Location and Identification of People in the Home Environment

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Abstract

The growing interest and development of smart home technology with location aware applications has lead to a surge in the developing of Indoor Positioning Systems. Existing commercial Positioning Systems, however are quite expensive and complex. In this work we introduce and survey the different existing technologies and techniques used for indoor positioning. Furthermore, we present and detail the development of own, very low cost indoor positioning system, using a radio network of fixed and mobile nodes, with room level precision. Finally, we describe the tests performed to validate the system and evaluation metrics.
Keywords: Indoor Positioning System; Context Aware Applications; Sensor Network; Assited Living

1. Introduction

1.1. Context and Motivation

With the development of home technology, the location and tracking of people is an increasingly useful information for a number of context aware applications in smart buildings, ranging from safety, security, resource efficiency, visitor navigation, health care and asset tracking.[5]

An Indoor Positioning System (IPS), is a system designed for determining the position of objects or people in an indoor physical environment. When used in real time, an IPSs could provide location information of users, for assistance in emergencies. Smart homes could make use of user location information provided by IPSs for optimizing resource efficiency by directing resources to target locations. They could also be used to detect anomalous behaviour in users with risk conditions.

Most commercially available IPSs, are designed for use in the industry, health-care and commerce. For asset tracking in factories and warehouses, for patient and equipment tracking in hospitals and clinics, and for client navigation and browsing behaviour analysis in shops and malls.

There is currently no standard for Indoor Positioning Systems. They differ on several characteristics, based on types of information provided, system topology, technologies used and location estimation methods implemented.

Positioning systems can be classified into two categories: Active or passive systems.[16] Active systems require the user to actively take part in the process of positioning (e.g., by carrying a fixed device). Oppositely, passive positioning, functions completely without the need for the users to interact with the system.

1.2. Objectives

Several commercially available indoor positioning systems have been designed for a large number of different contexts, like industry, healthcare and commerce. In spite of this, we found none that was as affordable for use at home as we recognize they could be.

The objective of this work is to design an open, low cost, Indoor Positioning System, that can locate a user in real time. At least room-level accuracy is required. Designing for low-cost takes precedence over a high accuracy. In this sense, a balance between cost and accuracy is our goal.

The proposed system should provide location to other applications or notify them when users enter areas or locations defined by them. Additionally, the system should be able to be used for analyzing and detecting anomalous or unusual behaviour of users that have a need to be under constant or frequent watch, such as, elderly people. For instance, detecting that a user has not moved in a long time, or that the stove as been left turned on, with no one nearby for a while.

Our system should also have some degree of scalability, that is, it should function well for small or big homes. It could also be interesting for the system to be installed in a nursing home or small hospital.

Finally, the system should be relatively easy to install.

2. Related Work

In this section we present the main positioning and location sensing algorithms, techniques and technologies relevant to positioning system design.

2.1. Positioning Algorithms and Techniques

There are 3 main categories of position estimation techniques, Triangulation, Scene Analysis and Proximity based techniques.[6]

2.1.1 Triangulation

The Triangulation method is based on using the geometric properties of triangles to estimate the subject location. Triangulation can further be categorized in two sub-categories, Lateration and Angulation.

Lateration computes the target position by measuring the distance from the tag location to the fixed receivers, anchors (Fig. 1). The distance measurement can be determined indirectly through the Time of Flight (TOF) or attenuation of signals. Three different TOF measurements can be used to compute distance: Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Round-Trip Time of Flight (RTOF).

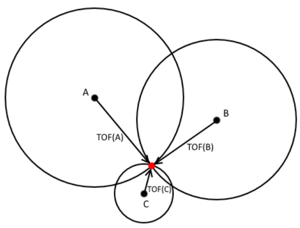

Figure 1: Time of Flight based trilateration. TOF can be determined through TOA or RTOF

The intensity of a signal decreases with distance. Computing distance with signal attenuation usually makes use of the Received Signal Strength Indicator (RSSI). Refraction and reflection of signal, as well as the multipath effect, affect the attenuation of signals non linearly.

Instead of distance between sender and receiver, Angulation uses Angle of Arrival (AOA) measurements to determine the position of the target. At least the angles at two receivers and the distance between them are necessary to compute the target position (Fig. 2).

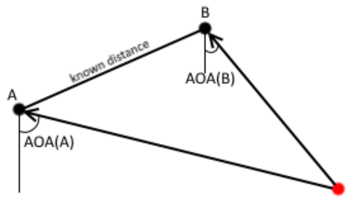

Figure 2: AOA based angulation. Only two receivers and the distance between them is required.

2.1.2 Scene Analysis

The Scene Analysis method consists of using observed or measured characteristics to infer the location. In static scene analysis observed characteristics are looked up in a predefined dataset, that maps them to the target location. This is also called Location Fingerprinting. Scene analysis can be made using images, captured by a camera, or using any other measurable propriety, like RSSI. RSSI based fingerprinting is commonly used in scene analysis. [10]

2.1.3 Proximity

Proximity location sensing methods usually depend on a grid of sensors, with shorter range than those used in other location sensing methods, with well known positions. The range of these sensors needs to be adapted to the corresponding location, so that when a target is within its range, it can be considered to be in that same location.

This technique can be implemented with physical contact detectors (e.g., pressure sensors, touch sensors), Infrared Radiation, passive or active Radio Frequency Identification (RFID), and Bluetooth. The accuracy of proximity location sensing methods depends mostly on the density of sensors deployed.

2.2. Relevant Technologies

2.2.1 Global Positioning System

Global Positioning System (GPS), has long since been the technology most used for outdoor positioning. However, due to satellite signal attenuation caused by walls and buildings it becomes unsuitable for indoor localization.[11]

2.2.2 RFID

Radio Frequency Identification, or RFID, is a way to retrieve information through electromagnetic transmission to a Radio Frequency (RF) compatible circuit. An RFID system is made up of readers, tags and the communication used among them.[12] RFID tags can be either passive or active.

Passive tags reflect and modulate the signal transmitted to them using no battery, therefore making them much cheaper. However, their read ranges are very short. Also, Passive RFID readers can have a relatively high cost.[10]

Active tags have a built-in battery and radio to broadcast their identity periodically or in reply to an interrogation. Because of this, active tags have a much longer range than passive tags.

SpotOn [7] is a positioning system based on active RFID tags designed by the researchers. Fixed readers then take RSSI from nearby tags and a central server aggregates the readings and triangulates the position of the tags. Each tag was estimated to have a 30-40$ cost after revision and manufacturing for quantity.

LANDMARC [12], also uses active RFID tags and fixed readers to compute the tag's position based on RSSI analysis. Additionally, they use extra tags with fixed positions that server as reference points to help with location calibration. LANDMARC also uses the K Nearest Neighbours method to determine the position of the tags.

2.2.3 Ultra Wideband

Different from other radio technologies, Ultra Wideband (UWB), concurrently transmits signals over multiple bands of frequencies. UWB works by transmitting ultrashort pulses with a low duty cycle [10]. Because of this, UWB signals have a high penetration capability, tags use less power and can be utilized near other radio signals without suffering or causing interference. Moreover, it is easy to determine which signals are correct and which resulted from multipath as well as determining an accurate TOA [2] [3].

The authors in [4] designed a positioning system based on a UWB radar built using off the shelf components and an android device. Able to achieve sub-meter level accuracy and maximum error, their system offers a cost of 120 euros per host per tag.

2.2.4 Bluetooth

Bluetooth is a very ubiquitous technology, available in most smartphone devices. Bluetooth is another one of the most popular technologies used for indoor positioning, particularly through the use of Bluetooth Low Energy (BLE) beacons. BLE beacons are essentially used as tags, have a very low power consumption and are relatively low cost. The main drawbacks of using beacons tags in an PS are the high signal attenuation and low range [9]. Bluetooth based IPSs can function using proximity or lateration techniques.

2.2.5 Wireless Local Area Network

Another popular way to build IPSs is using the WiFi in a Wireless Local Area Network (WLAN). Relative to other technologies, this method has a higher energy cost and lower positioning accuracy, with a mean error of over 2 meters. However, since it is an infrastructure already present in most indoor environments, it can become a very cheap alternative. Most WiFi Positioning Systems (WPS) determine positions based on proximity detection via RSSI analysis or through fingerprinting techniques. [8]

In [1] the authors present a methodology for indoor localization based on fingerprinting using RSSI. They report results with an accuracy of 2m.

Recently, researchers have started using channel response, instead of RSSI, to determine location in WiFi networks [15]. Channel response is the power feature of the PHY layer and it is able to discriminate multipath characteristics, allowing for more accurate location sensing. It used to be only obtainable by professional equipment, however, as it becomes available in off-the-shelf equipment in the format of Channel State Information (CSI), some works have reported sub-meter level accuracy [16][13][14].

2.3. Commercial Solutions

Many different commercial solutions exist. Most solutions we found online are designed specifically for one or more industries, the most common being warehouse and stock management, mining, factories and healthcare.

The most common technology used seems to be Ultra Wideband. Systems using UWB consist of a number of fixed anchors and mobile tags. At least three anchors are needed, four for a 3D space, and more depending on the area to cover. A mobile tags is designated for each asset to track. The system then uses TOA measurements to triangulate each target.

Another common solution is to use BLE or Active RFID in the same way as UWB systems, with RSSI to laterate the mobile tags locations.

Hybrid systems are also commonly used. Tracktio[1] employs a hybrid GPS and BLE system to seamlessly locate assets both indoors and outdoors.

Sewio[2] and Pozyx[3] were the only ones we found with pricing information available to the public. They both sell their Ultra Wideband real time location systems kit, with five and six anchors, respectively, and a mix of six tags for different use cases. The Sewio kit costs 2850$ and the Pozyx kit costs 4490$. Additionally, Pozyx also sell a developer version of their tags/anchors for 135$.

[1] tracktio.com
[2] sewio.net
[3] pozyx.io

3. Solution Description

3.1. Choice of Hardware

Because designing for low cost is one of our main objectives, choosing the hardware to use in our location system will be one of the most important decisions. In fact, our accuracy requirements are low enough (room level) that cost should be the driving factor in choosing the equipment used. Taking this into consideration, and after analysing several options we decided to build our solution with the Arduino Nano as our development board and the nRF34L01+ radio transceiver module.

With the simple RSSI capabilities of the nRF24L01+ the most suitable location sensing technique we can implement is proximity based. Each Arduino Nano and nRF24 will form a pair and each pair will the basis for the proximity nodes that will be spread throughout the home.

The power source will depend on the type and position of node. Mobile nodes will have a battery, while fixed nodes may either connect directly to a power socket or also have a battery.

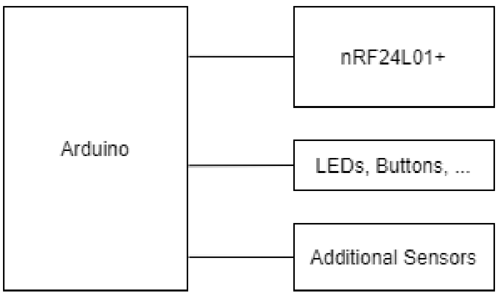

Figure 3: Diagram of the node.

3.2. The System

Our IPS consists of a node network with fixed anchor nodes and mobile nodes. Each user will carry with them a mobile node, which will periodically broadcast a message to all fixed nodes in range. Fixed radios are arranged in a tree network, and upon receiving a broadcast from a mobile node, will direct the message up through the network to the root node, also called the master node or central node. The master node in turn is feeding the messages to the server application, running in a computer.

The fixed radios are positioned one or more per each room in the house. When a fixed node receives a mobile broadcast, the system positions the respective user in the same room as the fixed node. When more than one fixed node receives the same broadcast a simple RSSI measurement is used. Further more, as users are not, usually, just standing about in a room, but rather doing something in a specific location, fixed nodes may be positioned for smaller, sub areas within rooms, e.g. in the desk or in the couch.

So, our system can be characterized as an active positioning system, because the users are required to carry a mobile node with them.

In regards to the techniques used, our solution uses both proximity sensing combined with RSSI measurements to determine the locations of the users.

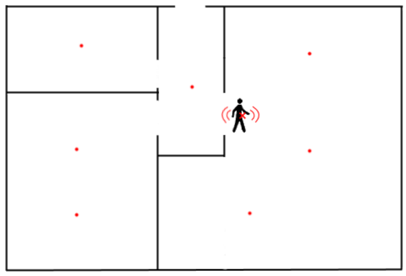

Figure 4: Possible deployment of the fixed nodes.

Server Application

This application reads and processes all the messages from the network in order to maintain and display a representation of the network and the house plan. Through this server application, users may also interact with the nodes in the network, changing their configuration with a series of commands. The server is also responsible for computing the location of each mobile node. To do this, the server implements some disambiguation logic as well as a feature to automatically find an appropriate power level for each mobile node.

The computer running the application could be a desktop, laptop or a single board computer like a Raspberry Pi.

4. The nRF24L01+ Transceiver Module

The nRF24L01+ is a low power, low cost, radio transceiver module that operates in the ISM band, between the 2.4 GHz and 2.525 GHz frequencies. The module allows for multiple modes of operation, implements automatic message acknowledgement and message re-transmission. It interfaces with a microcontroller unit through SPI.

When operating in Receive Mode the nRF24L01+ works as a Multiceiver (***Multi***ple transmitters single re***ceiver***). This is a feature that allows a single module to have six different data pipes, each corresponding to a different address. This means that a nRF24L01+ operating in Receive mode can receive data from up to six other modules in Transmit mode sharing the same frequency channel.

The radio module supports an air data rate of 250Kbps, 1Mbps or 2Mbps. At 250Kbps and 1Mbps we can have non overlapping channels with 1MHz spacing between each channel. This way, between 2.4GHz and 2.525GHz, we can have up to 126 different channels with no overlaps. At

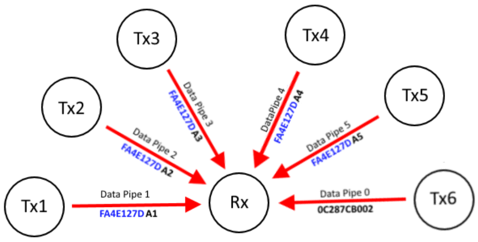

Figure 5: Depiction of a nRF24L01+ multiceiver. Note the shared bytes of the addresses for pipes 1 - 5.

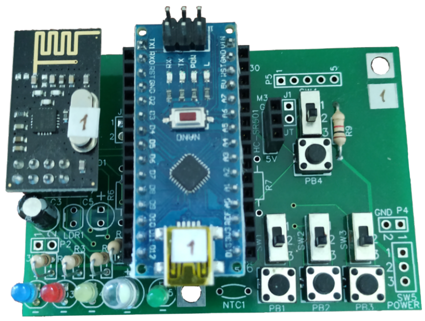

Figure 6: The node, with the components soldered and an Arduino Nano and nRF24L01+ radio module mounted.

2Mbps, 2MHz channel spacing is required for no channels to overlap. Receiver sensitivity is also affected by by the air data rate. With -82dBm receiver sensitivity at 2Mbps, -85dBm at 1Mbps and -94dBm at 250Kbps. This means that using a 250Kbps should result in a significant increase in the range of communication.

In terms of power amplification, the device has 4 options for transmitting packets. At maximum power it will transmit at 0dBm, at high -6dBm, at low -12dBm and at minimum it will transmit at -18dBm. These options consume 11.3mA, 9mA, 7.5mA and 7mA of current, respectively.

The NRF24L01 has 5 different main modes of operation, Receive mode, Transmit mode, Standby-I, Standby-II and Power Down mode.

The device features a very basic RSSI mechanism to differentiate between messages through signal strength. This mechanism is called Received Power Detector (RPD) and it turns a bit in a register ON when a signal is present in the current channel with power above -64dBm.

Finally, to control the radio device we are using the RF24 driver library[4], by TMRh20. This is an existing library designed to use the radio in accordance with the specifications from the manufacturer.

5. Implementation

This section details the implementation of our solution.

5.1. Node Board

Besides the Nano and the transceiver module, the board features five different colored LEDs. These may be used to signal different internal states or actions in the node or network. Furthermore, three buttons and switches can be used to change the operation of the node.

5.2. Network Layer

The network layer we are using is implemented by the RF24 Network Layer library[5], by TMRh20, which runs on top of the RF24 driver library. This network layer library implements network ACKs, automatic routing, multicasting and an intuitive addressing format. In addition to these features, we also implemented some basic fault detection capabilities. The next few sections detail these features.

5.2.1 Topology and Addressing Format

Motivated by the radio's multiceiver capabilities, where a receiver can listen up to six other addresses, the network takes the shape of a tree. This way, each node can be listening to one parent and up to 5 children. Applying this to our intended solution, since fixed nodes need to also receive messages from the mobile nodes, we reserve one of the children's spot for the multicasting address. So, each fixed node, is listening to one parent fixed node, up to 4 children fixed nodes and the multicasting address for the mobile nodes.

Each node, has a two byte address which corresponds to a child index, '1' through '4', followed by its parent's address. So, starting with the central node, with address '0', and its children addresses '1', '2', '3' and '4', the addresses for node '1''s children would be '11', '21', '31' and '41'. The children of node '41' are '141', '241', '341' and '441'. This means that the address represents a node's position in the network and therefore, the only information a node needs to route a message is its own address and the message's destination address. Mobile nodes take the addresses with '5' as the least significant digit, which correspond to the unused branch of the network tree.

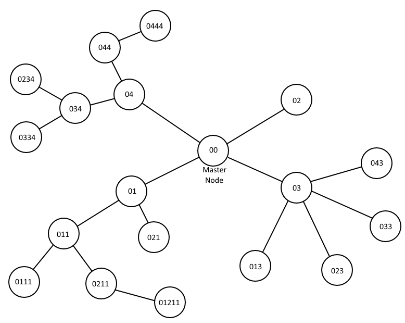

Figure 7: An example of a possible topology for the fixed node network.

[4]http://tmrh20.github.io/RF24
[5]http://tmrh20.github.io/RF24Network

Also, since only numbers 0 through 5 are used to represent addresses, they can be stored in octal format, using only 3 bits per digit. This also allows for easy masking and manipulation of addresses. Taken this format, with 2 bytes an address can have up to 5 octal digits. So while in one hand, we may have up to 1365 fixed nodes, including the master node, on the other hand, no node can be more than 4 hops away from the master node. This means that, in large houses, with horizontal layouts, the fixed node network coverage could be limited by the distance to the central node. However, in these cases more than one network could be used.

5.2.2 Network Messages

Messages in the network consist of a header and a payload. The header is 8 bytes long and contains the destination address, the origin address, a message id, a message type, and another field reserved for use by the library. The payloads can be dynamic and be to up to 24 bytes long.

The message type field is used to identify the kind of message, so that the receiver knows the payload structure. Additionally, message types 65 through 127 will receive a network ACK and message types 128 through 255 are reserved for library use.

5.2.3 Configuration Commands

There are three operation parameters that are configurable from the server, these are, power amplifier level, air data rate and frequency channel.

To change the PA level the server will send a message to a fixed node with the new PA level and a mobile address. If the mobile address is 0 the command is addressed to the fixed node and it will change its PA level to the new one, otherwise the command is addressed to a mobile node broadcasting from nearby and the fixed node will broadcast the command. A mobile node with address matching the mobile address field in the message will change its PA level.

To change the air data rate or the frequency channel the server will send a message to all fixed nodes with the new parameter. Upon receiving the message, every fixed node will broadcast it to potential mobile nodes in the area before changing the corresponding parameter. Because, changing either the data rate or the frequency channel will affect the communication between nodes, the server must send the command to the nodes in order, by furthest away from the central node first.

5.3. Mobile Node

Periodically, mobile nodes will multicast a message to a shared address between all fixed nodes and the master node. This message contains an updated broadcast counter, which serves two purposes. The first is to identify the order of departure from the mobile node, so the server can tell which message is the most recent. The other is to avoid sending duplicate broadcasts, as they will be ignored. The broadcasting period is defined by the Location Rate, which is the parameter that determines how frequently location broadcasts are made.

Besides the configuration commands shared with other node types, mobile nodes have one other configurable parameter, the location rate. To change the location rate the server will send a message to all fixed nodes, just like when changing the air data rate or the frequency channel, the only difference being that the fixed nodes don't change anything, just broadcast the message to nearby mobile nodes.

5.3.1 Synchronization

As several Mobile Nodes can be present in the same location, each of them multicasting to all nearby Fixed Nodes, collisions become more frequent. Furthermore, since all mobile nodes are multicasting with the same period, if a collision happens then it is very likely to happen again in the future. Since multicasts cannot be acknowledged, the nodes will never know when collisions happen, therefore message retransmissions are not a viable solution. To help mitigate this problem we implemented a simple mechanism to synchronize the nodes and allot different timing windows to each one. This works by having the master node send a message to all mobile nodes. The mobile nodes will all receive the message at around the same time. Upon receiving the message the mobile nodes will delay the next multicast by an amount determined by each own unique address.

5.3.2 Addressing

Addressing in mobile nodes is similar to addressing in fixed nodes, with a few extra rules.

As mentioned above, mobile nodes take the addresses from the unused branch of the fixed node network tree. This means that all mobile nodes addresses have a '5' as the least significant digit. Besides this, each digit after the least significant will be multiplied by a fraction of the broadcast period. The more significant the digit, the smaller the fraction. After the least significant digit, the second least significant will be multiplied by 200ms, assuming a 1000 milliseconds multicast period, the third digit will be multiplied by 40ms and the forth digit will multiplied by 8. In order to avoid different addresses mapping to the same delay, as we can see in figure 8, digits after the least significant digit cannot be '5'. The only exception to this rule is node '55', this is because both address '55' and '05' map to the same delay, this way, we opted to keep the node '55' in favor of '05' because otherwise there would be no address mapping to delays between 0 ms and 200 ms.

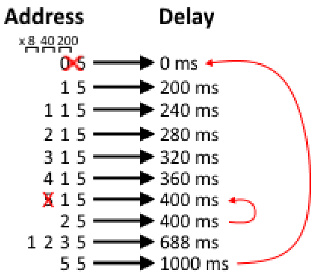

Figure 8: Addressing in mobile nodes and sync delays.

5.4. Fixed Node

The fixed nodes act as the communication infrastructure in our system. Their job in the network is to route messages from the mobile nodes to the server and also from the server to the mobile nodes.

Whenever a fixed node picks up a broadcast from a mobile node, it makes a new message with the counter from the broadcast message, the mobile address from the header, the signal strength from the RPD flag and sends it to the master node through the fixed network.

Moreover, the fixed nodes have a fault detection mechanism that allows the server and the users to know which fixed nodes may have issues that prevent communication with the rest of the network, like having no power or operating outside range of communication or improper configuration parameters.

In the next two subsections we detail the fault detection mechanism and commands specific to fixed node.

5.4.1 Fault Detection

Every five seconds, each fixed node sends a ping to their parent node. After sending this life signal, the fixed node updates its list of children alive based on the pings received. Finally, nodes send their list of children to the master node. This allows the server to know if and which nodes and sections in the network may be unreachable.

To avoid congestion in the master node, fixed nodes only send their children list if they have changed from the last one sent.

5.4.2 Commands

Besides the configuration commands there are 2 other commands a fixed node can receive from the server.

'Reset Children List' makes the node empty its own list of children nodes. This will force a change in the list if the node actually has any children nodes, thereby triggering the node to re-send the list to the master node. This command is useful when loading a previously used network configuration and or when a node that was previously unreachable becomes available again.

'Request Children List' directly asks the node to send its list of active children to the master node. While 'Reset Children List' command is targeted at all fixed nodes, 'Request Children List' is usually targeted at only one fixed node at a time.

5.5. Master Node

The master node is the bridge between the server and the wireless network. Its job is to send the location messages from mobile nodes and children node lists from fixed nodes to the server, via USB, as well as distributing and routing commands from the server to the network.

Serial Communication

As the master node receives messages from the fixed node network and from the mobile nodes, it encodes these messages as byte arrays and sends them through the serial interface to the server.

Furthermore, every program cycle, the node will check for available commands from the server. The master node does this by first reading a single byte. This byte identifies the command and how many arguments it has. Following the command identifier, the master node will read the available corresponding arguments.

When a command is addressed to several nodes, as is the case of some of the configuration commands, the master node will read one address at a time and send the command to the corresponding fixed node. In order to not block, the master node will only read one address per cycle and send the respective command. Because of reasons explained earlier, in section 4.5.1, the list of addresses will start with farthest nodes first, this way the last address is 00 and it marks the end of the list and the end of the command arguments.

5.6. Server's Application

The server runs an application that controls the network and interfaces with the user. The server essentially combines the information received from mobile and fixed nodes to maintain a representation of the network and derive each mobile node's positioning. It was made with Java and other platform independent tools, designed to be platform independent itself, so it should be able to compile and run on Windows, Mac OS or Linux desktops, laptops or single board computers, like a Raspberry Pi.

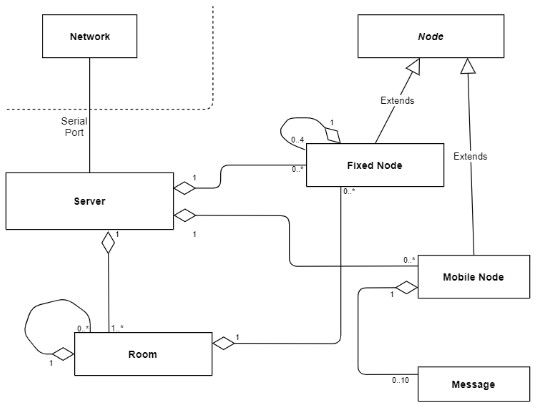

Figure 9: Model of the Server's Application.

This section will describe in detail how the network is represented in the server, the communication between the application and the master node, and other functionalities.

5.6.1 Message

The message class main purpose in the server is for deriving the mobile nodes' location.

Messages in the server have 5 fields: Mobile node address, fixed node address, counter, time of arrival and signal strength. These are the same fields as a location message from a fixed node, plus a time of arrival attributed as they reach the server. This time of arrival will serve as context for when displaying the history of locations of a mobile node.

A message is also used in the server to decode the bytes from the serial port.

5.6.2 Fixed Nodes

In the server, each fixed node class, besides the address and power level, is associated with a location, maintain list of fixed children nodes and a field detailing if it is currently reachable.

Every time a fixed node is registered in the server, the server finds the new node's parent node and adds the new node to its children node list. Additionally, the server also looks for children nodes that may already have been registered, and adds them to the new node's list of children. This means the fixed nodes can be registered in the server in any order. When created in the server, fixed nodes start out as unreachable until its parent reports it as alive in a children list.

5.6.3 Mobile Nodes

Each mobile node class keeps its address, power level and an ID of the person holding the node. Mobile nodes also keep a list of the last 20 messages received in the server corresponding to its own location broadcasts.

When a packet arrives in the server from a fixed node receiving a location broadcast from a mobile node, the server adds it to the list of messages of the corresponding mobile node. The list is then sorted in descending order by the message's Counter first, Signal Strength second and finally in ascending order by Time of Arrival.

This way, the last messages to leave the mobile node are at the beginning of the list, with ties broken by the "Strong Signal" field and further ties broken by the Time of Arrival; e.g., message with counter: 1000, strong signal: false, ToA: 00:00:10 $>$ message with counter: 999, S.S.: true, ToA:00:00:09 $>$ message with counter: 999, S.S.: false, ToA: 00:00:08 $>$ message with counter: 999, S.S.: false, ToA: 00:00:09 (use a table for this example?). Finally, if the list contains more than the maximum, messages are removed from the end of the list; i.e. the older ones. This list is key in determining the location of each mobile node.

When inspecting a mobile node in the interface, the full list of messages can be displayed as a history of previous broadcasts.

5.6.4 Floor Plan

The floor plan is represented as a graph, implemented as an adjacency list, where each room has a list of connected rooms. Additionally, each room has a name and a list of fixed nodes located in the room. Each fixed node in a room may be associated with a sub-location within a room or with the whole room.

The purpose of keeping the floor plan in the system is to help solve ambiguities in location sensing. For example, if the system is locating a user by two different locations but both locations are in the same room, then the user must be in that room.

5.6.5 Positioning

Mobile node location is determined from the list of messages kept by each mobile node. Location is determined directly from the first message if there are no ties at the beginning of the list and if the message was received less than two seconds ago. If there is a tie, we first check if the tied locations are in the same room. If they are not in the same room we then count the number of messages from the tied locations present the message list. This should help as the closest fixed node should also receive messages more consistently. If the tie persists, we count the number of messages from the tied rooms. If there is still a tie then, the system will indicate all tied locations.

5.6.6 Auto-Ranging

Auto-Ranging is what we call a feature that automatically helps adjust the power amplifier in the mobile nodes, to find a setting that doesn't cause an ambiguous positionings.

Whenever a mobile node has had an ambiguous location for more than two straight seconds, the system will increase its PA level, or set to minimum if its already at max level.

6. Testing and Evaluation

In this section describes the tests carried out to evaluate the system's capabilities and location sensing accuracy.

6.1. General Testing

This test consists of moving both a mobile node and a fixed node around another fixed node. By moving the onboard antenna we intend to study message reception and signal strength variation between mobile to fixed and fixed to fixed communications. Finally, we also vary the the data rate to observe the receiver sensitivity.

Observations

From this test we noted that for fixed nodes to communicate consistently between adjacent rooms the power amplifier should be be kept at MAX level. In the case of fixed nodes communicating in the same room, power amplifier can be lowered to HIGH or even to LOW level.

Another important observation to note is that a strong signal is almost never received from the other side of a wall. This may vary with wall thickness, the walls in our test environment were approximately 20 cm thick.

Finally, regarding the data rate variation, we didn't find the difference in the reception to be very meaningful. Furthermore, when nodes get reset, either by ran out of battery or by manually resetting a malfunctioning node, data rate gets reset to a predefined value, which may not coincide with data rate being used by the network This results in the node not being able to communicate with the rest of the network. Because of these reasons we decided to not have the data rate be configurable.

6.2. One Node per Room

This test consists of analysing regular system operation, with one fixed node per room.

To position fixed nodes for this test we considered the center of each room. The mobile nodes testing locations were chosen based on the consideration that people spend most time doing things in specific locations, opposed to commuting between locations. Therefore we chose to focus on testing positions that relate to where time is most likely to be spent within the home environment, like sleeping (bed), working (desk), cooking (kitchen counter), watching TV (sofa).

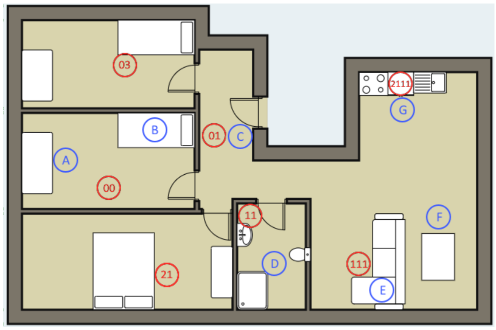

Figure 10: One fixed node per room.

In figure 10 we can see fixed node positions in red with node addresses and in blue the mobile positions being tested. In table 1 we see the location accuracy in function of the mobile node PA level.

Node Position	PA Level			
	Min	Low	High	Max
A	99%	100%	100%	100%
B	24%	93%	21%	13%
C	46%	47%	100%	88%
D	0%	100%	100%	100%
E	35%	0%	85%	91%
F	100%	0%	0%	0%
G	2%	90%	99%	76%

Table 1: Location accuracy.

Looking at the table, we can see that increasing the power level not always helps, in truth, it may make it so fixed nodes farther away detect the mobile node with the same signal strength as fixed nodes closer. We can see this having a big impact in locating positions F and and B.

Otherwise, the most important thing to note from the results from this test is that all tested locations seem to have a broadcast PA level for which the system accurately determines the correct room.

7. Conclusions

In this work we surveyed existing techniques, technologies and solutions in order to build our own low cost Indoor Positioning Systems.

We were able to design an indoor location solution with a cost of about 7 euros per node, even less when manufactured in scale, which is a fraction of the cost of other existing solutions. Besides having a low cost, our system is capable of identifying the room each user is in with high accuracy.

Our system is easy to install, requiring only pre-planning the network topology placing the nodes and a rehearsal to confirm correct functioning. Finally in terms of scalability, several node networks can be deployed in parallel, with several instances of the server application running in tandem.

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