Localization in Wireless Sensor Networks

Ustijana R. Shikoska¹, Dancho Davčev²

¹ University for Information Sciences & Technologies „Sv. Apostol Pavle“ – Ohrid, Republic of Macedonia
ustijana@t-home.mk

² University „Sv. Kiril i Metodij“, Faculty of Electrical Engineering – Skopje, Republic of Macedonia
etfdav@feit.ukim.edu.mk

Abstract. Due to the close integration of sensor networks with the real world, the categories time and location are fundamental for many applications of sensor networks, to interpret sensing results or to coordinate sensor nodes in Wireless Sensor Networks (WSNs). Time synchronization and sensor node localization are fundamental and closely related services in sensor networks. The most relevant techniques for Localization in Wireless Sensor Networks - lateration, angulation and scene analysis are discussed. A comparison is made between several localization systems. A choice for a certain system or technique depends on the intended application. A possible system for determining the position of a moving device is given. The system’s possible advantage over most other existing systems is short deployment time in a new environment and reasonable accuracy. It could be used for indoor and outdoor environments. Improvements can be made with respect to accuracy and mobility.

Keywords: wireless sensor networks, space-time localization, localization methods

1 Introduction

A Wireless Sensor Network (WSN) is a network of many small sensing and communicating devices called sensor nodes. Each node has a CPU, a power supply and a radio transceiver for communication. Interconnection between nodes is achieved via transceiver. A WSN contains one node, the base station, which connects the network to a more capable computer and probably to a network of general purpose computers through it. Sensors attached to these nodes allow them to sense various phenomena within the environment.
The typical purpose of a sensor network is to collect data via sensing interfaces and propagate those data to the central computer, allowing easy monitoring of an environment.

A node is capable of dealing with a variety of jobs. The nodes currently available are battery-operated, they have limited life-time. Memory capacity of a node is also limited.

Life-time, processing and storage restrictions directly affect the algorithms designed for sensor networks. A routing algorithm for WSNs must be energy and memory efficient. Since radio transmissions consume a significant amount of energy, researchers generally seek ways to reduce radio communication as much as possible. When more information is stored and more computation is done as to reduce the communication costs, energy consumption of the processor and memory components are becoming an important issue. Design choices have to be made, they also depend on the intended application.

Currently there is a prototype of a system available, developed using motion sensors to secure an area [1] based on the Smart Dust concept. The idea of the system is to monitor an area or room by a network of sensors with the size of a dust particle. The Smart Dust project is exploring whether an autonomous sensing, computing and communication system can be packed into a cubic-millimeter mote, to form the basis of integrated, massively distributed sensor networks. In the prototype, the size of a sensor is significantly bigger than a dust particle. The moment a sensor detects movement in the area a message is sent to a central server.

The server processes the data and then uses Google Maps to produce a map which shows the detected movement. A GPS receiver is used to determine an absolute position, while RSSI (Received Signal Strength Indicator) is used to locate the sensors relative to the GPS receiver. RSSI uses the decrease in energy of the radio signal as it propagates in space to estimate the distance. Experimentation with the prototype system shows this method becomes unreliable when the batteries of the sensors are getting weaker [1]. Using GPS receivers for all sensors is not an option as GPS cannot function in indoor and many outdoor applications, especially when there is no direct line of sight from nodes to terrestrial satellites. Usage of these devices on sensor nodes is still a challenging issue due to their size, energy and price constraints. As a result, there is a need for reliable localization in WSNs without using of GPS receivers.

A Wireless Sensor Network is deployed to monitor its environment and for disaster response and recovery systems. Applications include health monitoring systems, monitoring of wildlife habitats [2] and nature reserves such as the Great Barrier Reef [3], and forest fire detection systems [4,5,6]. Examples of military applications are battlefield surveillance [7,8] and the previously mentioned securing of an area or room.
An accent is put to localization in mobile indoor WSNs. Localization can be used for tracking objects or people. It is helpful to people navigating indoors where GPS is not available. Mobile devices such as laptops may be tracked within a building in order to locate them easily. Location dependent network services, with application examples ranging from building automation to targeted advertising or augmented reality, also require reliable localization techniques [9].

2 Related work

All the approaches discussed next in this paper are range-based, because the accuracy of range-free algorithms is often limited by requiring dense deployments of sensor nodes. The tracking of moving devices has been studied by Smith et al. [24] under an active mobile and a passive mobile infrastructure using the Cricket location system. Cricket uses the time difference in arrival of concurrent radio and ultrasound signals to estimate distances. In the active mobile architecture, the mobile device actively chirps, and the fixed infrastructure nodes then reply either over a radio channel or a cabled infrastructure, reporting the measured distances to the mobile device or some central processor. In the passive variant, the infrastructure has beacons that periodically transmit signals to a passively listening mobile device, which in turn estimates distances to the beacons.

Priyantha et al. [27] note it is almost impossible to deploy nodes in a typical office or home to achieve sufficient connectivity across all nearby nodes. It is hard to obtain ranging between nodes placed inside and outside a room in a standard building. Capkun et al. introduce the Self-Positioning Algorithm (SPA) [32]. SPA defines and computes relative positions of nodes in a mobile ad-hoc network without using GPS. It is a distributed algorithm that does not use nodes with fixed or known positions. It assumes some method to estimate the distances between nodes and builds a relative coordinate system. A simulation with 400 nodes was performed by the authors. The nodes follow a random movement pattern: they move using a random velocity, wait for a fixed time, and then move again. It is shown that if a larger (three-hop) neighborhood is used instead of a two-hop neighborhood, the mobility of the center of the network decreases. No accuracy information has been provided - reducing the position error is being mentioned as subject of future work.

As the algorithm is focused on providing location information to support basic network functions, accuracy requirements should not be high. Communication costs are relatively high in multi-hop networks as the algorithm requires a broadcast to all the nodes in the network. An Online Person Tracking (OPT) system for an indoor environment is presented by An et al. [20]. OPT employs a passive mobile architecture. The average RSSI of 200 measurements was used to estimate the location. An et al. only used the three strongest received signal strengths because they
claim using more does not guarantee a higher accuracy. Experiments with a static sender and receiver were performed to measure the influence of the antenna orientation on the strength of the received signal. The RSSI value varied up to 15 dBm depending on the antenna's orientation. This leads to bigger error on distance estimation when two motes are farther apart, because the variation in RSSI becomes smaller as the distance becomes larger. The authors applied a bounding box algorithm to select an area in which the optimal position was sought. If there was no overlapping area of circles, the estimation area was expanded to make sure that the potential target position was included in the search area (Figure 1).

Fig. 1. Boundary selection without overlapping area.

The Minimum Mean Square Error (MMSE) algorithm was employed for target location estimation within the selected area. This method is commonly used in statistics and signal processing. In the conventional MMSE method (dubbed C-MMSE) all range estimates were given the same importance in minimizing the position error. A weighted version (W-MMSE) is also proposed by the authors. The higher the slope of the empirical curve between distance and RSSI is, the higher is the assigned weight. Higher RSSI values are considered to be more reliable than low ones.

Lee et al. [9] present an algorithm enabling localization of moving wireless devices in an indoor setting. An active mobile infrastructure is employed; a burst of five packets in 50 ms is sent by the mobile node every 0.6 seconds. Ten nodes were deployed at fixed locations and one mobile node was being localized.

The mobility of the users is modeled by learning a function which maps a short history of signal strength values to a 2D position. During the training phase, ground truth locations of the mobile user are required; however, locations of infrastructure nodes are not needed. The authors used radial basis function fitting to learn a reliable estimate of a mobile node's position given its past signal strength measurements. RSSI measurements were filtered by a box filter and then fed into the learned function to obtain the position of the mobile node.

Nine different trajectories were evaluated: five for training and four for testing. An area of approximately 30 m x 25 m was used for experimentation. Experimental data
shows that the variance due to reflections is particularly severe when either 
transmitter or receiver was moving, even at low speeds. Several parameters of the 
algorithm were optimized. The number of past measurements determines how much 
historical information about the trajectories is available. Using four past values was 
found to be optimal. In 50% and 97.5% of the cases the accuracy is 1.0 m and 4.1 m, 
respectively. Since they use past measurements at fixed time intervals, the authors 
implicitly assume that the speed of the mobile user at a given position is similar 
during training and localization. Explicitly handling speed differences is subject of 
future work. In Table 1 the localization systems are compared with respect to 
accuracy, node density and technique. The table is partially based on a comparison by 
Kaseva et al. [25], but some values have been corrected after having carefully 
reviewed the cited papers. The Self-Positioning Algorithm is not included in the 
overview because it has only been tested in simulations and no accuracy 
measurements were provided. Although trajectory matching uses RSSI measurements 
it is considered to perform scene analysis as it requires training for a specific 
environment.

**Table 1. Comparison of Localization Algorithms**

<table>
<thead>
<tr>
<th>Localization system</th>
<th>Accuracy (m)</th>
<th>Anchor node density (m² per node)</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferret [17]</td>
<td>0.6-1.0 (A)</td>
<td>2-4</td>
<td>RSSI/potentiometer</td>
</tr>
<tr>
<td>Cricket [24]</td>
<td>0.02-0.2 (M)</td>
<td>2</td>
<td>Ultrasound time-of-flight</td>
</tr>
<tr>
<td>MoteTrack [26]</td>
<td>2 (M)</td>
<td>87</td>
<td>Scene analysis</td>
</tr>
<tr>
<td>RADAR [33]</td>
<td>2.9 (M)</td>
<td>326</td>
<td>Scene analysis</td>
</tr>
<tr>
<td>Online Person Tracking [20]</td>
<td>2/3 (M)</td>
<td>8/48</td>
<td>RSSI</td>
</tr>
<tr>
<td>Trajectory Matching [9]</td>
<td>1.0 (M)</td>
<td>52</td>
<td>Scene analysis</td>
</tr>
</tbody>
</table>

A number of comments should be made to put the accuracy of the different systems 
into perspective. The anchor node density is defined as the number of square meters 
one anchor node has to cover. It is important for making a comparison because the 
lower the value, the easier is to obtain a relatively high accuracy. RADAR is an 
exception in the sense that it uses WLAN technology for anchor nodes as opposed to 
sensor nodes. In Ferret between five and eleven nodes are used, which explains the 
variation in accuracy and node density. The accuracy level of Cricket depends on the 
mobile node's speed. OPT has been evaluated in a corridor and office rooms; as the 
corridor covers a smaller area and has no interfering walls, a higher accuracy is 
obtained. Cricket and the Trajectory Matching algorithm are the only systems having 
tested accuracy of moving nodes; MoteTrack, RADAR and OPT track devices which 
may change their location but need to be stationary for localization. Ferret and Cricket
were tested in only one room, while other systems were evaluated in office environments having multiple obstructions and realistic error sources. Which system is best depends on the application.

3 Localization

Localization algorithms can be categorized according to a number of different aspects [10, 11, 12]:

- **Input data**: range-free, range-based - Range-free localization algorithms simply rely on connectivity information. Range-based methods extract distance information from radio signals.

- **Accuracy**: fine-grained, coarse-grained - A location discovery algorithm should estimate sensor position accurately. Accuracy, or grain size, can be expressed as percentage of sensor transmission range, or in meters. The level of accuracy usually depends on range measurement errors. Range measurements with less error will lead to more accurate position estimates. Certain accuracy is the precision and it is expressed in a percentage. For example, some inexpensive GPS receivers can locate positions to within 10 meters for approximately 95% of measurements. More expensive units usually do much better, reaching 1 to 3 meter accuracies, 99% of the time. The distances denote accuracy, the percentages precision. If there is less accuracy, there may be a trade for increased precision.

- **Dynamics**: mobile, fixed - In fixed networks, nodes can establish their location in the initialization phase. Their only task is to report events or relay information sent by other nodes. In mobile networks, nodes need to be aware of changes in their position and perhaps of position changes of other nodes. Systems provide more accurate location information when a node is at rest than when it is in motion: tracking a moving node is harder because the inevitable errors that occur in the distance samples are easier to filter out if the node's position itself does not change during the averaging process.

- **Beacons**: beacon-free, beacon-based - Nodes with known positions are called beacon or anchor nodes. Beacon-based algorithms usually produce an absolute location system where absolute positions of nodes are known - latitude, longitude and altitude. The accuracy of the estimated position is highly affected by the number of anchor nodes and their distribution in the sensor field. The ratio of beacon nodes to blind nodes is small. The location of a beacon node can be determined using an attached GPS device or by manual deployment.

Beacon-free algorithms do not make any assumptions regarding node positions. In this case, instead of computing absolute node positions, relative positioning is used in
which the coordinate system is established by a reference group of nodes. Each object can also have its own frame of reference [13].

- Computational model: centralized, distributed - If an algorithm collects localization related data from the network and processes the data collectively at a single station, then it is said to be centralized. If, on the other hand, each node collects partial data relevant to it and executes an algorithm to locate itself, then the localization algorithm is categorized as distributed. Locally centralized algorithms are distributed algorithms that achieve a global goal by communicating with nodes in some neighborhood only. The sensor network can be divided into local clusters, where each cluster has a head. All the range measurements in a certain cluster are forwarded to the cluster head, where computation takes place.

- Hops : single-hop, multi-hop - A direct link between two neighbor nodes is called a hop. When the distance between two nodes is larger than the radio range but there are other nodes that create a continuous path between them, the path is called a multi-hop path.

3.1 Wireless communication

As sensor nodes use electromagnetic waves to communicate with each other we need to understand the basics of how these waves propagate.

Signal Propagation - a signal emitted by an antenna travels in the following three types of propagation modes: ground-wave propagation, sky-wave propagation and Line-Of-Sight (LOS) propagation. MW and LW radio is a kind of ground-wave propagation, where signals follow the contour of the Earth. Shortwave radio is an example of sky-wave propagation, where radio signals are reflected by ionosphere and the ground along the way. Beyond 30 MHz, line-of-sight propagation dominates, meaning that signal waves propagate on a direct, straight path in the air. Radio signals of line-of-sight propagation can also penetrate objects, especially signals with frequencies just above 30 MHz [14].

Sensor motes support tunable frequencies in the range of 300 to 1000 MHz and the 2.4-GHz band. This means LOS propagation is dominant. The industrial, scientific and medical (ISM) radio bands were originally reserved internationally for the use of RF electromagnetic fields for industrial, scientific and medical purposes other than communications. They have become a part of the radio spectrum that can be used by anybody without a license in most countries.

Multipath Propagation - for visible light we are well aware of the following effects: shadowing, reflection and refraction. In general, electromagnetic waves are also subject to diffraction and scattering [14].

Radio communication is affected by the physical properties of waves; the combined effects may cause a transmitted radio signal to reach a receiver by two or more paths.
Shadowing and reflection occur when a signal encounters an object that is much larger than its wavelength. Though the reflected signal and the shadowed signal are comparatively weak, they in effect help to propagate the signal to spaces where line-of-sight is impossible [14]. Reflections occur from the surface of the earth and from buildings and walls.

- Refraction occurs when a wave passes across the boundary of two media [14]. Compare this to how sunlight refracts when it enters water.
- Diffraction occurs at the edge of an impenetrable body that is large compared to the wavelength of the radio wave. When a radio wave encounters such an edge, waves propagate in different directions with the edge as the source [15]. Thus, signals can be received even when there is no line-of-sight path between transmitter and receiver.
- Scattering occurs when the medium through which the wave travels consists of objects with dimensions that are small compared to the wavelength, and where the number of obstacles per unit volume is large. Scattered waves are produced by rough surfaces, small objects, or by other irregularities in the channel [16].

If there is line-of-sight between receiver and transmitter, diffraction and scattering are generally minor effects, although reflection may have a significant impact. If there is no clear LOS, such as in an urban area at street level, then diffraction and scattering are the primary means of signal reception.

4 Localization methods

Triangulation, scene analysis and proximity are the three principal techniques for automatic location-sensing [13]. Location systems may employ them individually or in combination. The triangulation location-sensing technique uses the geometric properties of triangles to compute object locations. Triangulation is divisible into subcategories of lateration, using distance measurements and angulations, using primarily angle or bearing measurements. Scene analysis observes features of its surroundings in order to determine the location of an object. In localization based on proximity, an object's presence is sensed using a physical phenomenon with limited range.

4.1 Lateration

Lateration computes the position of an object by measuring its distance from multiple reference positions [13]. Calculating an object's position in two dimensions requires distance measurements from three points that do not lie on a single line (non-collinear points). In three dimensions, distance measurements from four points not lying in the
same plane are required. Domain-specific knowledge may reduce the number of required distance measurements.

The 2D lateration technique works well when the three circles intersect at a single point, but this is rarely the case when estimates are used in ranging. When the range of anchor nodes is sufficiently large, the object to be located falls into a geometric region that is the intersection of three circles. This is called bounded intersection by Terwilliger [17] and is illustrated in Figure 2. It is also possible that the region of intersection is empty. This will occur if at least one ranging estimate is too small. Some methods overcome this problem by selecting the point for localization that gives the minimum total error between measured estimates and distances.

Fig. 2. Bounding the location of a node - the location of 'X' is computed by taking the center of the intersection of the three circles.

Lateration is quite expensive in the number of floating point operations that is required. A similar, but computationally less expensive solution is to use a bounding box approach. The main idea is to construct a bounding box for each anchor using its position and distance estimate, and then to determine the intersection of these boxes. The position of the node is estimated to be the center of the intersection box. Figure 3 illustrates the bounding box method for a node with distance estimates to three anchors. The estimated position by the bounding box is close to the true position computed through lateration.

Two general approaches to measuring the distances required by the lateration technique, being attenuation and time-of-flight are discussed.
4.1.1 Attenuation

The intensity of an emitted signal decreases as the distance from the emission source increases. The decrease relative to the original intensity is the attenuation [13]. The signal strength decays with respect to distance. Under the ideal circumstances, signal power attenuation is proportional to $d^2$, where $d$ denotes the distance between the transmitter and the receiver. This effect is referred to as free space loss [14].

Usage of Received Signal Strength Indicator (RSSI) is one of the most commonly studied approaches for localization purposes because almost every node in the market has the ability to analyze the strength of a received message [18]. Given a function correlating attenuation and distance for a type of emission and the original strength of the emission, it is possible to estimate the distance from an object to some point $P$ by measuring the strength of the emission when it reaches $P$. The widely used radio propagation model, the log-distance path loss model, considers the received power as a function of the transmitter-receiver distance raised to some power. Since this model is a deterministic propagation model and gives only the average value, another propagation model, the log-normal shadowing model, is introduced to describe the RSSI irregularity:

$$\text{RSSI (dBm)} = \text{RSSI}_{\text{ref}} - 10n \log_{10} \left( \frac{d}{d_{\text{ref}}} \right) + X_a$$ \hspace{1cm} (1)

In equation (1), $d$ is the transmitter-receiver distance, $n$ is the attenuation constant (rate at which the signal decays), $X_a$ a zero-mean Gaussian (in dB) with standard deviation $a$ and $\text{RSSI}_{\text{ref}}$ is the signal strength value at reference distance $d_{\text{ref}}$. Usually, $n$ and $a$ are obtained through curve fitting of empirical data. RSSI is measured in dBm, which is a logarithmic measurement of signal strength. RSSI value does not only depend on the distance, but also on the environment, antenna orientation and the power supply.
A commonly used model for calculating the distance $d$ is given in Equation (2), in which $RSSI_{ref}$ is measured at $d_{ref} = 1\ m$. It is based on Equation (1), but multipath effects are omitted ($X_a$ is assumed to be zero with probability one).

$$d(RSSI) = 10^{(RSSI_{ref} - RSSI)/10n}$$  \hspace{1cm} (2)

The attenuation constant is around 2 in an open-space environment, but its value increases if the environment is more complex (walls, large metallic objects, etc.). In environments with many obstructions such as an indoor office space, measuring distance using attenuation is usually less accurate than time-of-flight [13]. An approximation of the attenuation constant for an indoor environment is around 3.5 [16]. There is empirical evidence that due to the unreliability of measurements, accuracy in the scale of meters can be achieved regardless of the used algorithm or approach.

In the localization system Ferret, described by Terwilliger, two different ranging techniques (potentiometer and RSSI) are used to help locate an object to within one meter. In the potentiometer technique, the object to be located - a mobile node begins by transmitting the beacon at the lowest power level and listens for replies from the infrastructure nodes. Increasing the power level with each transmission, once the mobile node gets three replies, it forwards its data to the base station for position computation. A calibration tool needs to be run each time the system is moved to a new environment in order to establish the communication ranges for given transmission power levels. Terwilliger also presents a location discovery algorithm that provides, for every node in the network, a position estimate, as well as an associated error bound and confidence level.

### 4.1.2 Time of Flight

Measuring distance from an object to some point $P$ using time-of-flight means measuring the time it takes to travel between the object and point $P$ at a known velocity. The object itself may be moving or it is approximately stationary and then, instead the difference in transmission, arrival time of an emitted signal is observed [13]. GPS is a well-known system which uses the time-of-flight technique. The first issue in using time-of-flight is to distinguish direct pulses from reflected ones because they look identical. Reflected measurements may be pruned away by aggregating multiple receivers’ measurements and observing the environment's reflective properties. The second issue is agreement about the time. Since the propagation speed of radio signals is very high, time measurements must be very accurate in order to avoid large uncertainties. A localization accuracy of 1 meter requires timing accuracy on the level of $1/(3\cdot10^8) = 3.3$ nanoseconds. This means a minimum clock rate of 300 MHz ($3\cdot10^8$ Hz) is required for hardware. As far as time synchronization goes, state-
of-the-art protocols such as FTSP [22] synchronize nodes in the order of microseconds. To avoid this issue, a node could reflect the radio signal back, but this once again requires constant delay for reflecting the signal.

Time difference of arrival can also be measured. Cricket [23, 24], a location-support system for in-building, mobile, location-dependent applications, uses concurrent radio, ultrasound signals and measures the difference between the received times of the two types of signals. As sound waves travel at the speed of sound less precise timing than in the case of RF time-of-flight is required. A difference with radio signals is that an ultrasound signal does not go through walls; a similarity is that ultrasonic reception also suffers from severe multipath effects caused by reflections from walls and other objects. Cricket allows applications running on mobile and static nodes to learn their physical location by using listeners that hear and analyze information from beacons spread throughout a building. A case distinction is made for various situations in order to overcome multipath and interference effects. Practical beacon configuration and positioning techniques are used to improve accuracy up to the centimeter level.

4.2 Angulation

In angulation method angles are used for determining the position of an object. This technique is also called angle-of-arrival. In general, two-dimensional angulations requires two angle measurements and one length measurement such as the distance between the reference points as shown in Figure 4. In three dimensions, one length measurement, one azimuth measurement, and two angle measurements are needed to specify a precise position [13]. Although the definition of azimuth depends on the coordinate system, in this case, the azimuth is the horizontal component of an angle, measured around the horizon, from the north toward the east. Angulations implementations sometimes choose to designate a constant reference vector as 0°.

![Fig. 4. Locating object ‘X’ using angles relative to a 0 reference vector and the distance between two reference points.](image)

Proposed solutions require special hardware. Phased antenna arrays are used to measure the angle. Antenna arrays consist of multiple antennas with known
separation in which each antenna measures the time of arrival of a signal. Given the differences in arrival times and the geometry of the receiving array, it is then possible to compute the angle from which the emission originated. If there are enough elements in the array and large enough separations, the angulations calculation can be performed [13]. Other approaches described in literature, Basaran [10], are compass sensors, rotating antennas and rotating light emitters combined with optical sensors.

### 4.2 Scene Analyses

The scene analysis location-sensing technique uses features of a scene observed from a particular vantage point to draw conclusions about the location of the observer or of objects in the scene [13]. In WSNs the measured feature of the scene is typically the signal strength value at a particular position and orientation. Scene analysis consists of an offline learning phase and an online localization phase. During the offline phase RSSI values to different anchor nodes are recorded at various positions. The recorded RSSI values and the known locations of the anchor nodes are used either to construct an RF-fingerprint database, or a probabilistic radio map. In the online phase, the node to be localized measures RSSI values to different anchor nodes. With RF-fingerprinting, the location of the user is determined by finding the recorded reference fingerprint values that are closest to the measured one. The unknown location is then estimated to be the one paired with the closest reference fingerprint or in the (weighted) centroid of k-nearest reference fingerprints. Location estimation using a probabilistic radio map includes finding the point(s) in the map that maximize the location probability [28].

The Microsoft Research RADAR location system is an example of RF-fingerprinting. RADAR uses a dataset of signal strength measurements created by observing the radio transmissions of an 802.11 wireless networking device at many positions and orientations throughout a building. The location of other 802.11 network devices can then be computed by performing table lookup on the prebuilt dataset. The median resolution of RADAR is in the range of two to three meters.

MoteTrack [26] extends the approach and claims to be more robust than RADAR. Base stations at fixed locations are used and a form of fingerprinting is used for determining the location of mobile nodes. The approach can tolerate the failure of up to 60% of the beacon nodes without severely degrading accuracy.

### 5 System description

A possible system setup depends on the intended application. On Figure 5, possible hardware setup is shown. One mote is attached to an interface board and acts as a base station. Together with other motes, the mote network is formed. The base station
collects information from the network and relays it to the PC. In turn, the PC processes network events and then updates the information on the server. The server computes the positions of nodes. The PDA asks the server for an update of the nodes' coordinates with a certain interval. The USB interface board provides connectivity to one mote at a time. Two serial ports are emulated over USB, one for communication with a mote and one for programming. A mote can also be reprogrammed over-the-air to receive an update of a program, but has to be programmed through the interface board first with the specific program.

Fig. 5. Possible hardware choice

The PC communicates with the base station over the USB connection and with the server over an Internet connection. It allows for communication between the base station and the server. The external server is used as an application server to which clients, such as the PDA, can be connected. Running the server application on the PC would be possible, but connecting to it from outside the network may be difficult if the network is protected with a firewall. It uses GPRS to connect to the server. This saves deployment time compared to using a PC for connecting to the server because the user does not have to keep walking back and forth to the PC between node registrations. In the localization phase, a mobile node and the PDA can be used together to show the position of the PDA on the map, or the PDA can be used to track another person holding the mobile node. The PDA is not connected to any sensor node. The way motes should be programmed depends on their function. The base mote is connected to the interface board and has to handle the communication between the PC and the mote network. All the non-mobile nodes listen for messages sent by mobile nodes. Each message contains the sender identification, packet number and sequence number. The mobile node sends a packet burst with a regular interval and increases the packet number by one each time this is done. The sequence number
is used to identify a packet within a burst. RSSI information is requested for each packet by the receiver. All the data of one packet burst is aggregated into one message and then sent to the base station. The sending is done using a multi-hop routing protocol, because not every mote may be in range of the base station. One solution for the motes is to use TinyOS. It is an open-source, event-driven operating system designed for wireless embedded sensor networks. It could be written in C programming language. Programs can be built out of components, which are assembled to form whole programs. TinyOS's component library includes network protocols, distributed services, sensor drivers and data acquisition tools.

There are two multi-hop routing protocols in TinyOS available: TYMO and the Collection Tree Protocol. TYMO is the implementation on TinyOS of the DYMO protocol, a point-to-point routing protocol for mobile ad-hoc networks. The current TYMO version is not stable. Therefore, the Collection Tree Protocol (CTP) [29,30] can be chosen. CTP is a tree-based collection protocol. Messages are collected at the roots of trees. Nodes form a set of routing trees to the tree roots. In this case, the only root would be the base station. CTP is the best effort protocol: it does not promise 100% reliable delivery and there are no ordering guarantees. CTP assumes that it has link quality estimates of some number of nearby neighbors. As a link estimator, an implementation of the four-bit wireless link estimation can be used, which can maintain a 99% delivery ratio with a transmission power of 0 dBm over large, multi-hop test-beds [31]. Nodes generate routes to roots, using a routing gradient. The protocol (CTP) uses the expected number of transmissions (ETX) as its routing gradient. CTP represents ETX values as 16-bit fixed-point real numbers with a precision of hundredths. A root has an ETX of 0. The ETX of a node is the ETX of its parent plus the ETX of its link to its parent. In general, CTP chooses the node with the lowest ETX value, unless it has reasons to do otherwise. CTP data frames also have a time has lived (THL) field, which the routing layer increments on each hop. CTP uses the ETX and THL fields to deal with routing loops and packet duplication. Edit, delete and load a map of the environment can be added. When adding or editing a map, the location that the map represents and a general description may be specified. The name and image file location must be specified. The width and height that the map represents in the physical world are also required. When a map is loaded the image is displayed. The position of the mobile node is updated regularly. If a map has been loaded, the user can enter the location of a static node on the map by clicking on it and entering the node number. These locations are saved and displayed. When the map is reloaded or another map is loaded, the nodes and their positions are deleted. The PDA can use a browser with good support of web standards on a mobile device.
6 Conclusions

The categories time and location are fundamental for many applications of Sensor Networks, to interpret sensing results or to coordinate sensor nodes in Wireless Sensor Networks (WSNs).

The most relevant techniques for Localization in Wireless Sensor Networks - lateration, angulation and scene analysis are discussed. A comparison is made between several localization systems. The choice for a certain system or technique depends on the intended application. The application requirements therefore determine for a great deal which hardware and software setup is feasible. The system can adapt itself to its environment within limited time by learning the relation between distance and signal strength. This system's main advantage over most other existing systems could be its short deployment time in a new environment while still achieving a reasonable accuracy. Improvements can be made with respect to accuracy and mobility. To be able to reach the desired accuracy in a large space, a relatively simple solution would be to increase the number of anchor nodes. This would also increase the cost of the system. Another way to improve accuracy would be to use a wall attenuation model, which systems such as RADAR and OPT employ. Such a model compensates for walls between sender and receiver. To better support a moving user, the mobile node could be attached to an accelerometer to detect if it is moving.

The Wireless Sensor Networks offer a huge palette of possibilities referring the localization issues. Of course, improvements referring accuracy, cost, mobility and sustainability are always possible and recommendable.

References


