September 2012

Localization in Medical Sensory Systems

Technical Report 2012-599

Telecommunications Research Lab (TRL)

School of Computing

Queen's University

Kingston, Ontario, Canada, K7L 3N6

Lobna Eslim

Hossam Hassanein

Email: {lobna.eslim,hossam]@cs.queensu.ca

Abstract

The proliferation of Information Technology (IT) in the healthcare domain enables healthcare institutions to deliver healthcare services to a wider audience in an efficient manner. Currently, patients can be monitored and treated remotely on time with high standards of care; caregivers can communicate together to achieve more timely and effective performance for the entire care process; assets which are scattered throughout the hospitals can be managed and utilized efficiently. These stakeholders: patients, caregivers and assets are mobile in nature and they are commonly tagged with sensory badges that can communicate either using the existing wireless infrastructure or using its own infrastructure. Hence, the term medical sensory system can be used to refer to the network of sensors that represent the stakeholders as mobile objects along with the backhaul infrastructure. Thereby, this network can be viewed as a Wireless Sensor Network (WSN) which has its own characteristics that result in some challenges. Among these challenges is the process of localizing objects, which is complicated due to the ad hoc deployment manner of a WSN, as well as the constraints on sensors in terms of cost, size, and energy consumption. Localization and tracking systems are those concerned with localizing multiple objects and keeping track of their locations over time to enhance services in different industries including healthcare. Currently, there are localization and tracking systems that have been proposed in the literature to address the localization problem; some of them are directed to the healthcare domain, while others are proposed for general usage. This paper discusses the healthcare domain stakeholders' requirements, presents different localization and tracking systems in the literature and provides qualitative analysis and critique of each system based on such requirements. The paper also touches on a few of the commercial systems in the industry.

1. Introduction

Recent advances in wireless communication and sensor technology facilitate the development of sensors (motes), which vary in terms of size, weight, architecture and battery lifetime. Such sensors can be easily deployed in pre-determined locations or in an ad hoc manner and wirelessly communicate to each other, forming a unique network paradigm named Wireless Sensor Network (WSN). This network paradigm has its characteristics such as: deployment manner, system lifetime, limited resources, scalability, and cooperation that result in some challenges to be taken into consideration. Among these challenges is to knowing nodes' locations in order to interpret and correctly utilize the collected data.

Localization in general refers to the process of determining the location of an object which might be either static or mobile. In the case of a static object, its location needs to be determined once. Otherwise, location sampling is required to periodically determine the location of a mobile object which defines the term "Tracking" used in this research. Accordingly, localization and tracking systems are those concerned with localizing multiple objects and keeping track of their locations over time to enhance services in different industries such as manufacturing, transportation and healthcare. In medical sensory systems, localization involves locating objects such as patients, assets or even staff.

1.1. Issues and Challenges

In the healthcare domain patients, caregivers and assets are commonly tagged with sensory badges hence they can be considered as mobile nodes that have their own requirements and challenges.

Patients: patients require different levels of care; some must be treated in special care facilities (e.g. emergency units) with close monitoring while others are allowed to move and are treated remotely wherever they are (indoor/outdoor) by monitoring their medical conditions and taking actions according to patients' needs. Thus, patients require immediate indoor/outdoor localization in an accurate and easy way while maintaining their privacy.

Caregivers: their role is dynamic and complex; they are expected to cooperate with other qualified professionals and care providers as a team to offer care for patients. Communication among such a cooperative team is critical to achieve more timely and accurate performance for the entire care process. They can be exposed to different dangerous and risky situations throughout their daily work routine. This adds a challenge to ensure the safety of such staff especially in a highly dynamic environment like a hospital. Thereby, they need to be localized in their area of responsibility, be able to locate the required assets, communicate patients' location and possibly retrieve their information on their mobile device, and be notified when necessary.

Assets: assets may be specialized equipment such as surgical equipment, measurement/test equipment, wheelchairs or hazardous drugs and materials that are not static in nature and scattered throughout the hospital. To improve asset utilization and to avoid excessive delays, caregivers should have the ability to locate the required equipment when needed in a timely manner allowing more time for serving patients. Moreover, they should be alerted when dangerous assets such as hazardous drugs are moved out of a designated area.

The demand of more professional and efficient care services coupled with the requirements of healthcare stakeholders foster the need to accurately localize patients, caregivers and assets. Localization and tracking systems have been proposed to fulfill this need and consciously face challenges such as environmental obstacles, mobility and privacy.

1.2. Requirements

Based on the issues and challenges faced by patients, caregivers and assets, along with challenges that would be introduced through the use of WSN, we identify the following generic and function-specific requirements:

Accuracy: Localization and tracking systems should be able to accurately localize mobile objects in both indoor and outdoor environments, while retaining the ability to provide multiple level of accuracy such as room-level or bed-level.

Robustness: systems operating in a highly dynamic environment should be able to perform the required functions regardless of environmental obstacles such as unavailability of signals, shortage of information and the possibility of failure in system components. In other words, fault tolerance should be considered at both system and network levels.

Scalability: healthcare is a large domain in terms of number of objects of interest and geographic areas to be covered. It may vary from a small clinic to a group of cooperated hospitals that contain thousands of mobile objects. Thus, localization and tracking systems should be able to sustain the required level of functionality and performance regardless of the domain size.

Integration and Privacy: hospitals achieve high quality and efficient health service delivery and ensure that each patient receives the right therapy in a timely fashion through effective software applications known as Healthcare Information System (HIS). In order to maintain such quality, localization and tracking systems should be able to integrate with such systems while in compliance with the standard privacy and security policies. Furthermore, such systems should be able to integrate with other localization and tracking systems deployed in hospitals that cooperate together in serving patients or utilizing assets.

Energy efficiency: mobile devices and mobile wireless sensors are mainly battery-based operated and in order to reduce the power consumption and maintain a better communication, the system should be able to utilize the energy efficiently to sustain its operation up to the end of its mission.

1.3. Purpose of Paper

The purpose of this paper is to present, evaluate and compare existing localization and tracking systems with respect to the healthcare domain requirements presented earlier and determine the extent to which these requirements are satisfied along with reviewing some of the commercial systems in industry. Although the hardware and the underlying technologies are mentioned; we focus on the systems' functionality issues. We use the term "localization and tracking system" as a generic term to refer to the systems reviewed. Typically, tags or badges refer to the sensors attached to any mobile objects such as a patient, asset or staff member. Other terminologies related to localization process will be explained in section 3. The systems' hardware components and deployment issues are outside the scope of this paper.

1.4. Organization of Paper

The remainder of this paper is organized as follows. In Section 2, a comprehensive definition of WSN is given followed with WSN's characteristics and challenges along with its applications. In Section 3, we define the localization problem and explain the measuring and positioning techniques found in the literature pointing out the challenges and concerns that can be experienced in localizing WSN's nodes. In Section 4, we discuss the healthcare domain attributes and requirements with respect to localization and tracking issues. Different systems are presented and compared from the healthcare viewpoint in Section 5 follows with a review of a few commercial systems. Finally, a conclusion is presented outlining the open research issues.

2. Wireless Sensor Networks (WSNs)

A Wireless Sensor Network (WSN) is a wide-spread network paradigm that deploys tiny, smart and limited resources nodes to sense, gather and disseminate information about phenomena under inspection [4] [5] [6]. WSNs have tremendous distinctions that result in a wide range of applications in many areas such as military, environment, health and commerce [5] [7] [8]. In this section, we provide an overview of WSNs with an attempt to understand the network infrastructure that is commonly used in medical sensory systems. Then salient characteristics of these networks are explained along with the main challenges that should be taken into consideration. In addition, applications of WSN are briefly described.

2.1. Definition

The objectives of WSNs are to gather information through a sensing process, optionally do some limited processing on sensed data, and transmit the collected information to a remote fusion center [8]. To achieve these objectives, WSNs consist of special type of nodes that can wirelessly communicate and are easily deployed in areas under investigation with little or no infrastructure. These sensor nodes are typically small, low-power, cheap, intelligent, multifunctional, and equipped with wireless interfaces that are used to communicate unfettered with each other to form a network [4] [9] [10]. Thus, WSNs can be viewed as a collection of sensor nodes (few tens to thousands) that observe information from the environment through sensing, and assist each other to communicate observed data back to a centralized collection point using a wireless channel, while maintaining its autonomous operation.

The sensor nodes (motes) vary in terms of size, weight, architecture, topology, battery lifetime, hence cost, and are usually deployed in pre-determined locations or in an ad hoc manner (scattered either inside the phenomenon or very close to it) according to its goal [9]. Based on the deployment manner, WSNs are typically classified into two types: structured where all or some nodes are deployed in a pre-determined manner and unstructured where a dense collection of sensor nodes are deployed in an ad hoc manner.

2.2. Characteristics and Challenges

WSNs have some characteristics that significantly distinguish them from other network paradigms. Some of these characteristics are a result of the unique manner of deployment, while others are due to resource constraints of sensor nodes. Due to such characteristics, new challenges are presented and must be accommodated when deploying WSNs.

2.2.1. Characteristics

Deployment of a WSN is strongly driven by its particular application. However in most cases a WSN depends on a dense number of sensor nodes which are scattered in certain region and coordinate to carry out their tasks. These sensor nodes need not have prior knowledge of their location and should have the capability to know its position as its data is meaningless without knowing the associated location. The following are the main characteristics of WSNs [4] [6] [8] [10]:

Deployment: WSNs are composed of typically large numbers of sensor nodes which are deployed in difficult-to-access locations in an ad hoc manner. Thus, the network topology is usually dynamic and depends on the characteristics of the physical environment and the communication channels. In other words, there is no infrastructure and it is up to sensor nodes to identify their distribution and connectivity in order to achieve network's reliability and robustness.

System lifetime: battery is the main source of power in a sensor node which might be impossible to replenish and if it runs out the node will be considered as malfunctioning. There is a reverse tradeoff between the system lifetime and the number of malfunctioning nodes. Thus, the system lifetime highly depends on the lifetime of sensor nodes. So, energy must be efficiently used and a secondary power supply that harvests power from the environment may be added. Moreover, power conservation can be achieved through multi-hop routing, data aggregation and compression, using short transmission range, and using low duty-cycle operations.

Limited resources: sensor nodes are highly constrained in terms of cost, size, energy consumption, computational complexity and implementation environments which result in limited computational capacities and memory that exacerbates the challenges.

Scalability: number of sensor nodes in a WSN may be very large (in the order of thousands) with high density. Hence they are responsible for sustain the network functionalities without any interruption or failure with no human intervention through reorganize and reconfiguration in case of any changes.

Cooperation: as mentioned earlier, the sensor nodes in WSNs are inherently resource constrained. They have limited storage capacity, processing speed and communication bandwidth. As the nodes share a common objective, they highly interact and such cooperation allows them to achieve substantial processing capability in the aggregate and enhances the network's efficiency.

2.2.2. Challenges

The major consideration in a sensor network is to extend the system lifetime as well as the system robustness. There are some factors that influence WSNs that include but are not limited to: production costs, hardware constraints, operating environment, transmission media, power consumption and fault tolerance [5] [11]. However, the main three challenges are: energy efficiency, routing, and localization [4].

Energy efficiency: the system should conserve power, achieve good utilization and operate for extended periods of time. In order to achieve such goals, aggregation and compression algorithms can be applied on the sensed data hence, transmit fewer bits. Another option is to reduce the overall power consumption through limiting the nodes' life cycle but on account of difficulties in network analysis and management [4] [5] [10].

Routing: nodes may need to communicate with other nodes that are out of their communication range. This can be achieved by having nodes relay messages for one another. Since there is no planned connectivity in ad hoc networks, ad hoc routing techniques are used to extend the communication range [4] [5] [10].

Localization: sensor nodes need not have prior location awareness. While each sensor node interacts only with its neighbors, it needs to know its own location and the identity and location of its neighbors to support processing and collaboration. The problem of identifying nodal positions is referred to as the localization problem [8] [12] [13] which is complicated due to the ad hoc deployment manner of WSNs, as well as the constraints on sensors in terms of cost, size, and energy consumption [14] [15] [16]. Localization techniques and systems have been proposed to overcome such problem.

2.3. Applications

We highlight two main applications of WSNs, monitoring and tracking. Monitoring applications include indoor/outdoor environmental monitoring, health and wellness monitoring, traffic control, inventory control and infrastructure security. Tracking applications include target tracking, traffic tracking and fleet management [5] [8] [10].

As mentioned earlier, sensors have sensing capabilities that may include temperature, humidity, light, radiation, presence of biological organisms, etc. This variety of sensing capabilities provides an unprecedented level of information about the area under inspection either indoors or outdoors. For example, in healthcare/wellness domain, sensor nodes can be deployed to monitor patients and assets and to assist disabled patients. In environment monitoring, sensors are used to detect and monitor environmental changes such as forest fires, disaster sites and monitoring natural habitats. Another scenario is to deploy video, acoustic and other sensors around facilities such as shopping malls or parking garages to provide early detection of possible threats. Tracking is also one of the important applications in which sensors continuously track a particular object(s) and report its position to a central base station enriching the area of field surveillance and intruder tracking. The tracked object may be enemy, animal, human and cars on highways. Besides all aforementioned applications, WSNs can be used to increase national safety by alerting to potential human or environmental threats [5] [7] [9] [11].

3. Localization Problem

The unique characteristics of WSNs in terms of cost, scalability and wireless information access availability allow unprecedented opportunities for a large number of applications. However, in many applications, the sensed data by itself is meaningless and may result in an incorrect interpretation without knowing the associated location [17] [18]. Hence, localization of sensor nodes in WSNs have become a crucial aspect that attracted significant research interest and is expected to grow with the proliferation of WSNs' applications [15] [18] [19] [20] [21]. Moreover, making the localization process self-configuring in response to surrounding conditions becomes very crucial for large-scale WSNs deployment and it will provide a number of new efficient protocols and applications as well [22] [23] [24] [25]. In this section, we give an exhaustive definition of the localization problem followed by explanation of measuring and positioning techniques found in the literature along with their characteristics. Finally, we end up with a subsection that briefly discusses the challenges and concerns that can be experienced in localizing WSNs' nodes.

3.1. Definitions and Exhaustive View

Localization is the process of identifying and determining coordinates of sensor nodes, or estimating their spatial relationship. It can be either network-centric localization or self-localization. In network-centric one, a central unit is used to estimate nodes' position based on information collected from some reference nodes. On the other hand, in self-localization, the position is estimated via the target node itself [12] [13] [19] [25]. In fact, the deployment of WSNs in an ad hoc manner, as well as the constraints on sensors in terms of cost, size, energy consumption and implementation environments, complicate the localization problem [8] [15]. According to the application's demand; the coordinates in a network can be one of the following types [12] [23] [26]:

- *Physical location*: which identifies a point on a 2D (or 3D) by giving its x, y and z coordinates.
- *Symbolic location*: which expresses a location using a natural-language (e.g. in the office, in the third-floor bedroom, etc.).
- *Absolute location* (global): when a common reference grid is used by all sensor nodes.
- *Relative location* (local): when location information is calculated based on the proximity to known reference points or base stations that are not common for all sensor nodes. However, if the absolute locations of some reference points are known; relative locations can be transformed into absolute ones [27].

In WSNs, there are nodes that know their location a priori or at deployment time. These nodes are called ***anchors*** or ***beacons*** and their placement can significantly affect the localization process. ***Anchors*** or ***beacons*** know their global coordinate either by manual configuration (hard coding) or using a Global Positioning System (GPS) through fitting them with a GPS receiver and a set of them might be mobile that improves the localization process on account of cost [18] [21] [27]. The latter consumes significant battery power which is typically limited in sensor nodes. Other nodes that do not know their location are called ***unknown nodes*** and they are required to know its position in two or three dimensions and possibly its velocity, orientation, etc. in both indoor and outdoor environments. For such nodes, manual entry of node coordinates is often impractical. GPS technology, despite its popularity as standardization for electronic outdoor localization, cannot provide an accurate localization in indoor [16] [20] [21] [25] [28] [29] or urban environments due to line-of-sight requirements, presence of obstacles, power consumption, production cost, and sensor node size constraints [13] [22] [23] [24] [26].

Other options to localize ***unknown nodes*** include the use of a Local Positioning System (LPS), or cooperative information sharing. LPS solutions suffer from the burden of cost as they rely on a high density ***anchors*** being deployed while in cooperative localization, sensor nodes work together in a peer-to-peer manner to make measurements and then form a map of the network [14] [18] [21]. Such measurements can take place between ***unknown nodes*** and ***anchors*** as well as between ***unknown nodes*** with each other providing more robustness, accuracy and coverage. Cooperative localization is also mentioned as distributed, multi-hop or self-localization in the literature [14] [21] [24].

In a general, localization techniques can be considered as measuring techniques used to measure some location metrics between ***unknown nodes*** and some ***anchors***, followed by a positioning technique. The latter uses the measured metrics to compute the location of the ***unknown nodes***, and optionally refine the nodes' positions to reduce positioning errors. However, we can consciously say that one localization technique considering its performance and effectiveness cannot fit all applications requirements in terms of cost, accuracy, scalability, energy efficiency, responsiveness and privacy [18]. In the following two subsections, we explain measuring techniques and positioning techniques and highlight the characteristics of each.

3.2. Measuring Techniques

The first step in the localization process is to measure some metrics for the node needs to be localized. These metrics may be distance, angle or connectivity information. According to the aforementioned information, measuring techniques can be broadly categorized as: distance based, angle (or direction) based and connectivity based [14] [15] [17] [19] [27] [30].

3.2.1. Distance-based measuring techniques

Distance based techniques calculate the distance between a node and anchor(s). The measured distance is highly affected by noise, interference and multipath [24].

- **Time of Arrival (ToA):** ToA mainly depends on the propagation time of a signal (e.g. Radio Frequency (RF), acoustic, ultrasound, or others) between unknown node and an anchor node to estimate the distance in between. ToA is measured by adding the time of a signal transmission to the time a signal takes to reach the anchor node. This can simply be calculated as the difference between the sending time of a signal at the transmitter and it's receiving time at the receiver. The key issues here are the time synchronization and time stamp information which allows the receiver to accurately estimate the signal arrival time but make ToA less attractive and impossible in asynchronous sensor networks [19] [27] [31].
- **Time Difference of Arrival (TDoA):** Named so because it depends on the difference between the arrival times of the same signal at two time synchronized receivers or between arrival times of two signals with different propagation models at the same receiver. TDoA techniques can be classified into two categories: (a) Multi-signal techniques in which a node is equipped with a

speaker and a microphone which generate signals with different propagation speeds (ultrasound/acoustic and radio signals) to estimate its distance to anchor node requiring extra hardware as in Figure 1(a). (b) Multi-node techniques that use ToA measurement of signals transmitted from multiple anchor nodes (typically three) with a tradeoff between anchors' separation and the accuracy. Doing so, no time synchronization between nodes is required as in ToA techniques but between the anchors. TDoA despite its accuracy suffers from high cost and difficult to meet line-of-sight conditions [19] [20] [21] [32].

- **Roundtrip Time of Flight (RToF):** RToF is similar to ToA with no time synchronization constraints. RToF calculates the time it takes to send a signal from a node to a second node and receiving a reply at the original node. The measured time between the transmission and the reception of the reply at the original node is twice the propagation delay plus a reply delay for handling the signal at the second node. Such reply delay is considered the major error source in RToF in addition to noise, interference and multipath [24].
- **Received Signal Strength (RSS):** The foundation of this technique is based on the existence of RSS Indicator (RSSI) as a standard feature of most wireless devices. RSS uses such indicator to estimate the distance between two nodes by relying on the fact that radio signals diminish with the square of the distance from the signal's source. Actually, the signal's propagation is inversely affected by environmental dependent factors such as diffraction, reflection and scattering. However, RSS is still attractive as it does not require any additional hardware nor consumes significant nodes' battery power. Another way to utilize the RSSI is to create a central database of vectors of signal strengths at given sample points (sniffing devices) in the coverage area where the i^{th} entry corresponds to the i^{th} anchor's transmitted signal. Such database is then used to create a map that is used later by unknown node to localize itself based on its RSS profile [18] [19] [20] [21] [33] [34] [35].

3.2.2. Angle-based measuring technique

- **Angle of Arrival (AoA):** This technique determines the propagation direction of the received signals with reference to a given orientation. The common approach is to use multiple antennas hence it defines the AoA by analyzing the phase or time difference for the transmitted signals at different array elements. Another approach uses directional antennas and define AoA by computing the RSS ratio between several well placed directional antennas such that their main beams are overlapped (Figure 1(b)). Due to direct line-of-sight constraint of the AoA technique the direction of the antennas along with the shadowing and multipath reflections significantly affects the AoA accuracy. The major disadvantage of the two mentioned approaches is that they require additional hardware, which increases the cost and size of sensor nodes [18] [19] [20] [27] [36] [37].

3.2.3. Connectivity-based measuring techniques

- **Radio hop count:** This technique relies on the fact that nodes can communicate if the distance between them is less than their radio ranges. So by using RSS as a built in connectivity indicator between sensor nodes a graph of vertices as nodes and edges as connectivity can be drawn. The hop count between two nodes can be considered as the length of the shortest path between their correspondent vertices in the graph. Hop-count based techniques highly depend on density of nodes and they are not suitable for anisotropic network topologies that contain holes which are unfortunately more likely to exist in practice. The two main demerits of such technique are: (a) The distance between nodes is always integral multiples of the maximum range of their radios, and (b) The lack of a solution to overcome the problem of the precluded edges in the graph due to environmental obstacles as depicted in Figure 1(c) [17] [21] [26].

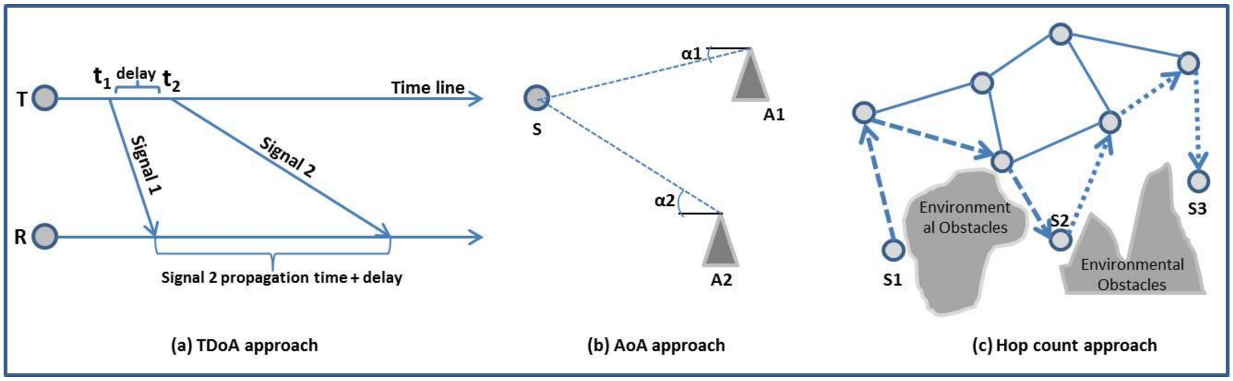

Figure 1: Some measuring techniques.

3.3. Positioning Techniques

Positioning techniques are algorithms that compute the locations of unknown nodes based on the measured metrics. The basic techniques used in position computation that are considered as a base to more advanced techniques are lateration, multilateration, and angulation (or triangulation) [12] [17] [18] [19] [20] [21] [38].

3.3.1. Lateration

This technique estimates the node position in 2-D from the intersection of 3 circles centered at 3 non co-linear anchor nodes formed based on the distance measurements between the node to be localized and such 3 anchors as illustrated in Figure 2(a). The distance can be calculated using ToA, TDoA, RToF and RSS as previously mentioned. This technique can be easily extended to estimate the node position in 3-D by referring to four anchors instead of three.

3.3.2. Multilateration

Maximum Likelihood Multilateration: The trilateration technique cannot accurately estimate the position of a node if distance measurements are noisy. A possible solution is to use the Maximum Likelihood (ML) estimation, which includes distance measurements from multiple neighbor nodes as per Figure 2(b). The scheme intends to minimize the differences between the measured distances and estimated distances.

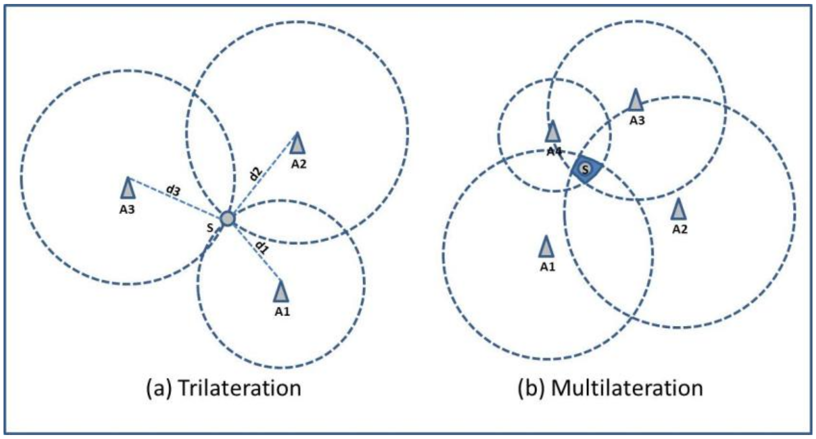

Figure 2: Trilateration and multilateration positioning techniques.

3.3.3. Angulation

This method estimates the 2-D position of a node by using at least two angles (or directions) relative to 2 anchors along with their positions instead of the distance in between. Using the angles information and the anchors' positions, trigonometry laws of sines and cosine are used to calculate the node's position. Without granularity, arguably that one anchor is used to estimate the position and the second is to confirm. The advantage of this method is that a node position can be estimated using as few as 2 anchors for 2-D and 3 anchors for 3-D with no time synchronization which is not the case as in lateration. However, the disadvantages are that extra and complex hardware is required and the accuracy is degraded as the node moves farther from the anchors.

3.3.4. Others

Some other positioning techniques are scene analysis (or radio map) and proximity [39] [40]. Scene analysis algorithms such as probabilistic, neural networks and support vector machine firstly collect features of a scene (fingerprints) offline, as a training phase, to create a database and then use such database online to locate an object by matching the calculated measurements with the closest fingerprint. RSS is the commonly fingerprinting method in scene analysis algorithms. The challenge with such techniques is that the database may become unreliable, and requires frequent updates due to changes in the channel and environment. On the other hand, proximity algorithms provide a symbolic location of an object based on a dense grid of well-known antennas. If the object is detected by only one antenna its position will be considered the antenna's location. Otherwise, the object location will be the location of the antenna that receives the strongest signal from such object.

3.4. Discussion

There are a number of measuring techniques for WSN localization. Selecting one or the other is application dependent. Techniques based on AoA and propagation time typically achieve better accuracy than techniques based on RSS but at the expense of equipment cost. RSS is most valuable in networks that have a large number of sensors. Both are impacted by time-varying errors such as those due to additive noise and interference, which can be reduced by taking the average of multiple measurements. Another source of unpredicted errors is the environment itself, e.g., presence of mountains, trees, building, walls, etc. Hence the concept of using hybrid measurements is proposed; in which multiple measurements such as ToA/TDoA or TDoA/AoA are employed in location estimation.

Typically many localization algorithms depend on node density like in hop count while others depend on density of anchor nodes. The latter, to some extent, have two advantages over algorithms with no anchors: (a) Scalable and decentralized localization can be achieved by distributing anchors throughout the area to be covered. (b) In the case of centralized localization, the accuracy can be increased by increasing the number of deployed anchors. However, in this case the anchors density, placements and configurations should be considered to avoid the problem of packet collision.

4. Healthcare Domain Attributes and Requirements

The healthcare domain is one of the most complex sectors due to the involvement of multiple and different stakeholders, which makes it a challenging industry. Challenges include, but are not restricted to, patient safety, tracking and tracing of hazardous drugs and medical devices, and efficient utilization of physicians and medical staff while keeping focus on personalized patient care and managing rising costs. In order to achieve high quality and efficient healthcare service delivery and to ensure that each patient receives the right therapy in a timely fashion, Information Technology (IT) must be adopted through effective software applications and hardware infrastructure deployment. Hence, IT can provide better patient care and management, enhance health service quality and improve the entire operation timeliness and efficiency through supporting activities such as: access to patient record transactions, tracking and monitoring patients in real time, allocating resources like drugs and medical devices, and alerting patients and medical staff on demand [41] [42] [43] [44] [45] [46] [47]. We focus on the main three entities of the healthcare/medical domain which are: patients, caregivers, and assets and identify the importance of localizing and tracking each of them which resulting in optimized workflow and streamlined care processes [48] [49] [50] [51].

4.1. Patients

Patients are the key elements that consume healthcare services. They expect to receive the right treatment on time with high standards of care. Furthermore, patients have become more involved in their therapy plans and require knowing more information about their medical records. These reasons lead to what is called 'patient-centered care" system whose goal is to improve the quality of service for patients by enhancing the level of care and achieving more positive patients' outcomes. However, not all patients require the same level of care; some must be treated in special care facilities (i.e. emergency units) with close monitoring while others can be treated remotely wherever they are (indoor or outdoor) by monitoring their medical conditions and take actions according to their needs. In such case, patients are allowed to be mobile such as in elderly patients and those with Alzheimer, dementia, psychological disorder or mental illness. These patients can wander away from their allocated beds or care areas as a part of their treatment; however at the same time this may increase the chance of more complicated accidents as well as the stress for their caretakers. So, such patients need to be localized, tracked, and alerted if necessary, in real time, in order to keep them safe and to avoid further complications. We layout patients' requirements from such localization and tracking system as follows:

4.1.1 Immediately locate and track patients in an accurate and simple manner to ensure their safety and security, and to reduce the waiting time for patients to contact with caregivers in waiting rooms or between multiple care stations.

4.1.2 Maintain the patients' privacy and ensure that their location information is only acquired by authorized personnel.

4.1.3 The localization and tracking system have to include personal alarm functionality and a self-navigation aid.

4.1.4 Tags or IDs used for tracking should be comfortable in terms of size, weight and usability.

4.2. Caregivers

Caregivers are the healthcare service providers who are concerned with maintaining and restoring patients' health through their engagement with patients. Their role is dynamic and complex, and they are expected to arrange and cooperate with other qualified professionals and care providers as a team to offer care for patients. Communication among such disparate team is critical to achieve more timely and accurate performance for the entire care process. Caregivers increasingly rely on mobile devices such as smart phones, tablets, mobile carts and notebooks to conveniently access, input and update patients' information. Medical staff can be exposed to different dangerous and risky situations throughout their daily routine work. This adds a challenge to ensure the safety of such staff especially in a highly mobile environment like hospitals. So, there is a need for localization and tracking systems that can regulate and monitor the medical staff in real time and enable them to work in a safe, efficient and effective manner. From their point of view, such system should provide the following:

4.2.1 Locate staff members anywhere in the hospital or in their area of responsibility, which contributes to patient safety, staff safety and at the same time increase the efficiency of care operations.

4.2.2 Communicate patient location and be notified when at-risk patients wander into restricted areas or exit the premises in an unauthorized manner.

4.2.3 Once the location of a patient is detected; patient information should be retrieved on the caregiver mobile device.

4.2.4 The accuracy of a location of patient or equipment should be defined in different levels such as bed-level, room-level or zone-level.

4.2.5 Determining the actual counts of patients in the hospital along with their conditions and track them from one care station to another while calculating the time the patient spends in each station.

4.2.6 The ability to integrate with localization and tracking systems of partner's healthcare facilities.

4.3. Assets

Assets (medical equipment) in the healthcare/medical domain can be specialized equipment such as surgical equipment, measurement/test equipment, infusion pumps, wheelchairs, laboratory instruments and diagnostic devices or hazardous drugs and materials that are mobile in nature and scattered throughout the hospitals. These valuable assets can belong to different departments. However, they can be used and maintained by other internal/external sources that make it susceptible to loss or theft. In order to accommodate for such loss or misplacement, hospitals always acquire or lease extra devices than required and unfortunately they waste valuable time finding them. The challenges are to improve asset utilization and to avoid time consuming or care delay through efficient management and coordination of those assets availability with scheduled medical services, while reducing capital expenditures and labor costs. So, with localization and tracking systems in hospitals, caregivers will have the ability to locate the required equipment when it is needed in less time to enable them to spend more time serving patients through the following system's capabilities:

4.3.1 Localize assets in real time anywhere in the hospital. This should reduce duplicate resources.

4.3.2 Track, record and report status of an asset and provide an alert signal when it moved out of a designated area and keep detailed logs of such information.

4.4. General System Requirements

There is an urgent demand in the healthcare domain for a localization and tracking system that help in coordinating and delivering care services in a more professional, efficient and safe manner through locating patients, medical staff, and assets anywhere anytime, especially during emergencies. By referencing to international medical associations such as [44] and [47] along with articles [45], [54], [55], [56] and [57], which discuss the different localization and tracking requirements, the localization and tracking system proposed for healthcare has to meet the following requirements, which are abbreviated and mapped to each entity's requirements in Table 1.

1) Localizing and tracking patients, medical staff members, and assets in a real time in both indoor and outdoor environments regardless of their mobility pattern.
2) Integrating and interoperating with Healthcare Information Systems (HISs) to retrieve patients' information to the point of care in a timely fashion with no need for any modification.
3) Including alarm functionality to be used at location-based events.
4) Achieving multiple levels of location accuracy (i.e. bed-level, room-level, zone-level, etc).
5) Achieving high scalability in terms of number of entities to be localized and area to be covered.
6) Maintaining robustness at the event of failure in the system or the network.
7) Using comfortable devices for the system users in terms of size, weight and usability.
8) Compliance with the standard privacy policies.
9) Utilizing the energy efficiently and maintaining the system lifetime up to the end of its mission.
10) Integrating with localization and tracking systems of predefined partners.

General system requirements (abbreviated)	Achieved requirements per domain entity		
	Patient	Caregivers	Assets

1	Real-time localization and tracking	**1**	2	3	4	**1**	**2**	3	4	**5**	6	**1**	**2**
2	HISs Integration	1	**2**	3	4	1	2	**3**	4	**5**	6	1	2
3	Alarm functionality	**1**	2	**3**	4	1	**2**	**3**	4	5	6	1	**2**
4	Accuracy	**1**	2	3	4	**1**	**2**	3	**4**	5	6	**1**	**2**
5	Scalability	**1**	2	**3**	4	**1**	**2**	3	**4**	5	6	**1**	**2**
6	Robustness	**1**	2	**3**	4	**1**	**2**	3	4	5	6	**1**	**2**
7	Users' satisfaction	1	2	3	**4**	1	2	3	4	5	6	1	2
8	Privacy	**1**	**2**	3	4	1	2	**3**	4	5	6	1	2
9	Sustainability	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**
10	Partner cooperation	1	2	3	4	1	2	3	4	5	**6**	1	2

Table 1: System to entities requirements mapping.

In Table 1, the first column represents the general system requirements as proposed in Section 4.4. The requirements of the 3 entities: Patients (Section 4.1), Caregivers (Section 4.2) and Assets (Section 4.3) are represented as numbers in the second, third and fourth columns, respectively. Shaded number indicates that this entity's requirement is provided by achieving the correspondent general requirement. For example, if the system can localize and track objects in real time (first general system requirement) then the patients' first requirement, the caregivers' first, second and fifth requirements and the assets' first and second requirements will be achieved. In other words, for each general system requirement, we shade each number of achieved requirements for patients, caregivers and assets.

Based on the previously mentioned requirements and based on my research; Table 2 represents the criteria, as performance metrics, that will be used to evaluate and assess the different schemes and systems proposed in the literature.

Table 2: Performance metrics based on my opinion.

Criterion	Description
Accuracy	The ability of the system to minimize localization error, where the error refers to the deviation from the true location.
Robustness	The ability to operate normally under environmental obstacles such as unavailability of signals or shortage of information.
Scalability	The ability of the system to sustain the required level of functionality and performance regardless of the domain size.
Integration & privacy	The ability of the system to integrate seamlessly with existing HIS and/or medical equipment, while providing patient's confidentiality.
Energy efficiency	The ability of the system to manage power consumption, resulting in sufficient lifetime and better communication.

5. Localization and Tracking Systems Classification

Different localization and tracking systems have been proposed in the literature to address the needs of a variety of applications, including ones for the healthcare domain. Such systems may utilize one or more of the previously explained measuring techniques, such as ToA, TDoA, RToF or RSS. Such approaches use different wireless technologies, and one of two approaches to carry out computations: centralized or distributed.

Several survey papers discussed different aspects of localization and tracking techniques and systems and pursued different directions to classify them. References [14], [17], [21], [26] and [29] classified localization algorithms and techniques based on their computational approach however [14] focused on the cooperative algorithms, while [29] considered localization methods for only mobile WSNs. Taxonomy has been pursued in [15] and [27] where techniques and systems have been classified according to used measurement techniques and further details have been given in [18] which classifies the WSN localization algorithms into three groups based on measurement techniques, positioning techniques and localization algorithm as either single hop or multi hop. In [12] and [58], systems for indoor situations have been discussed and classified based on the wireless technology schemes such as RFID, UWB, WLAN and Bluetooth, while in [20] the authors discussed only the localization techniques that based on ToA along with their technical issues. This section is concerned with reviewing, classifying and evaluating some selected systems from the literature along with a few commercial systems from the healthcare perspective.

5.1.Performance Metrics and Ranking Technique

Based on the performance metrics defined in Table 2 along with the system requirements defined in Table 1 which consider all health care domain entities (patient, caregivers and assets) requirements, I define different ranks to assess each of the proposed systems as per Table 3.

Table 3: Systems assessment technique in my point of view

Criterion	System requirements in the ideal scenario	Assessment		
		Good	Fair	Poor
Accuracy	(a) Accurate indoor localization. (b) Accurate outdoor localization. (c) Achieve multiple levels of location accuracy.	(a), (b), (c)	(a), (c)	(a)
Robustness	(a) Maintain the functionality at system failure. (b) Maintain the functionality at network failure.	(a), (b)	(a)	None
Scalability	(a) Scale with the number of entities. (b) Scale with the area to be covered.	(a), (b)	(a)	None
Integration & privacy	(a) Integrating with HISs. (b) Integrating with localization and tracking systems of predefined partners. (c) Maintaining privacy.	(a), (b), (c)	(a), (c)	(a)
Energy efficiency	(a) Utilize the energy efficiently. (b) Sustain the system lifetime up to the end of its mission.	(a), (b)	(a)	None

5.2. System Classification and Presentation

In the literature, different systems have been proposed to address the needs of localization and tracking. In the following subsections we present, comment and highlight each system's characteristics taking into consideration the metrics defined in Table 2. We classify systems as fingerprint-based, distance-based, proximity-based and light-based. Fingerprint-based systems are based on collecting significant features -named signatures- of known locations, either offline or online, and storing them in a database. Then, objects can be located online by fetching the closest signature that matches their own. Whereas, distance-based systems locate objects by calculating their distance from three or more anchor nodes based on ToA, TDoA or RSS and then apply one of the positioning techniques such as trilateration or multilateration. On the other hand, proximity-based systems are generally based on a dense grid of well-known anchor nodes and the object position is considered as the position of the nearest anchor node. Finally, light-based systems depend on light-aware sensors for light sensing to measure either distance or angle of objects to be located which obviously require line-of-sight and then follow different approaches to locate them.

5.2.1. Fingerprint-based Systems

RADAR [59] is a RF-based localization and tracking system for indoor environments. As a fingerprint-based system; RADAR consists of two phases: First, it starts with building a centralize database of RSS signatures offline based on a set of anchor nodes using a mobile node at different pre-known locations. RADAR considers the mean, standard deviation and the median of the correspondent RSS values for each anchor nodes. Each RSS signature includes RSS, a synchronized timestamp and direction of the mobile node along with the coordinates of the pre-known location. Second, RADAR uses such database online to localize a node of interest. It depends on the overlapping between anchor nodes and triangulates the node's coordinates by finding the closest RSS signature to the node's observed RSS's providing 2 to 3 meters accuracy.

Although RADAR provides good accuracy in indoor environments, it fails to realize many requirements of healthcare domain such as providing multiple levels of accuracy, outdoor localization, scalability in terms of area to be covered and being robust in case of failure. In addition, the system does not consider the users' devices in terms of size, weight and usability.

Another RF-based system that uses an algorithm similar to RADAR is MoteTrack [60]. MoteTrack operates in a decentralized and robust fashion with no backend server or specific network infrastructure. It uses a network of battery-operated, programmable and inexpensive wireless anchor nodes to measure, store and compute location information. The system is designed to tolerate failure of anchor nodes, loss of information and perturbations in RF signals without severely degrading accuracy by replicating the database of RSS signatures across anchor nodes themselves and using a new signature distance metric that takes loss into account. As in RADAR, the system consists of two phases: offline and online. The difference is that the offline phase takes place using a decentralized approach. Another difference is that, during the online phase, the location of the tracked object is considered as the centroid of the geographic location of k-nearest reference signatures. The latter can be weighted or limited to a certain ratio. Three methods for location computation are proposed that vary in accuracy on account of communication overhead and two algorithms are proposed to handle the database distribution. MoteTrack does not enhance the accuracy of RADAR but rather improves the robustness.

While MoteTrack achieves good robustness against failure in anchor nodes or loss of information while keeping the same accuracy of RADAR, it may suit only small scale healthcare facilities due to shortcomings in integration, security and scalability.

The main objective of LANDMARC system [61] is to enhance the indoor location accuracy by utilizing active RFID tags and RFID readers to locate objects. The system depends on the power level of the active tags and uses an algorithm to reflect the relation between power level and RSS readings. Its main idea is to have extra and carefully positioned fixed location tags to help location calibration by comparing the RSS readings of the nodes to be localized with those of reference tags to increase the accuracy. All RFID readers send over the tags information to a centralized location server along with readers' ID, power level and the mode of readings as continuous or exception. The authors tested the effect of the number of reference tags in a reference cell and they end up with the 4-nearest approach as it works the best in terms of position accuracy. Their idea increases the overall accuracy while keeps the cost of the entire system low. Their tests show that the accuracy is between 1 to 2 meters and each reader can detect up to 500 tags in 7.5 seconds. The tags' battery life is 3-5 years.

Although this system achieves an acceptable accuracy in indoor environments, has a long system life time and works in a centralized manner that allows integration with HIS systems, it shows poor privacy and robustness. This may impede the usability of LANDMARC in the highly dynamic healthcare facilities.

Horus [62] is another localization and tracking system that uses RSS signatures to infer the user location using a probabilistic technique. Horus introduces a new clustering module to group radio map locations based on anchor nodes covering them to reduce the computational requirements of the system. The authors of Horus propose two probabilistic modules to return the user location: Discrete Space Estimator which returns the location with the maximum probability given the RSS readings from different anchor nodes and Continuous Space Estimator which returns a more accurate location in the continues space as an average over a few most likely locations. Horus works in two phases: offline phase during which the radio map is built, the locations are clustered and the RSS distribution for each anchor point is estimated and an online phase during which the user location is estimated with 1.4 meters accuracy.

Despite the good accuracy of the Horus system, it does not address robustness and HIS integration. Also, the system scalability is constrained by the location server capability. Thus, HORUS may only be suited for small scale and less dynamic healthcare facilities.

Another localization and tracking system called Online Person Tracking (OPT) is presented in [63] for an indoor environment, which consists of anchor nodes and a PC as a central computation device to process location information data and estimate the location. Being a fingerprint-based system, OPT starts with a data collection phase. In this phase it considers the average of RSS readings in four different directions for each empirical point and stores such data on the central device. Mobile objects can be tracked either by increasing the rate of measuring RSS or by reducing the number of samples in each estimation. The authors compare the system performance using three different optimization algorithms and end up with a weighted Minimum Mean Square Error algorithm which shows the best result in terms of location accuracy however the system accuracy depends on the proximity of the tracked object with respect to the anchor nodes.

OPT can localize objects in an indoor environment and uses a centralized and powered server as a location server. This central approach increases the system security. However, OPT does not fair well in terms of accuracy, scalability and robustness, and hence not suited for large scale healthcare facilities.

COMPASS [64] comes with an idea that avoids localization errors due to user orientation. It applies digital compasses to append the orientation information to the RSS information while constructing the fingerprint database. Then a probabilistic positioning algorithm is proposed to determine the user position based on such data. The idea behind this algorithm is that: after sampling RSSs readings for selected orientation at each anchor node, an orientation-specific signal strength distribution is computed and utilized each time a user requests a position estimate to increase the accuracy of such estimation. COMPASS outperforms the accuracy of RADAR as per their evaluation where it achieves 1.65 meters accuracy in comparison to 2.26 meters for RADAR.

While COMPASS performs well in terms of accuracy in indoor environment, it depends on digital compass capability which is not a default capability in most mobile devices. This hardware requirement will hinder the utilization of such system especially in vast domains such as healthcare. Furthermore, the system does not provide robustness and increases energy consumption.

In [65] the authors propose a general purpose, adaptable and centralized localization system for an indoor environment named GRAIL. The system depends on some anchor nodes and does not require any software to be installed on the devices to be localized. The system components are transmitters which are devices that transmit radio packets and landmarks or anchor nodes which are deployed at known locations and continuously monitor the channels and forward their observation in terms of RSS and receiving time to a centralized server. The latter collects location measurements and decides on which localization algorithm to use. The localization algorithms are mapped to which called solvers which are decoupled from the server to provide more scalability and load balancing on the cost of localization latency. The location information is passed back to the server and stored on a central database which can be used for offline data analysis and summary. No performance results were reported.

GRAIL is reasonable in terms of availability of integration and maintaining security. However, it fails to realize outdoor localization and is not scalable. Also, the system does not provide multiple levels of accuracy or propose mechanisms to achieve robustness and hence does not fit the highly dynamic healthcare facilities.

The core idea of SurroundSense [66] is to sense numerous ambient attributes of logical locations such as light, sound and color through mobile phones to construct a database of signatures to be used for logical localization. The system consists of two phases: fingerprint generation and fingerprint matching. During the first phase, some mobile phone users visit unknown locations and collect, preprocessed and transmit to a server the sensed data from the visited location. Such data may include sound, light, color, anchor node and accelerometer. On the server side, this data is distributed to respective fingerprint modules to be prepared for operation. During the second phase, SurroundSense combines 4 filtering/matching operations to output the phone's logical location. During authors' evaluation, different levels of accuracy show up but, when all sensors are employed for localization, the average accuracy of over 85% is achieved.

SurroundSense depends on the ambient attributes of locations to be covered. However, almost all healthcare facilities have similar attributes in terms of color and sound. So, the accuracy may not be reasonable in such domains. Furthermore, SurroundSense works only for indoor environments and does not take robustness, scalability and energy efficiency into consideration.

EZ [67] introduces a new trend in indoor localization, which does not need a prior knowledge of the RF environment or the transmit power of deployed anchor nodes. The scheme depends on three basic assumptions: (1) there are enough anchor nodes to fully cover the indoor environment, (2) the users use mobile devices such as smart phones or notebooks and (3) occasionally such mobile devices obtain absolute locations via GPS. Mobile devices are required to report RSS measurements corresponding to anchor nodes in their range at different unknown locations to a centralized localization server. After gaining enough information as well as three global known points as a minimum, the server uses a genetic algorithm to determine the anchor nodes location and their transmission powers thereby learns the characteristics of the RF propagation to be able to localize the users. The authors' evaluation shows that EZ can achieve accuracy within 2 to 7 meters according to the building size.

EZ has a key advantage over many systems in reducing the effort needed for area calibration and it does not require explicit pre-deployment effort. However, its accuracy is beyond the average and it works only in indoor environments. Furthermore, EZ depends on assumptions which are not usually available without considering any fault tolerance. So, EZ is not a good candidate for the healthcare domain.

5.2.2. Distance-based Systems

The Cricket system [68] is proposed as an indoor location-support system rather than a location-tracking one. It avoids using a centralized database for location information and allows mobile and static nodes to learn their location by analyzing information generated by anchor nodes throughout the building. The system is decentralized in terms of anchor installation, configuration and integration with one another. Each anchor in Cricket generates two signals: RF and ultrasound, which are used by nodes to be localized to determine their distance from the anchor nodes based on TDoA. A listener, location receiver hardware, is attached to each node of interest and uses an inference algorithm to determine the area in which it is currently located based on the pairs of RF and US signals received from anchor nodes. The authors suggest three different inference algorithms: Majority, MinMean and MinMode.

System evaluation shows that MidMode algorithm is robust and performs well for static and mobile nodes with accuracy smaller than few inches. However, special concern should be given to anchor nodes placement.

Cricket is a prominent localization system in terms of scalability, privacy and accuracy. However, it consumes mobile devices' battery, works only indoors, requires a significantly high number of anchor nodes and does not provide a good integration mechanism. It suits healthcare facilities where each unit has its own administration and the mobile devices can easily recharge their batteries.

PinPoint [69] is a distributed ToA-based location tracking system for indoor and outdoor environments that does not require time synchronization or area calibration. It depends on a set of message exchanges between mobile nodes where sending and receiving timestamps are leveraged to calculate the distance between a node and its neighbors. PinPoint consists of two steps: a ranging step at which each node estimates the distance to all its neighbors and a range combining step at which the entire network topology is estimated. The authors of this system propose a PinPoint node which consists of three modules: a clock module, a communication module and a computation module. In addition, the authors propose a protocol that operates in three phases: measurement phase, information exchange phase and computation phase. Their tests show that PinPoint has an average accuracy of 1.2 to 1.8 meters in different environments.

Although PinPoint works in both indoor and outdoor environments and achieves reasonable accuracy, it may not be suited to large scale healthcare facilities due to the following: (a) It uses a special mobile device which is not evaluated in terms of size, weight and life time. (b) Robustness is not realized and scalability and integration capabilities are constrained. (c) All computations take place on the mobile devices, which vastly consumes the battery.

SNOW BAT [70] is a decentralized ultrasonic system for tracking mobile objects based on the TDoA technique. In this system, mobile objects are equipped with sensor nodes carrying an ultrasonic transmitter and the anchor nodes are equipped with an ultrasonic receiver in addition to the radio transceivers on both types of nodes for time synchronization and data transmission. The TDoA between the two signals (radio and ultrasonic) is used to compute the distance from each anchor node which then is sent back to the mobile object to multilaterate its position. SNOW BAT increases the precision of calculated location by sending several chirps and uses the average TDoA for distance calculation. The authors show that three chirps produce a good tradeoff between localization time and accuracy. There is no preinstalled infrastructure and no need to position anchor nodes along a specific pattern. However, a mobile node should always reach a number of anchor nodes that exceeds the required location dimensions by one. The system evaluation shows that the achieved accuracy is less than 15mm.

While SNOW BAT achieves very high accuracy, such accuracy comes at the expense of requiring line-of-sight connectivity and using a special type of sensor nodes, which carry an ultrasonic transmitter. SNOW BAT delegates the location computations to such nodes, which require special software. In addition, it does not address the integration and privacy issues and it is not robust against failure of static nodes. Due to the aforementioned reasons it may be reasonable to use SNOW BAT only in closed areas that have line-of-sight.

The authors in [71] propose a GPS-UWB-based indoor/outdoor localization and tracking system to be used in a hospital environment. The concept behind their system is the integration of GPS and Ultra Wide Band (UWB) signals to accurately locate objects regardless of where they are. Inside the building, a network of fixed-position UWB anchor nodes is deployed and GPS repeaters are installed at the entrance points of the indoor premises to ensure a seamless transition between UWB and GPS. The tags used by objects composed of a GPS receiver and UWB tag which automatically switch between indoor and outdoor modes. Throughout buildings, an object is located using the AoA and the TDoA of its signal with respect to UWB anchor nodes. The indoor and outdoor location information is sent to a location server. Experiments show that the accuracy for indoor tracking is 15 centimeters whilst for outdoor is 10 meters or above.

The GPS-UWB-based system is basically directed to hospital environments. It localizes objects in both indoor and outdoor areas with a good accuracy for both cases. However, it depends on mobile nodes that contain both GPS receiver and UWB tag, which may be impractical in terms of size, weight and battery lifetime. Nevertheless, the GPS-UWB-based system presents a good idea and opens a gate for developing new systems that work in both indoor and outdoor environment.

The authors in [72] propose a zero-configuration and robust indoor localization and tracking system using a new adaptable localization algorithm. Their system depends on RSSs between anchor nodes and between a mobile device and its neighboring anchor nodes. The RSSs among anchor nodes help in eliminating the effects of RF multi-path fading, human mobility, temperature and humidity variation on the RSS measurements. The system consists of anchor nodes with known locations and wireless monitors that work as additional anchor points in areas that have 3 or fewer anchor nodes to enhance the accuracy. According to the operation mode, either a client or the infrastructure measures the RSSs, maps the signals to distances and estimates the client location via trilateration. The authors' empirical results indicate that their system is robust and achieves localization with 3 meters accuracy.

Although this system is designed to be quite robust and responsive of environmental dynamics, it achieves such robustness through: (a) online measurements between all anchor nodes and (b) deployment of wireless monitors to solve the problem of insufficient number of anchor nodes. The former increases communication overhead while the latter increases the cost of the entire system. In addition, neither an integration mechanism is proposed nor high scalability is maintained. Due to the aforementioned reasons, the system may not be suited for large scale healthcare facilities.

Although many localization and tracking systems are based on RSS readings, one cannot neglect that RSSI may easily be affected by path loss, multipath fading and shadowing which decrease the system's accuracy. Therefore, the authors of FILA system [73] propose using Channel State Information (CSI) from the physical layer instead of RSSI to calculate the distance between a mobile node and an anchor node along with a fast training algorithm for anchor nodes calibration. CSI estimates the channel in each subcarrier in case of Orthogonal Frequency Division Multiplexing (OFDM) systems and describes how a signal propagates from transmitters to the receiver. Hence FILA require a new component for CSI processing at the receiver. FILA depend on a modified radio propagation model according to CSI and can be broken down into three main steps: CSI processing, calibration and location determination. In the latter, the distances between the target object and three anchor nodes are calculated and the simplest trilateration method is applied. FILA can achieve 1.2 meters accuracy within several milliseconds.

FILA system utilizes the current communication system and achieves an acceptable accuracy for healthcare domain. However, it works only for indoor environments and it fails to realize robustness and HIS integration. Moreover, it requires a new component to be installed on receivers, which limits its popularity in addition to location computations that take place on the mobile devices which consumes the battery.

5.2.3. Proximity-based Systems

Session Initiation Protocol (SIP) is an application-layer control protocol that controls creating, modifying and terminating sessions between two or more parties. SIP-RLTS [74] is an RFID-based localization and tracking system which utilizes SIP to provide localization and tracking of RFID tagged objects. The authors propose a location-oriented FRID middleware to overcome the limited resources of RFID tags and readers, filter noisy or missing data and aggregate redundant data based on given specifications. In addition, they add an RFID ontology infrastructure, a semantic location computation scheme and an SIP event-notification component. One of the main components of middleware is the location engine, which calculates the device's approximate location based on the presence of the device's tag in the area covered by the RFID reader.

SIP-RLTS is a good system as it provides a semantic location of objects, has notification capabilities, has a powered location server that can maintain security and privacy and has an application layer that facilitates different clients' communication. However, the system scalability is constrained by the capacity of the location server and no mechanisms are proposed to achieve system robustness. SIP-RLTS is a good candidate for small to medium scale healthcare facilities, which are not highly dynamic.

TraceMe [75] is an indoor localization and tracking system based on RFID technology with alarm generation capability. TraceMe consists of RFID active tags, which can use different transmission frequencies, RFID readers, a centralized server and a database to store RFID data. Beside these hardware components, the authors propose a java-based middleware to control the flow of information between the mentioned components. RFID readers upon receiving data from a tag send such data to the server which in turn updates the database with available information about area, reader and the tag. The authors propose two localization algorithms: one based on the short range communication between a tag and a reader, and the second is based on triangulation using RSSI readings of long range communication between a tag and multiple readers. Experiments conducted in [75] do not discuss accuracy or precision.

This system can be applied in healthcare domain with some limitations: (a) it works only in indoor environment; (b) it depends on active tags which consume energy without taking the system life time into consideration and (c) it is not scalable enough in terms of number of nodes and covered area.

The site survey, the process of collecting radio signatures, is an initial step in most of the radio-based systems despite its drawbacks in terms of cost, effort and inflexibility to environment dynamics. WILL [76] bypass this step by considering the anchor node's signal strength to distinguish different rooms without explicit users' participation. It depends on smart phones and their accelerometer sensors to obtain users movements and utilizes their traces to assist room-level localization. WILL consists of two phases: training and service. In the training phase, while users follow their daily routines, raw data which consists of anchor node signal strength and accelerometer readings are collected on the mobile phone side. The WILL server uses this data, as well as data mining techniques to construct virtual rooms based on readings with high similarities, which are mapped later to physical ones. During the service process, the user may query the WILL sever by sending its signal measurements and sensory data. The localization engine of the WILL system localizes the virtual room in which the user exists and retrieves the physical room that is matched with the virtual room and sends it back to the user.

Although WILL provides room-level accuracy without a need for a site survey which makes its deployment easy and rapid, it depends on mobile devices. Furthermore, WILL does not realize other requirements such as extra levels of accuracy, outdoor localization, robustness and HIS integration. The dependency on mobile devices and their sensors lead to extra energy consumption and affecting system life time. WILL may integrate with other systems to provide localization and tracking in healthcare facilities.

5.2.4. Light-based Systems

In [77] the authors propose an outdoor, centralized and line-of-sight based localization and tracking system named Spotlight. It uses the spatio-temporal properties of well controlled events such as light to localize sensors. All the hardware infrastructure and computations take place on a centralized single Spotlight device that uses a steerable laser light source and requires a line of sight with the sensor nodes need to be localized. Spotlight localization technique consists of three steps: First, the generation of light as a controlled event through Event Distribution Function in the area where sensors are deployed. Second, the ToA of such event at the sensor node along with its spatio-temporal properties are reported to the Spotlight device through Event Detection Function. Last, the location of the sensor node is computed through a Localization Function. Three methods for the Event Distribution Function as a core function are proposed with different tradeoffs in terms of localization time, communication overhead and energy consumption. The system accuracy depends on some factors such as size of the event and time synchronization between sensor nodes and the Spotlight device. However, through experiments conducted in [77], Spotlight shows only 20cm localization error in a 2500m2 outdoor area.

Although Spotlight achieves high accuracy, the line-of-sight constraint is a handicap for the system utilization in healthcare facilities indoor. Spotlight may be useful in very limited cases such as in a hospital's yard that does not contain any kind of obstacles or in outdoor extensions, which serve healthcare facilities.

Based on light sensing, iTracking [78] is proposed as a mobile light source localization and tracking system. It achieves centimeter-level accuracy. The system depends on light-aware sensors and composed of three processes: the first is the distance mapping based on light intensity at multiple anchor nodes. Second, analysis of such distance takes place. Last is updating the calculated location for tracking purpose. It is obvious that line-of-sight is a must and hence, the system utilization is restricted to areas that satisfy this condition. The author's experiments show that their system achieves 5 centimeters accuracy.

iTracking is not a good candidate for large scale healthcare facilities due to the following reasons: (a) it works only under line-of-sight condition, (b) it does not scale with the number of objects or the area to be covered, (c) it does not achieve any kind of robustness, and (d) it depends on light which is not practical for most of mobile devices. However, it may suits closed areas that have line-of-sight.

iLight [79] is another light-based localization and tracking system that localizes and tracks moving device-free objects in indoor environment using a group of light sensors with general light sources. Each sensor node is equipped with one light sensor and at least one transceiver in order to communicate with each other forming a connected WSN. The system works by grouping such sensors into clusters and install them face to face in the area to be monitored. The authors propose a probabilistic method to track objects efficiently and accurately through dividing the monitored area into cells and assigning probabilities to such cells based on the collected data per each time slot. The cell with the highest probability is considered as the current position of the moving object.

While iLight may localize and track device-free objects with centimeter-level accuracy, it fails to realize all other requirements such as localizing objects outdoors, achieving robustness, scalability and providing integration capabilities. So, we can say that this system is not suitable for the healthcare domain.

5.3.Comparative Analysis

In this section, the existing localization and tracking systems presented in the previous sections are evaluated from a healthcare perspective. The systems are ranked using our proposed ranking technique (Table 3) which fully focuses on healthcare domain requirements as defined in Table 1 with respect to the various aspects as defined in Table 2. These aspects include accuracy, robustness, scalability, integration & privacy and energy efficiency. Our evaluation and assessment is shown in Table 4, where each horizontal record represents the assessment of one system.

There are many ways to utilize such table. One way to look at this table is to know the result of the assessment of a certain system. For example, considering LANDMARC system (3rd record), one can see that LANDMARC is fair in its accuracy because it locates objects within 1 to 2 meters (indoors only). Also, it performs poorly in terms of robustness. However, if energy efficiency is a concern, it can be considered a good system. Another way to look at the table is to decide on which system to use when a certain scenario is at hand. So assume that we need a localization and tracking system that can work in both indoor and outdoor environments with acceptable accuracy, then SIP-RLTS can be a candidate. Whereas, when robustness is added to the requirements, SIP-RLTS will not be a good option and Cricket will come to the front with scalability as a value added feature.

Table 4: Localization and tracking systems comparison

System Name	Accuracy	Robustness	Scalability	Integration & Privacy	Energy efficiency
Fingerprint-based systems					
RADAR [59]	**Poor.** *It provide indoor localization with 2-3 meters accuracy*	**Poor.** *No mechanisms proposed*	**Fair.** *It depends on a centralized approach that has limited scalability in terms of covered area*	**Fair.** *It uses a central location server which can integrate with HIS by implementing suitable API's*	**Poor.** *It depends on PC's and AP's and does not consider energy consumption*
MoteTrack [60]	**Poor.** *As in RADAR*	**Good.** *It tolerates failure of infrastructure and loss of information*	**Fair.** *Due to database replication, the system has a limited scalability in terms of covered area*	**Poor.** *It depends on decentralized approach that faces many integration and security issues*	**Fair.** *It uses a low-power battery-operated nodes with no mention of lifetime*
LANDMARC [61]	**Fair.** *It provides indoor localization with 1-2 meters accuracy*	**Poor.** *No mechanisms proposed*	**Fair.** *It detects 500 node in 7.5 seconds*	**Fair.** *It uses a central location server, which can integrate with HIS by implementing suitable API's*	**Good.** *Computations take place on powered location server and the tags' battery life is from 3 to 5 years*
Horus [62]	**Poor.** *It provide indoor localization with 1.4 meter accuracy*	**Poor.** *No mechanisms proposed*	**Fair.** *Its scalability depends on the capacity of the location server*	**Poor.** *No integration mechanism is proposed*	**Fair.** *Computations take place on powered server with no mention of tags' lifetime*
OPT [63]	**Poor.** *It provides indoor localization with 1.5 to 3.8 meters accuracy*	**Poor.** *No mechanisms proposed*	**Poor.** *It does not consider scalability issues*	**Fair.** *It uses a central location server which can integrate with HIS by implementing suitable API's*	**Fair.** *Computations take place on powered server with no mention of tags' lifetime*
COMPASS [64]	**Fair.** *it provides indoor localization with 1.65 meters accuracy*	**Poor.** *No mechanisms proposed*	**Poor.** *It does not consider scalability issues.*	**Fair.** *It uses a central location server, which can integrate with HIS by implementing suitable API's*	**Poor.** *It depends on digital compass that adds extra energy consumption to the mobile devices*
GRAIL [65]	**Poor.** *It provides indoor localization without mention its accuracy*	**Poor.** *No mechanisms proposed*	**Fair.** *It is centralized but scales with number of nodes*	**Fair.** *It provides only a simple approach to maintain privacy*	**Fair.** *Computations take place on powered server(s) with no mention of tags' lifetime*
SurroundSense [66]	**Poor.** *It provides logical localization based on ambient*	**Poor.** *No mechanisms proposed*	**Fair.** *Scalability with area to be covered is not visible.*	**Poor.** *No integration mechanism is proposed*	**Poor.** *It depends on many sensors of mobile devices*

	attributes				*that consume their batteries*
EZ [67]	**Poor.** *It provides indoor localization with 2-7 meters accuracy*	**Poor.** *No mechanisms proposed*	**Fair.** *Its scalability depends on the capacity of the location server*	**Fair.** *It uses a central location server which can integrate with HIS by implementing suitable API's*	**Fair.** *Computations take place on powered server. Mobile devices do some calculations*
Distance-based systems					
Cricket [68]	**Fair.** *It provides indoor localization with less than few inches accuracy*	**Good.** *With special concern to anchor nodes placement*	**Good.** *It is scalable due to its decentralized behavior*	**Poor.** *No integration mechanism is proposed but it highly maintains privacy*	**Poor.** *Computations take place on mobile nodes which consumes their battery*
PinPoint [69]	**Fair.** *It provides indoor and outdoor localization with 1.2 to 1.8 meters accuracy*	**Poor.** *No mechanisms proposed*	**Fair.** *It works in a distributed manner*	**Poor.** *No integration mechanism is proposed*	**Poor.** *Computations take place on mobile nodes which consumes their battery*
SNOW BAT [70]	**Poor.** *It provides indoor localization with less than 15 mm accuracy*	**Fair.** *It supports self-configuration as long as number of static nodes is enough*	**Good.** *It is decentralized with high scalability*	**Poor.** *No mechanisms proposed*	**Fair.** *Computations take place on anchor nodes with no mention of lifetime*
[71]	**Good.** *It provides indoor localization with 15 centimeters accuracy and outdoor localization with GPS accuracy (1 to 100 meters)*	**Poor.** *No mechanisms proposed*	**Good.** *Readers can be networked together as in cellular network however; GPS repeaters are required in each entrance point*	Fair. *Theoretically applicable however; no practical solution is proposed*	**Poor.** *UWB tags consume less power however it is the opposite with GPS receivers*
[72]	**Poor.** *It provides indoor localization with accuracy based on number of wireless monitors*	**Good.** *Through the SVD techniques*	**Fair.** *Scalability with area to be covered is not visible.*	**Poor.** *No mechanisms proposed*	**Fair.** *Depends on where the computations take place*
FILA [73]	**Fair.** *It provides indoor localization with 1.2 accuracy*	**Poor.** *No mechanisms proposed*	**Good.** *It is scalable due to its decentralized design*	**Poor.** *No integration mechanism is proposed but it highly maintains privacy*	**Poor.** *Computations take place on mobile nodes which consumes their battery*
Proximity-based systems					
SIP-RLTS [74]	**Good.** *It provides proximity localization with*	**Poor.** *No mechanisms proposed*	**Fair.** *Its scalability depends on the capacity of the*	**Fair.** *It has application layer that can integrate with*	**Fair.** *Computations take place on powered server.*

	multiple levels of accuracy		*location server*	*other business applications*	*The lifetime depends on the used tags.*
TraceMe [75]	**Fair.** *Multiple levels of accuracy can be achieved using different frequencies*	**Poor.** *No mechanisms proposed*	**Fair.** *It is centralized with limited scalability*	**Fair.** *Policies can be applied on its location server*	**Fair.** *Database is stored in central server. It uses active tags without mention its lifetime.*
WILL [76]	**Fair.** *It provides indoor localization with room-level accuracy*	**Poor.** *No mechanisms proposed*	**Fair.** *Its scalability depends on the capacity of the location server*	**Poor.** *No integration mechanism is proposed*	**Poor.** *It depends on many sensors of mobile devices that consume their batteries*
Light-based systems					
Spotlight [77]	**Poor.** *It provides outdoor localization within limited area with 20cm accuracy*	**Poor.** *It depends on a centralized single device that requires line-of-sight*	**Fair.** *It scales with number of nodes but covers only limited area*	**Fair.** *Theoretically applicable however; no practical solution is proposed*	**Fair.** *All computations are performed on the central device that can be powered. No sensor's lifetime is mentioned*
iTracking [78]	**Fair.** *It provides 5 centimeters accuracy under line-of-sight condition*	**Poor.** *No mechanisms proposed*	**Poor.** *It does not consider scalability issues.*	**Poor.** *No mechanisms proposed*	**Poor.** *It uses light-aware sensors with no mention of lifetime*
iLight [79]	**Poor.** *It provides indoor localization with centimeters-level accuracy*	**Poor.** *No mechanisms proposed*	**Poor.** *It does not consider scalability issues.*	**Poor.** *No mechanisms proposed*	**Poor.** *It uses light-aware sensors with no mention of lifetime*

5.4.Commercial Localization and Tracking Systems

Real-time Awareness Solution [49] is a localization and tracking system provided by Awarepoint Inc. for healthcare industry to continuously locate assets and personnel in an indoor environment. The system consists of a mesh network of sensors, based on ZigBee®, acting as anchor nodes which can be simply plugged into general outlets. The raw sensor data is collected from Awarepoint RFID tags by such anchor nodes and forwarded through coordinating bridge node to Awarepoint's RTLS components to be transformed into positioning information as depicted in Figure 3. The system accuracy is proposed as defined area location accuracy such as room level, hallways and open waiting areas and precision to within 1.5 meters. In addition, the system can scale to more than 65,000 active nodes and accommodate their mobility. Awarepoint develops its own positioning algorithms and software however; no details are given to explain the system's positioning engine algorithms. Integration with other systems can be achieved through using standard XML Web service API's however, no integration with other wireless systems is proposed. Awarepoint tags are wearable, reusable and powered by batteries that last up to 5 years according to [49].

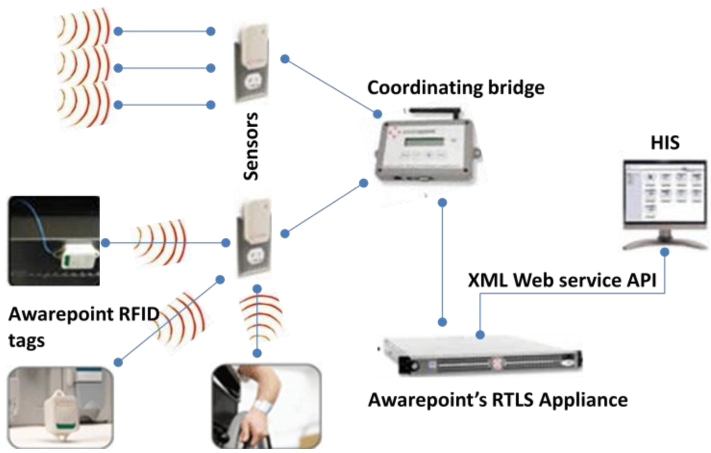

Figure 3: Awarepoint system architecture (reproduced from [49])

Ekahau [50] is a localization and tracking system based on Wi-Fi networks to continuously track mobile Wi-Fi devices and tags in indoor environments. As in fingerprint-based systems, Ekahau starts with a site survey as a pre-deployment phase to construct a database of RSS signatures with respect to some reference points using a mobile device. This is tedious, error-prone and needs to be repeated upon changes in radio environment. Then, Ekahau's positioning engine utilizes this database along with the online RSSI readings for a mobile device at different access points to localize it. Ekahau provides a variety of tags to be used for assets, patients and equipment which last up to 5 years; some of them contain two configurable buttons to be used for sending alarms or notifications as shown in Figure 4. The system accuracy depends on the number of access points covering the mobile device of interest. 1 meter accuracy can be achieved if there are 3 or more overlapped access points. Ekahau proposes the use of a Location Beacon, a small battery-powered infrared transmitter typically mounted on a wall or ceiling, to enhance the accuracy in areas where Wi-Fi coverage is not sufficient. Ekahau scales to tens of thousands of mobile objects per positioning engine and can handle multiple of physical locations across multiple campuses.

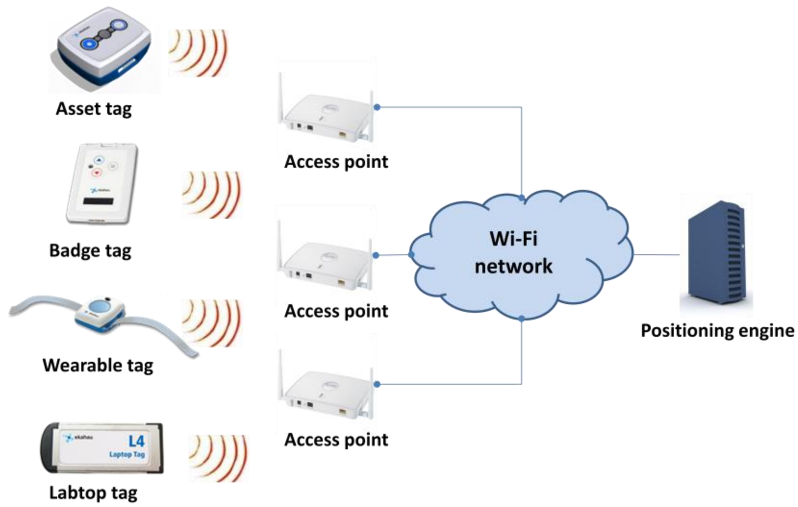

Figure 4: Ekahau System components [50] and infrastructure

Based on ultrasound, Sonitor technologies Inc. provides Sonitor ultrasound IPS [80] as an indoor localization and tracking system. The system leverages the fact that ultrasound signals cannot penetrate through walls to provide proximity location information with room-level accuracy. Sonitor's tag is a small battery powered device attached to movable object and transmits ultrasound signals with its unique ID to wireless detectors fixed in various locations (rooms or public indoor areas). The detectors forward this information to a central server which store the tag's location along with associate time in a database which can be used by applications such as HIS. Sonitor propose an energy efficiency method in which the tags are activated only at location change which prolongs tag's battery lifetime. The system accuracy is only limited to a room level with the existence of detectors at each room or area of interest.

AeroScout RTLS [51] is another Wi-Fi-based localization and tracking system for indoor and outdoor environments that mainly is proposed for asset monitoring using Wi-Fi-based active RFID tags. It uses multiple algorithms for localization: TDoA in case of outdoor and RSSI in case of indoor. The system works as follows: Each tag sends a very short signal periodically containing sensed data using AeroScout's own beaconing method. The access points receive such signals and forward to AeroScout's location engine. The location engine uses either TDoA or RSSI to localize tags and sends such information to AeroScout mobile view which provides visibility, map display, alerts, search and integration with other applications like HIS (see Figure 5). The system has the capability to integrate with other location technologies such as GPS, Passive RFID and ultrasound-based systems. Furthermore, its tags can be triggered by a new hardware component named AeroScout Exciter to send Wi-Fi messages under predefined conditions such as being in a specific area or wandering away of certain range. The system provides multiple location modes such as chokepoint, egress/entrance point, room-level, sub-room-level and absolute coordinate without mentioning its averaged accuracy. In addition, AeroScout propose Location Receivers, as optional hardware components for outdoor or harsh environments, which execute extra radio signal measurements and calculations and send them to the AeroScout Engine to enhance the location accuracy. Location Receiver can process over 300 location measurements per second hence enlarge AeroScout's scope of application.

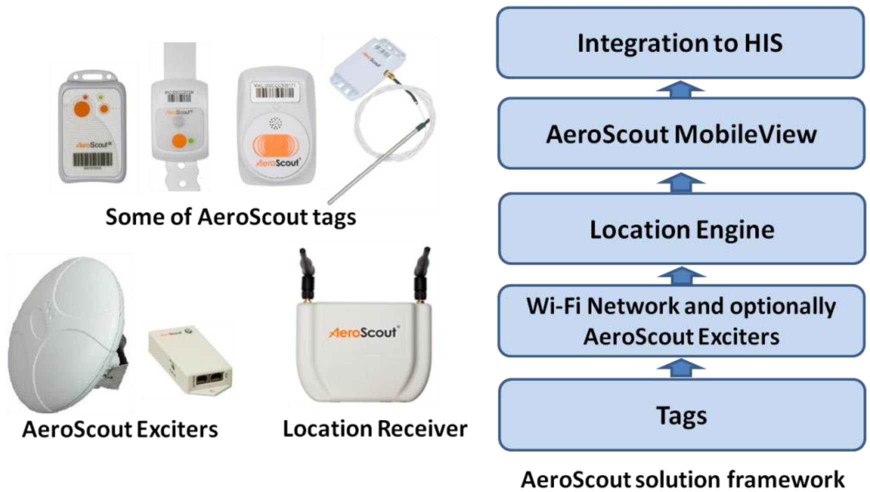

Figure 5: AeroScout framework and some AeroScout hardware components (lift) (reproduced from [51])

Versus Technology Inc. [81] introduces to healthcare domain a new localization and tracking system named VERSUS based on IR technology. Patients, staff and assets can be tagged using IR-RFID badges which emit signals containing their unique ID codes. The system utilizes the low-power RF signals to generally localize objects. Then, it utilizes the IR signals as it is bounded by walls to provide room-level and bed-level accuracy as can be depicted from Figure 6. The localization process done by a VERSUS hardware component works as location engine, while the VERSUS server is the front end for integration with other systems such as HIS. No details about the localization algorithms are available though.

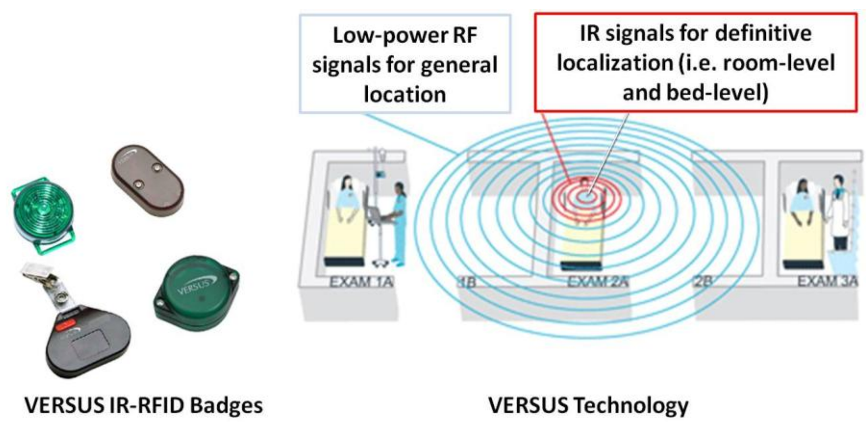

Figure 6: VERSUS technology and IR-RFID badges (lift) (reproduced from [81])

6. Open Research Issues and Conclusion

In this section, we discuss different open issues that were discovered throughout systems review. The lack of some functionality will be highlighted along with the limitations of the reviewed systems followed by suggestions to be done to address these limitations. Then we will conclude the paper.

6.1.Open research issues

In most fingerprint-based systems, site calibration is a major step that takes place in the pre-deployment phase. This step is costly, prone to errors, typically done offline and hence it does not cope with radio dynamics and need to be maintained over time. Furthermore, most systems depend on the signal strength to create the fingerprint database, which, as previously mentioned, is inversely affected by indoor environmental dependent factors. All aforementioned limitations are handicaps for the system scalability and robustness. The idea of online site calibration and the utilization of extra information in creating the fingerprint database are proposed in the literature. However, it depends on unrealistic assumptions and the use of smart devices without taking power consumption into consideration. So, the online site calibration is still an open issue and there is a need for an approach that can depend on sensors deployed and face changes in radio map without consuming the mobile devices' power.

In highly mobile environments like hospitals it is common to face failure in accessing some anchor nodes, loss of information and perturbations in radio signals. However, most systems do not provide some form of fault tolerance mechanism to achieve robustness. Although a few systems show robustness, it is on account of either scalability, communication between anchor nodes or deployment of extra hardware devices. As a result, robustness of the localization and tracking system without the need for special anchor nodes and without affecting accuracy and scalability is still an open issue. In addition, the system capability to provide multiple accuracy levels is also an open issue. In some cases a room-level or bed-level accuracy is enough while in other cases physical location is more beneficial. So, the localization and tracking system should be capable to estimate objects location and to give multiple accuracy levels based on the application demand.

Another open issue is to design a hybrid system that can integrate two localization approaches to fully utilize all the available resources. For example, cooperative localization depends on density of nodes, which is common in healthcare domain especially in hospitals. Despite its poor performance in anisotropic networks and at obstacles; it can be integrated with other approaches to decrease cost and computations. Another example at which hybrid system is beneficial is when localization is required in both indoor and outdoor environments. A few systems do so by adopting GPS outdoors while utilizing other technologies indoors.

Another direction in localization and tracking is to use RFID systems. RFID readers are used to detect the existence of RFID tags and report such information to a central server, which provides proximity-based location information. This trend has challenges in indoor environments such as the existence of substantial amount of metal and other reflective materials, which causes multi-path effects, dead spots and interference. Furthermore, the accuracy of RFID-based localization and tracking system depends on the number of RFID readers deployed in the area to be covered, which reflects on the system cost and the collision between RFID readers. The open issues in such direction are: (a) using passive tags to localize objects, (b) deploying a minimum number of RFID readers and (c) providing high accuracy with multiple levels of location information.

6.2.Summary

This paper defines characteristics, challenges of localization in WSN. The paper provides background on the different measuring and positioning techniques that have been proposed in the literature. It discusses the healthcare domain attributes and requirements with respect to localization and tracking issues. The paper presents a comprehensive overview and qualitative analysis (from a healthcare perspective) of localization and tracking systems proposed in the literature along with the functional aspects of these systems. It touches on a few commercial systems proposed in the industry to address the localization and tracking problem.

References

[1] Bluetooth Technology, Internet: http://www.bluetooth.com, [Last update July 15, 2012].

[2] Wi-Fi Alliance, Internet: http://www.wi-fi.org, [Last update July 10, 2012].

[3] ZigBee Alliance, Internet: http://www.zigbee.org, [Last update July 10, 2012].

[4] A. Bharathidasan and V. Anand, sensor Networks, technical report, Dept. of Computer Science, University of California at Davis 2002.

[5] C.-Y. Chong and S. Kumar, "Sensor networks: evolution, opportunities, and challenges," *Proceedings of the IEEE*, vol. 91, no. 8, pp. 1247 – 1256, Aug. 2003.

[6] J. Barros., sensor Networks: An Overview. In Learning from Data Streams - Processing Techniques in Sensor Networks, Ed. M. Gaber, J. Gama, Springer Verlag, 2007.

[7] D. Culler, D. Estrin, and M. Srivastava, "Guest editors' introduction: Overview of sensor networks," *Computer*, vol. 37, no. 8, pp. 41 – 49, Aug. 2004.

[8] J. Yick, B. Mukherjee, and D. Ghosal, "Wireless sensor network survey," *Computer Networks*, vol. 52, no. 12, pp. 2292 – 2330, 2008. [Online]. Available: http://www.sciencedirect.com/science/-article/pii/S1389128608001254

[9] V. Rajaravivarma, Y. Yang, and T. Yang, "An overview of wireless sensor network and applications," in *System Theory, 2003. Proceedings of the 35th Southeastern Symposium on*, Mar. 2003, pp. 432 – 436.

[10] I. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "A survey on sensor networks," *Communications Magazine, IEEE*, vol. 40, no. 8, pp. 102 – 114, Aug 2002.

[11] K. Lorincz, D. Malan, T. Fulford-Jones, A. Nawoj, A. Clavel, V. Shnayder, G. Mainland, M. Welsh, and S. Moulton, "Sensor networks for emergency response: challenges and opportunities," *Pervasive Computing, IEEE*, vol. 3, no. 4, pp. 16 – 23, Oct.-Dec. 2004.

[12] H. Liu, H. Darabi, P. Banerjee, and J. Liu, "Survey of wireless indoor positioning techniques and systems," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 37, no. 6, pp. 1067 –1080, Nov. 2007.

[13] G. Sun, J. Chen, W. Guo, and K. Liu, "Signal processing techniques in network-aided positioning: a survey of state-of-the-art positioning designs," *Signal Processing Magazine, IEEE*, vol. 22, no. 4, pp. 12 – 23, July 2005.

[14] N. Patwari, J. Ash, S. Kyperountas, I. Hero, A.O., R. Moses, and N. Correal, "Locating the nodes: cooperative localization in wireless sensor networks," *Signal Processing Magazine, IEEE*, vol. 22, no. 4, pp. 54 – 69, July 2005.

[15] G. Mao, B. Fidan, and B. D. Anderson, "Wireless sensor network localization techniques," *Computer Networks*, vol. 51, no. 10, pp. 2529 – 2553, 2007. [Online]. Available: http://-www.sciencedirect.com/science/article/pii/S1389128606003227

[16] A. Sayed, A. Tarighat, and N. Khajehnouri, “Network-based wireless location: challenges faced in developing techniques for accurate wireless location information,” *Signal Processing Magazine, IEEE*, vol. 22, no. 4, pp. 24 – 40, July 2005.

[17] A. Kulaib, R. Shubair, M. Al-Qutayri, and J. Ng, “An overview of localization techniques for wireless sensor networks,” in *Innovations in Information Technology (IIT), 2011 International Conference on*, Apr. 2011, pp. 167 –172.

[18] M. Bal, M. Liu, W. Shen, and H. Ghenniwa, “Localization in cooperative wireless sensor networks: A review,” in *Computer Supported Cooperative Work in Design, 2009. CSCWD 2009. 13th International Conference on*, Apr. 2009, pp. 438 –443.

[19] S. Gezici, “A survey on wireless position estimation,” *Wireless Personal Communications*, vol. 44, pp. 263–282, 2008, 10.1007/s11277-007-9375-z. [Online]. Available: http://dx.doi.org/10.1007/s11277-007-9375-z

[20] I. Guvenc and C.-C. Chong, “A survey on toa based wireless localization and nlos mitigation techniques,” *Communications Surveys Tutorials, IEEE*, vol. 11, no. 3, pp. 107 –124, quarter 2009.

[21] Y. Liu, Z. Yang, X. Wang, and L. Jian, “Location, localization, and localizability,” *Journal of Computer Science and Technology*, vol. 25, pp. 274–297, 2010, 10.1007/s11390-010-9324-2. [Online]. Available: http://dx.doi.org/10.1007/s11390-010-9324-2

[22] N. Bulusu, J. Heidemann, D. Estrin, and T. Tran, “Self-configuring localization systems: Design and experimental evaluation,” *ACM Trans. Embed. Comput. Syst.*, vol. 3, no. 1, pp. 24–60, Feb. 2004. [Online]. Available: http://doi.acm.org/10.1145/972627.972630

[23] D. Niculescu, “Positioning in ad hoc sensor networks,” *Network, IEEE*, vol. 18, no. 4, pp. 24 – 29, July-Aug. 2004.

[24] H. Wymeersch, J. Lien, and M. Win, “Cooperative localization in wireless networks,” *Proceedings of the IEEE*, vol. 97, no. 2, pp. 427 –450, Feb. 2009.

[25] Y. Kwon, K. Mechitov, S. Sundresh, W. Kim, and G. Agha, “Resilient localization for sensor networks in outdoor environments,” in *Distributed Computing Systems, 2005. ICDCS 2005. Proceedings. 25th IEEE International Conference on*, June 2005, pp. 643 –652.

[26] J. Bachrach and C. Taylor, localization in Sensor Networks, in Handbook of Sensor Networks: Algorithms and Architectures (ed I. Stojmenoviز‡), John Wiley & Sons, Inc., Hoboken, NJ, USA. doi: 10.1002/047174414X.ch9 2005.

[27] J. Wang, R. Ghosh, and S. Das, “A survey on sensor localization,” *Journal of Control Theory and Applications*, vol. 8, pp. 2–11, 2010, 10.1007/s11768-010-9187-7. [Online]. Available: http://dx.doi.org/-10.1007/s11768-010-9187-7

[28] J. Werb and C. Lanzl, “Designing a positioning system for finding things and people indoors,” *Spectrum, IEEE*, vol. 35, no. 9, pp. 71 –78, Sep. 1998.

[29] I. Amundson and X. Koutsoukos, "A survey on localization for mobile wireless sensor networks," in *2nd International Workshop on Mobile Entity Localization and Tracking in GPS-less Environments (MELT)*, Sept. 2009.

[30] C. Wang and L. Xiao, "Sensor localization under limited measurement capabilities," *Network, IEEE*, vol. 21, no. 3, pp. 16 –23, May-June 2007.

[31] D. Dardari, A. Conti, U. Ferner, A. Giorgetti, and M. Win, "Ranging with ultrawide bandwidth signals in multipath environments," *Proceedings of the IEEE*, vol. 97, no. 2, pp. 404 –426, Feb. 2009.

[32] G. Shen, R. Zetik, and R. Thoma, "Performance comparison of toa and tdoa based location estimation algorithms in los environment," in *Positioning, Navigation and Communication, 2008. WPNC 2008. 5th Workshop on*, Mar. 2008, pp. 71 –78.

[33] L. Xu, F. Yang, Y. Jiang, L. Zhang, C. Feng, and N. Bao, "Variation of received signal strength in wireless sensor network," in *Advanced Computer Control (ICACC), 2011 3rd International Conference on*, Jan. 2011, pp. 151 –154.

[34] H. Laitinen, S. Juurakko, T. Lahti, R. Korhonen, and J. Lahteenmaki, "Experimental evaluation of location methods based on signal-strength measurements," *Vehicular Technology, IEEE Transactions on*, vol. 56, no. 1, pp. 287 –296, Jan. 2007.

[35] W. Ibrahim, A.-E. Taha, and H. Hassanein, "Scalability issues in localizing things," in *Local Computer Networks (LCN), 2011 IEEE 36th Conference on*, Oct. 2011, pp. 673 –680.

[36] Y. Zhu, D. Huang, and A. Jiang, "Network localization using angle of arrival," in *Electro/Information Technology, 2008. EIT 2008. IEEE International Conference on*, May 2008, pp. 205 –210.

[37] P. Rong and M. Sichitiu, "Angle of arrival localization for wireless sensor networks," in *Sensor and Ad Hoc Communications and Networks, 2006. SECON '06. 2006 3rd Annual IEEE Communications Society on*, vol. 1, Sept. 2006, pp. 374 –382.

[38] A. Roxin, J. Gaber, M. Wack, and A. Nait-Sidi-Moh, "Survey of wireless geolocation techniques," in *Globecom Workshops, 2007 IEEE*, Nov. 2007, pp. 1 –9.

[39] K. Kaemarungsi and P. Krishnamurthy, "Modeling of indoor positioning systems based on location fingerprinting," in *INFOCOM 2004. Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies*, vol. 2, Mar. 2004, pp. 1012 – 1022 vol.2.

[40] V. Ramadurai and M. L. Sichitiu, "Localization in wireless sensor networks: A probabilistic approach," 2003.

[41] S. Wamba and E. Ngai, "Importance of the relative advantage of rfid as enabler of asset management in the healthcare: Results from a delphi study," in *System Science (HICSS), 2012 45th Hawaii International Conference on*, Jan. 2012, pp. 2879 –2889.

[42] C. Palacio, J. Harrison, and D. Garets, "Benchmarking electronic medical records initiatives in the us: a conceptual model," *Journal of Medical Systems*, vol. 34, pp. 273–279, 2010, 10.1007/s10916-008-9238-5. [Online]. Available: http://dx.doi.org/10.1007/s10916-008-9238-5

[43] Demiris G, Afrin LB, Speedie S, et al. Patient-centered applications: use of information technology to promote disease management and wellness. A white paper by the AMIA knowledge in motion working group. J Am Med Inform Assoc 2008;15:8–13.

[44] Internet: http://www.amia.org, [Last update July 11, 2012].

[45] Internet: http://www.phoenix.edu/profiles/faculty/nancy-wood/articles/patients-demand-customer-focused-practices-in-the-health-care-industry.html, [Last update June 2, 2012].

[46] W. C. S. L. for the Health Care Industry, internet: http://www.worldcongress.com, [Last access June 4, 2012].

[47] A. M. Association, internet: http://www.ama-assn.org, [Last update June 7, 2012].

[48] Internet: http://www.intelligentinsites.com, [Last update June 9, 2012].

[49] Awarepoint, Internet: http://www.awarepoint.com, [Last update June 7, 2012].

[50] Ekahau, Internet: http://www.ekahau.com, [Last update June 7, 2012].

[51] AeroScout, Internet: http://www.aeroscout.com, [Last update June 7, 2012].

[52] Medscape, Internet: http://www.medscape.com, [Last update June 7, 2012].

[53] G. Gentili, F. Dori, and E. Iadanza, "Dual-frequency active rfid solution for tracking patients in a children's hospital. design method, test procedure, risk analysis, and technical solution," *Proceedings of the IEEE*, vol. 98, no. 9, pp. 1656 –1662, Sept. 2010.

[54] L. Wirola, T. Laine, and J. Syrja andrinne, "Mass-market requirements for indoor positioning and indoor navigation," in *Indoor Positioning and Indoor Navigation (IPIN), 2010 International Conference on*, Sept. 2010, pp. 1 –7.

[55] J. Rantakokko, P. Ha andndel, M. Fredholm, and F. Marsten-Eklo andf, "User requirements for localization and tracking technology: A survey of mission-specific needs and constraints," in *Indoor Positioning and Indoor Navigation (IPIN), 2010 International Conference on*, Sept. 2010, pp. 1 –9.

[56] E. Elnahrawy and R. Martin, "Studying the utility of tracking systems in improving healthcare workflow," in *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2010 8th IEEE International Conference on*, Apr. 2010, pp. 310 –315.

[57] I. D'Souza, W. Ma, and C. Notobartolo, "Real-time location systems for hospital emergency response," *IT Professional*, vol. 13, no. 2, pp. 37 –43, Mar.-Apr. 2011.

[58] Y. Gu, A. Lo, and I. Niemegeers, "A survey of indoor positioning systems for wireless personal networks," *Communications Surveys Tutorials, IEEE*, vol. 11, no. 1, pp. 13 –32, quarter 2009.

[59] P. Bahl and V. Padmanabhan, “Radar: an in-building rf-based user location and tracking system,” in *INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, vol. 2, 2000, pp. 775 –784 vol.2.

[60] K. Lorincz and M. Welsh, “Motetrack: A robust, decentralized approach to rf-based location tracking,” 2005.

[61] L. Ni, Y. Liu, Y. C. Lau, and A. Patil, “Landmarc: indoor location sensing using active rfid,” in *Pervasive Computing and Communications, 2003. (PerCom 2003). Proceedings of the First IEEE International Conference on*, Mar. 2003, pp. 407 – 415.

[62] M. Youssef and A. Agrawala, “The horus wlan location determination system,” in *Proceedings of the 3rd international conference on Mobile systems, applications, and services*, ser. MobiSys ’05. New York, NY, USA: ACM, 2005, pp. 205–218. [Online]. Available: http://doi.acm.org/10.1145/-1067170.1067193

[63] X. An, J. Wang, R. V. Prasad, and I. G. M. M. Niemegeers, “Opt: online person tracking system for context-awareness in wireless personal network,” in *Proceedings of the 2nd international workshop on Multi-hop ad hoc networks: from theory to reality*, ser. REALMAN ’06. New York, NY, USA: ACM, 2006, pp. 119–121. [Online]. Available: http://doi.acm.org/10.1145/1132983.1133008

[64] T. King, S. Kopf, T. Haenselmann, C. Lubberger, and W. Effelsberg, “Compass: A probabilistic indoor positioning system based on 802.11 and digital compasses,” in *Proceedings of the 1st international workshop on Wireless network testbeds, experimental evaluation & characterization*, ser. WiNTECH ’06. New York, NY, USA: ACM, 2006, pp. 34–40. [Online]. Available: http://doi.acm.org/-10.1145/1160987.1160995

[65] Yingying Chen, Gayathri Chandrasekaran, gRAIL: a general purpose localization system. Sensor Review, Vol. 28 Iss: 2, pp.115 - 124

[66] M. Azizyan, I. Constandache, and R. Roy Choudhury, “Surroundsense: mobile phone localization via ambience fingerprinting,” in *Proceedings of the 15th annual international conference on Mobile computing and networking*, ser. MobiCom ’09. New York, NY, USA: ACM, 2009, pp. 261–272. [Online]. Available: http://doi.acm.org/10.1145/1614320.1614350

[67] K. Chintalapudi, A. Padmanabha Iyer, and V. N. Padmanabhan, “Indoor localization without the pain,” in *Proceedings of the sixteenth annual international conference on Mobile computing and networking*, ser. MobiCom ’10. New York, NY, USA: ACM, 2010, pp. 173–184. [Online]. Available: http://-doi.acm.org/10.1145/1859995.1860016

[68] N. B. Priyantha, A. Chakraborty, and H. Balakrishnan, “The cricket location-support system,” in *Proceedings of the 6th annual international conference on Mobile computing and networking*, ser. MobiCom ’00. New York, NY, USA: ACM, 2000, pp. 32–43. [Online]. Available: http://doi.acm.org/-10.1145/345910.345917

[69] M. Youssef and U. Shankar, "Pinpoint: An asynchronous time-based location determination system," in *In Fourth International Conference on Mobile Systems, Applications, and Services (MobiSys 2006*. ACM Press, 2006, pp. 165–176.

[70] M. Baunach, R. Kolla, and C. Mühlberger, "SNoW Bat: A high precise WSN based location system," Institut für Informatik, Universität Würzburg, Tech. Rep. 424, May 2007.

[71] L. Jiang, L. N. Hoe, and L. L. Loon, "Integrated uwb and gps location sensing system in hospital environment," in *Industrial Electronics and Applications (ICIEA), 2010 the 5th IEEE Conference on*, June 2010, pp. 286 –289.

[72] H. Lim, L.-C. Kung, J. C. Hou, and H. Luo, "Zero-configuration indoor localization over ieee 802.11 wireless infrastructure," *Wirel. Netw.*, vol. 16, no. 2, pp. 405–420, Feb. 2010. [Online]. Available: http://-dx.doi.org/10.1007/s11276-008-0140-3

[73] K. Wu, J. Xiao, Y. Yi, M. Gao, and L. Ni, "Fila: Fine-grained indoor localization," in *INFOCOM, 2012 Proceedings IEEE*, Mar. 2012, pp. 2210 –2218.

[74] Z. Li, C.-H. Chu, and W. Yao, "Sip-rlts: An rfid location tracking system based on sip," in *RFID, 2008 IEEE International Conference on*, Apr. 2008, pp. 173 –182.

[75] P. Silva, M. Paralta, R. Caldeirinha, J. Rodrigues, and C. Serodio, "Traceme #x2014; indoor real-time location system," in *Industrial Electronics, 2009. IECON '09. 35th Annual Conference of IEEE*, Nov. 2009, pp. 2721 –2725.

[76] C. Wu, Z. Yang, Y. Liu, and W. Xi, "Will: Wireless indoor localization without site survey," *Parallel and Distributed Systems, IEEE Transactions on*, vol. PP, no. 99, p. 1, 2012.

[77] R. Stoleru, T. He, J. A. Stankovic, and D. Luebke, "A high-accuracy, low-cost localization system for wireless sensor networks," in *Proceedings of the 3rd international conference on Embedded networked sensor systems*, ser. SenSys '05. New York, NY, USA: ACM, 2005, pp. 13–26. [Online]. Available: http://doi.acm.org/10.1145/1098918.1098921

[78] A. Zhan, S. Li, T. Li, L. Guan, P. Yang, X. Wu, and G. Chen, "itracking: Accurate light-based location-tracking in wireless sensor networks," in *Mobile Adhoc and Sensor Systems, 2009. MASS '09. IEEE 6th International Conference on*, Oct. 2009, pp. 1065 –1067.

[79] X. Mao, S. Tang, X. Xu, X.-Y. Li, and H. Ma, "ilight: Indoor device-free passive tracking using wireless sensor networks," in *INFOCOM, 2011 Proceedings IEEE*, Apr. 2011, pp. 281 –285.

[80] Sonitor, internet: http://www.sonitor.com, [Last update June 7, 2012].

[81] Versus, internet: http://www.versustech.com, [Last update June 7, 2012].