Novel concepts and devices in RFID based indoor localization using Smart Reader Networks and Intelligent Antennas

Roland Király, Tamás Helfenbein, Sándor Király, Emőd Kovács and Tamás Balla

***Abstract*—Industrial, logistic, and several other applications require the discovery, localization, and tracking of objects using existing passive radio frequency identification (RFID) based systems. We have analysed system concepts, methods, and protocols to enhance accuracy and coverage of RFID localization systems in order to find a moving transponder in an area with high precision over time using reading parameters and also to estimate the location of the transponder with low error rate if the reading information is not available. This research is also focusing on the infrastructure requirements of determining or recovering the location or path of the tag. The extension of the RFID localization beyond the area covered by the RFID reader system could be a solution. This can be carried out by using a special device called "Nodding antenna" or by supplying the transponders and antennas with the information on how to determine or store their respective positions. Advantages and application areas of the Location-on-Tag (LoT) concept and a novel localization method based on intelligent antennas that can enhance reliability and robustness of indoor RFID localization systems and ensure inter-building tag path tracking are introduced in this paper.**

***Index Terms*—Indoor localization, RFID, Intelligent antennas**

I. Introduction

RFID technology is the most prevalently used in identifying objects and the system is gaining more widespread use. This technology can be made viable for tracking objects in real-time and pinpointing their exact location. These solutions are not without difficulties because of radio frequency (RF) interference, and the sensitivity of the RFID tag affixed to the object, even the location of the reader can weaken the signal and its spread. Because of these reasons, determining the position of an object is one of the hardest and most fundamental problems.

Today, RFID-based localization systems are not very reliable therefore they cannot be used in several industrial environments or only with low efficiency. Our concept (LoT - see in section IV) to make it more precise is based on combining different solutions, such as smart algorithms developed for antennas, smart solutions implemented in tags (positioning, triangulation) and a mathematical model applied on the server side that enhances the measurement accuracy and the estimation of temporarily visible location transponders [[1]]. This algorithm performs likelihood probability calculations based on previously saved positions of the tags.

In addition, the transponders can store information that can be used to validate the location of tags estimated by the mathematical model in the following way: when a tag can be seen neither by the antenna nor the antenna connected to the cloud, its location will be estimated using its previous locations. If an antenna, that is not online, can see the tag it writes data into the tag. If an online antenna can see this tag, it reads off the positions of the tag, and sends them to the cloud immediately where the framework interprets them. This semantic information will be attached to the previously stored data and the framework can apply them. The results will be compared to the values estimated by the mathematical model. This method ensures more accurate measurement. These components, the algorithm of the antenna, the skill of the tag that can localize itself, and the mathematical framework, can be combined with the concept of LoT. After working out the model, a special smart tag has been prepared that can localize itself using the positions of the nearest antennas. (The system can also be used with standard RFID EPC C1 Ge2 transponders but they cannot localize themselves.) Besides, an intelligent antenna, the nodding antenna, a mathematical framework, and cloud based system have been developed. Smart tags, smart antennas and different frameworks existed previously[3], but our system combines them to increase accuracy. That is the reason why it is difficult to compare other systems.

The combination of existing and novel components and methods enhances the robustness and scalability of the system.

Our system employs fixed antennas to identify the tags affixed to the objects, however the method is also applicable in the case of mobile antennas. During our research we focused on three types of system architectures: A Smart Reader Network (SRN) where the reader antenna pairs connect to a network or server, fixing is done by the intelligent infrastructure, and the data describing the location of the object is created on the infrastructure side. A Smart Tag (ST) where intelligent and active RFID tags are used instead of traditional reader antenna pairs, fixing is done by the tag, and data describing the location of the object is created on the tag side, and a Hybrid System where the two approaches are

R. Király is with Institute of Mathemathics and Informatics, Eszterházy Károly University, e-mail: kiraly.roland@uni-eszterhazy.hu
T. Helfenbein is with Research Lab, Chebio Ltd., e-mail: tamas.helfenbein@chebio.net
S. Király is with Institute of Mathemathics and Informatics, Eszterházy Károly University, e-mail: kiraly.sandor@uni-eszterhazy.hu
E. Kovács is with Institute of Mathemathics and Informatics, Eszterházy Károly University, e-mail: kovacs.emod@uni-eszterhazy.hu
T. Balla is with Institute of Mathemathics and Informatics, Eszterházy Károly University, e-mail: balla.tamas@uni-eszterhazy.hu
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combined.

Several algorithms have been integrated into the system in order to ensure the reliable localization of the objects in extended spatial and temporal domains. The next generation ”nodding” antenna prototype, and operational principles and the algorithms required for their operation and control are described in chapter IV.

Our goal was to find a solution to extend the detection process to permanently or temporarily uncovered areas by upgrading current RFID technologies and possibly by enhancing current RFID localization protocols.

In addition, we have examined how a new generation of RFID antennas and transponders may broaden the detection process. Therefore, RFID systems cannot only determine the presence of the transponder, but can also locate its position with higher accuracy.

The principle of operation of our antenna prototype, called a ”Nodding antenna”, and the potential of the developed novel intelligent control methods - with the suggested modifications of the protocols in order to extend the localization - are also described in this article.

Moreover, we also outline our plans on how we imagine the transmission and the storage of information required to determine the position of transponders, incorporating the Antenna Information Broadcasting (AIB) technology developed by Bánlaki, Hoffman, and Juhász [2]. The development of the novel antenna and the control algorithms are also presented in this article. They complement the localization with the transmission of information relation to the location of the transponders, and thus the system is capable of indoor localization without GPS based information (which is typically not available in indoor environments).

The system described in this article can be considered novel since it combines the RSSI-based distance measurement and direction detection [1] by using mathematical methods (likelihood functions[4]) and also implements new technologies, prototypes and models in the field of hardware development.

II. Related work

There are systems based on measuring the received signal strength indicator (hence, it will be referred to as RSSI), and also ones that accomplish either indoor localisation or introduce new models and different techniques. The most popular techniques are lateration, triangulation, statistical interference or simple Min-Max localization [6], [7], [8], [9].

The Multilateration is a simple range based decentralised algorithm [6], [9] based on geometric principles. This algorithm collects the beacons' messages and estimates the distance between the nodes and the beacons. There are some range-based algorithms, such as the ROCRSSI [10] and the Min-max, and some range-free algorithms, for example the Maximum Likelihood (ML), that are based on classical statistical interference theory [11], [12]. There are a few published papers that combine a variety of techniques and apply them as a uniform system for localisation.

In order to localize an object, perception based localization can be used. It binds the position of the object and the infrastructure node while the object is close to the node. In most cases and applications this resolution is not sufficient.

Using only perceptional sensors and RFID based systems, it is relatively difficult to determine the position of an object accurately.[13] RFID can also be used as a perception based technology, and there are possibilities of expanding the perceptional capabilities of the mentioned devices (RFID readers, antennas, antenna networks, and transponders) with the implementation of intelligent algorithms.

Joho et al.[14] incorporated the signal strength into the sensor model to improve the mapping accuracy of RFID tags. Ran Liu et al.[15] used a 3D sensor model and a pair of antennas to estimate the 3D positions of the RFID tags. They installed two antennas at different heights on the robot to solve the ambiguity problem of heights estimation introduced by antennas placed at the same height. Germa et al.[16] combined RFID measurements with visual information to track people and other object using a mobile robot in a crowded environment. In their case, the RFID system was used to determine the direction of the object and its readings have to be fused with a vision algorithm to get a better estimation of the position. Deyle et al.[17] presented a solution that generated the RSS image of a tagged object for manipulation tasks of mobile robots. They constructed this image by rotating (for example panning and tilting) a mobile antenna and recorded the signal strength at the same time.

III. Location on Tag (LoT) concept

A Smart Reader Network can be extended with offline or temporally online Smart Readers that can only be manipulated with the tags using read and write operations. This alleviation allows the extension of the network to large areas without the need of infrastucture but temporally reduces accesibility to the location information. The concept of Location-on-Tag (LoT) enables storing and managing location information using offline readers until an online reader gathers the whole path.

Therefore, LoT means that the location information can be written into the memory of the given transponder by the reader-antenna pairs placed on the travel path of transponder. The method is as follows. Each pair along the path:

- reads the memory of the transponder containing the list of the previous locations,
- saves the list of the previous locations, and
- writes the current location information to the memory.

This is also possible in multiple phases which are a chance to write more than the status into the memory of the transponders. Accordingly, with every tag movement between different discrete locations that are covered by different antennas, the given antenna saves the previous positions and writes the current one into the tag memory. During this operation the antenna-reader pair sends the localization information to the edge server connected to the system, and stores the information about the position of the given transponder. This information is visible if we have security access.

Assuming that we have a set of reader-antenna pairs $RA = \{RA_1, .., RA_n\}$ and an RFID tag T, and a discrete time t_i

when the tag has appeared at the given antenna-reader pair RA_i.

RFID transponder memory can be organized as a circular buffer of location information. The buffer has a dedicated memory address that contains a pointer (BP) to the current location.

We can represent location information using a labelling function $L : RA \rightarrow P$, thus $L(RA_i) = L_i$. Here, P has a finite number of elements and $P \subset \mathbb{N}^+$. The size of a position element (S_T) in bytes can be calculated as follows.

$$S_P = \lceil \frac{\log_2 |P|}{8} \rceil = \lceil \frac{\log_2 n}{8} \rceil \quad (1)$$

If the size of the given tag T memory in bytes is S_T, the maximum number of the positions that the tag can store in the list is

$$c = \lfloor \frac{S_T}{S_P} \rfloor \quad (2)$$

.

If we take into account the size of the buffer pointer S_{BP}, we can calculate the corrected number of elements c' in the buffer.

$$S_{BP} = \lceil \frac{\log_2 c}{8} \rceil \quad (3)$$

$$c' = c - S_{BP} \quad (4)$$

The implementation of the extended commands for localization can be performed by RFID read/write commands.

- $READC(t) : c'$: reads capacity c' of tag t according to (3) and (4)
- $READBP(t) : BP$: Reads BP of tag t
- $READPOS(t, BP, i) : L$: Reads i-th position from BP of tag t, $i \in \{1..c'\}$.
- $WRITEPOS(t, BP, L)$: Writes the current antenna label L to position BP in the memory of tag t.
- $INCBP(t)$ Increments BP of tag t according to (**??**).

According to the above commands, the following algorithm can be used to locate tags in the area covered by connected antenna A.

We can also execute $SMART\_FIND(A)$ procedure for all connected antenna.

By using LoT, the system can follow and draw the path of the given transponder. This feature is very useful to solve some indoor localization problems.

In addition to indoor usage, the Smart Reader infrastructure is also suitable for inter-building localization if the reader-antenna pairs are deployed in separate buildings.

Since location data is stored in a circular buffer and the current position is pointed to a buffer pointer (BP) that is also kept in the memory, a data consistency is an important problem to solve. Especially, when the tag moves outside the antenna range, the operations ($READC$, $READBP$, $READPOS$, $WRITEPOS$, $INCBP$) can be interrupted at any time.

If Algorithm 1 is interrupted before $WRITEPOS$, no integrity error will occur. But if the method is interrupted after $WRITEPOS$ is performed successfully, then the buffer pointer BP will turn invalid. The next reader RA_k along the tag path will find the RA_i as the last position in the list.

```
LRA := L(RA)
T:=FINDTAGS(A)
for all valid tag t in T do
  c':=READC(t)
  if c' > 0 then
    LIST:=∅
    BP := READBP(t)
    i:=0;
    while i ≤ c' do
      L:=READPOS(t, BP, i)
      LIST := LIST ⋃{L}
    end while
    Send record (LRA, t, LIST, TimeStamp) to server
    LIST := ∅
    WRITEPOS(t, BP, LRA)
    INCBP(t)
  end if
end for
```

Algorithm 1: $SMART\_FIND(A)$

RFID UHF C1G2 protocol does not contain basic command to write to a memory starting from more than one memory addresses. Thus, we suggest introducing commands $AWRITE$ and $COMMIT$ that can be defined as follows:

- $AWRITE(T, A, D, L)$, where T is the tag, A is the write address, D is the data, and L is the write length. This command writes data to a buffer at tag side and data is not written into the memory until $COMMIT$ is executed.
- $COMMIT(T)$, where T is the tag. This command copies data of all finished $AWRITE$ commands.

To ensure privacy, reader authentication must be used and/or location information must be encrypted before it is written to the tag memory.

RFID has limited encryption and authentication capabilities due to the power consumption of these methods (we should consider a passive tag).

Data can be protected by only allowing authenticated readers to access the location buffer in the memory of the tag. UHF RFID protocols offer passwords (access codes) and custom commands for accessing tag memory and protecting it from unwanted reads and/or writes. Our goal is to find methods for more structured and also more sophisticated reader authentication using current RFID commands or make proposals to extend the protocol.

Data can also be protected by encryption, but due to the limited capabilities it is better if the Smart Reader infrastructure performs the encryption rather than the tag. Except BP, data can be encrypted by method E using a secret key K that can be individual for reader-antenna pairs:

$$C_{RA_i} = E(K, L_{RA_i}) \quad (5)$$

Unfortunately, C_{RA_i} only depends on RA; thus, if one can read encrypted location once (e.g. by putting a fake tag T' to the area covered by RA_i reader-antenna pair) then one can easily track tag T along its path without knowing K.

To eliminate this, we suggest encrypting data using the ID of the tag T too.

$$C_{RA_i,ID_T} = E(K, L_{RA_i}, ID_T) \quad (6)$$

Consequently, decryption can be done using D.

$$L_{RA_i} = D(K, C_{RA_i}, ID_T) \quad (7)$$

Alternatively, an RSA based method can be used to encrypt location data on the tag. Smart Readers can generate a public key PK_T and secret key SK_T for tag T. Using them, the reader can encrypt data using tag PK_T and write it to the tag. Smart Readers can send SK_T to the server to ensure decryption. To ensure encrypted write operations, readers have to know the public key of tag T, thus, PK_T must be written to the tag memory.

According to the encryption schemes above, although one can read encrypted data C_{RA_i,ID_T} and tag ID ID_T or public key PK_T, it is hard to find L_{RA_i} without knowing K or PK_T.

IV. Intelligent antennas

In order to conduct indoor localization, a certain type of intelligent antenna is applied that can change the antenna characteristics by determining the current location of the transponders and using three integrated patch antennas. The antenna is able to discover the transponders at a given location by turning to the appropriate direction (without mechanical movement).

The goal was to expand the localization in order to be able to determine the status of a given transponder, even in such areas that are hard to cover, and if we manage to detect it we will also be able to follow its movement.

Our expectations regarding the antenna were the following: It should not require external power supply, and it's working range of frequencies should be between 865-868 MHz. It must be made in accordance with the ISO 18000 and the EU standards, and it should be able to form at least five different kinds of characteristics in the given output. This is the most important feature of the antenna. This is the device that we use to make the indoor localization more accurate.

The reading range is mostly identical to the local antennas (typically 6-8 dBi), which is also important because of the working standards.

Control of RF signals can be completed by using the GPIO (general-purpose input/output) output of the RFID reader. Control could also be completed via Ethernet connection, but this would mean bringing new protocols into the system, which would further complicate its operation. The overall size should not go above 60 * 60 * 5 cm.

Employing the possibilities extended by the three antennas, the control unit is able to turn its characteristics into three discrete directions. (Electricaly adjustable characteristics.) The controlling electronics accomplish switching between the antennas by addressing the GPIO port located on the reader.

This solution is efficient with three antennas, however, in our case, the set of antennas needs to see in five directions instead of two, which implies that the GPIO port, in its current form, is insufficient to be used as a control unit.

Thus, a new method and device were deployed for switching any number of antennas part. A TP Link has been changed that requires a separate power source but it allows the antenna to be switched through the Internet and does not require manual switching. A virtual switch has been built in the TP link device that can control the antenna directly and get commands by means of standard TCP/IP based communication. The reader linked to the antenna can not perceive this but passes the measured values to the system. As the system sends the command to the antenna orientation, it knows which antenna characteristic received measured value belong to which antenna characteristic. It also knows the relative positions of the given transponders compared to the position of the antenna. This information is stored in the cloud and it is required in the memory of the transponder. Thus a special, dual control is obtained.

We have also designed and developed the software that can control the antennas in a way to be able to store the data collected from the transponders. It can control the special antenna set intelligently and manage to carry out the information spreading orders, which is described in the chapter III.

The Nodding antenna prototype can be turned in two or possibly three directions which is not adequate in all cases. Thus, we decided on the development of a variant of the antenna prototype that is capable of six different orientations. For this purpose, the number of integrated patch antennas were increased to six. With this solution the efficiency of indoor localization can be greatly improved.

Beside the above benefits, we found problems that led us to be able to discover new possibilities and results.

The first one is the control of the antenna. As the antenna uses six separate patch antennas (see in [1]), control of the GPIO port is insufficient to produce different antenna characteristics, because it can only generate low and high signals. This solution is adequate in the case of three patch antennas but with a set consisting of six antennas it becomes inoperable. Thus, the control of the antenna can be done by using an additional tool, namely a modified TPLink type device. This means that the power state of the pairs and triplets of patch antennas that produce different directions is controlled via an Ethernet link and UDP protocol. This controls the antenna on a higher level of abstraction that makes the reading of data and software control easier and more scalable.

The other problem that needed to be solved that the earlier control of the characteristics of the antenna resulted the coverage of separated space segments. For the new antenna, these space segments become overlapped.

In practice, this means that turning the characteristics of the antenna left in the right side space segment we do not receive a signal of 0 dBm strength but some easily measured strength from the the transponder.

This makes the operation of previously used algorithms impossible, but considering the problem it is clear that this attribute would prove to be useful during the measurement of localization information.

The previous antenna, which could be turned in two directions did not use output power information, therefore it can solely provide the information whether the transponder is readable or not. If yes, then the transponder can be considered to be in the space segment where the antenna is directed to.

Using the antenna that scans in multiple overlapping directions we can measure the strength of the signal scattered by the transponders in the space segment with patch antenna pairs.

As every pair can see it with different strengths and the measurements are not simultaneously performed, the position of the fixed transponder can be determined with significantly better precision from the received signals.

While in the first case only the two sides could be differentiated now not only can we differentiate six directions but can even determine the possible location of the transponder within these space segments using the signal strength. At present we are using this type of the antenna prototype to make measurments.

The measurement results of the model and the prototype have supported our assumptions, that its localization ability.

With the contractor produced the prototype we have performed measurements jointly to confirm our thesis.

The frequency range of the antenna is 865 - 868 MHz, the input reflection for the whole band is larger than 13 dB, and the gain is 6 - 8 dBi. Six different characteristics can be configured that cover separate space segments. Its dimensions are 510x360x50 cm. The power controller is made using an RJ45 (ethernet) connector with POE.

The structure of the main beamer is made of a left and right half-circle which means that we have left and right coiled antenna type. The types can be used together, however, better results can be achieved if a standard RFID antenna is used since the transmitter and a nodding antenna are used as the receiver.

Figure 2 represents the block diagram of the antenna. On the left side, the patch antennas can be found and the numbering represent their positions in the matrix. For example, patch11 PCB (Simple Printed Circuit Board, the structure of the PCB is not important in this paper.) is the first antenna in the first row. An itegrated patch antenna can be controled by the system software. As it can be seen in Figure 2, one antenna and one controller make up a unit, called patch antenna. On the right side, the controller of the antennas (antenna control unit) can be seen. One patch antenna can be controlled through a standard RJ45 (at present instead of GPIO), Ethernet (PoE) connection by the antenna software (12..48V DC voltage). The functions have been added to the system by changing the TPLink device that also redeems the control of the GPIO antenna.

The antenna with the switching of phases can select exactly six spatial angles.

Because of limitations due to size (the usability of antenna requires them), maximally a patch antenna grid of 3x2 cells can be established on the surface of the antenna. These are situated in a single plane and face forward in a single direction (see in Figure 1).

The setup of the antenna beam with controllable phase shifters with a given possible amplitude distribution results

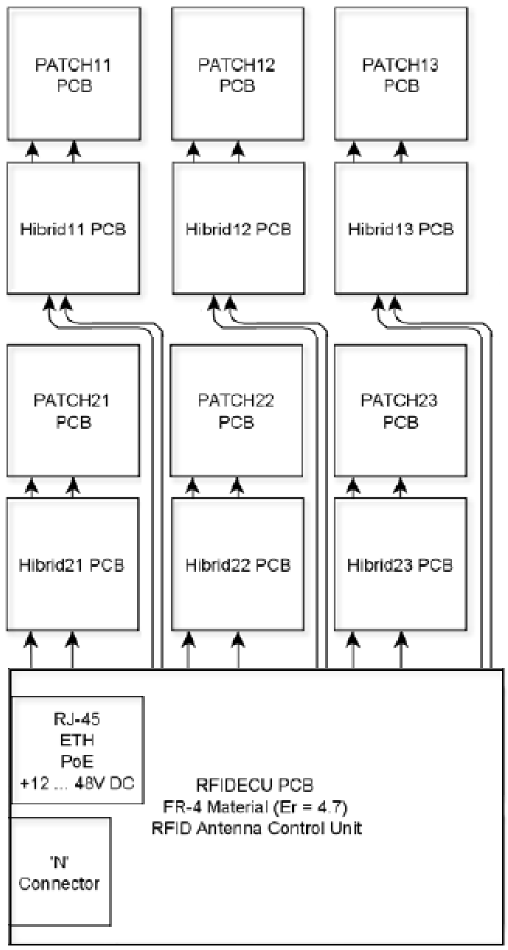

Fig. 1. Integrated patch antenna set

in the following directions:

- Beam looking at $-30°$, with distance of 210, 150, illuminance of 0,5 - 1, 0,75, and phase of 180, 270, 40, see in figure 2.
- Beam looking at $0°$, with distance of 210, 150, illuminance of 0,5 - 1, 0,75, and phasee of 180, 270, 40, see in figure 3.
- Vertical beam looking at $0°$ - with distance of 210, 150, illuminance of 0,5 - 1, 0,75, and phase of 180, 270, 40.
- Beam looking at $30°$ - with distance of 210, 150, illuminance of 0,5 - 1, 0,75, phase of 180, 90, 30.
- Beam looking at $15°$ - with distance of 210.150, illuminance of 0,5 - 1, 0,75, phase of 180, 270, 40.
- Switching on all patch antennas of the antenna system produces behaviour similar to standard RFID antennas.

If we consider an intelligent antenna control logic which can set antenna characteristics to d different directions $\{A_0, .., A_{d-1}\}$, the control logic can switch them using the round-robin method. The switching logic can be implemented using the following formula:

$$A_{current} := A_{((current+1)(\mod d))} \tag{8}$$

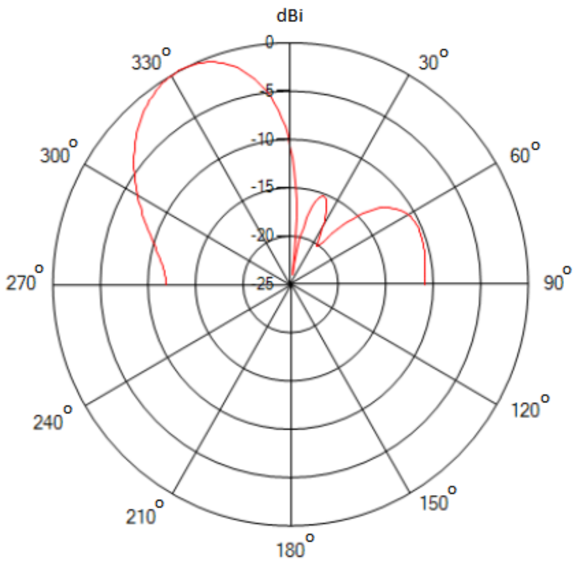

Fig. 2. Beam looking at $-30°$. The red curve represents the covered area. (Measured values.)

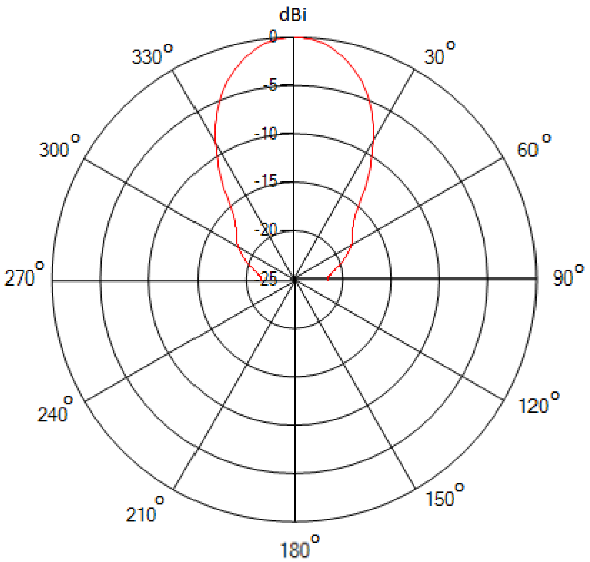

Fig. 3. Beam looking at $0°$. The red curve represents the covered area. (Measured values.)

It is possible to extend our LoT command set with commands for intelligent antennas. These can be implemented using basic antenna commands.

- $NODDING(A)$: *bool*: TRUE if A is a Nodding antenna.
- $ANTINIT(A)$: d: Initializes the controller logic of Nodding antenna A and sets direction to A_0. Returns the number of directions d.
- $ANTLOOK(A, d_i)$: Changes the antenna characteristics of Nodding antenna A to i ("look at i-th direction");
- $ANTNEXT(A)$: d_i: Sets the next direction of Nodding antenna A and returns with its number d_i.

$d := ANTINIT(A)$
$d_i := 0$
while $d_i \leq d$ **do**
  LRA := $L(RA_{d_i})$
  T:=$FINDTAGS(A)$
  for all valid tag t in T **do**
    c':=$READC(t)$
    if $c' > 0$ **then**
      LIST:=$\emptyset$
      BP := $READBP(t)$
      $i := 0$
      while $i \leq c'$ **do**
        L:=$READPOS(t, BP, i)$
        LIST := $LIST \bigcup \{L\}$
      end while
      Send (LRA,t,LIST, TimeStamp) to server
      LIST := $\emptyset$
      $WRITEPOS(t, BP, LRA)$
      $INCBP(t)$
    end if
  end for
  $d_i = d_i + 1$
  $ANTLOOK(A, d_i)$
end while

Algorithm 2: $SMART\_FIND\_NODDING(A)$

According to the above commands and the $SMART\_FIND\_NODDING(A)$ procedure, cyclic reading can be used for localization with both Nodding and normal antennas.

The antenna broadcasts in the following ways. First, it performs a detection check in all possible area sections that the patch antennas can separate from each other (one-by-one, in order), which means that it detects the transponders that are currently there, and it stores their identifiers with the help of the control software. In the next step, if there is previous information in the transponder, it saves it in a different memory block of the tag memory and writes the current position of the detected devices into their memories. It repeats this procedure in all possible area sections and then restarts with the first one after the configured synchronisation time has been reached.

In the case of detecting a tag with more then one antennas, there are three options (naturally, in the order they are written down):

- we attempt to determine its location from the information that was previously written to the transponder,
- we decide which discrete area section the transponder is currently from the the calibration data of the given location and measuring the received signal strength (RSS),
- if the transponder is a Smart Tag its information will be read.

- if neither can be done, then it is possible to determine the most likely location of the transponder we are looking for with our mathematical subsystem.
  The subsystem should be able to calculate the coordinates of the transponder (or maybe even a moving reader in the future), that is fixed in the system. These calculations are based on the previously stored detections (see in [1], [4]). The subsystem attached to the localization framework is not able to perform the localization alone but can be used to estimate the location of the given transponder in the case of either receiving uncertain information or undetectable space parts. We are currently working on developing the subsystem based on mathematical foundations and according to our results this kind of localization method can be used as an independent subsystem.

It was necessary to know, whether the data written on the transponder by the previous antenna must be stored or it is needed to make it possible to set the value of this data in the given system (SET). By using this algorithm, it is definable which area section the transponder comes from and what its current location is.

In this case, the antenna informs the transponder about its own location, and through it, to the other readers or a nodding antenna records where the transponders are located in the given space.

Both solutions can be used for the extension of the RFID based identification. In the first scenario, a predefined number of transponders (5 tags/cell) can be placed in a closed area where the readers and the antennas are fixed and configured on every important control point. The antennas spread their current status onto the transponders by broadcasting, transmitting the information needed for every other reader that wishes to gather data for indoor localization as well.

In the area that is covered this way, we can even use a simple handheld reader to gather information about the status of every transponder all along the way, which can then be processed by the navigation software that is integrated into the reader, and we can navigate the user of the system to the appropriate direction. During our research, we have also developed navigation software and it worked according to our expectations. (In this phase of the research, the information required for determining current status was written to the transponders, used for navigation, manually by using an another handheld reader before putting out information but considering the proof of theorem it is irrelevant.)

In the second case, we can monitor the status and the movement of each device equipped with a transponder and this movement can even be presented in a graphical display (we have software development project in this field).

There is a third aspect that is connected to the social acceptance of RFID. In the described situation, the transponder contains information about its path so that it can only be read by readers that have permission.

This option could be influenced by the small memory capacity of the transponders, but if we write all the positions of the path using a few bits for encoding, we can track their movements in a relatively large area. If we place reference points along the path, that save and store information that belong to the transponders, whose memories are almost full, in database in the edge server of the system and assign an identifier and an authentication code (with password), the memory of the tag can be deleted so it is suitable to travel further on the path without a third party having access to this information. The user who owns the transponder can permit or prohibit the reading of the location information.

In contrast, in our model the RSSI value is not the most important factor. In addition to the measurements, the space can be separated by changing characteristics of the antennas that allow the determination of the position of the transponder relative to the position of the antenna. The resolution depends on the quality and quantity of antennas. On the other hand, the previous positions of transponders are stored in them so it can be followed and used as additional data for the analytic system that is connected to the antenna.

V. Localization framework

The methods developed and presented can be combined effectively for the purpose of implementing RFID-based localisation efforts.

To enhance the possibility of finding the location of the tag, the methods can be integrated into one system. In the case of the Smart Reader localization method using LoT, the locations (path) are in the tag memory, thus, Smart Readers can recover the entrie path when the tag enters to the Online Readers area.

If it is known that the tag is in the area but it cannot be read for a while (e.g. because it is temporary in an uncovered area), its position can be still estimated using the mathematical framework. Using these methods, location can be determined or estimated in all cases and at all discrete times. This combination of localization methods is suitable for various indoor and outdoor localization tasks.

An algorithm that performs likelihood probability calculations based on the previously saved positions supports the system. This estimates the current position of the tag in case it cannot be seen temporarily or it has disappeared. It is also able to complement the path with estimates when the tag cannot be temporarily seen.

Three data sources are available for finding the position of the tag: data measured by the tag, data measured by the nodding antenna and the mathematical subsystem. From these three data sources, it is possible to pinpoint the position of tag even in extreme circumstances, for example high shading or poor coverage. The system can cover huge areas such as airports or train stations.

We use antenna side RSSI measurement based detection, self-localisation in the tag-side, as well as novel mathematical techniques to support the localization [1]. This article analyses the entire system components of the Smart Reader Network.

The localization framework is presented in figure 4.

The principle of the developed framework is as follows: the system divides the space into six parts in two dimensions with the help of the the nodding antenna. The transponder is detected in each of the obtained subspaces but at different strengths, thus the location can be determined.

Since this resolution is not sufficient, the location of the transponder can be determined approximately in a subspace by

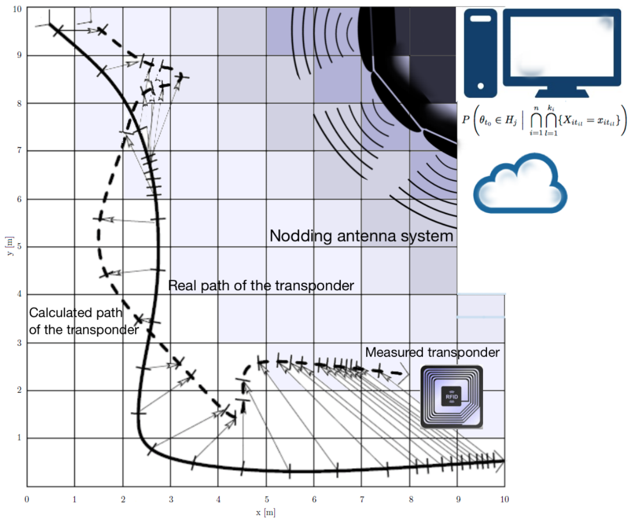

Fig. 4. The system architecture. (One grid covers 1 m^2 area in real life.)

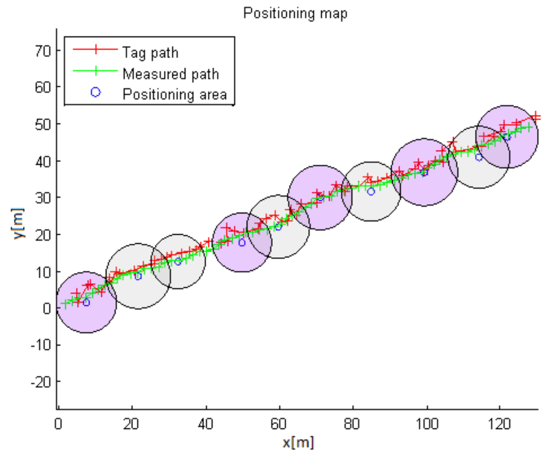

Fig. 5. Localization map with path(green), measured positions(red) and positioning areas: online (purple circles) and offline(grey circles)

using both the calculations of the mathematical subsystem [1], [4] and the previously measured positions of the transponder that are stored in the cloud. The location of the transponders can be estimated by the stored data and the mathematical calculations even if the transponder is temporarily not seen by the antennas and readers. The algorithms applied to complete the mentioned functions are discussed in this article. The tag-side (ST) localisation will be published in our next article.

VI. RESULTS

The error of a localization system can be defined as the (Eucledian) distance between the current position and the estimated position of a given object (or an RFID tag in this case). The error of the RFID localization system varies over time. Between measurements, when a tag is not visible for any online readers, only an estimate of the position can be given. The precision of this estimated position strongly decreases over time. In the case of the LoT concept, the offline smart readers can locate the tags and the next online reader can reestimate the position using the location and time information stored in the tag memory. Thus, the LoT concept enhances scalability and reduces localization error in RFID systems.

We analyzed how can LoT method increase localization accuracy in a positioning system using simulation. As can seen on Figure 5 we assumed online (purple) and offline (grey) localization areas with along the path moving transponder. A localization accuracy for a system with positive deviation ($\sigma_p > 0$) is used. Path (green) is generated by a random walk on the positioning map and localization error using Gaussian with $\sigma_p > 0$ is added (red). The tag is only measurable in any (online or offline) localization area.

The positioning error can be defined as a function of the time. In time t, the squered norm of the difference of actually (in time t) known position $(m(s,t))$ of time $0 \leq s \leq t$ and the position $m(t)$ in the same time:

$$E(t) = \sum_{s=0}^{t} \|m(s,t) - p(s)\|^2 \qquad (9)$$

Using values above, localization error of the systems with and without using LoT method was calculated. We simulated 40 points in a path and generated 10 localization areas using k-means clustering of path points (Figure 5). The areas are divided to online (purple) and offline (grey) area groups.

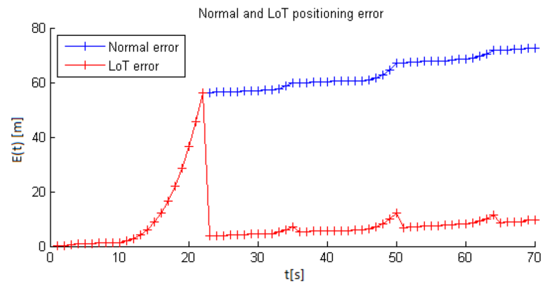

Fig. 6. Localization results with and without LoT method

$E(t)$ is calculated over time and the results can be seen in Figure 6. This means that the total error is reduced by 5.7 times with LoT method.

The accuracy of the localization is affected by other tags nearby, thus, a minimum distance of 20 cm is selected empirically. However, this criterion solves the field drain problem, the read time increases with the number of the tags. We did not focus on large tag numbers in this research, therefore measurements is are done with a maximum density of five tags per localization area.

A novel antenna type has been implemented in order to improve the reliability of the localization procedure and provide extended information on the transponders detected by the antenna that not only determines the status of the transponder in the surveyed area, but also gives information to the transponder (LoT concept).

This process provides an opportunity for us to determine the status of a transponder assuming that the developed control software of the reader writes the identifier of the given sector of the area onto the transponder (using LoT method) for each case of an area covered by changing characteristics. If the antenna notices the same transponder at another location at a different time, it places the previous area section identifier to another memory address then writes the current identification into the memory as well.

These are complemented by the localization system operating on a mathematical foundation [1] that can pinpoint the exact location of objects using the measured and stored positions and RSSI (Received Signal Strength Indicator) values unlike previously known models.

The system can calculate the actual position of the given transponder when the transponder is temporarily covered by something. This calculation is based on the previously stored detections. Figure 4 shows the valid and the measured route of an experimental transponder detected by the system. The route 1 (continous curve) and a characteristics estimation (dotted line). The current and estimated positions at the same moment are connected by arrows. The squared error for the estimation is commonly 5.8 cm (see more in [1]).

As a solution for the aforementioned expectations, a web-service has been implemented in Java programming language observing REST (Representational State Transfer) principles. The chosen service application sever was JBoss, since it readily supports the creation of RESTful APIs.

The permanent storage of the detection items is completed inside a database, in our case, this is a PostgreSQL database. Communication between the database and the server is accompolished by the help of an ORM (Object/Relational Mapping). Our choice for an ORM tool fell upon Hibernate.

The implemented version can select the object that is most likely to be localized from the temporarily or permanently uncovered discreet areas.

VII. CONCLUSION

Indoor dynamic positioning problem in RFID systems was presented and current application challanges was described. Current methods and systems for enhancing positioning accuracy of dynamic RFID systems was analyzed.

Novel methods was introduced including Location on Tag concept to reduce positioning error over time by writing known positions to the tag memory along its path. Novel methods for ensuring data security of RFID localization systems was presented.

A novel 'Noddling Antenna' was designed to extend area of coverage and find tags in a more sophisticated way. A Smart Reader Network based positioning method was introduced where the network consists of online and offilne intelligent antennas running a noddling method and Location on Tag readings. A likelihood probability based framework was used to estimate tag positions based on previously saved positions when tag reading cannot be done. A combination of RSSI measurements, the Smart Reader Network framework and the position estimator framework was presented.

Concepts and methods are analyzed using simulations and measurements. Promising results was seen in the RFID positioning scenario. It was found that the novel methods reduce position estimation error over time while increase the precision and the amount of information availiable for a moving RFID tag in a given time.

In the future, by making antennas, transponders, frameworks, and developing more intelligent protocols, as well by employing middleware that applies the novel tools, the RFID technology could be made capable of locating objects more accurately. As a result, many new - currently unknown - applications hopefully will be developed by the RFID technology.

During our research, we paid close attention to both the examination of the dynamic modifying possibilities of the characteristics of the antenna and creating algorithms that can most precisely determine the location of certain objects by the readings of the intelligent antennas that redundantly cover the area. As a side result of our research, it is necessary to make a suggestion regarding to the extension of the EPCGlobal RM (Reader Management) standards, where the localizing ability appears at the level of the Read Point (antenna) instead of the level of the Reader Device (interogator).

By dynamically changing the characteristics of the antennas, we would like to work out a general model in line with upgrading of the hardware and software which results in the commonly used global positioning that could be performed in an indoor environment.

Smart Tag (ST) RFID localization architecture is the inside out version of the SRN solution above. To be able to enhance reliability and precision of localization, our mission is to develop a new type of Smart Tag and a hybrid localization system. This combination could keep the advantages both SRN,ST and the mathematical based localization systems. The tag-side (ST) localisation will be published in our next article.

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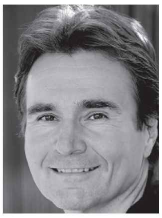
Roland Király In 2002 he graduated from Eszterházy Károly University as an ICT teacher. He gained his MSc in 2005 at Veszprém University. He attended his PhD course at the Institute of Informatics at ELTE University and obtained doctorate in 2015. He has been teaching at Eszterházy Károly University since 2002, now he is an associate professor of the Institute of Mathematics and Informatics. Between 2006 – 2012, he was a member of a research team dealing with Refactoring Erlang Programs at ELTE Univerity. In 2011, he was appointed the Secretary of the Magyar Rektori Tanács Informatikai és Tudományos Bizottság. Since 2013, he has been the head of the EKF RFID/NFC research team. This research focuses on the RFID/NFC technologies and Future Internet. In 2007, 2008 and 2009 – he received scolarship at Eötvös Lóránd University – Institute of Informatics IKKK. In 2013 and 2014, he received Jedlik Ányos Doctoral Scolarship for research activities. This research was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP 4.2.4. A/2-11-1-2012-0001 National Excellence Program.

Tamás Helfenbein received the M.Sc. degree from the Budapest University of Technology and Economics (BME) in 2008. Between 2006 and 2008, he worked on the research and development of information and database systems of large datasets at the Research Institute of Physics (KFKI), Hungarian Academy of Sciences (HAS). From 2006, he is a lecturer of database and information systems courses at Forrai School. Between 2008 and 2011, during he was attended the doctoral school of BME, he worked as a scholar researcher at the Bay Zoltán Foundation for Applied Research (BZAKA). At the foundation and the university, he participated in several international research and development projects on machine vision, image processing, wireless sensor systems and ambient intelligence. From 2008, he teaches laboratory measurement practices at the university. From 2008-2014, he was working as a lead researcher at the Institute of Infocommunications Technology, Bay Zoltán Nonprofit Ltd. for Applied Research (BAY-IKTI), and currently, he is working as a researcher at Chebio Ltd. and focuses on embedded systems, wireless sensor networks, image processing, and machine vision as main research areas.



Sándor Király in 1995 he graduated from the University of Debrecen as an ICT teacher. He attended his PhD course at the Institute of Informatics at the University of Debrecen and obtained doctorate in 2013. He has been teaching at Eszterházy Károly College since 2010, now he is an associate professor of the Institute of Mathematics and Informatics. Since 2013, he has been working as a researcher in the EKF RFID/NFC research team. This research focuses on the RFID/NFC technologies and Future Internet.

Emőd Kovács the M.Sc. degree in teacher of mathematics-descriptive geometry- informatics from the University of Debrecen in 1991. In 2003 he obtained PhD degree in Computer Science and Mathematics, University of Debrecen, Faculty of Informatics. From 1991 he works in Eszterházy Károly College. Emőd Kovács is an associate professor and head of the Institute of Mathematics and Informatics. His research interests focus on Computer Graphics, Internet of Things and Teacher Training. He is a leader of research group, which is care with the virtual world problem in young generation from the teacher of computer science training aspect. From 2013 to 2015 he was a coordinator of research project "Development possibilities in the RFID / NFC technology in the concept of Internet of Things".

Tamás Balla in 2014 he graduated from Eszterházy Károly University of Applied Sciences as an Software Information Technologist BSc. He has attend his Master of Science faculties in Eszterházy Károly University of Applied Sciences, ha has learned as ICT and educational assessment and measurement teacher. Since 2013, he has been working as a researcher in the EKF RFID/NFC research team. This research focuses on the RFID/NFC technologies and Future Internet. Since 2015, he has been a demonstartor in Institute of Mathematics and Informatics and he also has worked in IoT Research Center, Eszterházy Károly University of Applied Sciences as research assistant.