration regards acquiring the physical relation like the distance between the two coils and other dynamic parameters during run-time. An approach is to find a known parameter that describes this physical relation. Cheng Da et al. shows that there is a relation between the sent power of the reader and the distance to the tag. The analysis has been concluded by altering the signal strength of the reader and checking if the tag has enough power to be active [4]. Another approach is distance bounding, which uses the delay between the request and the response as known parameter to calculate the physical distance between reader and tag to detect relaying attacks [5]. To use this information to determine the PTF, the parameter has to be measured during run-time. Furthermore, transmission characteristics (e.g. coil dimensions) have to be included into the determination. These characteristics depend on the system's setup which also depend on the set-up of the system (e.g. different types of tags). Xunteng Xu et al. uses power stepping to detect different positioned tags (distance to the reader) in its environment [6]. This consideration does not include the physical principles of the power transfer but leads to a evaluation of a parameter, close to the distance, during run-time. Another method is through sensing the voltage on tag side and to use it for determination of the power transfer function [7].

4.2 Power requirements of the passive tag

Another fact which has to be considered is that the tag is passive and it's supply depends on the provided supply from the reader [8]. This means that the tag cannot respond if the provided power falls under the threshold. Furthermore the power consumption of the tag itself depends on the current executed operation which influences the level of needed power [9]. Power consuming operations are especially encryptions/ decryptions [10]. Julien Mercier et al. show the relation between the provided power and the consumption of the circuit [11]. To consider this in the determination of the PTF the tag has to be in a state that is aware of its power consumption. The last point of consideration is the transmission of the data (response), which is realized through ohmic load modulation on tag side. The influence on the modulation is similar to the power consumption of the tag [12].

4.3 System based power-management for NFC

Jianhua Liu et al. describe energy provisioning services. They show that knowing the system can lead to optimization possibilities. Their concept focuses on multi-tag multi-reader application but it can be adapted to this problem [13]. This knowledge can be used to optimize the system in terms of power consumption and stability. This should be especially considered in combination with mobile readers [14]. The challenge is to manage the distributed information and the calculation among the system for power-optimization and usability. The Cinder operating system is an example how such optimizations can be done by including the whole system. This approach is designed for smart phones but the model can be extended to include external powered devices as well [15].

V. EXPERIMENTAL RESULTS

This Section gives an overview over the the practical work, describing how the contributed method is implemented and tested. The overview is split into three parts. The first part describes the implementation and how it was done. In the second part the simulation of the case study is described and the results are shown. In the third part the implementation is deployed on real hardware and the measurement results are shown.

5.1 Case Study: Limiting the physical relation factor

In this case study the PTF-Determinator is implemented on reader-side in the card detection phase. The result of the method is used to scale the magnetic field strength according to the determined PTF. Furthermore, the result is used to limit the physical relation factor x_{max} between reader and tag. When the limit is reached, the system automatically cuts off the power transfer to the tag to save energy. The power consumption and timings are examined in two phases of development. In the first phase, the design is run on a simulation model. In the second phase the design is implemented and deployed on real hardware and measured for verifications in terms of the power consumption and the timing.

5.2 Simulation of the PTF-Determinator

In the first phase the PTF-Determinator is designed, implemented and tested using a simulation model for a NFC-System consisting of reader and tag. The program is based on C++ and includes the functionality described in Section 5.1. The SystemC simulation model is based on the target NFC-System but the possible values for R_{rel} have been modified to show the possibility of the method to approximate the physical relation factor over the whole transmission range. The original target hardware has limited possibilities to alter the value R_{rel}.

The used simulation model has the possibility to provide the current power consumption of its components and the whole system. The model is implemented on transaction layer and is therefore not cycle accurate. The power values are based on measurement results of the target NFC-reader and tag.

The simulation procedure is configured to step through different distances between reader and tag. The simulator assumes that the two coils are oriented coaxial. The procedure is designed to wait until the execution of the PTF-Determinator is finished before the next step is invoked. To deliver more realistic results, a certain time is waited after the detection, which represents the transaction process.

Figure 8 shows the comparison of the physical and the approximated relation factor of the method between the reader and the tag. The steps of the approximation depend on the resolution of the R_{rel} (see Section II.). With the modified hardware (more possible values for R_{rel}) the physical relation factor can be approximated over the whole transmission range.

In Figure 9 the power consumption is shown when detecting a tag with and without the PTF-evaluation. The case of $x > x_{max}$ is shown in Figure 10. The power increase of the central processing unit is simulated with a 10% on reader side while executing the method. The result shows that the effectiveness of the PTF-evaluation depends on the time needed for the data exchange between the reader and the tag. If this time is is smaller then the evaluation time the overhead gets to great to save energy.

Figure 10 shows the result of the simulation in case of the physical relation factor $x > x_{max}$. This leads to a forced cut-off in the power transfer on reader side to the tag. With this method a energy wastage is prohibited.

A comparison of the saved energy in relation to the simulated distance d between reader and tag is shown in Table 2. The saving decreases if the physical relation increases because the transmission power has to be increased to provide enough power for the tag. If the physical relation factor x is higher than x_{max}, then the power supply is cut off to prevent a waste of energy. This leads to a power saving of 44% with the disadvantage of loosing connectivity to the tag. To reestablish a communication, the tag's curent physical realtion factor has to be below the maximum allowed physical relation factor.

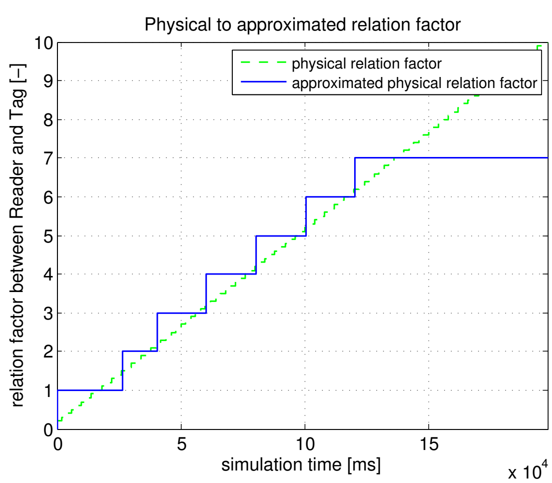

FIGURE 8 - RESULT OF SIMULATION, WHICH SHOWS THE COMPARISON BETWEEN THE PHYSICAL AND THE APPROXIMATED DISTANCE OF THE PTF-DETERMINATOR BETWEEN READER AND TAG

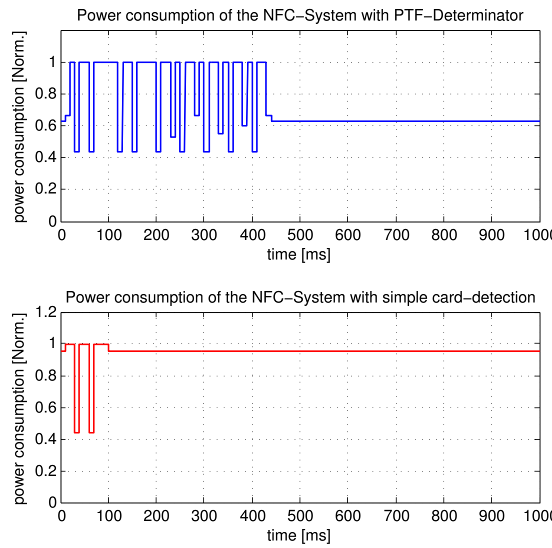

FIGURE 9 - RESULT OF SIMULATION, WHICH SHOWS THE DETECTION OF THE TAG WITH AND WITHOUT THE PTF EVALUATION IN CASE $x < x_{max}$

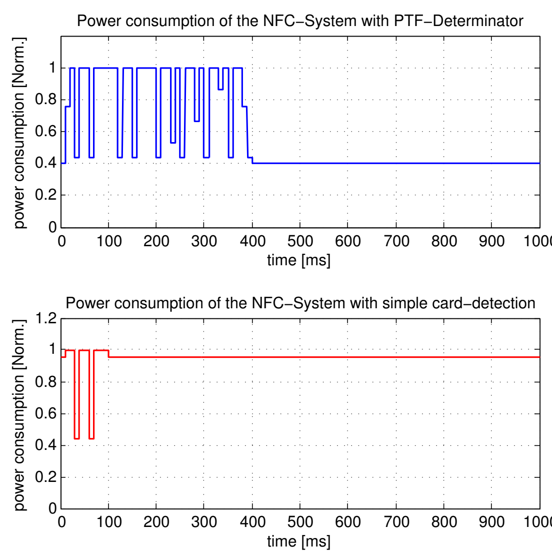

FIGURE 10 - RESULT OF SIMULATION, WHICH SHOWS THE DETECTION OF THE TAG WITH AND WITHOUT THE PTF EVALUATION IN CASE $x > x_{max}$

Simulated distance [cm]	Energy with PTF [Norm.]	Energy no PTF [Norm.]	Energy saved [%]
0-1	0,561	1.000	43.87
1-2	0.663	1.000	33.71
2-3	0.682	1.000	31.79
3-4	0.753	1.000	24.71
4-5 $x > x_{max}$	0.558	1.000	44.17
5-6 $x > x_{max}$	0.558	1.000	44.17

TABLE 2 - COMPARISON OF THE SAVED ENERGY IN PERCENT BETWEEN THE METHOD WITH AND WITHOUT PTF EVALUATION IN THE SIMULATION

5.3 Measurement of the PTF-Determinator

In the second phase the PTF-Determinator is implemented and tested on real hardware. Power consumption measurements are conducted for verification purposes. The program is based on Java and includes the functionality described in Section 5.1. The used set-up is described in Table 3.

Program language	Java
Development board	Beagleboard
Operating system	Android 2.3.4
NFC-Reader	USB-Reader connected to the development board
Measurement device	hardware-in-the-loop measurement-suite

TABLE 3 - SET-UP FOR THE MEASUREMENT

To verify the method and compare the resulting power consumption of the simulation and a real environment behavior, the method is deployed and tested on a target NFC-System. To get the needed measurement data, the hardware is placed into a hardware-in-the-loop measurement suite. The suite is configured to acquire the power consumption of the whole system while the program under test is executed. For comparison a simple card-detection is also implemented and measured. The physical relation between reader and tag is altered to validate the functionality of the program and to evaluate its influence on it's power consumption. The measurement window is set to 5000 ms.

Figure 11 shows the power consumption of the NFC-System with and without the PTF-Determinator. The time needed by the method is about four times higher than the simple card detection. Using the PTF-Determinator the power consumption is about 25 % lower compared to a simple detection algorithm.

In Figure 12, the power consumption of the NFC-System is shown when physical relation factor $x > x_{max}$. This leads to cutting off the power supply of the tag. This cut-off prevents the energy waste invoked by the power loss in the reader circuit and the loose coupled power transfer to the tag. The power consumption is about 50 % lower relative to the simple detection algorithm when the execution time of the PTF-Determinator itself is not considered. To consider is that the operator has to put the tag closer to the reader to reenable the communication which also consumes energy.

The measurement results also show that the influence of the physical relation factor on the consumed energy, invoked by the influence of the reader and tag coil, has to be considered. If the tag is brought closer to the reader, the coupling rises and the needed energy declines. Results show an average decrease of about 13% of the needed energy by closer distances. The execution of the PTF-Determinator results in a time-overhead. Measurements show that the algorithm takes about four times longer than a simple detection.

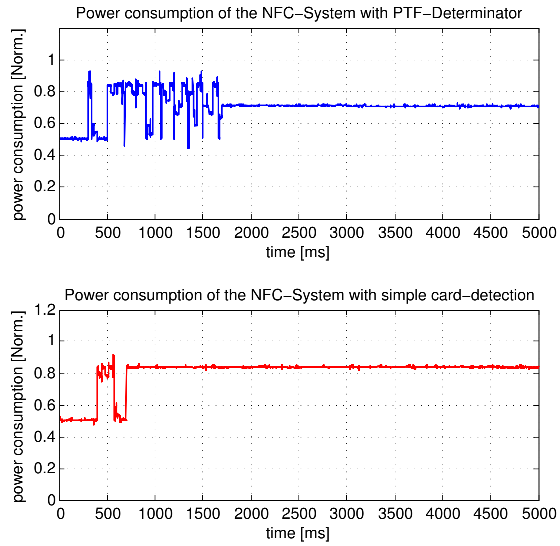

FIGURE 11 - RESULT OF THE POWER CONSUMPTION MEASUREMENT WITH THE CONDITION PHYSICAL RELATIVE FACTOR $x < x_{max}$

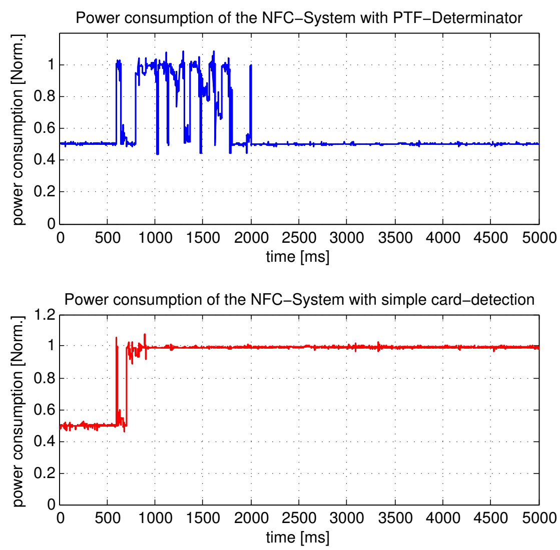

FIGURE 12 - RESULT OF THE MEASUREMENT OF THE POWER CONSUMPTION WITH THE CONDITION PHYSICAL RELATIVE FACTOR $x > x_{max}$

In Table 4, a comparison between the simple detection and usage of the PTF-Determinator is made. It includes the the needed energy of the whole procedure. The needed energies are compared and the saved energy can be evaluated when using the PTF-Determinator instead of the simple card detection. The approximation of the physical relationship is limited on the real hardware. The limitation regards the number of possible steps to scale the magnetic field strength which have been expanded in the simulation which is not possible on real hardware. But it can be shown that the needed energy is 12 % lower when considering the execution of the PTF-Determinator in case of

Physical condition	Energy with PTF [Norm.]	Energy no PTF [Norm.]	Energy saved [%]
$x <= x_{max}$	0.763	0.870	12.29
$x > x_{max}$	0.634	1.000	36.68

TABLE 4 - COMPARISON OF THE SAVED ENERGY IN PERCENT BETWEEN THE METHOD WITH AND WITHOUT PTF EVALUATION IN THE MEASUREMENT

$x <= x_{max}$. An effect can also be seen that a decrease of the physical relation factor leads also to a decrease of the needed energy with a simple card detection. This effect can be explained through the better coupling between reader and tag which has the effect of a more efficient power transmission between them (less losses in the power transmission path). This effect can also be explained through the effect of untuning of the reader coil through inserting the tags coil into the field.

VI. CONCLUSION

This work has shown that the integration of the run-time method to determine the Power Transfer Function (PTF) on reader side is feasible. The energy saving potential by the presented PTF-Determinator, using the PTF to scale down the magnetic field strength, is shown by simulation and verified through measurement. 12% of the energy can be saved in average compared to a simple card-detection method. The implemented feature to set a maximum physical relation factor, by cutting off the power supply to avoid energy consuming transactions, has proven to reduce the energy wastage by up to 40%.

The simulation of the model has given a good estimation of the power consumption to expect on the real target system. Simulation is a good way to test and optimize such a method as the PTF-Determinator before measurement. It also gives the opportunity to reconfigure the hardware (design hardware and software together) to fit the run-time method to optimize the power-consumption even more.

The hardware-in-the-loop measurement has proven to be a good choice to verify the simulated results. By integrating a complete measurable NFC-System, the results can be compared to the simulation and misleadings can easier be detected.

In future work this method shall be improved, focusing on optimizing the approximation of the physical relation factor. Furthermore, this method will be integrated into the communication flow to send periodical updates to react on the dynamic relation between reader and tag while in range (e.g. operator holds the tag in his hand and gets closer to the reader).

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