

# Location Information Dissemination Scheme for RFID-based Distributed Localization Systems

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**Abstract**—The availability of location information is essential for context- and location-aware services, which are typically provided by a large number of applications. RFID systems are extensively utilized to provide localization service typically through a centralized and coordinated approach. In this paper, we propose a distributed location information dissemination scheme using heterogeneous uncoordinated mobile RFID readers with the support of inexpensive “memory spots”. In the proposed scheme, mobile RFID readers localize passive RFID-tagged objects and leverage the available memory spots in a given smart environment to disseminate location information. Mobile RFID readers use such memory spots to store tag locations and queries enabling exchange location information without the need for direct communication among each other. We study the behavior of the proposed scheme and compare its performance with a typical pull dissemination strategy through extensive simulations using ns-3. Our results indicate that the proposed scheme outperforms the typical pull dissemination strategy in terms of localization delay and average overhead under different dynamicity settings.

## I. INTRODUCTION

The Internet of Things (IoT) can be broadly defined as a decentralized system of smart objects, which are seamlessly integrated into an information network to provide a variety of smart services over the Internet [1] [2]. This vision unlocks the door for a new generation of applications and solutions which span a wide and diverse range of domains (e.g. smart environments, healthcare, transportation, manufacturing, etc.) [3]. IoT applications are inherently distributed as they are built on spatially disseminated smart objects to offer users more convenient context- and location-aware services. Locating smart objects along with the availability of the location information is a key requirement for IoT applications. In the literature, many wireless technologies such as Infrared, Ultrasound, Radio Frequency Identification (RFID), Ultra Wide Band (UWB) and Bluetooth [4] have been leveraged to provide localization service. Recently RFID, which is one of the key enabling technologies in IoT [5], has attracted significant research interests. RFID has a number of unique features rendering it a strong candidate to provide localization service in an inexpensive, reliable, flexible and scalable manner – key requirements in IoT applications.

A typical RFID system is composed of a set of tags (passive, semi-passive or active) and a set of readers [6]. Several RFID localization systems have been proposed for mobile/stationary tagged objects or mobile readers [7]. For tagged-object localization, objects are localized through a set

of coordinated readers that report to a central server for location estimation. While such systems are cost effective, they are based on a centralized and fixed infrastructure which provides limited scalability and may not be plausible in typical IoT large-scale dynamic scenarios.

In this paper, we propose a distributed RFID-based localization and location dissemination scheme to localize mobile or stationary passive RFID tagged-objects using heterogeneous uncoordinated mobile RFID readers. The system uses a minimal inexpensive and flexible component known as “memory spots”. A memory spot is limited storage and processing device that can use WiFi, Bluetooth, Zigbee or RFID technology. Memory spots are used to disseminate passive RFID tagged-objects’ locations and to exchange location queries; providing high location information availability with lower overhead<sup>1</sup>. In the proposed scheme, readers periodically interrogate tags in their vicinities and synchronize tags’ location information with memory spots they may pass by. In the synchronization process, a reader: (1) updates the memory spot with interrogated tags, (2) obtains location of tags beyond its interrogation zone and (3) either replies to or carries on and propagates location queries that may exist. Carrying a query allows rapid propagation of such query towards other memory spots. Readers interested in the location of a tag can interrogate the nearest memory spot to pull location information obtained from other passing readers, or to register a location query. Specifically, we contribute by:

- leveraging heterogeneous uncoordinated mobile RFID readers to localize surrounding tags through indirect cooperation;
- introducing the concept of “memory spots” – a minimal inexpensive and flexible component to maintain location information availability; and
- designing a distributed protocol for location information dissemination amongst RFID readers through the memory spots.

The remainder of this paper is organized as follows: Section II reviews the related work and motivates our approach. Section III defines our assumptions and explains in detail our proposed scheme. Section IV discusses some practical considerations. Section V presents performance evaluation and results analysis. Finally, conclusions are provided in Section VI.

<sup>1</sup> For convenience, we use the terms tag and reader to represent passive RFID-tagged object and mobile RFID reader, respectively.

## II. RELATED WORK

RFID systems have been extensively utilized to localize mobile or stationary objects, these are broadly known as tag localization systems. In addition, the possibility of having shared memories in a given environment persuaded researchers to take advantage of such resources in data exchange [8], smart transportation [9] and cooperative localization [10].

In tag localization systems, objects are identified by RFID tags either active or passive to be localized through a set of coordinated RFID readers which detect tags and report detection information to a central server for location estimation [11]-[16]. Some systems support coordinated readers by a typically large set of reference tags to enhance the location estimation as in LANDMARC [11] and its enhancement in [12]. In these systems, the location server compares a tag's Received Signal Strength (RSS) at the readers with those of reference tags and estimates the tag location based on the locations of the  $k$ -nearest reference tags. Similarly, the schemes VIRE [14] and L-VIRT [15] use virtual reference tags instead of dense deployment of reference tags. VIRE [14] for instance, calculates the RSS of each virtual reference tag based on the RSS of surrounding reference tags. Then, the scheme compares a tag's RSS to those of reference tags either real or virtual, obtains all credible locations and filters them using an elimination algorithm. The use of mobile readers to localize tagged objects is proposed in [13] and [16] with support of landmarks, where reader-tag distance and tag-landmark distance are used to estimate a tag's location. Such systems, especially those based on passive RFID components, are cost effective. However, central- and fixed infrastructure-based solutions provide limited scalability and may not be practical in dynamic and/or mobile IoT settings. To seek scalability, the study in [17] leverages a set of heterogeneous mobile RFID readers to cooperatively localize tagged-objects in a distributed manner, and introduces a protocol for timely dissemination of location information among the mobile RFID readers.

Recently, shared resources by means of residual memories on passive RFID tags have been proposed for different purposes. For instance, reference [8] proposes a new paradigm to exchange data among a group of RFID readers by using tags' resources as a virtual channel. Similarly, the approach in [10] uses tags' resources to store spatial information obtained from different readers for distributed localization. The objective of our work is to design a distributed location information dissemination scheme for RFID-based distributed localization systems; working on increasing location information availability with less overhead using minimal inexpensive infrastructure.

## III. LOCATION INFORMATION DISSEMINATION SCHEME

Our approach aims to provide high location information availability in RFID-based distributed localization systems with the support of a minimal inexpensive and flexible infrastructure. Our scheme relies on memory spots that are typically distributed in smart areas to be used by ad hoc readers that are mobile and uncoordinated to disseminate tags' locations and exchange location queries. Fig. 1 shows the general framework of our proposed scheme. The following

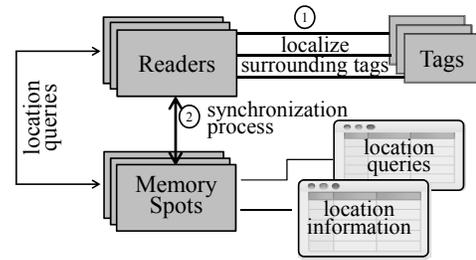


Fig. 1: General framework of the proposed scheme.

subsections detail the scheme's components, assumptions along with the exchanged information and scheme's operation.

### A. Scheme Components and Assumptions

As represented in Fig. 1, the operation of our proposed scheme depends on three main entities: (1) *Tags*, representing the objects to be localized, which can be either stationary or mobile and are identified by passive RFID tags, (2) *Memory Spots*, which represent the available memory spots in a given environment offering information storage and retrieval and (3) *Readers*, representing the ad hoc uncoordinated, dynamic and heterogeneous RFID readers, which can localize surrounding *Tags* and update *Memory Spots* accordingly. Each *Memory Spot* holds two types of information: location information and location queries. Location information contains the estimated positions of interrogated *Tags*. This information is created and periodically updated by passing *Readers*. Location queries hold queries about *Tags* that are of interest and need to be localized. Location queries information is updated either by a *Reader* communicating with a *Memory Spot* to pull location information, which is not currently available or by a passing *Reader* carrying a location query from another *Memory Spot*. In this work, we assume that *Readers*, as mobile devices, can acquire their own locations via one of the positioning systems for mobile devices. Readers can interrogate surrounding tags and communicate with and update all shared *Memory Spots*.

### B. Scheme Operation

We define two events: *localize* and *synchronize* which are conducted by *Readers* such that each *synchronize* event may witness multiple *localize* events. At each *localize* event, a *Reader* interrogates surrounding tags; generating time-stamped location information about tags in its vicinity. At each *synchronize* event, a *Reader* communicates with any *Memory Spot* it may pass by, updates the location information on such *Memory Spot* and carries location information that needs to be disseminated for interests of other *Readers*. In addition to the two aforementioned events, we define an occasional event, named *query*, which is conducted according to a need. When a *Reader* is interested in localizing a *Tag(s)* beyond its interrogation zone, it checks any *Memory Spot* it may pass by to pull the required location information or to submit a location query to be manipulated during coming *synchronize* events. Fig. 2 explains the schema of location information and location queries on both *Readers* and *Memory Spots*. We describe the *Tags* localization, location query, and synchronization process from the perspective of both the *Reader* and the *Memory Spot* along with an illustrative example.



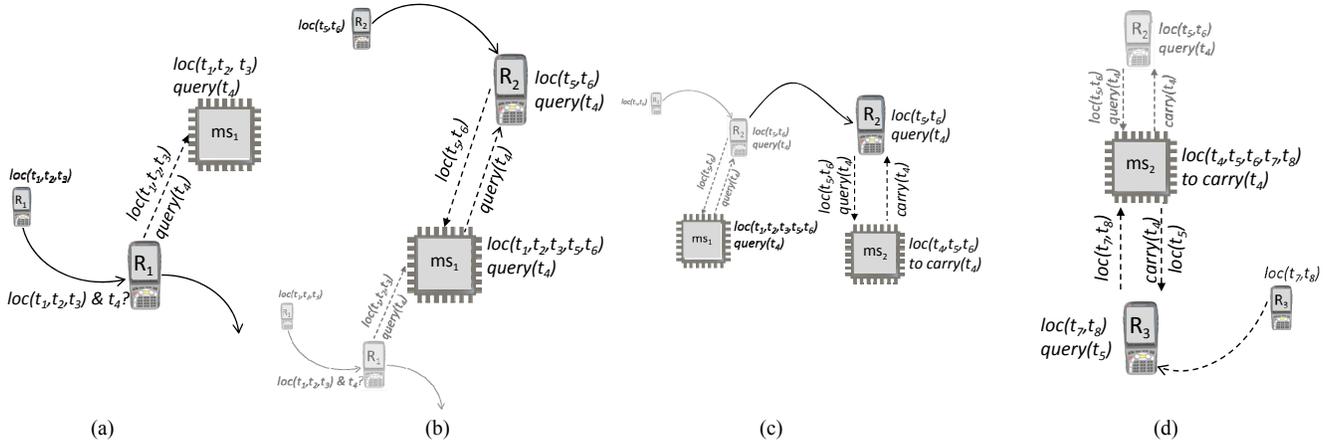


Fig. 3: Illustrative example. (a)  $R_1$  updates  $ms_1$  and register a query about  $t_4$ . (b)  $R_2$  updates  $ms_1$  and carry the query generated by  $R_1$ . (c)  $R_2$  updates  $ms_2$  and disseminates the query generated by  $R_1$ , accordingly  $ms_2$  marks  $t_4$  as "to\_carry" thus,  $R_2$  carries  $t_4$ . (d)  $R_3$  updates  $ms_2$ , looks for  $t_5$  and carries  $t_4$  as well.

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**Algorithm III** Queries filtration Algorithm - run by *Memory spot*


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**Input:** location queries      **Output:** filtered location queries

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set  $loc(Memory\ Spot\_ID) = Memory\ Spot\_ID.location\ information$ 
set  $query(Memory\ Spot\_ID) = Memory\ Spot\_ID.location\ queries$ 
for each query  $q_i$  in  $query(Memory\ Spot\_ID)$  do
    if  $q_i.tag\_ID$  is exist in  $loc(Memory\ Spot\_ID)$  then
        set  $loc(Memory\ Spot\_ID) \rightarrow q_i.tag\_ID.to\_carry = 1$ 
        delete  $q_i$ 
    else if  $q_i.timeout < 0$  then delete  $q_i$ 
    end if
end for
    
```

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Running Algorithm III helps in releasing both the *Memory Spot* resources and the passing *Readers* communication overhead to serve only unanswered queries and stop propagating useless ones. Algorithm IV explains the last action in the synchronization process (i.e. action 4) to be run by passing *Readers* for the purpose of information dissemination. In this algorithm, a *Reader* carries both the remaining unanswered queries in addition to the "to-carry" location information to be considered in the next synchronization process. To avoid any loopback, the queries that are originally created by such *Reader* are ignored. When a *Reader* updates its location information, it only considers time-stamped tags locations irrespective of the reader that localized such tags.

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**Algorithm V** Carry location queries Algorithm - run by *Reader*


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**Input:** location queries      **Output:** updated location queries

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set  $loc(Reader\_ID) = Reader\_ID.location\ information$ 
set  $query(Reader\_ID) = Reader\_ID.location\ queries$ 
set  $loc(Memory\ Spot\_ID) = Memory\ Spot\_ID.location\ information$ 
set  $query(Memory\ Spot\_ID) = Memory\ Spot\_ID.location\ queries$ 
for each record  $ms_j$  in  $loc(Memory\ Spot\_ID)$  do
    if  $ms_j.to\_carry = 1$  then
        add ( $ms_j.time, ms_j.tag\_ID, ms_j.tag\_position$ ) to  $loc(Reader\_ID)$ 
    end if
end for
for each query  $q_i$  in  $query(Memory\ Spot\_ID)$  do
    if  $(q_i.r\_ID \neq Reader\_ID)$  then
        add ( $q_i.query\_ID, q_i.r\_ID, q_i.tag\_ID, q_i.timeout$ ) to  $query(Reader\_ID)$ 
    end if
end for
    
```

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Fig. 3 shows an illustrative example for the operation of our proposed scheme. In Fig. 3 (a), the reader  $R_1$  localized tags:  $t_1, t_2, t_3$  and it was interested in localizing  $t_4$ . Then,  $R_1$  communicated with the nearest memory spot  $ms_1$ , updated  $ms_1$  with locations of  $t_1, t_2, t_3$  and registered a query asking about  $t_4$ . The reader  $R_2$  was in the vicinity of  $ms_1$  as well (see Fig. 3 (b)). So,  $R_2$  updated  $ms_1$  with locations of  $t_5, t_6$  and carried the query that was generated by  $R_1$  about  $t_4$ . As in Fig. 3 (c),  $R_2$ , while it moves, communicated with memory spot  $ms_2$  and did the following: updated  $ms_2$  with locations of  $t_5, t_6$ , pushed the query about  $t_4$  into  $ms_2$ .  $ms_2$  had the location of  $t_4$  which was previously updated by another passing reader, therefore  $ms_2$  turned the *to\_carry* flag of  $t_4$  location to *1*. Accordingly,  $R_2$  carried this location information to disseminate it across other memory spots. As in Fig. 3 (d), at  $ms_2$ , another reader  $R_3$  was interested in locations that was updated by  $R_2$ , so it acquired such information (location of  $t_5$ ) without query registration. In addition,  $R_3$  updated  $ms_2$  with locations of  $t_7, t_8$  and carried the location of  $t_4$  as well.  $R_1$  while it moves, communicated with a memory spot that has been updated by either  $R_2$  or  $R_3$  hence, it acquired the location of  $t_4$ .

#### IV. PRACTICAL CONSIDERATIONS

Our approach suggests that in typical IoT settings, mobile RFID readers along with the available memory spots can be leveraged to provide localization service. This is achieved by allowing the mobile readers to localize surrounding tags<sup>2</sup>, disseminate location information and exchange location queries indirectly by means of memory spots. From the practical perspective two points arise: the popularity of mobile RFID readers which can acquire their locations and the availability of memory spots in a given environment. The popularity of "mobile RFID readers" is a result of rapid adoption of embedded RFID readers in mobile devices due to the great interest by RFID manufacturers and the rapid advancements in antenna design for handheld RFID readers. Such mobile devices can acquire their locations outdoors using GPS-based positioning with typical accuracies of 1-3 meters and indoors using other wireless technologies such as WiFi, Ultra Wide Band (UWB) or RFID with meter-level accuracy.

<sup>2</sup> Maintaining security and user privacy is subject to further research.

On a parallel scope, the market awareness of the business values generated by deploying smart building solutions fosters the growth of the smart technologies that can be deployed in all building types, including residential and commercial. The memory spots as limited storage and processing devices [19] [20] that can use WiFi, Bluetooth or Zigbee technology can play a role in such smart building solutions. A lower cost alternative is a semi-passive RFID tag, which has a relatively long read/write range compared with a typical passive RFID tags, on-board processor and data storage. Mobile devices, according to their different wireless communication capabilities, can use compatible memory spots to disseminate location information or location queries.

## V. SIMULATIONS AND RESULTS

In this section, we evaluate our scheme and compare its performance with the peer-to-peer pull dissemination strategy as proposed in [17] through extensive simulation experiments using ns-3 [21]. We are interested in two performance metrics: (1) *localization delay* which represents the average time the scheme takes to respond to a location query and (2) *average overhead* which represents the average number of messages the scheme's participants exchange to respond to a location query. In our evaluation, we study the effect of two main parameters; number of *Memory Spots* and number of *Readers*.

### A. Simulation Setup

Using ns-3 and based on Graph-Based Mobility Model for Ad hoc networks, we simulate an area of  $200m \times 200m$  containing 14 points of interest. The points are linked using pathways of  $8m$  width through which *Readers* are allowed to move using pedestrian speed ranging from  $0.75m/sec$  to  $1.25m/sec$ . During the simulation, *Readers* are allowed to pause for a period of time (say  $10sec$ ) at each point of interest during their tour. Each *Reader* has a reading range  $4m$  to interrogate surrounding tags and a  $30m$  reading range to communicate with *Memory Spots*. We deploy abundant number of stationary tags (1000) while we consider only a 100 randomly selected tags to be used during generating queries. In addition, we deploy different numbers of *Memory Spots* at points of interest and in the pathways, which have  $30m$  reading ranges and may be partially overlapped. We execute the simulation experiments under different settings in terms of number of *Readers* and number of *Memory Spots*. During the simulation, we periodically allow each *Reader* to be interested in a random tag

and accordingly generate a location query (every  $60sec$ ). In calculating the localization delay, we compute the time it takes for the *Reader* to get a reply and take the average over all generated queries. In calculating the average overhead, we count number of messages exchanged between *Readers* and *Memory Spots* to satisfy a query and take the average over all generated queries. The total simulation time is  $5000sec$ , all values are averaged over 10 different independent runs with distinct random seeds.

### B. Simulation Results

We examine the simulation results for two dissemination strategies; peer-to-peer pull strategy where *Readers* directly communicate with one another to pull location information on demand [17], and our proposed strategy where *Readers* make use of the available *Memory Spots* to disseminate location information with no direct communication.

#### 1) Localization delay

Fig. 4 and Fig. 5 respectively depict the impact of the number of *Readers* and the number of *Memory Spots* on the localization delay while considering 3 different *synchronization* intervals ( $60sec$ ,  $90sec$  and  $120sec$ ). As Fig. 4 shows, increasing the number of *Readers* helps our scheme to rapidly disseminate location queries on *Memory Spots* hence answers more queries with less delay. In case of pull strategy, the localization delay is dramatically decreased but on account of average overhead as seen in Fig. 6. However, the better delay for both strategies is for the scenario of more frequent *synchronization* events. Increasing the number of *Memory Spots* slightly affects the localization delay (by an average of only 3% as shown in Fig. 5). This effect is due to that the travel time of either the location queries or replies may be longer at higher number of *Memory Spots* with less frequent *synchronization*, resulting in increasing the average overhead as explained in Fig. 7.

#### 2) Average overhead

The impact of the number of *Readers* and the number of *Memory Spots* on the average overhead is depicted in Fig. 6 and Fig. 7, respectively. As shown in Fig. 6, increasing number of *Readers* in pull strategy magnifies the average overhead due to broadcasting location queries and replies among *Readers*. While in our scheme, the average overhead is enhanced by an average of 70% even at less frequent *synchronization* when the number of *Readers* is tripled. This enhancement is because more *Readers*, *Memory Spots* are updated in a timely fashion, hence location queries are satisfied with fewer carry and

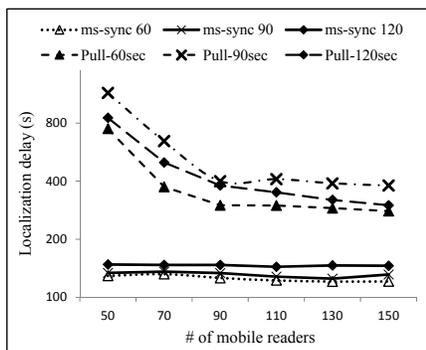


Fig. 4: Effect of # of *Readers* on localization delay (15 *memory spot*).

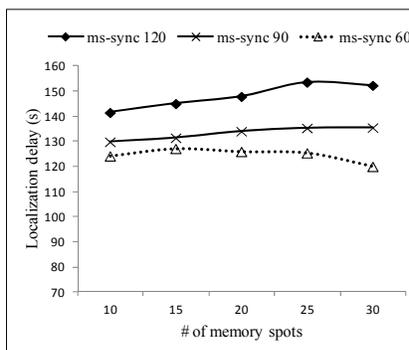


Fig. 5: Effect of # of *Memory Spots* on localization delay (75 *readers*).

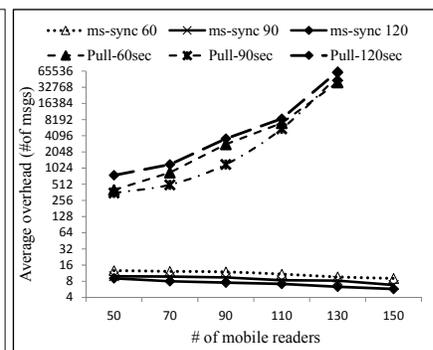


Fig. 6: Effect of # of *Readers* on average overhead (15 *memory spot*).

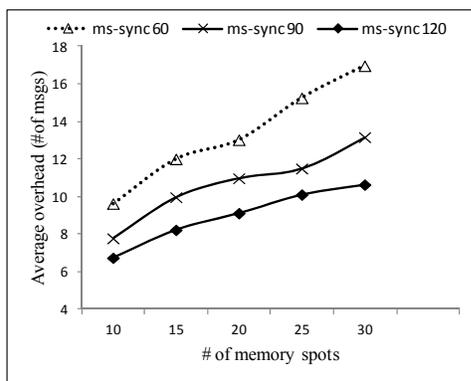


Fig. 7: Effect of # of *Memory Spots* on average overhead (75 reader).

forwarding messages. When the number of *Memory Spots* is doubled (see Fig. 7), location queries and replies are required to traverse more *Memory Spots*, which generates more messages and increases the average overhead accordingly. The better average overhead is for the less frequent *synchronization* where *Readers* maintain their location information and carried queries for longer time before updating *Memory Spots*.

## VI. CONCLUSION

In this paper, we propose a distributed localization and location information dissemination scheme for typical IoT large-scale dynamic scenarios. Our scheme uses heterogeneous uncoordinated mobile RFID readers to localize mobile or stationary passive RFID tagged-objects and provides high location information availability by means of “memory spots”. Memory spots have limited storage and processing capabilities and can use WiFi, Bluetooth, Zigbee or RFID technology to disseminate the locations of passive RFID-tagged objects, and to exchange location queries with lower overhead. The contributions in our approach are that we: (1) employ heterogeneous uncoordinated mobile RFID readers to localize surrounding tags, (2) use memory spots to maintain location information availability and (3) design a distributed protocol for location information dissemination amongst RFID readers through the memory spots. We evaluate our proposed scheme and compare its performance with typical peer-to-peer pull dissemination strategy through extensive simulation experiments using ns-3. Results show that in high dynamic environments, using the pull strategy is infeasible due to its tremendous overhead which inspired us to propose the usage of memory spots as a cost effective enabling infrastructure for distributed location information dissemination. In addition, we concluded that when the number of memory spots increases, generating more coverage overlap, the average overhead is more likely to be high. We plan to investigate the parameters that control the optimal deployment of memory spots in a given environment and application. In our work, we assume that memory spots can only communicate with mobile readers, we plan to investigate the case where memory spots can communicate with one another.

## VII. ACKNOWLEDGMENT

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