Chapter 6

RFID Deployment for Location and Mobility Management on the Internet

6.1. Introduction

Although RFID has a history of more than 50 years in the field of wireless communications, it is only the last decade that it has received considerable attention for becoming a useful general purpose technology in different applications. Actually, RFID was initially used as an automatic identification (ID) system consisting of two basic components: a reader and a tag [WAN 06]. The reader is able to read the IDs of tags in its vicinity by running a simple link-layer protocol over the wireless channel. RFID tags can be either active or passive, depending on whether they are powered by battery or not. Passive tags are prevalent in supply chain management as they do not need a battery to operate. They are cheaper than active tags. This makes their lifetime long and cost-negligible. The low cost of passive tags, the non-line-of-sight requirement, simultaneous reading of multiple tags and reduced sensitivity regarding user orientation has motivated the academia and industry to explore its potentials in more intelligent applications [BAU 05].

Chapter written by Apostolia PAPAPOSTOLOU and Hakima CHAOUCHI.

The Internet of Things: Connecting Objects to the Web Edited by Hakima Chaouchi

As described in Chapter 5, RFID technology is mainly used for identification and tracking applications. In this chapter we study whether RFID technology can be used to enhance network functionalities by combining this technology with existing ones, such as WiFi or any other connecting technology. We investigate RFID deployment for the purpose of two popular and significant network functionalities that are conventionally performed by network-layer protocols, as in IP networks. More precisely, we investigate how this technology can be applied and combined with existing technologies to support *localization* and *mobility management* tasks. This is originally from the RFID point of view, since RFID technology was mainly used for identification and tracking applications.

The significance of location awareness and the requirement for fast adaptation to frequent location changes due to mobility are critical issues that need to be addressed for the success of future ubiquitous and mobile networks. Location information is important for enabling location-based services (LBS) in commercial, healthcare, public safety, and military domains. Furthermore, location awareness can be utilized for improving or enhancing network functionalities, such as mobility management for quality of service provisioning.

Localization and *mobility management* are two concepts that are tightly inter-connected. The need to determine the unknown location of an entity stems from the mobility capability of this entity. On the other hand, managing the issues raised due to mobility can be alleviated by the provision of location-related information.

While determining the location of objects in outdoor environments has been extensively studied and addressed with technologies such as GPS (global positioning system) [KAP 05], the localization problem for indoor radio propagation environments is recognized to be very challenging. This is mainly due to the presence of severe multipath and shadow fading [PAH 05]. Similarly, for mobility support over IP networks, mobile IP (MIP) [PER 96] is the most well-known protocol proposed by the Internet Engineering Task Force (IETF). However, latency delays and losses in IP traffic due to the time needed to perform the handover process are its main limitations. Detecting the movement of the mobile node has been proposed for reducing the handover latency. However, these solutions either introduce an additional message overhead or only apply to specific wireless networks.

Exploring whether and how the RFID can be applied to help both localization and mobility management operations is the main topic discussed in this chapter. In section 6.2, we provide substantial background and literature related to both of these network tasks. In section 6.3 we suggest a conceptual framework for performing them by taking advantage of the key features of the RFID. In addition, in section 6.4 we discuss the main technological issues of RFID that might cause trouble and therefore should be taken into consideration before the design and implementation of an RFID-assisted localization or mobility management mechanism. In section 6.5 simulation-based numerical results provide an indication of the performance of both systems under different configurations. Finally, in section 6.6 we summarize the main points and conclusions of this chapter.

6.2. Background and related work

In this section we provide some background and literature related to the *localization* and *mobility management* problems in an indoor environment.

6.2.1. *Localization*

The localization problem is defined as the process of determining the current position of a mobile node or an object within a specific region, indoor or outdoor. The position can be expressed in several ways, depending on the application requirements or the positioning system specifications. For instance, absolute coordinates, relative or symbolic locations are possible formats. Location information is important for enabling LBS in commercial, healthcare, public safety and military domains. Furthermore, location awareness can be utilized for improving or enhancing network functionalities, such as mobility management for quality of service provisioning.

Localization using radio signals has attracted considerable attention in the fields of telecommunications and navigation. The most well-known positioning system is the GPS [KAP 05], which is satellite-based and is successful for tracking users in outdoor environments. However, the inability of satellite signals to penetrate buildings can cause the complete failure of GPS in indoor environments. For indoor location sensing, a number of wireless technologies have been proposed, such as infrared [WAN 92], ultrasound [PRI 00], WiFi [BAH 00] and ultra-wide band [ING 04]. However, the indoor radio propagation channel is characterized as site specific, exhibiting severe multipath effects and low probability of line-of-sight signal propagation between the transmitter and receiver [PAH 05], making accurate indoor positioning very challenging.

Localization techniques, in general, utilize metrics of the received radio signals (RRS). The most traditional received signal metrics are based on angle of arrival (AOA), time of arrival (TOA), time difference of arrival (TDOA) measurements or RSS measurements from several reference points.

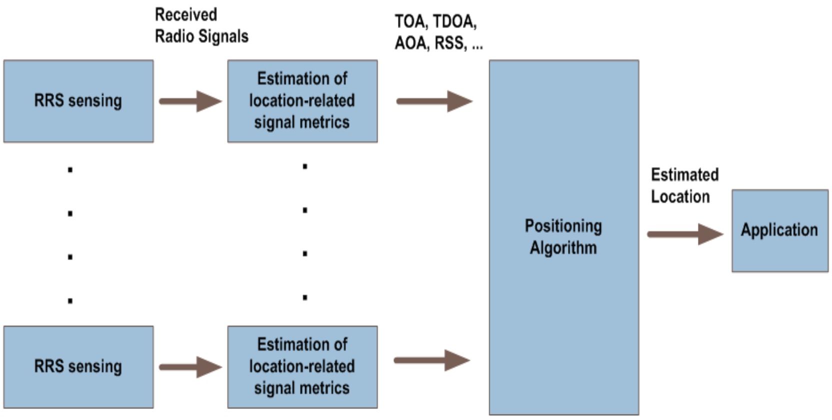

Figure 6.1. *General framework of RRS-based positioning*

The general framework of an RSS-based positioning system is illustrated in Figure 6.1. Radio signals transmitted by the fixed reference points (such as access points or base stations) and sensed/measured by the RRS-sensing devices of the receiver. They are converted into location-related signal metrics, such as TOA, TDOA, AOA and RSS. The reported signal metrics are then processed by the positioning algorithm for estimating the unknown location of the receiver, which is finally utilized by the application. The accuracy of the signal metrics and the complexity of the positioning algorithm define the accuracy of the estimated location.

Depending on how the signal metrics are utilized by the positioning algorithm, we can identify three major families of localization techniques [HIG 01], namely *triangulation*, *scene analysis* and *proximity*.

6.2.1.1. *Triangulation*

Triangulation methods are based on the geometric properties of a triangle to estimate the receiver's location. Depending on the type of radio signal measurements, they can be further subdivided into *multilateration* and *angulation* methods, illustrated in Figures 6.2 and Figure 6.3, respectively.

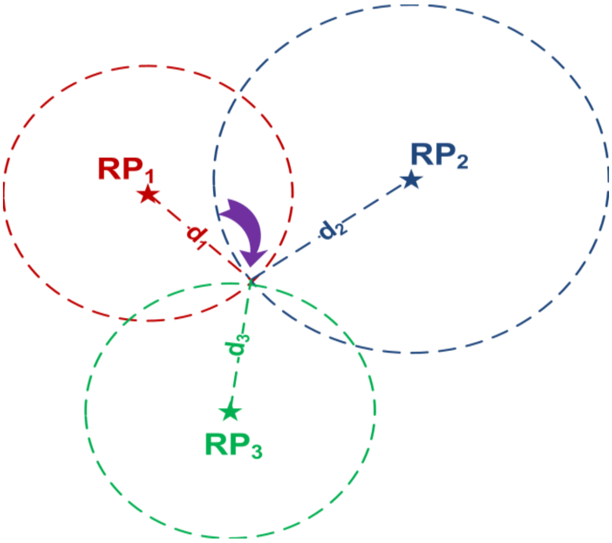

Figure 6.2. *Multilateration positioning technique*

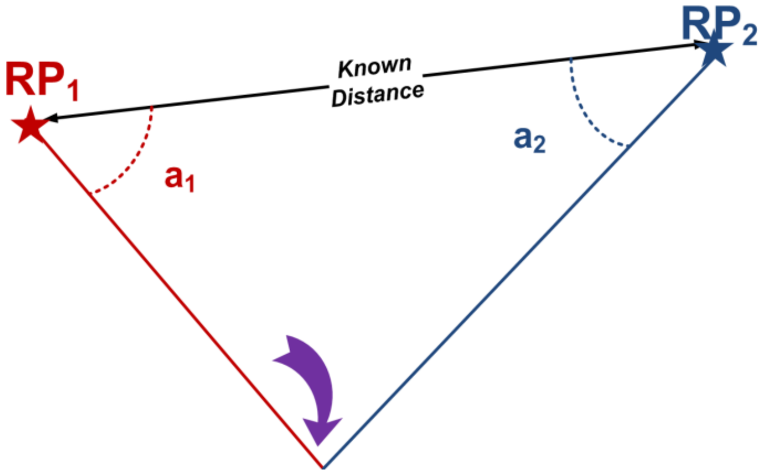

Figure 6.3. *Angulation positioning technique*

In *multilateration* techniques, TOA, TDOA or RSS measurements from multiple reference points are converted into distance estimations with the help of a radio propagation model. Examples of such positioning systems include GPS [KAP 05], the cricket location system [PRI 00], and the SpotON *ad hoc* location [HIG 00]. Models for indoor localization applications must, however, account for the effects of harsh indoor wireless channel behavior on the characteristics of the metrics at the receiving side. These characteristics affect indoor localization applications in ways that are very different from how they affect indoor telecommunication applications.

In *angulation* techniques, AOA measurements with the help of specific antenna designs or hardware equipment are used for inferring the receiver's position. The Ubisense [UBI] is an example of an AOA-based location sensing system. The increased complexity and the hardware requirement are the main hindrances of such systems.

6.2.1.2. *Scene analysis*

Scene analysis or *fingerprinting* methods require an offline phase for learning the radio characteristics in a specific area under study. This signal information is then stored in a database called Radio Map.

During the online localization phase, the receiver's unknown location is inferred based on the similarity between the Radio Map entries and real-time signal measurements. The similarity in signal space can be based either on pattern-matching techniques (deterministic schemes) or on probability distributions (probabilistic schemes).

Figure 6.4 depicts the general mechanism of scene analysis localization. RADAR [BAH 00], HORUS [YOU 05], COMPASS [KIN 06] and WIFE [PAP 09] are fingerprinting localization approaches. The main limitation and weakness of scene analysis methods is due to the frequent environmental changes that cause inconsistency of signal behavior between the training phase and time of the actual location determination phase.

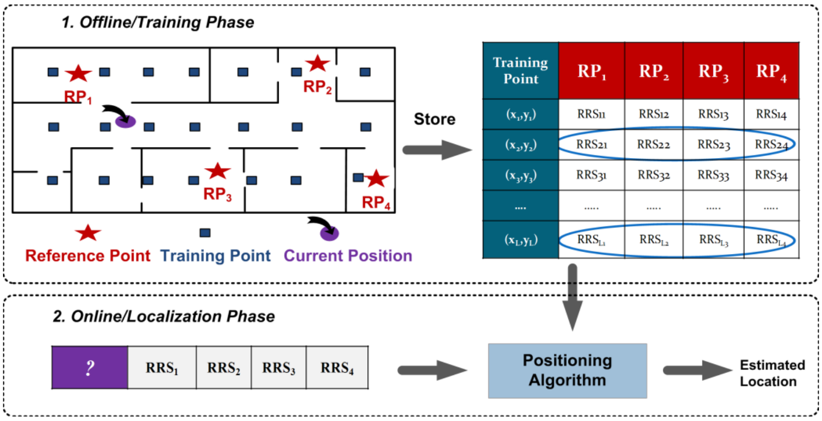

Figure 6.4. *Scene analysis positioning technique*

6.2.1.3. *Proximity*

Proximity methods are based on the detection of objects with a known location, as shown in Figure 6.5. This can be done with the aid of sensors, such as Touch MOUSE [KEN 99], or based on topology and connectivity information, such as in the active badge location system [WAN 92], or finally with the aid of an automatic identification system, such as the credit card point of cell terminals. Such techniques are simple but usually suffer from limited accuracy.

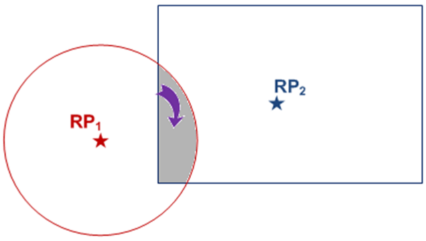

Figure 6.5. *Proximity positioning technique*

6.2.2. *Mobility management*

The second network functionality we are interested in improving with RFID technology is mobility. Over recent years, we have witnessed an increasing demand for wireless access to Internet applications. This is due the remarkable success of wireless networking, mobile computing and the growing popularity of the Internet. Mobility is a requirement not appropriately addressed by the Internet Protocol (IP), however, which was originally designed for static, wired networks.

According to the IP, an IP address has two major functionalities: to uniquely identify a particular terminal in the entire network and for routing the traffic between two endpoints. The IP address is indicative of the IP subnetwork in which the terminal resides. Apparently, the problem arises when the terminal changes subnetworks due to the mobile node’s mobility. Based on this observation, we can conclude that a mobile terminal needs to have a stable IP address in order to be stably identifiable to other network nodes. It also needs a temporary IP address for routing purposes.

IP mobility management has widely been recognized as one of the most important and challenging problems for supporting seamless access to mobile services via wireless networking. The MIP protocol extends IP by allowing a mobile node to effectively utilize two IP addresses, one for identification and the other for routing. While the mobile node changes its access point to the network, handover (or handoff) management enables the network to maintain a mobile node's connection. However, the latency delay during handover causes interruption of the IP traffic, which may be prohibitive for real-time applications. In the following, a more detailed description of both MIP and handover process is provided.

6.2.2.1. *MIP*

The standardized mobility support in IP networks is MIP [PER 96], an IETF communication protocol that is designed to let mobile nodes move from one network to another while maintaining a permanent IP address. This is done through the interaction of a home agent and a foreign agent.

A mobile node is identified by its home address, regardless of its current point of attachment to the network. While situated away from its home, the data packets flowing from a corresponding node are transparently routed via the home agent to a care of address that represents its current location. The main issue when transmitting real-time traffic is non-synchronization of the handover process at the link and network layers.

6.2.2.2. *Link-layer handover*

A Layer 2 (L2) handover occurs because the mobile node must establish a physical connection to a new access point. This is because, due to mobility, the RSS from the mobile node's current access point may decrease, causing degradation of their communication. Even though several protocols have been proposed for different wireless access technologies, we focus on the IEEE 802.11 standard [IEE 99] for its popularity and the availability of numerical results regarding its latency analysis; it is also the vector of wireless Internet today.

According to its specifications, the handover process follows three phases; the handover initiation, the handover decision and the handover execution. It includes three main steps: *discovery*, *authentication* and *association*, as illustrated in Figure 6.6. During the *discovery* phase, the mobile node searches for an access point with a stronger RSS to associate with. This is accomplished through a medium access control (MAC) layer function, called *scan*. There are two modes of scanning: *active* and *passive*.

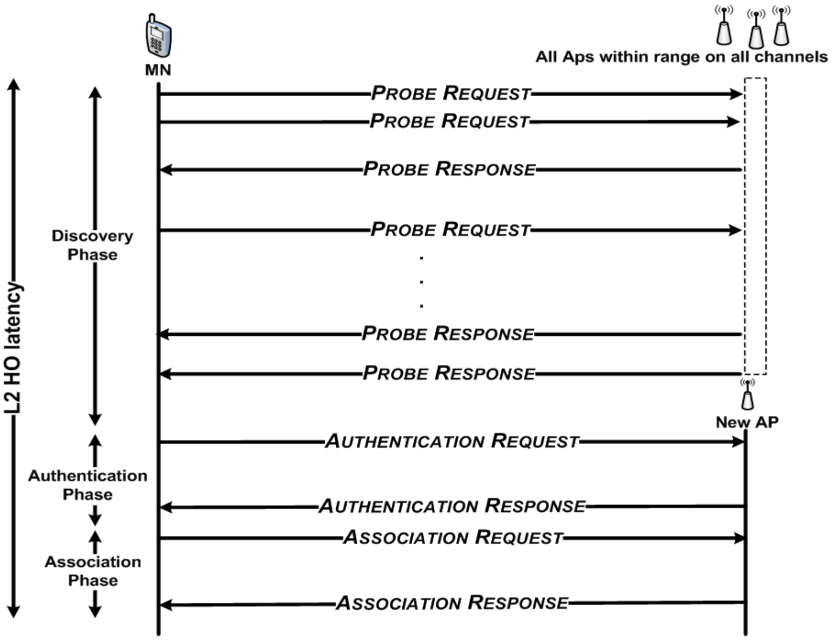

Figure 6.6. *Link layer handover process*

In the *passive* mode the mobile node listens for beacon messages (sent periodically by the access points), on assigned channels. In the *active* mode, the mobile node sends in additional PROBE broadcast packets on each channel and receives probe responses from access points.

After scanning all channels, the mobile node selects a target access point and enters the *authentication* step, which includes the transmission of the mobile node's identity to the access point and the access point's AUTHENTICATION RESPONSE. The L2 handover terminates upon the reception of an ASSOCIATION RESPONSE message.

The L2 handover latency is mainly due to the time needed for the *discovery* phase, since the mobile node has to wait for PROBE RESPONSE messages even if no access points are operating on specific channels. According to the results in [MIS 03] the L2 handover latency is between 58.74 ms and 396.76 ms

6.2.2.3. *Network-layer handover*

If a mobile node roams between two access points of the same subnetwork, no routing issues occur and its session is not interrupted, since the mobile node keeps the same IP address and is already authenticated. However, if the access points belong to different IP subnetworks, the routing subnetwork prefix changes and thus the IP (L3) handover follows the L2 handover. Figure 6.7 illustrates the handover process as described in MIP [PER 96]. It includes three stages: *movement detection*, *address configuration* and *binding update*. The movement detection stage starts after a mobile node has attached itself to the new network at the physical and link layer (L2 handover). In this stage a mobile node detects that it has moved to a new network, based on messages broadcasted by the access routers-access routes (ARs) in either a *passive* or *active* mode.

In the *passive* case, the ARs are regularly sending broadcast ROUTER ADVERTISEMENT messages that contain their identity and their IP addresses. In the ACTIVE mode, the mobile node is sending in addition ROUTER SOLICITATION requests to the ARs regularly in order to discover new point of attachment to the network. The mobile node receives relevant information from the network that will allow it to configure its new temporary address, the care of address and other network settings. Finally, it sends a BINDING UPDATE to the home agent (HA) in order to register its care of address with its permanent address.

The L3 handover latency is mainly due to the time needed for the movement detection phase, which depends on the frequency of the ROUTER ADVERTISEMENT or ROUTER SOLICITATION messages. Statistically, the longer the time between two consecutive messages, the longer it takes the movement detection to be completed. According to results found in [LEE 04] movement detection is on average 36 ms to 58 ms when ROUTER ADVERTISEMENTs are broadcasted every 0.05 s to 1.5 s. Note that the frequent advertisement of AR is also posing the problem of traffic overhead on the wireless link.

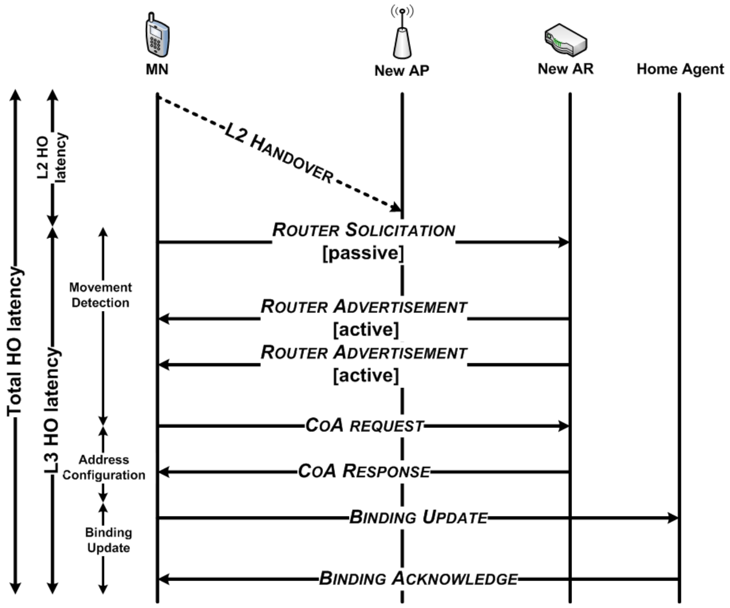

Figure 6.7. *Network layer handover process*

6.2.2.4. *Movement detection process*

Reviewing the current literature, several protocols are proposed for optimizing the movement detection process in order to provide seamless handover, i.e. handoff with minimum delay and consequently less packet loss.

Movement detection mechanisms may be broadly divided into *advertisement based* and *hint based* [FIK 01]. The first rely on the periodic broadcasting of AR advertisements that include mobility-related information. CARD (candidate access router discovery) [CAR 03] is an IETF proposal where an AR announces its capabilities in broadcast messages. In such schemes, there is an inherent trade-off between the bandwidth wasted by advertisements and the movement detection performance. The higher the rate that periodic advertisements are broadcasted; the more bandwidth is wasted by these messages.

Hint-based mechanisms attempt to deal with this bandwidth wastage by relaying on hints or triggers from lower layers. In fast MIP [KOO 05], it is assumed that at the mobile node's terminal link layer triggers are sent to the network layer so that the delay between the L2 handover and L3 handover are better synchronized.

By minimizing the L3 movement detection delay, the mobile node can proactively proceed with its mobility registration at the network level. This, however, implies that terminals can exchange triggers between the two layers, which is not always supported by all technologies; this is more cross-layer design, which is different from the classical seven layers open system interconnection and simplified five layer transmission control protocol (TCP)/IP where layers are not exchanging any information. Moreover, next generation networks are anticipated to be heterogeneous, making *hint-based* mechanisms necessary but difficult to implement.

6.3. Localization and handover management relying on RFID

Radio frequency identification (RFID) is an attractive technology for a wide range of applications. In this section we suggest employing it for achieving accurate *localization* and time-efficient *movement detection*, both of which are critical for the success of mobile and wireless communications. After providing a brief technology overview regarding key features of RFID (for further details see Chapter 2), we describe the concept and mechanism for both RFID-assisted operations; location and mobility.

6.3.1. *A technology overview of RFID*

RFID is an automatic ID system that consists of two basic hardware components: a *tag* and a *reader*. A tag has an ID stored in its memory that is represented by a bit string. The *reader*, which is typically a powerful device with memory and computational resources, is able to read the IDs of *tag*s located within its vicinity by running a simple link-layer protocol over the wireless channel. Various types of tags exist that differ significantly, mainly in their power supply and computational capabilities. They range from dump *passive* tags, which operate without battery but respond simply to reader's queries, to smart *active* tags that contain radio transceiver, memory and a power supply. Thus, passive tags compared to active tags are less expensive and have unlimited lifetime but have reduced read range capability. Due to their low cost, passive tags are anticipated to be a popular choice, especially for large-scale deployment, as in the Internet of Things (IoT).

Communication between a reader and a passive tag is done using either magnetic or electromagnetic coupling. Coupling is the transfer of energy from one medium to another medium, and tags use it to obtain power from the reader to transfer data. There are two main types of coupling – inductive and backscatter – depending on whether the tags are operating in the near-field or far-field of the interrogator, respectively. A key difference between them is that far-field communication has a longer read range compared to near-field communication. RFID systems operate in the industry, scientific and medical frequency band that ranges from 100 KHz to 5.8 GHz, but they are further subdivided into four categories according to their operating frequency: low frequency (LF), high frequency (HF), ultra-high frequency (UHF) and microwave.

Tags operating at UHF and microwave frequencies use far-field and couple with the interrogator using backscatter. Recently, UHF-band passive RFID systems have received a great deal of attention and, thus, we focus our research interest on these tag types.

6.3.2. *How RFID can help localization and mobility management*

The low cost of passive tags, the non-line-of-site requirement, the fast reading of multiple tags, and the relatively reduced sensitivity to user orientation motivated to explore the potential of RFID in solving both problems of indoor localization and mobility management improvement. In the following, we describe the general concept of RFID-enabled schemes.

6.3.2.1. *RFID-enabled localization*

Positioning schemes relying on RFID can follow two basic procedures, depending on the type of the RFID component supported by the target's device, i.e. tag or reader. In fact, in the context of IoT service, mobile devices might be tagged with an RFID tag (e.g. passive); or might carry RFID reader as with the near-field communication technology. We know that a mobile node carrying an RFID reader will be more expensive than a tag. We also considered depending on the IoT service scenario as being either a massive deployment of RFID tags or RFID readers surrounding the mobile device. Again, deploying RFID readers will be more expensive than deploying RFID tags (passive).

Regarding the RFID-enabled localization, if the mobile nodes device is equipped with a tag, a number of *reference readers* are placed in the area, any of the general positioning techniques, i.e. *triangulation*, *scene analysis* or *proximity* can be employed to estimate the location of the mobile node. [NI 04, BEK 07] are indicative positioning systems following this approach.

If the user's terminal is equipped with an RFID reader, passive tags with known coordinates are deployed in the area as *reference tags* and their IDs are associated with their location information. For estimating the mobile node's location, a proximity technique is followed based on the location information corresponding to the *reference tags* detected by the reader embedded in the mobile node's device. [WAN 07] and [YAM 04] rely on the deployment of tags in the area and try to locate a single user who is equipped with an RFID reader. [PAP 09] studies the problem of simultaneous tracking of multiple users equipped with RFID readers.

We focus on the second type of positioning schemes because they are easier to implement, since low-cost passive tags can be deployed in a large extent in most indoor environments; such as a smart floor tagged with RFIDs. Additionally, it is anticipated that future mobile terminals will have a reader extension capability for gaining access to a wide range of innovative applications and services supported by

RFID systems. There are already cell phones on the market that are RFID tag reader enabled.

6.3.2.2. *RFID-enabled movement detection*

For the same reason presented earlier, we believe there will be a massive deployment of *reference* passive tags for the purpose of *movement detection* of a mobile node whose terminal is reader-enabled [PAP 10]. One possible way for accomplishing this is by associating the *reference* tag IDs with network topology information. For instance, each tag ID can be matched to its best point of access according to certain criteria. Then, during the mobile node's mobility, such topology-related information corresponding to the *reference tags* ID retrieved by its reader, can be used for detecting its movement faster. This is because the tags are informing the mobile node about the access points covering the area, and thus the mobile node can also anticipate the handover and at the same time select its next best point of access.

6.3.3. *Conceptual framework*

From an architectural point of view, location determination or movement detection schemes can either be user-based, network-based or a combination. In the first case, each mobile node is responsible for collecting and processing the information necessary for determining its location or detecting its movement. In the second case, a dedicated server is responsible for gathering all required data and taking the relevant decisions that are finally forwarded to the mobile nodes. Processing capabilities, privacy and scalability issues are usually the main factors for selecting the appropriate approach. Here we present a mobile node-assisted architecture as a compromise between the schemes. Each mobile network is responsible for collecting the appropriate information and sending it to the RFID-server, which is in charge of determining the location and the next best point of access of all mobile nodes.

The main network is divided into a set of subnetworks, each of which is served by one AR. Each AR is in charge of a number of access points that are responsible for providing wireless access to the Internet. Additionally, RFID-passive tags are deployed within the floor of the entire area so that a grid of *reference tags* is formed. This is totally feasible in the context of emerging IoT services where ubiquity will take advantage of RFID technology to better consider the environment in computing services. The terminal of any mobile node located within this area, apart from a wireless interface, is also equipped with a RFID reader. Finally, a dedicated server within the network domain, called RFID-server maintains a database for storing information regarding the reference tags and the network. The information stored in the RFID-server is such that it can be utilized for the purpose of both the *localization* and *movement detection* procedures during the roaming of a mobile node.

6.3.3.1. *Training phase*

As aforementioned, the RFID-server maintains a database for storing location and topology information related to the *reference tags*. This database is built during an offline *training phase*. As location information, the location coordinates are associated with the corresponding tag IDs. As topology information, several characteristics can be considered as the most appropriate to be stored depending on the requirements of the network and preferences of the users or network provider. We consider a simple scenario according to which each tag ID is associated with its best point of access. Best point of access covering a specific tag is considered as the AR that is in charge of the access point from which the RSS at that tag's position is stronger, similar to the RSS-based L2 handover. Other decision functions are also possible considering more parameters than signal strength; this is more plausible in the case of handover between different technologies.

6.3.3.2. *Real-time phase*

Figure 6.8 illustrates the message exchange diagram of the proposed mechanism for both localization and handover management, during the real-time movement of a mobile node. Initially, the RFID reader of its device queries periodically (or on demand) for tags within its coverage in order to retrieve their IDs. A list of the retrieved IDs is then forwarded to the RFID-server in a TAG LIST message. The time interval between consecutive tag readings and the frequency of the TAG LIST updates are system design parameters. Based on the TAG LIST updates received and the database that correlates the IDs of the reference tag with their location coordinates and best point of access, the RFID-server estimates the location of that mobile node. It predicts the most suitable point of access the mobile node should associate with, based on a *positioning algorithm* and a *decision function*, respectively. Then it sends the estimated *location estimation* back to the mobile node; the location information can be used by a LBS but also in our case by the improved movement detection process. If the selected next point of access is different from the current one of the mobile network, the RFID-server sends a HANDOVER NEEDED message to the mobile node, which contains information required for the new care of address acquisition. Hence, movement detection does not rely on ROUTER ADVERTISEMENTS or ROUTER SOLICITATIONS messages that add to the handover delay and consume valuable bandwidth. Upon successful association with the target point of access (if different from the current one), the mobile node can configure a new care of address using the IP prefix included in the HANDOVER NEEDED message and immediately send a BINDING UPDATE message to its home agent.

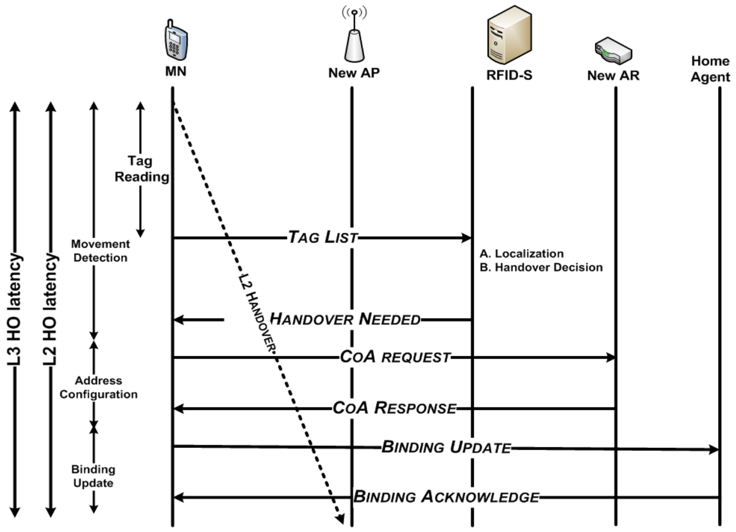

Figure 6.8. *RFID-assisted localization and handover management*

Note that, the L2 handover process is not explicitly modified and can be assumed to be the one described in the IEEE 802.11 standard [IEE 99]. However the movement detection stage in the above proposal can be initiated in parallel with it or even trigger its initiation. In this case, this proposal helps L3 handover to better synchronize with L2 handover. After the reception of a successful BINDING ACKNOWLEDGEMENT message, the handover is completed and the mobile node can continue its ongoing communication. In the case of movement between APs within the same subnetwork (same AR), no L3 registration is needed since the care of address has not changed. In this case, our proposal triggers the L2 handover to proactively start the scanning phase for discovering the best AP's RSS before losing the signal from the current AP. This proposal works both in horizontal and vertical handover, where tags are covered by different wireless technologies' access points.

6.3.3.3. *Positioning algorithm*

A positioning algorithm defines the way the location information from the detected tags is utilized for estimating the mobile node's location. Let D_u denote the set of *reference* tags successfully detected from a mobile node's reader r_u. We select a simple positioning algorithm, according to which the mobile node's location is estimated as the *simple average* of the coordinates (x_t, y_t) of all tags $t \in D_u$, i.e.

$$\left(\hat{x}_u, \hat{y}_u\right) = \left(\frac{\sum_{t \in D_u} x_t}{|D_u|}, \frac{\sum_{t \in D_u} y_t}{|D_u|}\right) \quad [6.1]$$

6.3.3.4. *Decision function*

Similar to the information selected for constructing the database during the training phase, defining the *decision function* for selecting the next point of access can also be flexible and based on the particular preferences of the network designer. We define a simple *decision function* here in order to focus our attention on the precision achieved by RFID technology in predicting the next point of access. Thus, given the set of detected tag IDs D_u (information contained in the TAG LIST message) and the set of their best point of access $\{(x_t, y_t), PoA_t\}, \forall t \in D_u$ (information obtained by looking up the database), each unique AR AR_j is assigned a frequency f_j equal to the number of tags in D_u assigned to this AR as their best point of access. Then, the AR_j, which appears most frequently (AR_j is maximum), is selected as the next PoA_u of the mobile node u, i.e.:

$$PoA_u = AR_{j \text{ arg max}} f_j \qquad [6.2]$$

6.4. Technology considerations

Even though RFID is a promising technology for both localization and mobility management, it has some limitations that should be considered before applying it. In this section, we present and model the communication properties among RFID components by considering technology specifications and main sources of error, especially in the presence of multiple tags and multiple readers.

6.4.1. *Path loss model*

The communication link between the main RFID components is half duplex: reader to tag and then tag to reader. In the forward link, the reader sends a modulated carrier to tags to power them up. In the return link, each tag receives the carrier for power supply and backscatters by changing the reflection coefficients of the antenna. In such a way, its ID is sent to the reader. The path loss of this two-way link may be expressed as:

$$PL(d) = PL_o + 10nN\,log\left(\frac{d}{d_o}\right) + X_\sigma \qquad [6.3]$$

where d is the distance between the reader and a tag, PL_o the path loss at reference distance and d_o given by:

$$PL_o = G_t G_r \Gamma g_t g_r \left(\frac{\lambda}{4\pi d_o}\right)^4$$

where G_t, g_t and G_r, g_r are the gains of the reader and tag transmission and receiving antennas, respectively. Γ is a reflection coefficient of the tag and λ the wavelength. $Nn = 2$, where n is the path loss component of the one way link and X_σ is a zero-mean Gaussian random variable in dB, having a standard deviation of $\sigma(dB)$. The variable X_σ is called the shadow fading and is used to model the random nature of indoor signal propagation due to the effect of various environmental factors, such as multipath, obstruction, orientation, etc. The path loss model defines the power received at the receiver P_s given the transmission power P_t, i.e. $P_s(d) = P_t - PL(d)$. In the absence of interference, the maximum read range a reader receiver can decode the backscattered signal from is such that:

$$R_{max} = \underset{d \leq 0}{max} P_s(d) \leq TH \qquad [6.4]$$

where TH represents a threshold value for successful decoding.

6.4.2. *Antenna radiation pattern*

It is assumed that the signal transmission from each reader forms a circle with a radius depending on its transmission power. In practice this is not real, due to different signal gains at different directions. To quantify this problem a degree of irregularity (DOI) has been proposed in [WAN 07]. According to this, if R_u and R_l are the maximum and minimum values of a reader transmission range, then the DOI is the maximum variation of the reader's transmission range per unit degree change.

6.4.3. *Multiple tags-to-reader collisions*

When multiple tags are simultaneously energized by the same reader, they reflect their respective signals back to the reader simultaneously. Due to a mixture of scattered waves, the reader cannot differentiate individual IDs from the tags. This type of interference is known as multiple tags-to-reader collisions.

6.4.3.1. *Anti-collision algorithms*

For resolving multiple tag responses, an anti-collision mechanism is essential. Reviewing the literature, several anti-collision protocols have been proposed, such as time-division multiple or binary tree-based schemes [JOH 08]. For instance, EPCglobal [EPC] (the organization that recognized the potential of RFID early on) proposed a bit-based binary tree algorithm (deterministic) and an aloha-based algorithm (probabilistic). The International Standards Organization (ISO) as part of the ISO 18000 family proposed the adaptive protocol, which is similar to the aloha-based algorithm proposed by EPCglobal, and binary tree search algorithm [ISO 03]. These protocols mainly differ in the number of tags that can be read per second, their power and processing requirements, as described in Chapter 5.

6.4.4. *Multiple readers-to-tag collisions*

A multiple readers-to-tag collision occurs when a tag is located at the intersection of two or more readers' interrogation ranges and the readers attempt to communicate with this tag simultaneously. Let R_i and R_j denote the read ranges of readers r_i and r_j with d_{ij} their distance. Apparently, if:

$$R_i + R_j > d_{ij} \qquad [6.5]$$

and r_i and r_j communicate at the same time, they will collide and the tags in the common area will not be detected. Figure 6.9 depicts two readers, r_1 and r_2, which simultaneously transmit query messages to a tag t_1 situated within their overlapping region. t_1 might not be able to read the query messages from r_1 and r_2 due to interference.

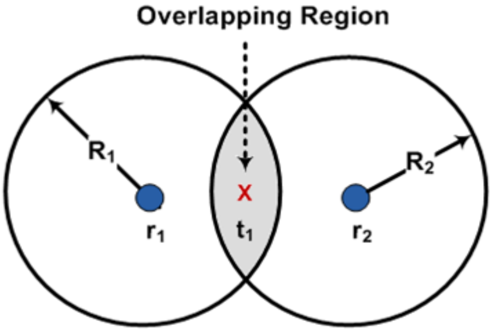

Figure 6.9. *Multiple-readers-to-tag collision*

6.4.4.1. *Reader collision probability*

The probability P_{ij}^{c} of such collision type between readers r_i and r_j, if equation [6.5] is satisfied, depends on the probabilities that r_i and r_j are simultaneously trying to communicate with their common tag. For characterizing the probability of simultaneous reader communication, we assume that each reader is in a scanning mode with probability P^{scan}. Thus, P_{ij}^{c} depends on the probabilities that r_i and r_j are in a scanning mode, P_i^{scan} and P_j^{scan}, respectively, i.e.:

$$P_{ij}^{c} = P_i^{scan} \times P_j^{scan} \qquad [6.6]$$

6.4.5. *Reader-to-reader interference*

Reader-to-reader interference is induced when a signal from one reader reaches other readers. This can happen even if there is no intersection among reader interrogation ranges but because a neighbor reader's strong signal interferes with the weak reflected signal from a tag. Figure 6.10 demonstrates an example of collision from reader r_2 to reader r_1 when the latter tries to retrieve data from tag t_1. Generally, the signal strength of a reader is superior to that of a tag and therefore if the frequency channel occupied by r_2 is the same as that between t_1 and r_1, r_1 is no longer able to listen to t_1's response.

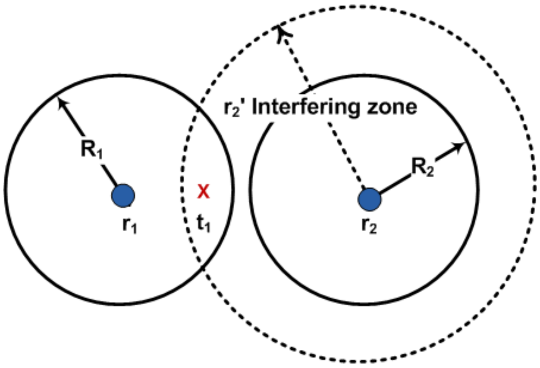

Figure 6.10. *Reader-to-reader interference*

6.4.5.1. *Read range reduction*

Reader-to-reader interference affects the read range parameter. In equation [6.4], this factor was neglected. However, when interfering readers exist, the actual interrogation range of the desired reader decreases to a circular region with radius $R_{\downarrow}\max{}^{\uparrow}I$, which can be represented by:

$$R_{\downarrow}\max{}^{\uparrow}I = \mathrm{a}_{\mathrm{rg}}\ \max{}_{\top}\left(d\in\left[O,R_{\downarrow}\,max\right]\right)\left[\left(SIR\left(d\right)\geq TH\right)\right] \quad [6.7]$$

where:

$$SIR\left(d\right)=\frac{P_s\left(d\right)}{\sum_i I_i}$$

and I_i is the interference from reader r_i.

The Class 1 Gen 2 UHF standard ratified by EPCglobal [EPC 05] separates the readers' from tags' transmissions spectrally so that tags only collide with tags and readers only collide with readers.

6.4.6. *Interference from specific materials*

Radio waves propagate from their source and reach the receiver. During travel, they pass through different materials, encounter interference from their own reflection and from other signals. They may be absorbed or blocked by various objects in their path. The material of the object to which the tag is attached may change the property of the tag, even to the point that it is not detected by its reader.

6.5. Performance evaluation

This section evaluates the performance of both RFID-assisted location and mobility schemes for the simulation environment described in section 6.5.1 and for the performance metrics defined in section 6.5.2.

6.5.1. *Simulation setup*

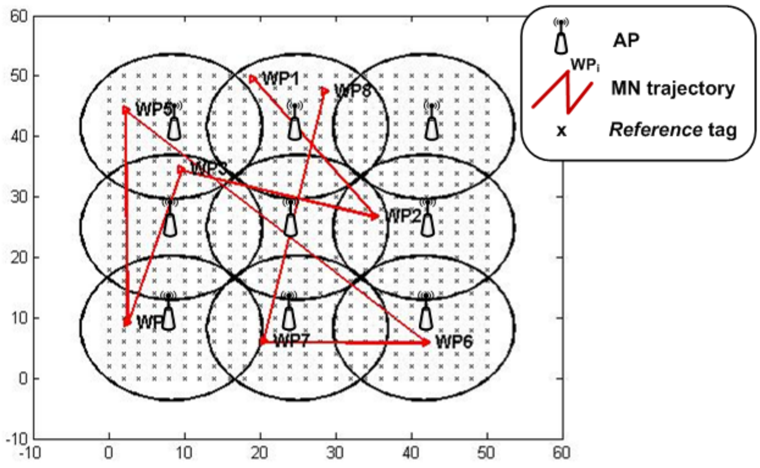

Figure 6.11. *Simulation environment*

Figure 6.11 depicts the simulation environment. It corresponds to a rectangular area 50 × 50 m^2 divided into nine subnetworks, each of which is served by a single AP.

Note that APs can also be considered as ARs. All APs are identical and follow the 802.11b (WiFi) standard with operating frequency at 2.4 GHz. Their placement is selected symmetrically in order to avoid any bias in the *decision function*. Heterogeneous and alternative radio technologies could have been assumed, since the proposed mechanism does not rely on triggers from lower layers. The indoor log-distance path-loss model, described in [RAP 02], has been selected to model the communication at the 802.11b channel:

$$PL(d) = PL(d_o) + 10n \log\left(\frac{d}{d_o}\right) + X_\sigma \qquad [6.8]$$

where d is the distance between transmitter (AP) and receiver (mobile node), $PL(d_o)$ the free-space path-loss at reference distance d_o, n the path loss exponent whose value depends on the frequency used, the surroundings and building type, and X_σ is a zero-mean Gaussian random variable in dB with a standard deviation of $\sigma(dB)$. The variable X_σ is called the shadow fading and is used to model the random nature of indoor signal propagation due to the effect of various environmental factors such as multipath, obstruction, orientation, etc. This path-loss model is used for calculating the RSS from each AP, based on its transmission power P_t, i.e. $RSS(d) = P_t - PL(d)$.

Within this region, mobile nodes whose terminals support an interface to the wireless local area network and an RFID reader roam among the nine available subnetworks. Regarding their mobility, we have used the random waypoint mobility model [CAMP 02]. Briefly, in the random waypoint model i) a mobile node moves along a zigzag line from one waypoint to the next, ii) the waypoints are uniformly distributed over the given area and iii) at the start of each leg a random velocity is randomly selected from the velocity distribution $\left[0, V_{max}\right]$. The red line in Figure 6.11 shows a random trajectory of a single mobile node whose mobility follows the random waypoint model.

In the RFID system, we have assumed the UHF case that operates within the frequency range of 890-960 MHz. For resolving multiple tags-to-reader collisions the pure aloha and slotted aloha anti-collision protocols [SCH 98] have been assumed. In pure aloha -based RFID systems a tag responds with its ID randomly after being energized by a reader. It then waits for the reader to reply with i) a positive acknowledgment, indicating its ID has been received correctly, or ii) a negative acknowledgment, meaning a collision has occurred.

If two or more tags transmit, a complete or partial collision occurs. The tags resolve this by backing off randomly before retransmitting their ID. In slotted aloha-based RFID systems, tags transmit their ID in synchronous time slots. If there is a collision, tags retransmit after a random delay. The collision occurs at slot boundaries only, hence there are no partial collisions. In our simulation setup, each tag's initial response follows a Poisson distribution with rate $\lambda = 30$. The retransmission time is divided in $K = 5$ slots of duration that correspond to the time needed to transmit an ID of 92-bits length over a link with data rate of 102 Kbps.

6.5.2. *Performance results*

Localization systems are predominantly evaluated according to their *accuracy*. Thus, as a performance metric for our localization scheme we define the mean location error measured as the Euclidean distance between the actual and estimated positions for all mobile nodes. For evaluating the movement detection-scheme, the accompanied *movement detection latency delay* is the principal performance metric. For our scheme, we measure the time needed to successfully read all tags, since this is the prevalent time component in the proposed RFID-based movement detection process.

6.5.2.1. *Localization accuracy*

Localization accuracy is highly dependent on the multiple readers-to-tag collision problem, since incorrect or no tag detection distorts the estimated location in equation [6.1]. In order to illustrate the performance degradation due to this type of interference problem and the essentiality of a mechanism for coordinating readers' transmissions, we considered four multi-user environmental cases that differ in the number of users (20 or 40) and the probability of collision between their readers' transmissions. Assuming that the tag scanning probability of mobile nodes' readers follows uniform distribution $U(\beta,1)$, we set either $\beta = 0$ or $\beta = 1$ for the second case. Apparently, for the second environment the readers from all mobile nodes simultaneously scan for their tags and thus the performance achieved is anticipated to be worse due to the collision problems among them.

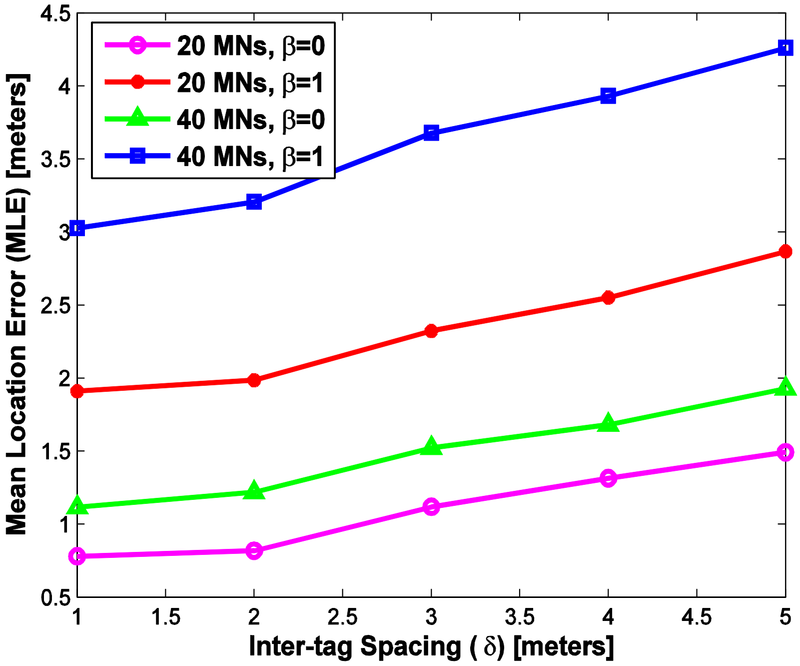

Figure 6.12. *Positioning accuracy versus reference tag density for* $R = 5$ *m*

Figures 6.12 and 6.13 illustrate the dependency of the mean location error on the tag density δ, when the readers range is $R = 3\,m$ and $R = 5\,m$, respectively. For all cases, increasing the inter-tag spacing reduces the accuracy. However, when the collision problem is severe, the accuracy reduction is worse and thus a dense tag deployment is required to provide robustness. Comparing Figures 6.12 and 6.13, we observe that when $R = 5\,m$ the collision problem is more intense due to the increased probability for the existence of overlapping interrogation zones.

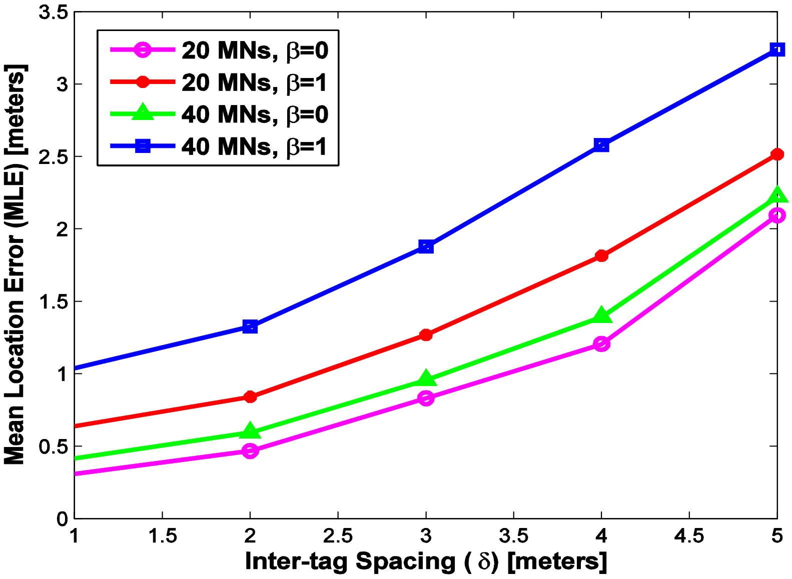

Figure 6.13. *Positioning accuracy versus reference tag density for* $R = 3\,m$

6.5.2.2. *Movement detection latency*

The time taken by the mobile node’s reader to successfully retrieve IDs from all reference tags within its vicinity depends on the tag singulation time. In other words, the time needed to successfully read a single tag in the presence of multiple tag responses, which in turn depends mainly on the anti-collision algorithm. For the slotted-aloha and pure-aloha anti-collision algorithms we have assumed (see section

6.5.1), the total time needed for successfully reading N tags [KLA 09] is given by:

$$T_{TR} = N \times \left\{ t \left[1 + \left(e^{xG_A} - 1 \right) \right] \alpha + \frac{1}{N\lambda} \right\} \quad [6.9]$$

where $G_A = N\lambda t$ is the offered load and $x = 1$ for pure aloha and $x = 2$ for slotted aloha that defines the vulnerability period.

In the following the *movement detection latency delay* is depicted for different read ranges, grid deployments and the two aloha variants. The x-axis corresponds to different values of inter-tag spacing δ. Obviously, as δ increases, the number of detected tags decreases. Figures 6.14 and 6.15 show the total time needed for reading all tags that are detected when $R = 3\ m$ and $R = 5\ m$, respectively.

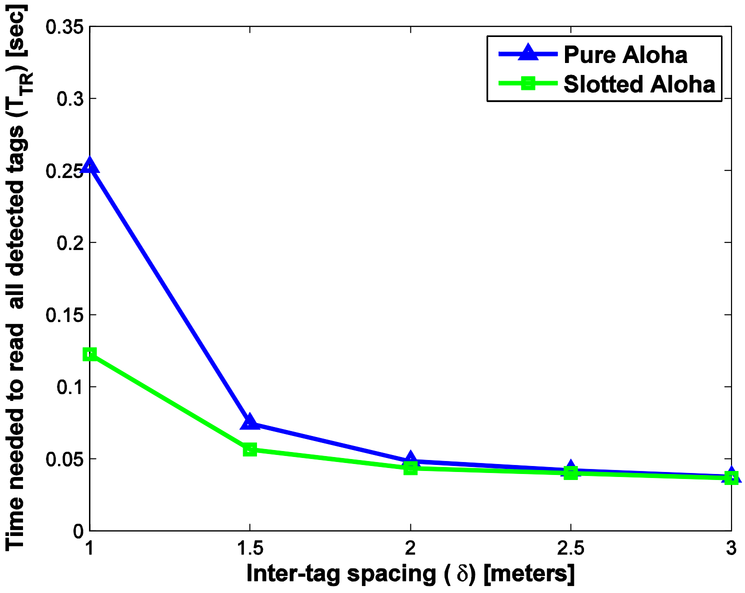

Figure 6.14. *Movement detection latency versus reference tag density for pure and slotted aloha for* $R = 3\ m$

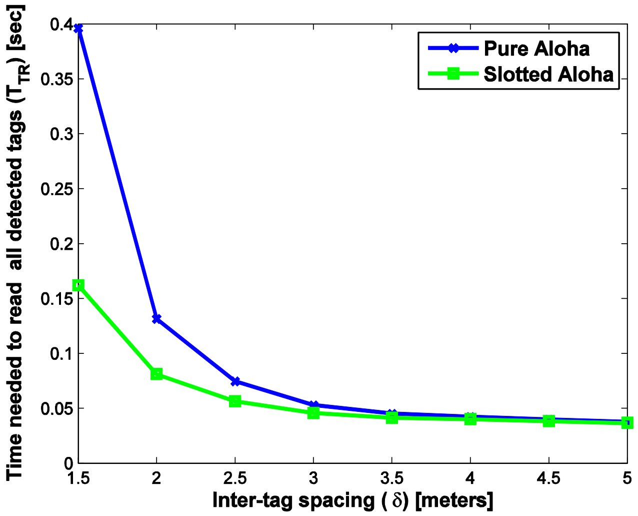

Figure 6.15. *Movement detection latency versus reference tag density for pure and slotted aloha for* $R = 5\ m$

First of all, we observe that slotted aloha has better performance than pure aloha, due to the reduction of the vulnerability period $2t$ [BUR 04]. When grid deployment is dense, the reading time is very high due to the large number of tags responding. We observe that the total time needed to read all tags keeps falling due to the smaller number of detected tags whose IDs need to be retrieved. Finally, we remark that when $R = 3\ m$, less total read time is required compared to the case where $R = 5\ m$, which is rational since fewer tags are detected. Overall, the minimum tag reading time $T_{TR}^{\min}$ is approximately 50 ms to 100 ms and is achieved for $\delta \le 2\ m$ when $R = 3\ m$ and for $\delta \le 3\ m$ when $R = 5\ m$. Thus, we managed to match L3 with the L2 handover, which takes 58.74 ms to 396.76 ms [MIS 03].

6.6. Summary and conclusions

In this chapter, we show that RFID technology can be used for purposes other than item identification and tracking. We presented how RFID technology can also help in improving network functionalities such as location and mobility. In fact, in the emerging IoT scenarios, massive tags will be deployed all around the user to better consider the environment in computing applications. Our approach is to consider a smart floor with tags everywhere, and carry an RFID reader in mobile devices, such as mobile phones. We could then take advantage of the RFID reading information matched with the network topology. We can use the access points covering the tags, to help the positioning algorithm and provide the location that can be used by a LBS. We will also benefit from our improved movement detection algorithm that will enable us to anticipate handover and minimize delay. More network functionalities can be investigated with the consideration of RFID information matched with the specific parameters of an application.

6.7. Bibliography

[BAH 00] BAH L P., PADMANBHAN V.N., *RADAR: An In-Building RF-based User Location and Tracking System*, vol. 2, IEEE INFOCOM, pp 775-784, 2000.

[BAU 05] BAUDIN M., *RFID Applications in Manufacturing*, MMTI – Manufacturing Management & Technology Institute, 2005.

[BEK 07] BEKKALI A., SANSON H., MATSUMOTO M., “RFID indoor positioning based on probabilistic RFID map and Kalman filtering”, *3rd IEEE International Conference on Wireless and Mobile Computing, Networking and Communications*, IEEE WiMob, 2007.

[BOU 08] BOUET M., PUJOLLE G., “A range-free 3-D localization method for RFID tags based on virtual landmarks”, *19th International Symposium on Personal Indoor and Mobile Radio Communications,* IEEE, PIMRC, 2008.

[BUR 04] BURDET L. A., *RFID Multiple Access Methods, Technical Report*, ETZ Zurich, 2004.

[CAM 02] CAMP T., BOLENG J., DAVIES V., “A survey of mobility models for ad hoc network research”, *Wireless Communications and Mobile Computing*, vol. 2, no. 5, p. 483–502, 2002.

[CAR 03] LIEBSCH M., SINGH A., CHASKAR H., FUNATO D., *Candidate Access Router Discovery*, draft-ietf-seamoby-card-protocol-01.txt, work in progress, March 2003.

[EPC 05] EPCGLOBAL, 2005, available at: http://www.epcglobalinc.org, accessed February 22, 2010.

[FIK 01] FIKOURAS N. A., GÖRG C., "Performance comparison of hinted- and advertisement-based movement detection methods for mobile IP hand-offs", *Computer Networks*, vol. 37, no. 1, p. 55-62, 2001.

[HIG 00] HIGHTOWER J., BORRIELLO G., *SpotON: An Indoor 3D Location Sensing Technology based on RF Signal Strength*, UW-SCE 00-02-02 2000, University of Washington, Department of Computer Science and Engineering, Seattle, WA, February 2000.

[HIG 01] HIGHTOWER J., BORRIELLO G., "Location systems for ubiquitous computing", *IEEE Computer*, vol. 34, no. 8, p. 57-66, 2001.

[IEE 99] IEEE. *Part 11: Wireless LAN Medium Access Control (MAC) and Physical (PHY) Layer Specifications*, IEEE Standard 802.11, 1999.

[ING 04] INGRAM S.J., HARMER D., QUINLAN M., "UltraWideBand indoor positioning systems and their use in emergencies", *IEEE Conference on Position Location and Navigation Symposium*, p.706-715, Monterey, USA, April 2004, 2004.

[ISO] ISO, ISO/IEC 18000-6:2003(E), *Part 6: Parameters for Air Interface Communications at 860-960 MHz*, ISO, November 26, 2003.

[JOH 08] JOSHI G.P., KIM S.W., "Survey, nomenclature and comparison of reader anti-collision protocols in RFID", *IETE Technical Review*, vol. 25, no. 5, p. 285-292, 2008.

[KAP 05] KAPLAN E.D., *Understanding GPS: Principles and Applications*, Artech House, 2005.

[KEN 99] KEN H., MIKE S., "Touch-sensing input devices", *Proceedings of the IGCHI Conference on Human Factors in Computing Systems*, p. 223-230, Pittsburgh, Pennsylvania, USA, May 15-20, 1999.

[KIN 06] KING T., KOPF S., HAENSELMANN T., LUBBERGER C., EFFELSBERG W., *COMPASS: A Probabilistic Indoor Positioning System Based on 802.11 and Digital Compasses*, p. 24-40, WinTeck, 2006.

[KLA 09] KLAIR D., CHIN K.W., RAAD R., "On the energy conception of pure and slotted aloha based RFID anti-collision protocols", *Computer Communications*, vol. 32, p. 961-973, 2009.

[KOO 05] KOODLI R., *Fast Handovers for Mobile IPv6 Internet Engineering Task Force (IETF), Request for Comments (RFC) 4068*, IETF, July 2005.

[LEE 04] LEE J. *et al.*, "Analysis of handoff delay for mobile IPv6", *IEEE Communications Letter*, vol. 4, p. 2967-2969, 2004.

[MIS 03] MISHRA A., SHIN M., ARBAUGH W., "An empirical analysis of the IEEE 802.11 MAC layer handoff process", SIGCOM Comput, *Commun Rev*, vol. 33, no. 2, p. 93-102, 2003.

[NI 04] NI L.M., LIU Y., LANDMARC, "Indoor location sensing using active RFID", p. 701-710, *Wireless Networks*, vol. 10, no. 6, p. 701-710, 2004.

[PAH 05] PAHLAVAN K., LEVESQUE A. H., *Wireless Information Networks*, 2nd edition, John Wiley & Sons, New York, 2005.

[PAP 09a] PAPAPOSTOLOU A., CHAOUCHI H., *WIFE: Wireless Indoor Positioning Based on Fingerprint Evaluation*, IFIP Networking, 2009.

[PAP 09b] PAPAPOSTOLOU A., CHAOUCHI H., "Exploiting multi-modality and diversity for localization enhancement: WiFi & RFID usecase", *20th International Symposium on Personal Indoor and Mobile Radio Communications*, IEEE, PIMRC, Tokyo, Japan, September 2009.

[PAP 10] PAPAPOSTOLOU A., CHAOUCHI H., "Handoff management relying on RFID technology", *IEEE Wireless Communications and Networking Conference*, IEEE WCNC, Sydney, Australia, April 2010.

[PER 96] PERKINS C., *IP Mobility Support*, *Internet Engineering Task Force (IETF), Request for Comments (RFC) 2002*, IETF, October 1996.

[PRI 00] PRIYYANTHA N.B., CHAKRABORTY A., BALAKRISHNAN H., "The Cricket Location-Support System", *Proceedings of the 6th International ACM MOBICOM*, August 2000.

[RAP 02] RAPPAPORT T., *Wireless Communications: Principles and Practice*, 2nd edition, Prentice Hall, 2002.

[SCH 98] SCHWARTZ M., *Telecommunication Networks Protocols Modeling and Analysis*, Addison-Wesley, USA, 1988.

[UBI] UBISENSE, http://www.ubisense.net/en/products, accessed March 22, 2010.

[WAN 07] WANG C., WU H., TZENG N.F., *RFID-based 3-D Positioning Schemes*, IEEE INFOCOM, p. 1235-1243, 2007.

[WAN 92] WANT R., HOPPER A., FALCAO V., GIBBONS J., "The active badge location system", *ACM Transactions on Information Systems*, vol. 40, no. 1, p. 91-102, 1992.

[WAN 06] WANT R., "An introduction to RFID technology", *IEEE Pervasive Computing*, vol. 5, no. 1, p. 25-33, 2006.

[YAM 04] YAMANOI K., TANAKA K., HIRAYMA M., KONDO E., KIMURO Y., MATSUMOTOTI M., "Self-localization of mobile robots with WID system by using support vector machine", *Proceedings of 2004 IEEWRSI International Conference on Intelligent Robots and Systems*, Sendai, Japan, 2004.

[YOU 05] YOUSSEF M., AGRAWALA A., *The Horus Location Determination System*, ACM MOBISYS, p. 205-219, 2005.